SECTION 1

Compounds and Molecules

KEY TERMS

chemical bond
chemical structure
bond length
bond angle

OBJECTIVES

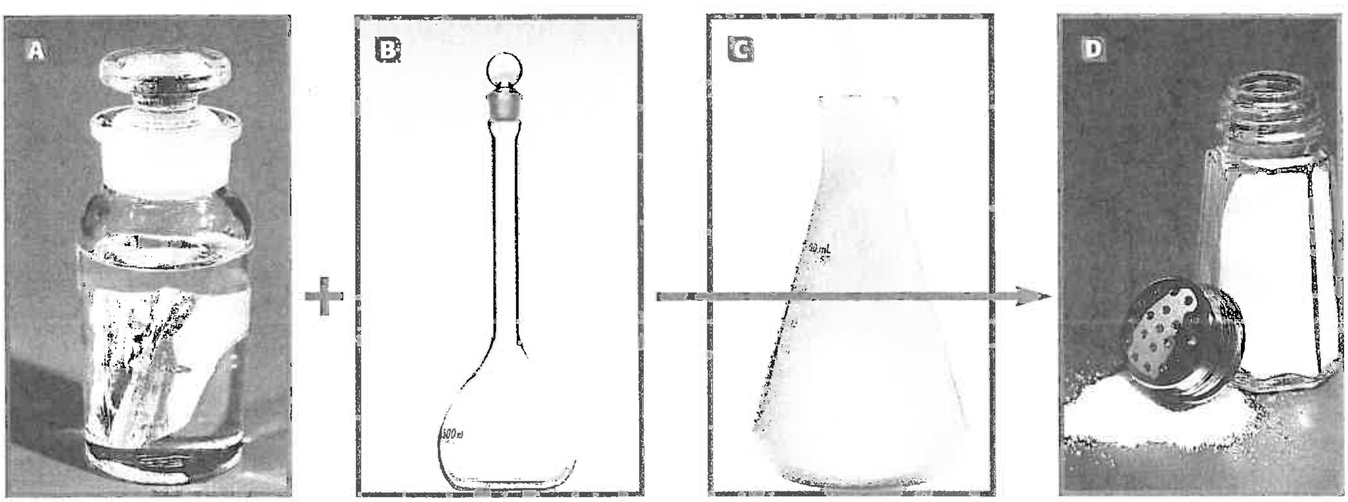
- **Distinguish** between compounds and mixtures.
- **Relate** the chemical formula of a compound to the relative numbers of atoms or ions present in the compound.
- **Use** models to visualize a compound's chemical structure.
- **Describe** how the chemical structure of a compound affects its properties.

If you step on a sharp rock with your bare foot, you feel pain. That's because rocks are hard substances; they don't bend. Many rocks are made of quartz. Table salt and sugar look similar; both are grainy, white solids. But they taste very different. In addition, salt is hard and brittle and breaks into uniform cubelike granules, while sugar does not. Quartz, salt, and sugar are all compounds. Their similarities and differences result from the way their atoms or ions are joined.

What Are Compounds?

Table salt is a compound made of two elements, sodium and chlorine. When elements combine to form a compound, the compound has properties very different from those of the elements that make it. ***Figure 1*** shows how the metal sodium combines with chlorine gas to form sodium chloride, NaCl, or table salt.

Figure 1
A The silvery metal sodium combines with **B** poisonous, yellowish green chlorine gas in a violent reaction **C** to form **D** white granules of table salt that you can eat.



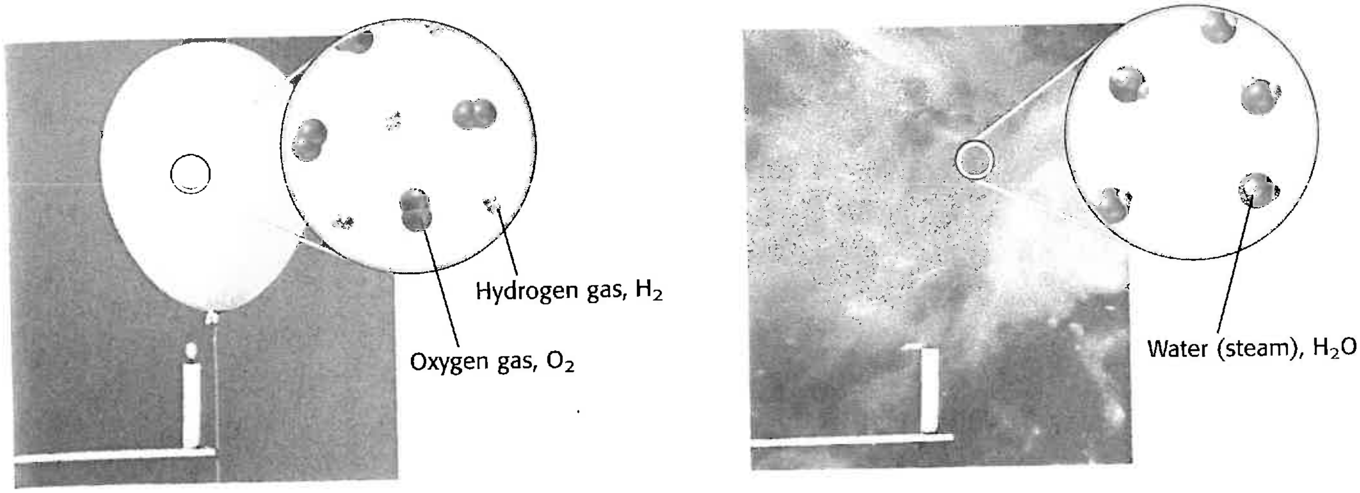


Figure 2

A Placing a lit candle under a balloon containing hydrogen gas and oxygen gas causes the balloon to melt, releasing the mixed gases.

B The mixed gases are ignited by the candle flame, and water is produced.

Chemical bonds distinguish compounds from mixtures

The attractive forces that hold different atoms or ions together in compounds are called **chemical bonds.** Recall how compounds and mixtures are different. Mixtures are made of different substances that are just placed together. Each substance in the mixture keeps its own properties.

chemical bond the attractive force that holds atoms or ions together

For example, mixing blue paint and yellow paint makes green paint. Different shades of green can be made by mixing the paints in different proportions, but both original paints remain chemically unchanged.

Figure 2 shows that when a mixture of hydrogen gas and oxygen gas is heated, a violent reaction takes place and a compound forms. Chemical bonds are broken, and atoms are rearranged. New bonds form water, a compound with properties very different from those of the original gases.

A compound always has the same chemical formula

The chemical formula for water is H_2O, and that of table sugar is $C_{12}H_{22}O_{11}$. The salt you season your food with has the chemical formula NaCl. A chemical formula shows the types and numbers of atoms or ions making up the simplest unit of the compound.

There is another important way that compounds and mixtures are different. Compounds are always made of the same elements in the same proportion. A molecule of water, for example, is always made of two hydrogen atoms and one oxygen atom. This is true for all water. That means water frozen in a comet in outer space and water at 37°C (98.6°F) inside the cells of your body both have the same chemical formula—H_2O.

chemical structure the arrangement of atoms in a substance

bond length the average distance between the nuclei of two bonded atoms

bond angle the angle formed by two bonds to the same atom

Chemical structure shows the bonding within a compound

Although water's chemical formula tells us what atoms it is made of, it doesn't reveal anything about the way these atoms are connected. You can see how a compound's atoms or ions are connected by its **chemical structure.** The structure of a compound can be compared to that of a rope. The kinds of fibers used to make a rope and the way the fibers are intertwined determine how strong the rope is. Similarly, the atoms in a compound and the way the atoms are arranged determine many of the compound's properties.

Two terms are used to specify the positions of atoms relative to one another in a compound. A **bond length** gives the distance between the nuclei of two bonded atoms. And when a compound has three or more atoms, **bond angles** tell how these atoms are oriented in space. ***Figure 3*** shows the chemical structure of a water molecule. You can see that the way hydrogen and oxygen atoms bond to form water looks more like a boomerang than a straight line.

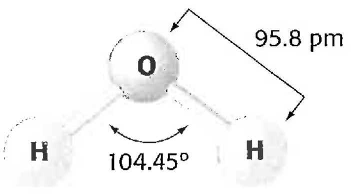


Figure 3
The ball-and-stick model in this figure is a giant representation of one molecule of water. A picometer (pm) is equal to 1×10^{-12} m.

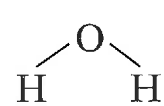
Models of Compounds

Figure 3 is a ball-and-stick model of a water molecule. Ball-and-stick models, as well as other kinds of models, help you "see" a compound's structure by showing you how the atoms or ions are arranged in the compound.

Some models give you an idea of bond lengths and angles

In the ball-and-stick model of water shown in ***Figure 3,*** the atoms are represented by balls. The bonds that hold the atoms together are represented by sticks. Although bonds between atoms aren't really as rigid as sticks, this model makes it easy to see the bonds and the angles they form in a compound.

Structural formulas can also show the structures of compounds. Notice how water's structural formula, which is shown below, is a lot like its ball-and-stick model. The difference is that only chemical symbols are used to represent the atoms.



Connection to FINE ARTS

Clay has a layered structure of silicon, oxygen, aluminum, and hydrogen atoms. Artists can mold wet clay into any shape because water molecules let the layers slide over one another. When clay dries, water evaporates and the layers can no longer slide. To keep the dry, crumbly clay from breaking apart, artists change the structure of the clay by heating it. The atoms in one layer bond to atoms in the layers above and below. When this happens, the clay hardens, and the artist's work is permanently set.

Making the Connection

1. Think of other substances that can be shaped when they are wet and that "set" when they are dried or heated.
2. Write a paragraph about one of these substances and why it has these properties. WRITING SKILL

Space-filling models show the space occupied by atoms

Figure 4 shows another way chemists picture a water molecule. It is called a space-filling model because it shows the space that is occupied by the oxygen and hydrogen atoms. The problem with this model is that it is harder to "see" bond lengths and angles.

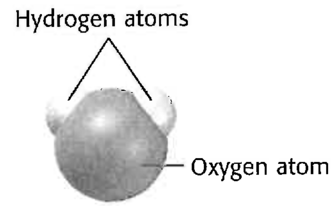


Figure 4

This space-filling model of water shows that the two hydrogen atoms take up much less space than the oxygen atom.

How Does Structure Affect Properties?

Some compounds, such as the quartz found in many rocks, exist as a large network of bonded atoms. Other compounds, such as table salt, are also large networks, but of bonded positive and negative ions. Still other compounds, such as water and sugar, are made of many separate molecules. Different structures give these compounds different properties.

Compounds with network structures are strong solids

Quartz is sometimes found in the form of beautiful crystals, as shown in ***Figure 5***. Quartz has the chemical formula SiO_2, and so does the less pure form of quartz, sand. ***Figure 5*** shows that every silicon atom in quartz is bonded to four oxygen atoms. The bonds that hold these atoms together are very strong. All of the Si–O–Si and O–Si–O bond angles are the same. That is, each one is 109.5°. This arrangement continues throughout the substance, holding the silicon and oxygen atoms together in a very strong, rigid structure.

This is why rocks containing quartz are hard and inflexible solids. Silicon and oxygen atoms in sand have a similar arrangement. It takes a lot of energy to break the strong bonds between silicon and oxygen atoms in quartz and sand. That's why the melting point and boiling point of quartz and sand is so high, as shown in ***Table 1***.

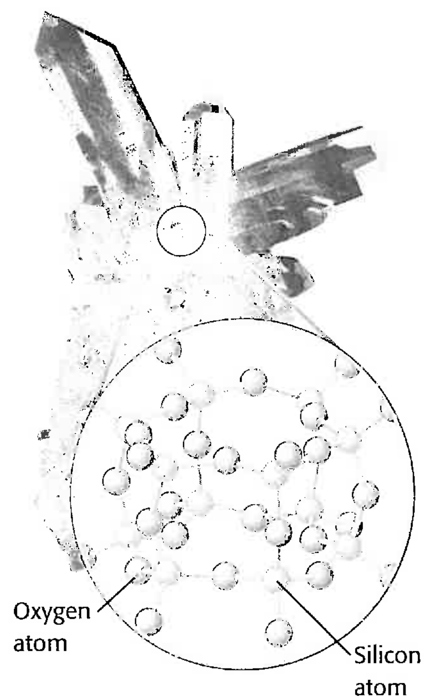


Figure 5

Quartz and sand are made of silicon and oxygen atoms bonded in a strong, rigid structure.

Table 1 **Some Compounds with Network Structures**

Compound	State (25°C)	Melting point (°C)	Boiling point (°C)
Silicon dioxide, SiO_2 (quartz)	solid	1700	2230
Magnesium fluoride, MgF_2	solid	1261	2239
Sodium chloride, NaCl (table salt)	solid	801	1413

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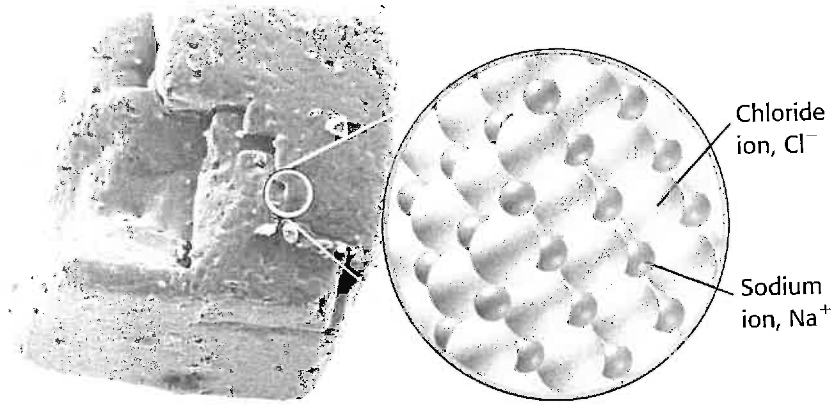
Figure 6
Each grain of table salt, or sodium chloride, is composed of a tightly packed network of Na^+ ions and Cl^- ions.



Some compounds are made of networks of bonded ions

Like some quartz, table salt—sodium chloride—is found in the form of regularly shaped crystals. Crystals of sodium chloride are cube shaped. Like quartz and sand, sodium chloride is made of a repeating network connected by strong bonds. The network is made of tightly packed, positively charged sodium ions and negatively charged chloride ions, as shown in **Figure 6.** The strong attractions between the oppositely charged ions cause table salt and other similar compounds to have high melting points and boiling points, as shown in **Table 1.**

Some compounds are made of molecules

Salt and sugar are both white solids you can eat, but their structures are very different. Unlike salt, sugar is made of molecules. A molecule of sugar, shown in **Figure 7,** is made of carbon, hydrogen, and oxygen atoms joined by bonds. Molecules of sugar do attract each other to form crystals. But these attractions are much weaker than those that hold bonded carbon, hydrogen, and oxygen atoms together to make a sugar molecule.

We breathe nitrogen, N_2, oxygen, O_2, and carbon dioxide, CO_2, every day. All three substances are colorless, odorless gases made of molecules. Within each molecule, the atoms are so strongly attracted to one another that they are bonded. But the molecules of each gas have very little attraction for one another. Because the molecules of these gases are not very attracted to one another, they spread out as much as they can. That is why gases can take up a lot of space.

Figure 7
Sugar, $C_{12}H_{22}O_{11}$, is made of molecules.

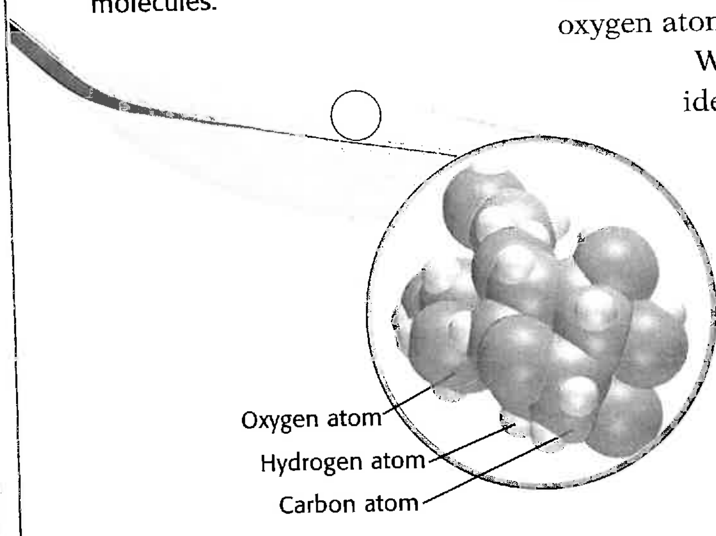


Table 2 **Comparing Compounds Made of Molecules**

Compound	State (25°C)	Melting point (°C)	Boiling point (°C)
Sugar, $C_{12}H_{22}O_{11}$	Solid	185–186	——
Water, H_2O	Liquid	0	100
Dihydrogen sulfide, H_2S	Gas	–86	–61

The strength of attractions between molecules varies

Compare sugar, water, and dihydrogen sulfide in ***Table 2.*** Although all three compounds are made of molecules, their properties are very different. Sugar is a solid, water is a liquid, and dihydrogen sulfide is a gas. That means that sugar molecules have the strongest attractions for each other, followed by water molecules. Dihydrogen sulfide molecules have the weakest attractions for each other. The fact that sugar and water have such different properties probably doesn't surprise you. Their chemical structures are not at all alike. But what about water and dihydrogen sulfide, which do have similar chemical structures?

Quick Lab

Which melts more easily, sugar or salt?

Materials

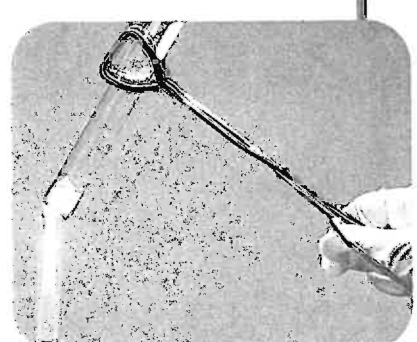
- *table salt*
- *Bunsen burner*
- *stopwatch*
- *table sugar*
- *2 test tubes*
- *tongs*

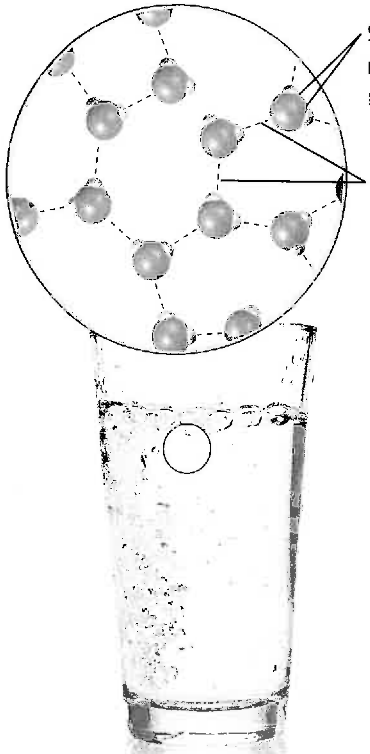
SAFETY CAUTION Wear safety goggles and gloves. Tie back long hair, confine loose clothing, and use tongs to handle hot glassware. When heating a substance in a test tube, always point the open end of the test tube away from yourself and others.

1. Use your knowledge of structures to make a hypothesis about whether sugar or salt will melt more easily.
2. To test your hypothesis, place about 1 cm^3 of sugar in a test tube.
3. Using tongs, position the test tube with sugar over the flame, as shown in the figure at right. Move the test tube back and forth slowly over the flame. Use a stopwatch to measure the time it takes for the sugar to melt.
4. Repeat steps 2 and 3 with salt. If your sample does not melt within 1 minute, remove it from the flame.

Analysis

1. Which compound is easier to melt? Was your hypothesis right?
2. How can you relate your results to the structure of each compound?





Attractions between water molecules are called hydrogen bonds

The higher melting and boiling points of water suggest that water molecules attract each other more than dihydrogen sulfide molecules do. Figure 8 shows how an oxygen atom of one water molecule is attracted to a hydrogen atom of a neighboring water molecule. This attraction is called a *hydrogen bond.* Water molecules attract each other, but these attractions are not as strong as the bonds holding oxygen and hydrogen atoms together within a molecule.

Figure 8
Dotted lines indicate the *inter*molecular attractions that occur *between* water molecules, which is often referred to as "hydrogen bonding." Water is a liquid at room temperature because of these attractions.

SECTION 1 REVIEW

SUMMARY

- Atoms or ions in compounds are joined by chemical bonds.
- A compound's chemical formula shows which atoms or ions it is made of.
- A model represents a compound's structure visually.
- Substances with network structures are usually strong solids with high melting and boiling points.
- Substances made of molecules have lower melting and boiling points.
- Whether a molecular substance is a solid, a liquid, or a gas at room temperature depends on the attractions between its molecules.

1. **Classify** the following substances as mixtures or compounds:
   a. air
   b. CO
   c. SnF_2
   d. pure water
2. **Explain** why silver iodide, AgI, a compound used in photography, has a much higher melting point than vanillin, $C_8H_8O_3$, a sweet-smelling compound used in flavorings.
3. **Draw** a ball-and-stick model of a boron trifluoride, BF_3, molecule. In this molecule, a boron atom is attached to three fluorine atoms. Each F—B—F bond angle is 120°, and all B—F bonds are the same length.
4. **Predict** which molecules have a greater attraction for each other, C_3H_8O molecules in liquid rubbing alcohol or CH_4 molecules in methane gas.
5. **Explain** why glass, which is made mainly of SiO_2, is often used to make cookware. (**Hint:** What properties does SiO_2 have because of its structure?)
6. **Critical Thinking** A picometer (pm) is equal to 1×10^{-12} m. O—H bond lengths in water are 95.8 pm, while S—H bond lengths in dihydrogen sulfide are 135 pm. Why are S—H bond lengths longer than O—H bond lengths? (**Hint:** Which is larger, a sulfur atom or an oxygen atom?)

SECTION 2

Ionic and Covalent Bonding

OBJECTIVES

- **Explain** why atoms sometimes join to form bonds.
- **Explain** why some atoms transfer their valence electrons to form ionic bonds, while other atoms share valence electrons to form covalent bonds.
- **Differentiate** between ionic, covalent, and metallic bonds.
- **Compare** the properties of substances with different types of bonds.

KEY TERMS

ionic bond
metallic bond
covalent bond
polyatomic ion

When two atoms join, a bond forms. You have already seen how bonded atoms form many kinds of substances. Atoms bond in different ways to form these many substances. The type of bonds that the atoms of a substance form affect the substance's properties.

What Holds Bonded Atoms Together?

Three different kinds of bonds describe the way atoms bond in most substances. In many of the models you have seen so far, the bonds that hold atoms together are represented by sticks. But what bonds atoms in a real molecule?

Bonded atoms usually have a stable electron configuration

Atoms bond when their valence electrons interact. You have learned that atoms with full outermost *s* and *p* orbitals are more stable than atoms with only partly filled outer *s* and *p* orbitals. Generally, atoms join to form bonds so that each atom has a stable electron configuration. When this happens, each atom has an electronic structure similar to that of a noble gas.

When two hydrogen atoms bond, as shown in ***Figure 9***, the positive nucleus of one hydrogen atom attracts the negative electron of the other hydrogen atom, and vice versa. This attraction pulls the two atoms closer together. Soon the electron clouds of the hydrogen atoms cross each other. The shared electron cloud of the molecule that forms has two electrons (one from each atom). A hydrogen molecule, which consists of two hydrogen atoms bonded together, has an electronic structure similar to the noble gas helium. The molecule will not fall apart unless enough energy is added to break the bond.

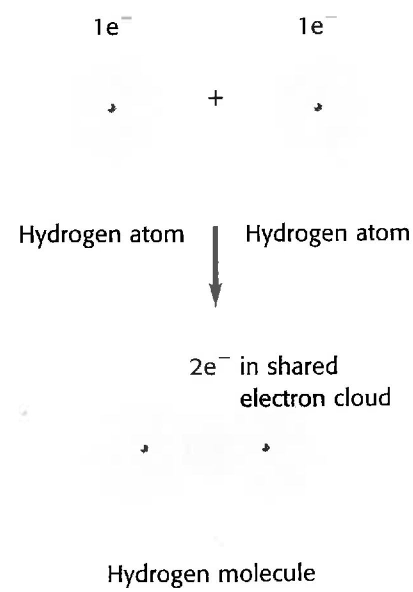
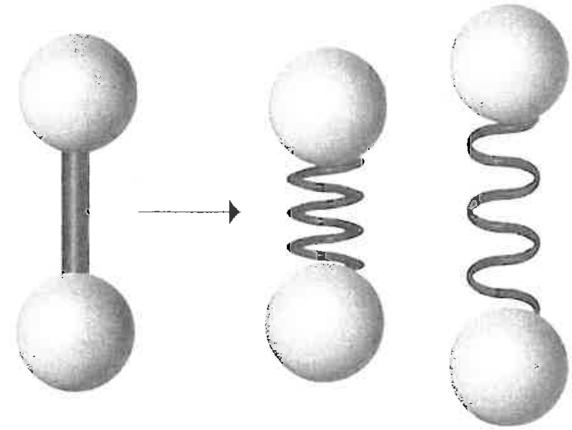


Figure 9
When two hydrogen atoms are very close together, their electron clouds overlap, and a bond forms. The two electrons of the hydrogen molecule that forms are in the shared electron cloud.

Figure 10

Chemists often use a solid bar to show a bond between two atoms, but real bonds are flexible, like stiff springs.



Bonds can bend and stretch without breaking

Although some bonds are stronger and more rigid than others, all bonds behave more like flexible springs than like sticks, as ***Figure 10*** shows. The atoms move back and forth a little and their nuclei do not always stay the same distance apart. In fact, most reported bond lengths are averages of these distances. Although bonds are not rigid, they still hold atoms together tightly.

ionic bond a bond formed by the attraction between oppositely charged ions

Ionic Bonds

Ionic bonds are formed between oppositely charged ions. Atoms of metal elements, such as sodium and calcium, form the positively charged ions. Atoms of nonmetal elements, such as chlorine and oxygen, form the negatively charged ions.

Ionic bonds are formed by the transfer of electrons

Some atoms do not share electrons to fill their outermost energy levels completely. Instead, they transfer electrons. One of the atoms gains the electrons that the other atom loses. Both ions that form usually have stable electron configurations. The result is a positive ion and a negative ion, such as the Na^{+} ion and the Cl^{-} ion in sodium chloride.

These oppositely charged ions attract each other and form an ionic bond. Each positive sodium ion attracts several negative chloride ions. These negative chloride ions attract more positive sodium ions, and so on. Soon a network of these bonded ions forms a crystal of table salt.

Connection to SOCIAL STUDIES

American scientist Linus Pauling studied how electrons are arranged within atoms. He also studied the ways that atoms share and exchange electrons. In 1954, he won the Nobel Prize in chemistry for his valuable research.

Later, Pauling fought to ban nuclear weapons testing. Pauling was able to convince more than 11 000 scientists from 49 countries to sign a petition to stop nuclear weapons testing. Pauling won the Nobel Peace Prize in 1962 for his efforts. A year later, a treaty outlawing nuclear weapons testing in the atmosphere, in outer space, and underwater went into effect.

Making the Connection

1. *Electronegativity* is an idea first thought of by Pauling. It tells how easily an atom accepts electrons. Which is more electronegative, a fluorine atom or a calcium atom? Why?
2. Nuclear weapons testing can harm living things because of the resulting radiation. Write a paragraph explaining how high levels of radiation can affect your body. **WRITING SKILL**

Ionic compounds are in the form of networks, not molecules

Because sodium chloride is a network of ions, it does not make sense to talk about "a molecule of NaCl." In fact, every sodium ion is next to six chloride ions, as shown in **Figure 6.** Instead, chemists talk about the smallest ratio of ions in ionic compounds. Sodium chloride's chemical formula, NaCl, tells us that there is one Na^+ ion for every Cl^- ion, or a 1:1 ratio of ions. This means the compound has a total charge of zero. One Na^+ ion and one Cl^- ion make up a *formula unit* of NaCl.

Not every ionic compound has the same ratio of ions as sodium chloride. An example is calcium fluoride, which is shown in **Figure 11.** The ratio of Ca^{2+} ions to F^- ions in calcium fluoride must be 1:2 to make a neutral compound. That is why the chemical formula for calcium fluoride is CaF_2.

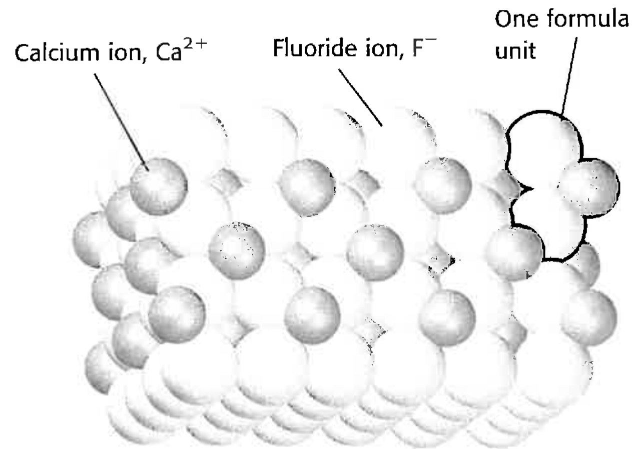


Figure 11
There are twice as many fluoride ions as calcium ions in a crystal of calcium fluoride, CaF_2. So one Ca^{2+} ion and two F^- ions make up one formula unit of the compound.

When melted or dissolved in water, ionic compounds conduct electricity

Electric current is moving charges. Solid ionic compounds do not conduct electricity because the charged ions are locked into place, causing the melting points of ionic compounds to be very high—often well above 300°C. But if you dissolve an ionic compound in water or melt it, it can conduct electricity. That's because the ions are then free to move, as shown in **Figure 12.**

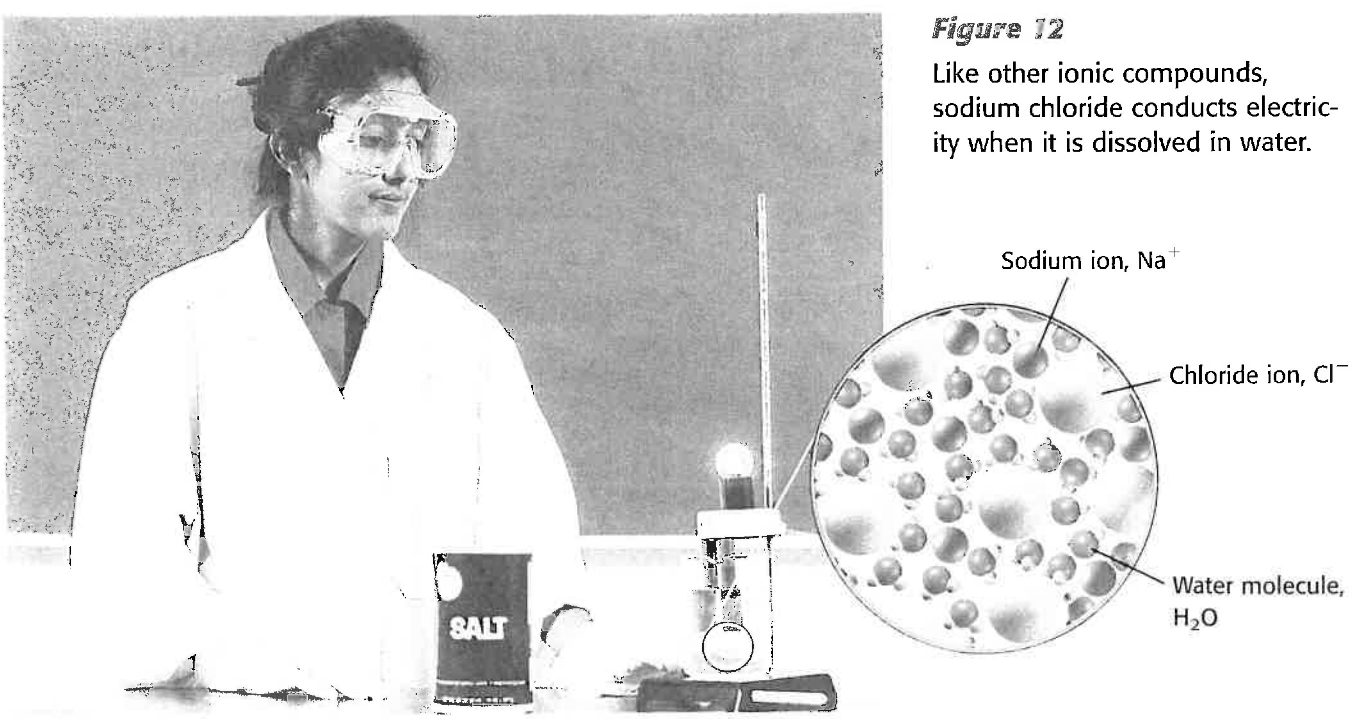


Figure 12
Like other ionic compounds, sodium chloride conducts electricity when it is dissolved in water.

Figure 13
Copper is a flexible metal that melts at 1083°C and boils at 2567°C. Copper conducts electricity because electrons can move freely between atoms.

Metallic Bonds

Metals, like copper, shown in ***Figure 13***, can conduct electricity when they are solid. Metals are also flexible, so they can bend and stretch without breaking. Copper, for example, can be hammered flat into sheets or stretched into very thin wire. What kind of bonds give copper these properties?

Electrons move freely between metal atoms

metallic bond a bond formed by the attraction between positively charged metal ions and the electrons around them

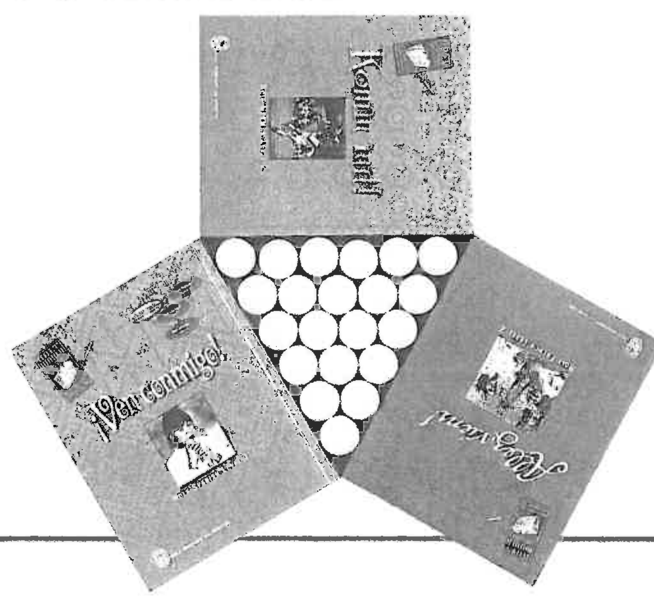
The atoms in metals like copper form **metallic bonds.** The attraction between one atom's nucleus and a neighboring atom's electrons packs the atoms closely together. This close packing causes the outermost energy levels of the atoms to overlap, as shown in ***Figure 13.*** Therefore, electrons are free to move from atom to atom. This model explains why metals conduct electricity so well. Metals are flexible because the atoms can slide past each other without their bonds breaking.

Quick ACTIVITY

Building a Close-Packed Structure

Copper and other metals have close-packed structures. This means their atoms are packed very tightly together. In this activity, you will build a close-packed structure using table-tennis balls.

1. Place three books flat on a table so that their edges form a triangle.
2. Fill the triangular space between the books with the spherical "atoms." Adjust the books so that the atoms make a one-layer, close-packed pattern, as shown at right.
3. Build additional layers on top of the first layer. How many other atoms does each atom touch? Where have you seen other arrangements that are similar to this one?



Covalent Bonds

Compounds that are made of molecules, like water and sugar, have **covalent bonds.** Compounds existing as networks of bonded atoms, such as silicon dioxide, are also held together by covalent bonds. Covalent bonds are often formed between nonmetal atoms.

Covalent compounds can be solids, liquids, or gases. Except for silicon dioxide and other compounds with network structures, most covalent compounds have low melting points—usually below 300°C. In compounds that are made of molecules, the molecules are free to move when the compound is dissolved or melted. But most of these molecules remain intact and do not conduct electricity because they are not charged.

covalent bond a bond formed when atoms share one or more pairs of electrons

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Atoms joined by covalent bonds share electrons

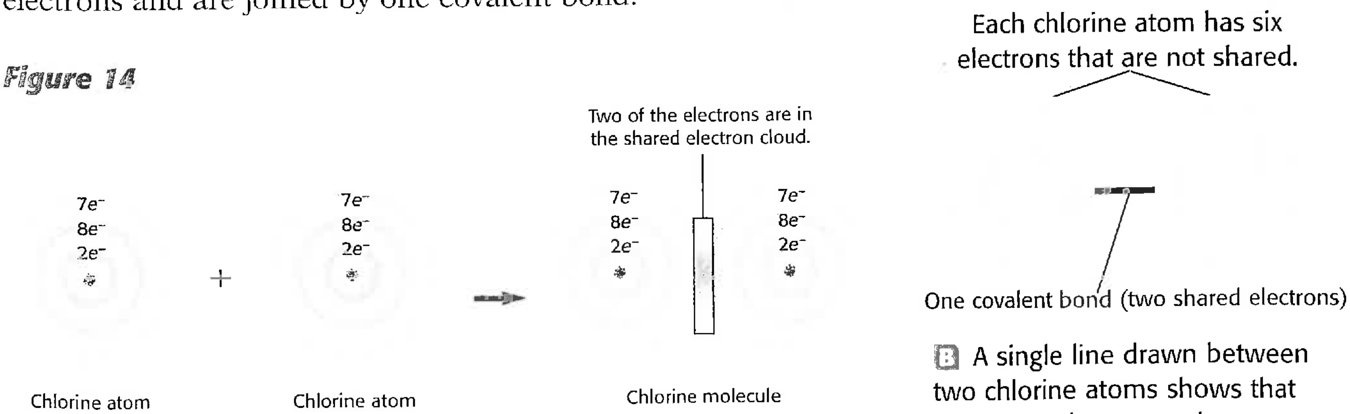
Some atoms, like the hydrogen atoms in *Figure 9,* bond to form molecules. ***Figure 14A*** shows how two chlorine atoms bond to form a chlorine molecule, Cl_2. Before bonding, each atom has seven electrons in its outermost energy level. The atoms don't transfer electrons to one another because each needs to gain an electron. If each atom shares one electron with the other atom, then both atoms together have a full outermost energy level. That is, both atoms together have eight valence electrons. The way electrons are shared depends on which atoms are sharing the electrons. Two chlorine atoms are exactly alike. When they bond, electrons are equally attracted to the positive nucleus of each atom. Bonds like this one, in which electrons are shared equally, are called *nonpolar covalent bonds.*

The structural formula in ***Figure 14B*** shows how the chlorine atoms are connected in the molecule that forms. A single line drawn between two atoms indicates that the atoms share two electrons and are joined by one covalent bond.

VOCABULARY Skills Tip

Co<u>valent</u> bonds *form when atoms share pairs of* <u>valence</u> *electrons.*

Figure 14

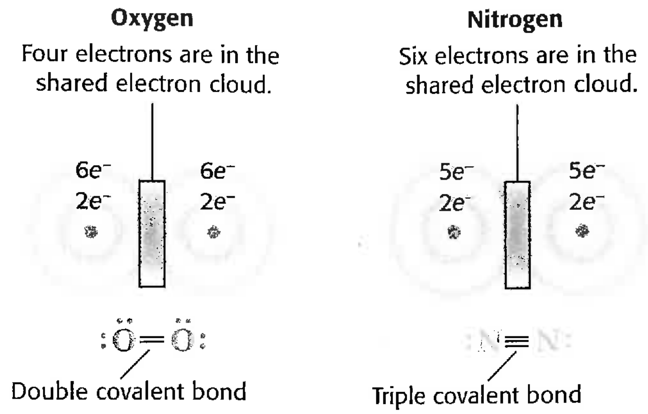


A Two chlorine atoms share electrons equally to form a *nonpolar covalent bond.*

B A single line drawn between two chlorine atoms shows that the atoms share two electrons. Dots represent electrons that are not involved in bonding.

Figure 15

The elements oxygen and nitrogen have covalent bonds. Electrons not involved in bonding are represented by dots.



Atoms may share more than one pair of electrons

Figure 15 shows covalent bonding in oxygen gas, O_2 and nitrogen gas, N_2. Notice that the bond joining two oxygen atoms is represented by two lines. This means that two pairs of electrons (a total of four electrons) are shared to form a double covalent bond.

The bond joining two nitrogen atoms is represented by three lines. Two nitrogen atoms form a triple covalent bond by sharing three pairs of electrons (a total of six electrons).

The bond between two nitrogen atoms is stronger than the bond between two oxygen atoms. That's because more energy is needed to break a triple bond than to break a double bond. Triple and double bonds are also shorter than single bonds.

PHYSICAL SCIENCE INTERACTIVE TUTOR

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Chemical Bonding
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Atoms do not always share electrons equally

When two different atoms share electrons, the electrons are not shared equally. The shared electrons are attracted to the nucleus of one atom more than the other. An unequal sharing of electrons forms a *polar covalent bond.*

Usually, electrons are more attracted to atoms of elements that are located farther to the right and closer to the top of the periodic table. The shading in **Figure 16** shows that the shared electrons in the ammonia gas, NH_3, in the headspace of this container, are closer to the nitrogen atom than they are to the hydrogen atoms.

polyatomic ion an ion made of two or more atoms

Polyatomic Ions

Until now, we have talked about compounds that have either ionic or covalent bonds. But some compounds have both ionic and covalent bonds. Such compounds are made of **polyatomic ions,** which are groups of covalently bonded atoms that have either lost or gained electrons. A polyatomic ion acts the same as the ions you have already encountered.

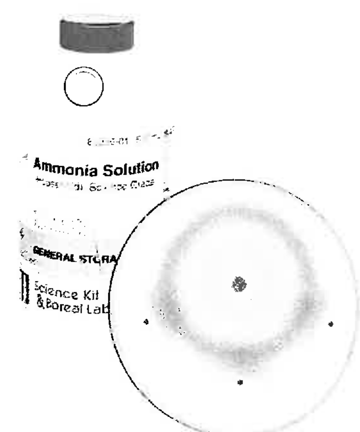


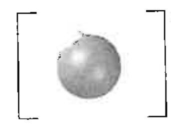
Figure 16

The darker shading around the nitrogen atom as compared to the hydrogen atoms shows that electrons are more attracted to nitrogen atoms than to hydrogen atoms. So the bonds in ammonia are *polar covalent bonds.*

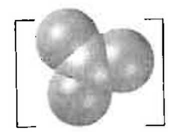
There are many common polyatomic ions

Many compounds you use either contain or are made from polyatomic ions. For example, your toothpaste may contain baking soda. Another name for baking soda is sodium hydrogen carbonate, $NaHCO_3$. Hydrogen carbonate, HCO_3^-, is a polyatomic ion. Sodium carbonate, Na_2CO_3, is often used to make soaps and other cleaners and contains the carbonate ion, CO_3^{2-}. Sodium hydroxide, NaOH, has hydroxide ions, OH^-, and is also used to make soaps. A few of these polyatomic ions are shown in ***Figure 17.***

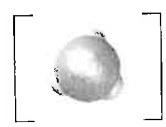
Oppositely charged polyatomic ions, like other ions, can bond to form compounds. Ammonium nitrate, NH_4NO_3, and ammonium sulfate, $(NH_4)_2SO_4$, both contain positively charged ammonium ions, NH_4^+. Nitrate, NO_3^-, and sulfate, SO_4^{2-}, are both negatively charged polyatomic ions.



Hydroxide ion, OH^-



Carbonate ion, CO_3^{2-}



Ammonium ion, NH_4^+

Figure 17

The hydroxide ion (OH^-), carbonate ion (CO_3^{2-}), and ammonium ion (NH_4^+) are all polyatomic ions.

Parentheses group the atoms of a polyatomic ion

You might be wondering why the chemical formula for ammonium sulfate is written as $(NH_4)_2SO_4$ instead of as $N_2H_8SO_4$. The parentheses around the ammonium ion are there to remind you that it acts like a single ion. Parentheses group the atoms of the ammonium ion together to show that the subscript 2 applies to the whole ion. There are two ammonium ions for every sulfate ion. Parentheses are not needed in compounds like ammonium nitrate, NH_4NO_3, because there is a 1:1 ratio of ions.

Always keep in mind that a polyatomic ion's charge applies not only to the last atom in the formula but to the entire ion. The carbonate ion, CO_3^{2-}, has a 2− charge. This means that CO_3, not just the oxygen atom, has the negative charge.

Some polyatomic anion names relate to their oxygen content

You may have noticed that many polyatomic anions are made of oxygen. Most of their names end with *-ite* or *-ate*. These endings do not tell you exactly how many oxygen atoms are in the ion, but they do follow a pattern. Think about sulfate (SO_4^{2-}) and sulfite (SO_3^{2-}), nitrate (NO_3^-) and nitrite (NO_2^-), and chlorate (ClO_3^-) and chlorite (ClO_2^-). The charge of each ion pair is the same. But notice how the ions have different numbers of oxygen atoms. Their names also have different endings.

An *-ate* ending is used to name the ion with one more oxygen atom. The name of the ion with one less oxygen ends in *-ite*. ***Table 3,*** on the next page, lists several common polyatomic anions. As you look at this table, you'll notice that not all of the anions listed have names that end in *-ite* or *-ate*. That's because some polyatomic anions, like hydroxide (OH^-) and cyanide (CN^-), are not named according to any general rules.

INTEGRATING

SPACE SCIENCE

Most of the ions and molecules in space are not the same as those that are found on Earth or in Earth's atmosphere. C_3H, C_6H_2, and HCO^+ have all been found in space. So far, no one has been able to figure out how these unusual molecules and ions form in space.

Table 3 **Some Common Polyatomic Anions**

Ion name	Ion formula	Ion name	Ion formula
Acetate ion	$CH_3CO_2^-$	Hydroxide ion	OH^-
Carbonate ion	CO_3^{2-}	Hypochlorite ion	ClO^-
Chlorate ion	ClO_3^-	Nitrate ion	NO_3^-
Chlorite ion	ClO_2^-	Nitrite ion	NO_2^-
Cyanide ion	CN^-	Phosphate ion	PO_4^{3-}
Hydrogen carbonate ion	HCO_3^-	Phosphite ion	PO_3^{3-}
Hydrogen sulfate ion	HSO_4^-	Sulfate ion	SO_4^{2-}
Hydrogen sulfite ion	HSO_3^-	Sulfite ion	SO_3^{2-}

SECTION 2 REVIEW

SUMMARY

- Atoms bond when their valence electrons interact.
- Cations and anions attract each other to form ionic bonds.
- When ionic compounds are melted or dissolved in water, moving ions can conduct electricity.
- Atoms in metals are joined by metallic bonds.
- Metals conduct electricity because electrons can move from atom to atom.
- Covalent bonds form when atoms share electron pairs. Electrons may be shared equally or unequally.
- Polyatomic ions are covalently bonded atoms that have either lost or gained electrons. Their behavior resembles that of simple ions.

1. **Determine** if the following compounds are likely to have ionic or covalent bonds.
   - **a.** magnesium oxide, MgO
   - **b.** strontium chloride, $SrCl_2$
   - **c.** ozone, O_3
   - **d.** methanol, CH_3OH
2. **Identify** which two of the following substances will conduct electricity, and explain why.
   - **a.** aluminum foil
   - **b.** sugar, $C_{12}H_{22}O_{11}$, dissolved in water
   - **c.** potassium hydroxide, KOH, dissolved in water
3. **Draw** the structural formula for acetylene. Atoms bond in the order HCCH. Carbon and hydrogen atoms share two electrons, and each carbon atom must have a total of four bonds. How many electrons do the carbon atoms share?
4. **Predict** whether a silver coin can conduct electricity. What kind of bonds does silver have?
5. **Describe** how it is possible for calcium hydroxide, $Ca(OH)_2$, to have both ionic and covalent bonds.
6. **Explain** why electrons are shared equally in oxygen, O_2, but not in carbon monoxide, CO.
7. **Analyze** whether dinitrogen tetroxide, N_2O_4, has covalent or ionic bonds. Describe how you reached this conclusion.
8. **Critical Thinking** *Bond energy* measures the energy per mole of a substance needed to break a bond. Which element has the greater bond energy, oxygen or nitrogen? (**Hint:** Which element has more bonds?)

SECTION 3

Compound Names and Formulas

OBJECTIVES

- **Name** simple ionic and covalent compounds.
- **Predict** the charge of a transition metal cation in an ionic compound.
- **Write** chemical formulas for simple ionic compounds.
- **Distinguish** a covalent compound's empirical formula from its molecular formula.

KEY TERMS

empirical formula
molecular formula

Just like elements, compounds have names that distinguish them from other compounds. Although the compounds BaF_2 and BF_3 may appear to have similar chemical formulas, they have very different names. BaF_2 is *barium fluoride,* and BF_3 is *boron trifluoride.* When talking about these compounds, you have little chance for confusing their names. You can see that the names of these compounds reflect the elements from which the compounds are formed.

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Naming Ionic Compounds

Ionic compounds are formed by the strong attractions between cations and anions. Both ions are important to the compound's structure, so it makes sense that both ions are included in the name.

Names of cations include the elements of which they are composed

In many cases, the name of the cation is just like the name of the element from which it is made. You have already seen this for many cations. For example, when an atom of the element *sodium* loses an electron, a *sodium ion,* Na^+, forms. Similarly, when a *calcium* atom loses two electrons, a *calcium ion,* Ca^{2+}, forms. And when an *aluminum* atom loses three electrons, an *aluminum ion,* Al^{3+}, forms. These and other common cations are listed in **Table 4.** Notice how ions of Group 1 elements have a 1+ charge and ions of Group 2 elements have a 2+ charge.

Table 4 Some Common Cations

Ion name and symbol	Ion charge
Cesium ion, Cs^+	1+
Lithium ion, Li^+	
Potassium ion, K^+	
Rubidium ion, Rb^+	
Sodium ion, Na^+	
Barium ion, Ba^{2+}	2+
Beryllium ion, Be^{2+}	
Calcium ion, Ca^{2+}	
Magnesium ion, Mg^{2+}	
Strontium ion, Sr^{2+}	
Aluminum ion, Al^{3+}	3+

Table 5 **Some Common Anions**

Element name and symbol	Ion name and symbol	Ion charge
Fluor~~ine~~, F	Fluoride ion, F^-	1−
Chlor~~ine~~, Cl	Chloride ion, Cl^-	
Brom~~ine~~, Br	Bromide ion, Br^-	
Iod~~ine~~, I	Iodide ion, I^-	
Ox~~ygen~~, O	Oxide ion, O^{2-}	2−
Sulf~~ur~~, S	Sulfide ion, S^{2-}	
Nitr~~ogen~~, N	Nitride ion, N^{3-}	3−

Names of anions are altered names of elements

An anion that is made of one element has a name similar to the element. The difference is the name's ending. **Table 5** lists some common anions and shows how they are named. Just like most cations, anions of elements in the same group of the periodic table have the same charge.

NaF is made of sodium ions, Na^+, and fluoride ions, F^-. Therefore, its name is *sodium fluoride.* **Figure 18** shows how calcium chloride gets its name.

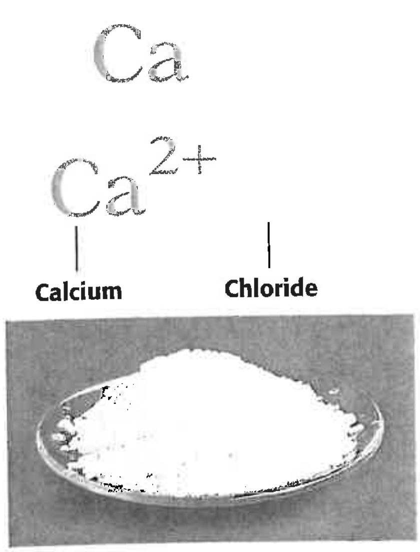


Figure 18
Ionic compounds are named for their positive and negative ions.

Some cation names must show their charge

Think about the compounds FeO and Fe_2O_3. According to the rules you have learned so far, both of these compounds would be named *iron oxide,* even though they are not the same compound. Fe_2O_3, a component of rust, is a reddish brown solid that melts at 1565°C. FeO, on the other hand, is a black powder that melts at 1420°C. These different properties tell us that they are different compounds and should have different names.

Iron is a transition metal. Transition metals may form several cations—each with a different charge. A few of these cations are listed in **Table 6.** The charge of the iron cation in Fe_2O_3 is different from the charge of the iron cation in FeO. In cases like this, the cation name must be followed by a Roman numeral in parentheses. The Roman numeral shows the cation's charge. Fe_2O_3 is made of Fe^{3+} ions, so it is named *iron(III) oxide.* FeO is made of Fe^{2+} ions, so it is named *iron(II) oxide.*

Table 6 **Some Transition Metal Cations**

Ion name	Ion symbol	Ion name	Ion symbol
Copper(I) ion	Cu^+	Chromium(II) ion	Cr^{2+}
Copper(II) ion	Cu^{2+}	Chromium(III) ion	Cr^{3+}
Iron(II) ion	Fe^{2+}	Cadmium(II) ion	Cd^{2+}
Iron(III) ion	Fe^{3+}	Titanium(II) ion	Ti^{2+}
Nickel(II) ion	Ni^{2+}	Titanium(III) ion	Ti^{3+}
Nickel(III) ion	Ni^{3+}	Titanium(IV) ion	Ti^{4+}

Determining the charge of a transition metal cation

How can you tell that the iron ion in Fe_2O_3 has a charge of 3+? Like all compounds, ionic compounds have a total charge of zero. This means that the total positive charges must equal the total negative charges. An oxide ion, O^{2-}, has a charge of 2−. Three of them have a total charge of 6−. That means the total positive charge in the formula must be 6+. For two iron ions to have a total charge of 6+, each ion must have a charge of 3+.

Writing Formulas for Ionic Compounds

You have seen how to determine the charge of each ion in a compound if you are given the compound's formula. Following a similar process, you can determine the chemical formula for a compound if you are given its name.

Math Skills

Writing Ionic Formulas What is the chemical formula for aluminum fluoride?

1. **List the symbols for each ion.**
   Symbol for an aluminum ion from ***Table 4:*** Al^{3+}
   Symbol for a fluoride ion from ***Table 5:*** F^-
2. **Write the symbols for the ions with the cation first.**
   $Al^{3+}F^-$
3. **Find the least common multiple of the ions' charges.**
   The least common multiple of 3 and 1 is 3. To make a neutral compound, you need a total of three positive charges and three negative charges.
   To get three positive charges: you need only one Al^{3+} ion because $1 \times 3+ = 3+$.
   To get three negative charges: you need three F^- ions because $3 \times 1- = 3-$.
4. **Write the chemical formula, indicating with subscripts how many of each ion are needed to make a neutral compound.**
   AlF_3

Practice HINT

Once you have determined a chemical formula, always check the formula to see if it makes a neutral compound. For this example, the aluminum ion has a charge of 3+. The fluoride ion has a charge of only 1−, but there are three of them for a total of 3−.

(3+) + (3−) = 0, so the charges balance, and the formula is neutral.

Practice

Writing Ionic Formulas

Write formulas for the following ionic compounds.

1. lithium oxide
2. beryllium chloride
3. titanium(III) nitride
4. cobalt(III) hydroxide

Table 7 **Prefixes Used to Name Covalent Compounds**

Number of atoms	Prefix
1	*mono-*
2	*di-*
3	*tri-*
4	*tetra-*
5	*penta-*
6	*hexa-*
7	*hepta-*
8	*octa-*
9	*nona-*
10	*deca-*

N_2O_4

Dinitrogen tetroxide

Figure 19

One molecule of *di*nitrogen *tetr*oxide has *two* nitrogen atoms and *four* oxygen atoms.

empirical formula the composition of a compound in terms of the relative numbers and kinds of atoms in the simplest ratio

Naming Covalent Compounds

Covalent compounds, like SiO_2 (silicon dioxide) and CO_2 (carbon dioxide), are named using different rules than those used to name ionic compounds.

Numerical prefixes are used to name covalent compounds of two elements

For two-element covalent compounds, numerical prefixes tell how many atoms of each element are in the molecule. ***Table 7*** lists some of these prefixes. If there is only one atom of the first element, it does not get a prefix. Whichever element is farther to the right in the periodic table is named second and ends in *-ide.*

There are one boron atom and three fluorine atoms in *boron trifluoride,* BF_3. *Dinitrogen tetroxide,* N_2O_4, is made of two nitrogen atoms and four oxygen atoms, as shown in ***Figure 19.*** Notice how the *a* in *tetra* is dropped to make the name easier to say.

Chemical Formulas for Covalent Compounds

Emeralds, shown in ***Figure 20,*** are made of a mineral called beryl. The chemical formula for beryl is $Be_3Al_2Si_6O_{18}$. But how did people determine this formula? It took some experiments. Chemical formulas like this one were determined by first measuring the mass of each element in the compound.

A compound's simplest formula is its empirical formula

Once the mass of each element in a sample of the compound is known, scientists can calculate the compound's **empirical formula,** or simplest formula. An empirical formula tells us the smallest whole-number ratio of atoms that are in a compound. Formulas for most ionic compounds are empirical formulas.

Covalent compounds have empirical formulas, too. The empirical formula for water is H_2O. It tells you that the ratio of hydrogen atoms to oxygen atoms is 2:1. Scientists have to analyze unknown compounds to determine their empirical formulas.

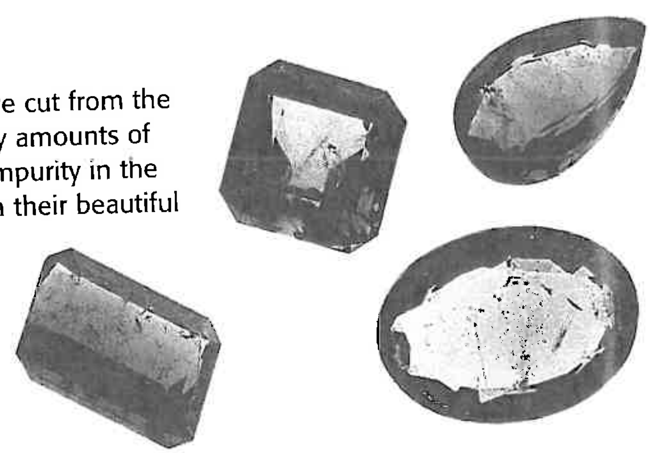


Figure 20

Emerald gemstones are cut from the mineral beryl. Very tiny amounts of chromium(III) oxide impurity in the gemstones gives them their beautiful green color.

Determining empirical formulas

If a 142 g sample of an unknown compound contains only the elements phosphorus and oxygen and is found to contain 62 g of P and 80 g of O, its empirical formula is easy to calculate. This process is shown in ***Figure 21.***

Exactly 142 g of Unknown Compound

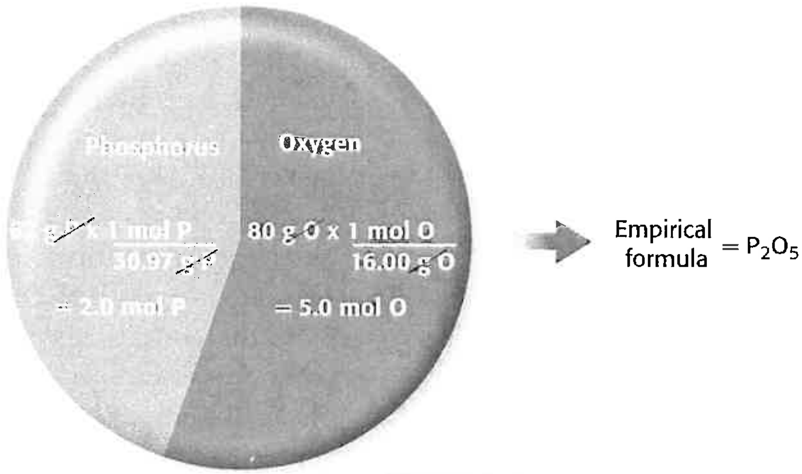


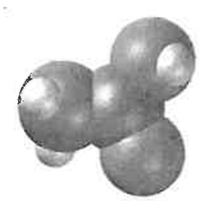
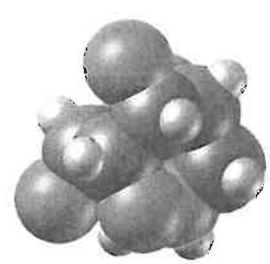
Figure 21

Once you determine the mass of each element in a compound, you can calculate the amount of each element in moles. The empirical formula for the compound is the ratio of these amounts.

Different compounds can have the same empirical formula

It's possible for several compounds to have the same empirical formula because empirical formulas only represent a ratio of atoms. Formaldehyde, acetic acid, and glucose all have the empirical formula CH_2O, as shown in ***Table 8.*** These three compounds are not at all alike, though. Formaldehyde is sometimes used to keep dead organisms from decaying so that they can be studied. Acetic acid gives vinegar its sour taste and strong smell. And glucose is a sugar that plays a very important role in your body chemistry. Some other formula must be used to distinguish these three very different compounds.

Table 8 **Empirical and Molecular Formulas for Some Compounds**

Compound	Empirical formula	Molar mass	Molecular formula	Structure
Formaldehyde	CH_2O	30.03 g/mol	CH_2O	
Acetic acid	CH_2O	60.06 g/mol	$2 \times CH_2O = C_2H_4O_2$	
Glucose	CH_2O	180.18 g/mol	$6 \times CH_2O = C_6H_{12}O_6$	

Molecular formulas are determined from empirical formulas

molecular formula a chemical formula that shows the number and kinds of atoms in a molecule, but not the arrangement of atoms

Formaldehyde, acetic acid, and glucose are all covalent compounds made of molecules. They all have the same empirical formula, but each compound has its own **molecular formula.** A compound's molecular formula tells you how many atoms are in one molecule of the compound.

In some cases, a compound's molecular formula is the same as its empirical formula. The empirical and molecular formulas for water are both H_2O. You can see from ***Table 8*** on the previous page that this is also true for formaldehyde. In other cases, a compound's molecular formula is a small whole-number multiple of its empirical formula. The molecular formula for acetic acid is two times its empirical formula, and that of glucose is six times its empirical formula.

SECTION 3 REVIEW

SUMMARY

- To name an ionic compound, first name the cation and then the anion.
- If an element can form cations with different charges, the cation name must include the ion's charge. The charge is written as a Roman numeral in parentheses.
- Prefixes are used to name covalent compounds made of two different elements.
- An empirical formula tells the relative numbers of atoms of each element in a compound.
- A molecular formula tells the actual numbers of atoms in one molecule of a compound.
- Covalent compounds have both empirical and molecular formulas.

1. **Name** the following ionic compounds, specifying the charge of any transition metal cations.
   a. FeI_2 c. $CrCl_2$
   b. MnF_3 d. CuS
2. **Name** the following covalent compounds:
   a. As_2O_5 c. P_4S_3 e. SeO_2
   b. SiI_4 d. P_4O_{10} f. PCl_3
3. **Explain** why Roman numerals must be included in the names of MnO_2 and Mn_2O_7. Name both of these compounds.
4. **Identify** how many fluorine atoms are in one molecule of sulfur hexafluoride.

Math Skills

5. **Critical Thinking** An unknown compound contains 49.47% C, 5.20% H, 28.85% N, and a certain percentage of oxygen. What percentage of the compound must be oxygen? (**Hint:** The sum of the percentages should equal 100%.)
6. What is the charge of the cadmium cation in cadmium cyanide, $Cd(CN)_2$, a compound used in electroplating? Explain your reasoning.
7. Determine the chemical formulas for the following ionic compounds:
   a. magnesium sulfate c. chromium(II) fluoride
   b. rubidium bromide d. nickel(I) carbonate

SECTION 4

Organic and Biochemical Compounds

INTEGRATING TECHNOLOGY and Society

OBJECTIVES

- **Describe** how carbon atoms bond covalently to form organic compounds.
- **Identify** the names and structures of groups of simple organic compounds and polymers.
- **Identify** what makes up the polymers that are essential to life.

KEY TERMS

organic compound
polymer
carbohydrate
protein
amino acid

The word *organic* has many different meanings. Most people associate the word *organic* with living organisms. Perhaps you have heard of or eaten organically grown fruits or vegetables. What this means is that they were grown using fertilizers and pesticides that come from plant and animal matter. In chemistry, the word *organic* is used to describe certain compounds.

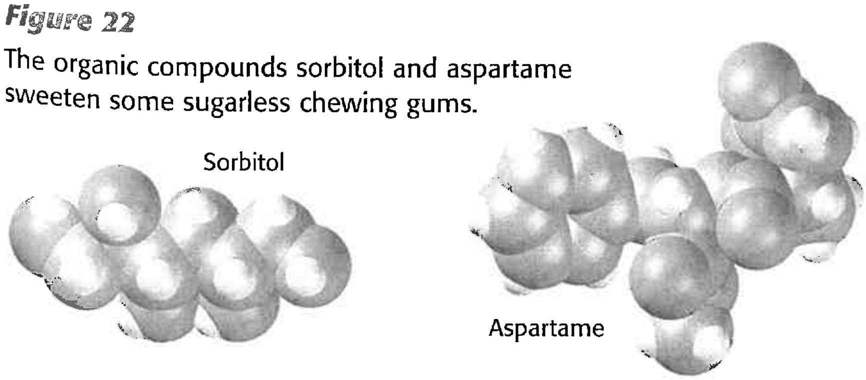
Organic Compounds

An **organic compound** is a covalently bonded compound made of molecules. Organic compounds contain carbon and, almost always, hydrogen. Other atoms, such as oxygen, nitrogen, sulfur, and phosphorus, are also found in some organic compounds.

organic compound a covalently bonded compound that contains carbon, excluding carbonates and oxides

Many ingredients of familiar substances are organic compounds. The effective ingredient in aspirin is a form of the organic compound acetylsalicylic acid, $C_9H_8O_4$. Sugarless chewing gum also has organic compounds as ingredients. Two ingredients are the sweeteners sorbitol, $C_6H_{14}O_6$, and aspartame, $C_{14}H_{18}N_2O_5$, both of which are shown in **Figure 22**.

Figure 22
The organic compounds sorbitol and aspartame sweeten some sugarless chewing gums.



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Carbon atoms form four covalent bonds in organic compounds

When a compound is made of only carbon and hydrogen atoms, it is called a *hydrocarbon*. Methane, CH_4, is the simplest hydrocarbon. Its structure is shown in Figure 23. Methane gas is formed when living matter, such as plants, decay, so it is often found in swamps and marshes. The natural gas used in Bunsen burners is also mostly methane. Carbon atoms have four valence electrons to use for bonding. In methane, each of these electrons forms a different C–H single bond.

A carbon atom may also share two of its electrons with two from another atom to form a double bond. Or a carbon atom may share three electrons to form a triple bond. However, a carbon atom can never form more than a total of four bonds.

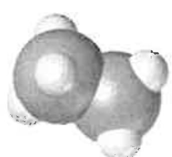
Methane

Figure 23
Methane is an alkane that has four C–H bonds.

Alkanes have single covalent bonds

Alkanes are hydrocarbons that have only single covalent bonds. Figure 23 shows that methane, the simplest alkane, has only C–H bonds. But alkanes can also have C–C bonds. You can see from Figure 24 that ethane, C_2H_6, has a C–C bond in addition to six C–H bonds. Notice how each carbon atom in both of these compounds bonds to four other atoms.

Many gas grills are fueled by another alkane, propane, C_3H_8. Propane is made of three bonded carbon atoms. Each carbon atom on the end of the molecule forms three bonds with three hydrogen atoms, as shown in Figure 25. Each of these end carbon atoms forms its fourth bond with the central carbon atom. The central carbon atom shares its two remaining electrons with two hydrogen atoms. You can see only one hydrogen atom bonded to the central carbon atom in Figure 25 because the second hydrogen atom is on the other side.



Ethane

Figure 24
Ethane, another alkane, has one C–C bond and six C–H bonds.

Figure 25
This camper is preparing his dinner on a gas grill fueled by propane. Propane is an alkane that has two C–C bonds and eight C–H bonds.

Arrangements of carbon atoms in alkanes

The carbon atoms in methane, ethane, and propane all line up in a row because that is their only possible arrangement. When there are more than three bonded carbon atoms, the carbon atoms do not always line up in a row. When they do line up, the alkane is called a *normal alkane,* or *n*-alkane for short. ***Table 9*** shows chemical formulas for the *n*-alkanes that have up to 10 carbon atoms. *Condensed structural formulas* are also included in the table to show how the atoms bond.

The carbon atoms in any alkane with more than three carbon atoms can have more than one possible arrangement. Carbon atom chains may be branched or unbranched, and they can even form rings. ***Figure 26*** shows some of the possible ways six carbon atoms can be arranged when they form hydrocarbons with only single covalent bonds.

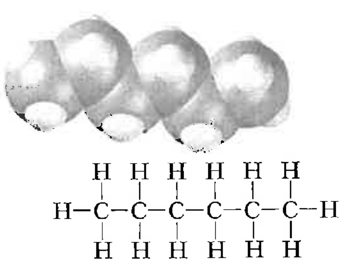
Table 9 **First 10 *n*-Alkanes**

n-Alkane	Molecular formula	Condensed structural formula
Methane	CH_4	CH_4
Ethane	C_2H_6	CH_3CH_3
Propane	C_3H_8	$CH_3CH_2CH_3$
Butane	C_4H_{10}	$CH_3(CH_2)_2CH_3$
Pentane	C_5H_{12}	$CH_3(CH_2)_3CH_3$
Hexane	C_6H_{14}	$CH_3(CH_2)_4CH_3$
Heptane	C_7H_{16}	$CH_3(CH_2)_5CH_3$
Octane	C_8H_{18}	$CH_3(CH_2)_6CH_3$
Nonane	C_9H_{20}	$CH_3(CH_2)_7CH_3$
Decane	$C_{10}H_{22}$	$CH_3(CH_2)_8CH_3$

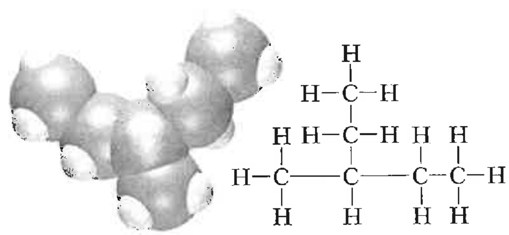
Alkane chemical formulas usually follow a pattern

Except for cyclic alkanes like cyclohexane, the chemical formulas for alkanes follow a special pattern. The number of hydrogen atoms is always two more than twice the number of carbon atoms. This pattern is shown by the chemical formula C_nH_{2n+2}.

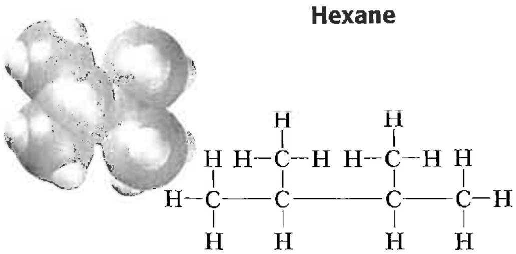
Some Six-Carbon Alkanes



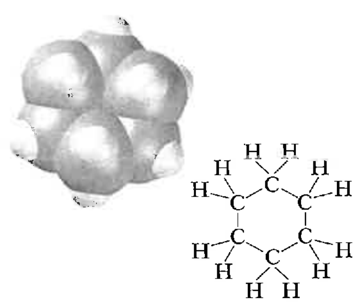
Hexane



2-Methylpentane



2,3-Dimethylbutane

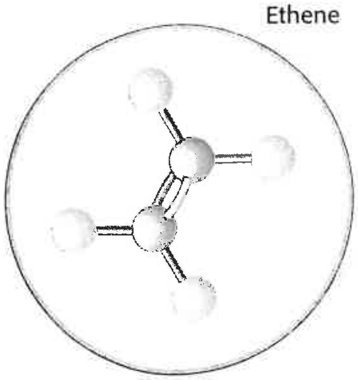


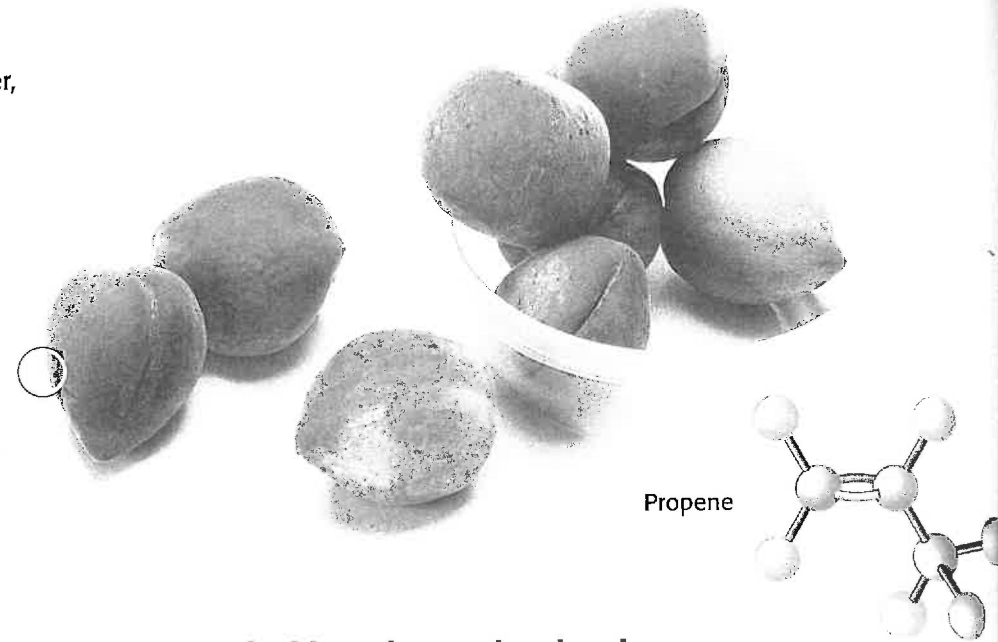
cyclohexane

Figure 26

Hexane, 2-methylpentane, 2,3-dimethylbutane, and cyclohexane are some of the forms six carbon atoms with single covalent bonds may take.

Figure 27
The peaches in this plastic container, which is made by joining propene molecules, release ethene gas as they ripen.



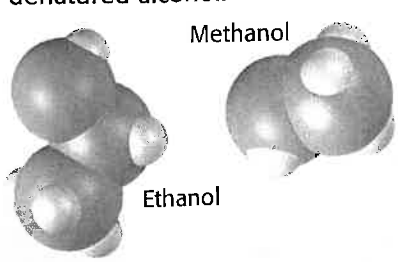


Alkenes have double carbon-carbon bonds

Alkenes are also hydrocarbons. Alkenes are different from alkanes because they have at least one double covalent bond between carbon atoms. This is shown by C=C. Alkenes are named like alkanes but with the *-ane* ending replaced by *-ene*.

The simplest alkene is ethene (or ethylene), C_2H_4. Ethene is formed when fruit ripens. Propene (or propylene), C_3H_6, is used to make rubbing alcohol and some plastics. The structures of both compounds are shown in ***Figure 27.***

Figure 28
Many products contain a mixture of the alcohols methanol and ethanol. This mixture is called "denatured alcohol."



Alcohols have –OH groups

Alcohols are organic compounds that are made of oxygen as well as carbon and hydrogen. Alcohols have *hydroxyl*, or –OH, groups. The alcohol methanol, CH_3OH, is sometimes added to another alcohol ethanol, CH_3CH_2OH, to make denatured alcohol. Denatured alcohol is found in many familiar products, as shown in ***Figure 28.*** Isopropanol, which is found in rubbing alcohol, has the chemical formula C_3H_8O, or $(CH_3)_2CHOH$. You may have noticed how the names of these three alcohols all end in *-ol*. This is true for most alcohols.

Alcohol molecules behave similarly to water molecules

A methanol molecule is like a water molecule except that one of the hydrogen atoms is replaced by a methyl, or $-CH_3$, group. Just like water molecules, neighboring alcohol molecules are attracted to one another. That's why many alcohols are liquids at room temperature. Alcohols have much higher boiling points than alkanes of similar size.

Polymers

What do the DNA inside the cells of your body, rubber, wood, and plastic milk jugs have in common? They are all made of large molecules called **polymers.**

Many polymers have repeating subunits

Some small organic molecules bond to form long chains called polymers. Polyethene, which is also known as polyethylene or polythene, is the polymer plastic milk jugs are made of. The name *polyethene* tells its structure. *Poly* means "many." *Ethene* is an alkene whose chemical formula is C_2H_4. Therefore, polyethene is "many ethenes," as shown in ***Figure 29.*** The original molecule, in this case C_2H_4, is called a *monomer.*

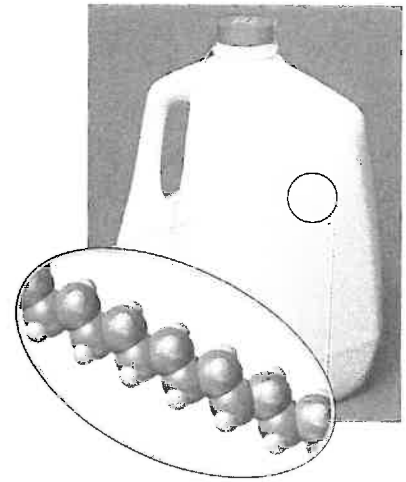


Figure 29 Polyethene

Polyethene is a polymer made of many repeating ethene units. As the polymer forms, ethene's double bonds are replaced by single bonds.

Some polymers are natural; others are man-made

Rubber, wood, cotton, wool, starch, protein, and DNA are all natural polymers. Man-made polymers are usually either plastics or fibers. Most plastics are flexible and easily molded, whereas fibers form long, thin strands.

Some polymers can be used as both plastics and fibers. For example, polypropene (polypropylene) is molded to make plastic containers, like the one shown in ***Figure 27,*** as well as some parts for cars and appliances. It is also used to make ropes, carpet, and artificial turf for athletic fields.

polymer a large molecule that is formed by more than five monomers, or small units

The elasticity of a polymer is determined by its structure

As with all substances, the properties of a polymer are determined by its structure. Polymer molecules are like long, thin chains. A small piece of plastic or a single fiber is made of billions of these chains. Polymer molecules can be likened to spaghetti. Like a bowl of spaghetti, the chains are tangled but can slide over each other. Milk jugs are made of polyethene, a plastic made of such noodlelike chains. You can crush or dent a milk jug because the plastic is flexible. Once the jug has been crushed, though, it does not return to its original shape. That's because polyethene is not elastic.

When the chains are connected to each other, or cross-linked, the polymer's properties change. Some become more elastic and can be likened to a volleyball net. Like a volleyball net, an elastic polymer can stretch. When the polymer is released, it returns to its original shape. Rubber bands are elastic polymers. As long as a rubber band is not stretched too far, it can shrink back to its original form.

Quick ACTIVITY

Polymer Memory

Polymers that return to their original shape after stretching can be thought of as having a "memory." In this activity, you will compare the memory of a rubber band with that of the plastic rings that hold a six-pack of cans together.

1. Which polymer stretches better without breaking?
2. Which one has better memory?
3. Warm the stretched six-pack holder over a hot plate, being careful not to melt it. Does it retain its memory?

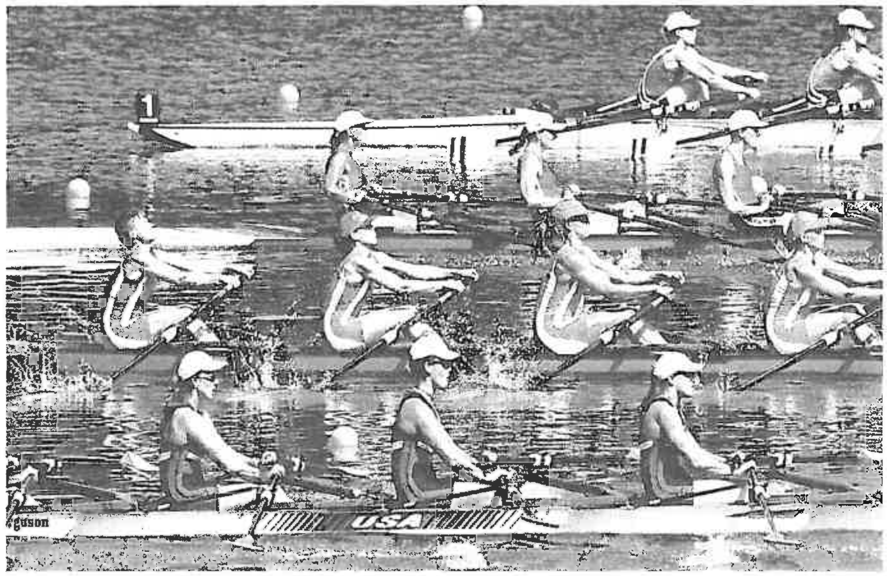


Figure 30
Athletes often eat lots of foods that are high in carbohydrates the day before a big event. This provides them with a ready supply of stored energy.

Biochemical Compounds

carbohydrate any organic compound that is made of carbon, hydrogen, and oxygen and that provides nutrients to the cells of living things

protein an organic compound that is made of one or more chains of amino acids and that is a principal component of all cells

amino acid any one of 20 different organic molecules that contain a carboxyl and an amino group and that combine to form proteins

Biochemical compounds are naturally occurring organic compounds that are very important to living things. Carbohydrates give you energy. Proteins form important parts of your body, like muscles, tendons, fingernails, and hair. The DNA inside your cells gives your body information about what proteins you need. Each of these biochemical compounds is a polymer.

Many carbohydrates are made of glucose

The sugar glucose is a **carbohydrate.** Glucose provides energy to living things. Starch, also a carbohydrate, is made of many bonded glucose molecules. Plants store their energy as chains of starch.

Starch chains pack closely together in a potato or a pasta noodle. When you eat such foods, enzymes in your body break down the starch, making glucose available as a nutrient for your cells. Glucose that is not needed right away is stored as *glycogen.* When you become active, glycogen breaks apart and glucose molecules give you energy. Athletes often prepare themselves for their event by eating starchy foods. They do this so they will have more energy when they exert themselves later on, as shown in ***Figure 30.***

Proteins are polymers of amino acids

Many polymers are made of only one kind of molecule. Starch, for example, is made of only glucose. **Proteins,** on the other hand, are made of many different molecules that are called **amino acids.** Amino acids are made of carbon, hydrogen, oxygen, and nitrogen. Some amino acids also contain sulfur. There are 20 amino acids found in naturally occurring proteins. The way these amino acids combine determines which protein is made.

Proteins are long chains made of amino acids. A small protein, insulin, is shown in ***Figure 31.*** Many proteins are made of thousands of bonded amino acid molecules. This means that millions of different proteins can be made with very different properties. When you eat foods that contain proteins, such as cheese, your digestive system breaks down the proteins into individual amino acids. Later, your cells bond the amino acids in a different order to form whatever protein your body needs.

DNA is a polymer with a complex structure

Your DNA determines your entire genetic makeup. It is made of organic molecules containing carbon, hydrogen, oxygen, nitrogen, and phosphorus.

Figuring out the complex structure of DNA was one of the greatest scientific challenges of the twentieth century. Instead of forming one chain, like many proteins and polymers, DNA is in the form of paired chains, or strands. It has the shape of a twisted ladder known as a *double helix.*

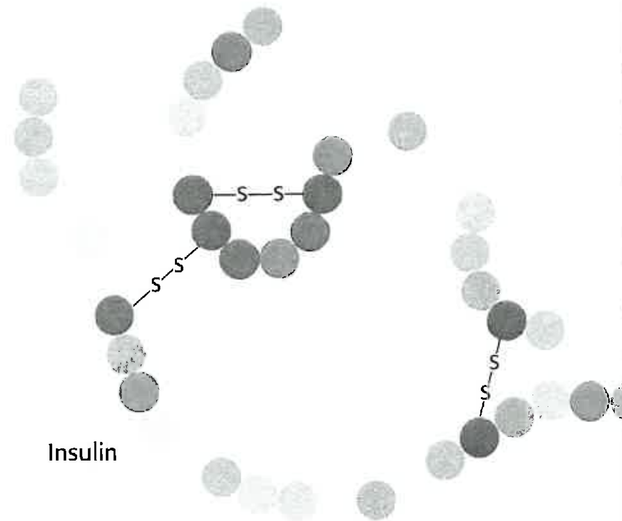


Figure 31
Insulin controls the use and storage of glucose in your body. Each color in the chain represents a different amino acid.

Quick Lab

What properties does a polymer have?

Materials *water*, *white glue*, *borax*, *250 mL beakers (2)*, *plastic spoons*, *plastic sandwich bags*

SAFETY CAUTION Wear safety goggles, gloves, and a laboratory apron. Be sure to work in an open space and wear clothes that can be cleaned easily.

1. In one beaker, mix 4 g borax with 100 mL water, and stir well.
2. In the second beaker, mix equal parts of glue and water. This solution will determine the amount of new material made. The volume of diluted glue should be between 100 and 200 mL.
3. Pour the borax solution into the beaker containing the glue, and stir well using a plastic spoon.
4. When it becomes too thick to stir, remove the material from the cup and knead it with your fingers. You can store this new material in a plastic sandwich bag.

Analysis

1. What happens to the new material when it is stretched, or rolled into a ball and bounced?
2. Compare the properties of the glue with those of the new material.
3. The properties of the new material resulted from the bonds between the borax and the glue particles. If too little borax were used, in what way would the properties of the new material differ?
4. Does the new material have the properties of a polymer? Explain how you reached this conclusion.

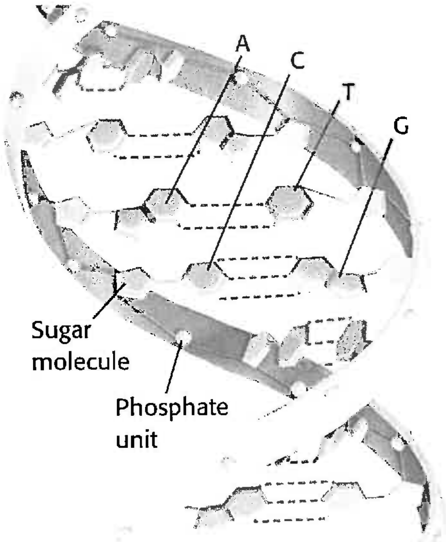


Figure 32
In DNA, cytosine, C, always pairs with guanine, G. Adenine, A, always pairs with thymine, T.

Your body has many copies of your DNA

Most cells in your body have a copy of your genetic material in the form of chromosomes made of DNA. For new cells to have the right amount of DNA, the DNA must be copied. Copying cannot happen unless the two DNA strands are first separated.

Proteins called helicases unwind DNA by separating the paired strands. Proteins called DNA polymerases then pair up new monomers with those already on the strand. At the end of this process, there are two strands of DNA.

DNA's structure resembles a twisted ladder

DNA's structure can be likened to a ladder. Alternating sugar molecules and phosphate units correspond to the ladder's sides, as shown in ***Figure 32.*** Attached to each sugar molecule is one of four possible DNA monomers—adenine, thymine, cytosine, or guanine. These DNA monomers pair up with DNA monomers attached to the opposite strand in a predictable way, as shown in ***Figure 32.*** Together, the DNA monomer pairs make up the rungs of the ladder.

SECTION 4 REVIEW

SUMMARY

- Alkanes have C–C and C–H bonds.
- Alkenes have C=C and C–H bonds.
- Alcohols have one or more –OH groups.
- Polymers form when small organic molecules bond to form long chains.
- Biochemical compounds important to living things are often polymers.
- Sugars and starches are carbohydrates that provide energy.
- Amino acids bond to form polymers called proteins.
- DNA is a polymer shaped like a twisted ladder.

1. **Identify** the following compounds as alkanes, alkenes, or alcohols based on their names:
   a. 2-methylpentane
   b. 3-methyloctane
   c. 1-nonene
   d. 2-butanol
   e. 3-heptene
   f. cyclohexanol
2. **Explain** why the compound CBr_5 does not exist. Give an acceptable chemical formula for a compound made of only carbon and bromine.
3. **Determine** how many hydrogen atoms a compound has if it is a hydrocarbon and its carbon atom skeleton is C=C–C=C.
4. **Compare** the structures and properties of carbohydrates with those of proteins.
5. **Identify** which compound is an alkane: CH_2O, C_6H_{14}, or C_3H_4. Explain your reasoning.
6. **Critical Thinking** *Alkynes*, like alkanes and alkenes, are hydrocarbons. Alkynes have carbon-carbon triple covalent bonds, or C≡C bonds. Draw the structure of the alkyne that has the chemical formula C_3H_4. Can you guess the name of this compound?

Study Skills

KWL Notes

KWL stands for "what I **K**now—what I **W**ant to know—what I **L**earned". The KWL strategy helps you relate your new ideas and concepts with those you have already learned.

1. **Read the section objectives.**

   We'll use the first objective, "Distinguish between compounds and mixtures," from Section 1.

2. **Divide a blank sheet of paper into three columns, and label the columns "What I know," "What I want to know," and "What I learned."**
3. **In the first column, write what information you know about the objective.**
4. **In the second column, write the information that you want to know about the objective.**
5. **After you have read the section, write in the third column what you have learned.**

What I know	What I want to know	What I have learned
water is a compound mixtures can be separated grape juice is a mixture	how to distinguish between compounds and mixture	Compounds are held together by chemical bonds, but mixtures are not. Compounds are always made of the same proportion of elements, but mixtures are not. Substances in mixtures keep their own identities.

Practice

Use the remaining objectives from Section 1 to create a table of KWL notes. Compare the ideas you wrote down in the first column with the items in the third column. If some of your initial ideas are incorrect, cross them out.

CHAPTER 5 REVIEW

Chapter Highlights

Before you begin, review the summaries of the key ideas of each section, found at the end of each section. The key vocabulary terms are listed on the first page of each section.

UNDERSTANDING CONCEPTS

1. Which of the following is not true of compounds made of molecules?
   a. They may exist as liquids.
   b. They may exist as solids.
   c. They may exist as gases.
   d. They always have very high melting points.

2. Compounds are different from mixtures because
   a. compounds are held together by chemical bonds.
   b. each substance in a compound maintains its own properties.
   c. each original substance in a compound remains chemically unchanged.
   d. mixtures are held together by chemical bonds.

3. What can be learned by looking at a model of a compound?
   a. chemical structure
   b. the strength of attraction between molecules
   c. the electron configuration of the atoms involved
   d. the types of bonds formed between the atoms

4. Crystals of salt, called sodium chloride, are
   a. made of molecules.
   b. made of a network of ions.
   c. chemically similar to sugar crystals.
   d. weak solids.

5. Ionic solids
   a. are formed by networks of ions that have the same charge.
   b. melt at very low temperatures.
   c. have very regular structures.
   d. are sometimes found as gases at room temperature.

6. A chemical bond can be defined as
   a. a force that joins atoms together.
   b. a force blending nuclei together.
   c. a force caused by electric repulsion.
   d. All of the above

7. Which substance has ionic bonds?
   a. CO **c.** KCl
   b. CO_2 **d.** O_2

8. Covalent bonds
   a. join atoms in some solids, liquids, and gases.
   b. usually join one metal atom to another.
   c. are always broken when a substance is dissolved in water.
   d. join molecules in substances that have molecular structures.

9. A compound has the empirical formula CH_2. Its molecular formula could be
   a. CH_2. **c.** C_4H_8.
   b. C_2H_4. **d.** Any of the above

10. The chemical formula for calcium chloride is
    a. CaCl. **c.** Ca_2Cl.
    b. $CaCl_2$. **d.** Ca_2Cl_2.

11. The empirical formula of a molecule
    a. can be used to identify the molecule.
    b. is sometimes the same as the molecular formula for the molecule.
    c. is used to name the molecule.
    d. shows how atoms bond in the molecule.

12. All organic compounds
    a. come only from living organisms.
    b. contain only carbon and hydrogen.
    c. are biochemical compounds.
    d. have atoms connected by covalent bonds.

USING VOCABULARY

13. Compare the *chemical structure* of oxygen difluoride with that of carbon dioxide. Which compound has the larger *bond angle*?

Carbon dioxide

Oxygen difluoride

14. Determine whether the *chemical formula* $C_5H_5N_5$ is the *empirical formula* or *molecular formula* for adenine.

15. Name the following *covalent* compounds:
    a. SF_4
    b. N_2O
    c. PCl_3
    d. P_2O_5

16. Compare the *metallic bonds* of copper with the *ionic bonds* of copper(II) sulfide. Why are metals rather than ionic solids used in electrical wiring?

17. Explain why *proteins* and *carbohydrates* are *polymers*. What is each polymer made of?

18. Discuss two ways that atoms share electrons using the terms *nonpolar covalent bonds* and *polar covalent bonds.*

19. Compare *ionic bonds* and *covalent bonds,* and list two differences between them.

20. What does an *organic compound* contain? List several organic compounds that can be found in your body or in your daily life.

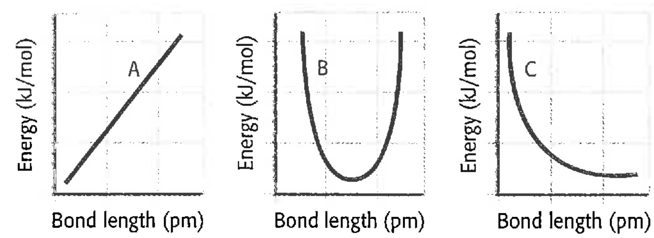
21. Describe the type of bonds that *alkanes* and *alkenes* have. How are they different? Are there any alkanes or alkenes that you are familiar with?

22. What is a *hydroxyl* group? What organic compound contains a hydroxyl group?

23. What is a *hydrocarbon* made of? Name the most simple hydrocarbon.

BUILDING MATH SKILLS

24. **Graphing** Which of the graphs below shows how bond length and bond energy are related? Describe the flawed relationships shown by each of the other graphs.



25. **Graphing** The melting points of elements in the same group of the periodic table follow a pattern. A similar pattern is also seen among the melting points of ionic compounds when the cations are made from elements that are in the same group. To see this, plot the melting point of each of the ionic compounds in the table below on the y-axis and the average atomic mass of the element that the cation is made from on the x-axis.
    a. What trend do you notice in the melting points as you move down Group 2?
    b. $BeCl_2$ has a melting point of 405°C. Is this likely to be an ionic compound like the others? Explain. (**Hint:** Locate beryllium in the periodic table.)
    c. Predict the melting point of the ionic compound $RaCl_2$. (**Hint:** Check the periodic table, and compare radium's location with the location of magnesium, calcium, strontium, and barium.)

Compound	Melting point (°C)
$MgCl_2$	714
$CaCl_2$	782
$SrCl_2$	875
$BaCl_2$	963

CHAPTER 5 REVIEW

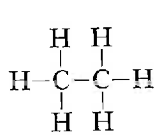
26. **Writing Ionic Formulas** Determine the chemical formula for each of the following ionic compounds:
    - **a.** strontium nitrate, an ingredient in some fireworks, signal flares, and matches
    - **b.** sodium cyanide, a compound used in electroplating and treating metals
    - **c.** chromium(III) hydroxide, a compound used to tan and dye substances
    - **d.** aluminum nitride, a compound used in the computer-chip-making process
    - **e.** tin(II) fluoride, the source of fluoride for many toothpastes
    - **f.** potassium sulfate, a compound used in the glass-making process

THINKING CRITICALLY

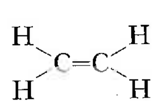
27. **Evaluating Data** A substance is a solid at room temperature. It is unable to conduct electricity as a solid but can conduct electricity as a liquid. This compound melts at 755°C. Would you expect this compound to have ionic, metallic, or covalent bonds?

28. **Creative Thinking** Dodecane is a combustible organic compound used in jet fuel research. It is an *n*-alkane made of 12 carbon atoms. How many hydrogen atoms does dodecane have? Draw the structural formula for dodecane.

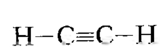
29. **Applying Knowledge** The length of a bond depends upon its type. Predict the relative lengths of the carbon-carbon bonds in the following molecules, and explain your reasoning.



Ethane



Ethene



Ethyne

30. **Critical Thinking** A classmate insists that sodium gains a positive charge when it becomes an ion because it gains a proton. Explain this student's error.

31. **Applying Knowledge** Compare the three types of bonds based on what happens to the valence electrons of the atoms.

32. **Applying Knowledge** In addition to carbon and hydrogen atoms, list four elements that can bond to carbon in organic compounds.

33. **Critical Thinking** Describe what attractive force(s) must be overcome to melt ice.

34. **Applying Knowledge** How many pairs of electrons are shared in the following types of bonds?
    - **a.** a single bond
    - **b.** a double bond
    - **c.** a triple bond

35. **Understanding Systems** Explain why most metals are malleable and ductile but ionic crystals are not.

DEVELOPING LIFE/WORK SKILLS

36. **Working Cooperatively** For one day, write down all of the ionic compounds listed on the labels of the foods you eat. Also write down the approximate mass you eat of each compound. As a class, make a master list in the form of a computer spreadsheet that includes all of the ionic compounds eaten by the whole class. Identify which compounds were eaten by the most people. Together, create a poster describing the dietary guidelines for the ionic compound that was eaten most often.

COMPUTER SKILL

37. **Making Decisions** People on low-sodium diets must limit their intake of table salt. Luckily, there are salt substitutes that do not contain sodium. Research different kinds of salt substitutes, and describe how each one affects your body. Determine which salt substitute you would use if you were on a low-sodium diet.

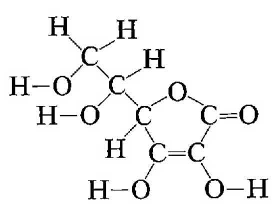
38. **Locating Information** Numerical recycling codes identify the composition of a plastic so that it can be sorted and recycled. For each of the recycling codes, 1–6, identify the plastic, its physical properties, and at least one product made of this plastic.

39. **Interpreting and Communicating** Covalently bonded solids, such as silicon, an element used in computer components, are harder than some pure metals. Research theories that explain the hardness of covalently bonded solids and their usefulness in the computer industry. Present your findings to the class.

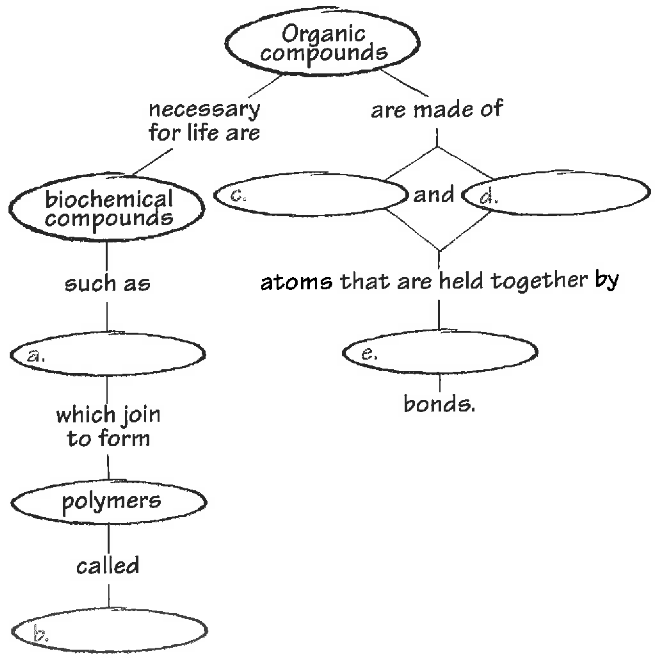
INTEGRATING CONCEPTS

40. **Connection to Health** The figure below shows how atoms are bonded in a molecule of vitamin C. Which elements is vitamin C made of? What is its molecular formula? Write a paragraph explaining some of the health benefits of taking vitamin C supplements.

WRITING SKILL



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



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Topic: Vitamin C SciLinks code: HK4147

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Skills Practice Lab

Introduction

Many polymers are able to "bounce back" after they are stretched, bent, or compressed. In this lab, you will compare the bounce heights of two balls made from different polymers.

Objectives

- ***Synthesize*** two different polymers, ***shape*** each into a ball, and ***measure*** how high each ball bounces.
- USING SCIENTIFIC METHODS ***Conclude*** which polymer would make a better toy ball.

Materials

acetic acid solution (vinegar), 5%
container, 2 L
ethanol solution, 50%
graduated cylinder, 10 mL
graduated cylinders, 25 mL (2)
liquid latex
meterstick
paper cups, medium-sized (2)
paper towels
sodium silicate solution
water, deionized
wooden craft sticks (2)

Comparing Polymers

Procedure

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

Making Latex Rubber

SAFETY CAUTION If you get a chemical on your skin or clothing, wash it off with lukewarm water while calling to your teacher. If you get a chemical in your eyes, flush it out immediately at the eyewash station and alert your teacher.

2. Pour 1 L of deionized water into a 2 L container.
3. Use a 25 mL graduated cylinder to pour 10 mL of liquid latex into one of the paper cups.
4. Clean the graduated cylinder thoroughly with soap and water, then rinse it with deionized water and use it to add 10 mL of deionized water to the liquid latex.
5. Use the same graduated cylinder to add 10 mL of acetic acid solution to the liquid latex-water mixture.
6. Stir the mixture with a wooden craft stick. As you stir, a "lump" of the polymer will form around the stick.
7. Transfer the stick and the attached polymer to the 2 L container. While keeping the polymer underwater, gently pull it off the stick with your gloved hands.
8. Squeeze the polymer underwater to remove any unreacted chemicals, shape it into a ball, and remove the ball from the water.
9. Make the ball smooth by rolling it between your gloved hands. Set the ball on a paper towel to dry while you continue with the next part of the lab.

Bounce Heights of Polymers

Polymer	Bounce height (cm) Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
Latex rubber						
Ethanol-silicate						

10. Wash your gloved hands with soap and water, then remove the gloves and dispose of them. Wash your hands again with soap and water.

Making an Ethanol-silicate Polymer

SAFETY CAUTION Put on a fresh pair of gloves. Ethanol is flammable, so make sure there are no flames or other heat sources anywhere in the laboratory.

11. Use a clean 25 mL graduated cylinder to pour 12 mL of sodium silicate solution into the clean paper cup.
12. Use a 10 mL graduated cylinder to add 3 mL of the ethanol solution to the sodium silicate solution.
13. Stir the mixture with the clean wooden craft stick until a solid polymer forms.
14. Remove the polymer with your gloved hands, and gently press it between your palms until you form a ball that does not crumble. This activity may take some time. Occasionally dripping some tap water on the polymer might be helpful.
15. When the ball no longer crumbles, dry it very gently with a paper towel.
16. Repeat step 10, and put on a fresh pair of gloves.
17. Examine both polymers closely. Record in your lab report how the two polymers are alike and how they are different.
18. Use a meterstick to measure the highest bounce height of each ball when each is dropped from a height of 1 m. Drop each ball five times, and record the highest bounce height each time in your data table.

Analysis

1. Calculate the average bounce height for each ball by adding the five bounce heights and dividing by 5. Record the averages in your data table.
2. Based on only their bounce heights, which polymer would make a better toy ball?

Conclusions

3. Suppose that making a latex rubber ball costs 22 cents and that making an ethanol-silicate ball costs 25 cents. Does this fact affect your conclusion about which polymer would make a better toy ball? Besides cost, what are other important factors that should be considered?