

BIG Idea

Just over 110 elements combine with chemical bonds to form a nearly infinite number of compounds.

20.1 Stability in Bonding**MAIN Idea**

When atoms form compounds, each atom is more stable in the compound than it was by itself.

20.2 Types of Bonds**MAIN Idea**

Atoms form ionic bonds by transferring electrons and form covalent bonds by sharing electrons.

20.3 Writing Formulas and Naming Compounds**MAIN Idea**

The oxidation numbers of the ions in ionic compounds determine the formula of the compounds.

Elements Form Chemical Bonds

Just like these skydivers are linked together to make a stable formation, the atoms in elements can link together with chemical bonds to form a compound. You will read about how chemical bonds form and learn how to write chemical formulas and equations.

Science Journal

Describe what makes some bonds more stable than others.

Chemical Bonds

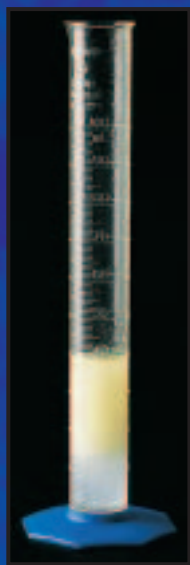


Start-Up Activities



Chemical Bonds and Mixing

You have probably noticed that some liquids like oil and vinegar salad dressings will not stay mixed after the bottle is shaken. However, rubbing alcohol and water will mix. The compounds that make up the liquids are different. This lab will demonstrate the influence the types of chemical bonds have on how the compounds mix.

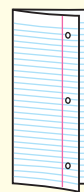


1. Pour 20 mL of water into a 100-mL graduated cylinder.
2. Pour 20 mL of vegetable oil into the same cylinder. Vigorously swirl the two liquids together, and observe for several minutes.
3. Add two drops of food dye and observe.
4. After several minutes, slowly pour 30 mL of rubbing alcohol into the cylinder.
5. Add two more drops of food dye and observe.
6. **Think Critically** In your Science Journal, write a paragraph describing how the different liquids mixed. Would your final results be different if you added the liquids in a different order? Explain.

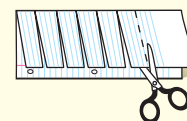
FOLDABLES™ Study Organizer

Chemical Formulas Every compound has a chemical formula that tells exactly which elements are present in that compound and exactly how many atoms of each element are present in that compound. Make the following Foldable to help identify the chemical formulas from this chapter.

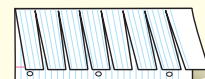
- STEP 1** Fold a vertical sheet of notebook paper from side to side.



- STEP 2** Cut along every third line of only the top layer to form tabs.



- STEP 3** Label each tab.



Read and Write Go through the chapter, find ten chemical formulas, and write them on the front of the tabs. As you read the chapter, write what compound each formula represents under the appropriate tab.



Preview this chapter's content and activities at gpscience.com

Stability in Bonding

Reading Guide

What You'll Learn

- **Describe** how a compound differs from its component elements.
- **Explain** what a chemical formula represents.
- **Explain** that the electric forces between oppositely charged electrons and protons are essential to forming compounds
- **State** a reason why chemical bonding occurs.

Why It's Important

The millions of different kinds of matter around us are a result of chemical bonds.

Review Vocabulary

compound: substance formed from two or more elements in which the exact combination and proportion of elements is always the same

New Vocabulary

- chemical formula
- chemical bond

Figure 1 The difference between the elemental copper metal and the copper compound formed on the Statue of Liberty is striking.



Elemental copper



Surface coated with a copper compound

Combined Elements

Have you ever noticed the color of the Statue of Liberty? Why is it green? Did the sculptor purposely choose green? Why wasn't white, or tan, or even some other color like purple chosen? Was it painted that way? No, the Statue of Liberty was not painted. The Statue of Liberty is made of the metal copper, which is an element. Pennies, too, are made of copper. Wait a minute, you say. Copper isn't green—it's . . . well, copper colored.

You are right. Uncombined, elemental copper is a bright, shiny copper color. So again the question arises: Why is the Statue of Liberty green?

Compounds Some of the matter around you is in the form of uncombined elements such as copper, sulfur, and oxygen. But, like many other sets of elements, these three elements unite chemically to form a compound when the conditions are right. The green coating on the Statue of Liberty and some old pennies is a result of this chemical change. One compound in this coating, seen in contrast with elemental copper in **Figure 1**, is a new compound called copper sulfate. Copper sulfate isn't shiny and copper colored like elemental copper. Nor is it a pale-yellow solid like sulfur or a colorless, odorless gas like oxygen. It has its own unique properties.

New Properties One interesting observation you will make is that the compound formed when elements combine often has properties that aren't anything like those of the individual elements. Sodium chloride, for example, shown in **Figure 2**, is a compound made from the elements sodium and chlorine. Sodium is a shiny, soft, silvery metal that reacts violently with water.

Chlorine is a poisonous greenish-yellow gas. Would you have guessed that these elements combine to make ordinary table salt?



Figure 2 Sodium is a soft, silvery metal that combines with chlorine, a greenish-yellow gas represented here as only one atom, to form sodium chloride, which is a white crystalline solid.

Describe how the properties of table salt are different from those of sodium and chlorine.

Formulas

The chemical symbols Na and Cl represent the elements sodium and chlorine. When written as NaCl, the symbols make up a formula, or chemical shorthand, for the compound sodium chloride. A **chemical formula** tells what elements a compound contains and the exact number of the atoms of each element in a unit of that compound. The compound that you are probably most familiar with is H₂O, more commonly known as water. This formula contains the symbols H for the element hydrogen and O for the element oxygen. Notice the subscript number 2 written after the H for hydrogen. *Subscript* means “written below.” A subscript written after a symbol tells how many atoms of that element are in a unit of the compound. If a symbol has no subscript, the unit contains only one atom of that element. A unit of H₂O contains two hydrogen atoms and one oxygen atom.

Look at the formulas for each compound listed in **Table 1**. What elements combine to form each compound? How many atoms of each element are required to form each of the compounds?

Table 1 Some Familiar Compounds

Familiar Name	Chemical Name	Formula
Sand	Silicon dioxide	SiO ₂
Milk of magnesia	Magnesium hydroxide	Mg(OH) ₂
Cane sugar	Sucrose	C ₁₂ H ₂₂ O ₁₁
Lime	Calcium oxide	CaO
Vinegar	Acetic acid	CH ₃ COOH
Laughing gas	Dinitrogen oxide	N ₂ O
Grain alcohol	Ethanol	C ₂ H ₅ OH
Battery acid	Sulfuric acid	H ₂ SO ₄
Stomach acid	Hydrochloric acid	HCl



Reading Check

Describe what a chemical formula tells you.

	1	2		13	14	15	16	17	18
	Li	Be		B	C	N	O	F	Ne
2									
3	Na	Mg		Al	Si	P	S	Cl	Ar

Figure 3 Note in this simplified representation of electron distribution, that the number of electrons in each group's outer level increases across the table, until the noble gases in Group 18 have a complete outer energy level.

Analyze Which of the groups pictured could form a diatomic compound with the elements in Group 2?

Figure 4 Electron dot diagrams of noble gases show that they all have a stable, filled outer energy level.

Atomic Stability

Why do atoms form compounds? The electric forces between oppositely charged electrons and protons hold atoms and molecules together, and thus are the forces that cause compounds to form. The periodic table on the inside back cover of your book lists the known elements, most of which can combine with other elements. However, the six noble gases in Group 18 seldom form compounds. Why is this so? Atoms of noble gases are unusually stable. Compounds of these atoms rarely form because they are almost always less stable than the original atoms.

The Unique Noble Gases To understand the stability of the noble gases, it is helpful to look at electron dot diagrams. Electron dot diagrams show only the electrons in the outer energy level of an atom. They contain the chemical symbol for the element surrounded by dots representing its outer electrons. How do you know how many dots to make? For Groups 1 and 2 and 13 through 18, you can use a periodic table or the portion of it shown in **Figure 3**. Look at the outer ring of each of the elements. Group 1 has one outer electron. Group 2 has two. Group 13 has three, Group 14, four, and so on to Group 18, the noble gases, which have eight.

Chemical Stability An atom is chemically stable when its outer energy level is complete. Recall that the outer energy levels of helium and hydrogen are stable with two electrons. The outer energy levels of all the other elements are stable when they contain eight electrons. The noble gases are stable because they each have a complete outer energy level. **Figure 4** shows electron dot diagrams of some of the noble gases. Notice that eight dots surround Kr, Ne, Xe, Ar, and Rn, and two dots surround He.

Energy Levels and Other Elements How do the dot diagrams represent other elements, and how does that relate to their ability to make compounds? Hydrogen and helium, the elements in row one of the periodic table, can hold a maximum of two electrons in their outer energy levels. Hydrogen contains one electron in its lone energy level. A dot diagram for hydrogen has a single dot next to its symbol. This means that hydrogen's outer energy level is not full. It is more stable when it is part of a compound.

In contrast, helium's outer energy level contains two electrons. Its dot diagram has two dots—a pair of electrons—next to its symbol. Helium already has a full outer energy level by itself and is chemically stable. Helium rarely forms compounds but, by itself, the element is a commonly used gas.

When you look at the elements in Groups 13 through 17, you see that each of them falls short of having a stable energy level. Each group contains too few electrons for a stable level of eight electrons.

Outer Levels—Getting Their Fill As you just learned, hydrogen is an element that does not have a full outer energy level. How does hydrogen, or any other element, trying to become stable, gain or lose its outer electrons? Atoms with partially stable outer energy levels can lose, gain, or share electrons to obtain a stable outer energy level. They do this by combining with other atoms that also have partially complete outer energy levels. As a result, each achieves stability. **Figure 5** shows electron dot diagrams for sodium and chlorine. When they combine, sodium loses one electron and chlorine gains one electron. You can see from the electron dot diagram that chlorine now has a stable outer energy level similar to a noble gas. But what about sodium?

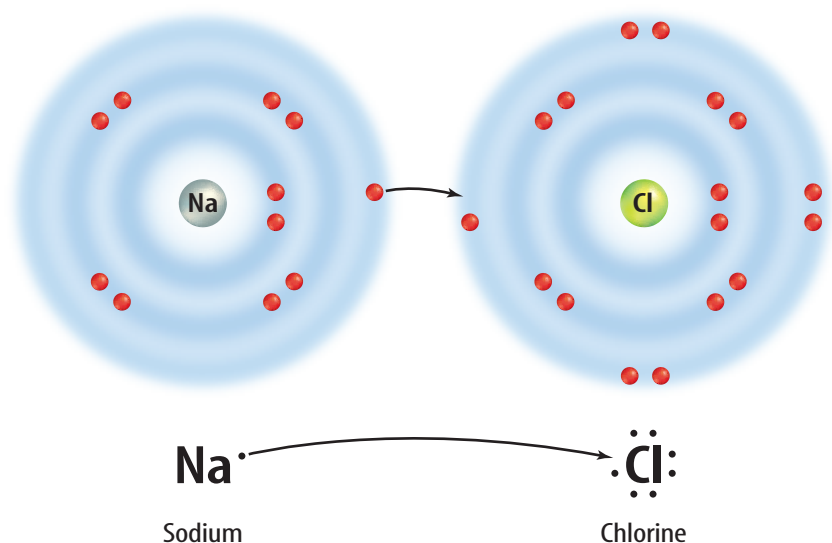


Figure 5 Each of these atoms has the potential of having a stable outer energy level by just adding or taking away one electron.



Topic: Dot Diagrams

Visit gpscience.com for Web links to information about using dot diagrams to represent outer energy level electrons.

Activity Draw a dot diagram of methane, CH_4 .

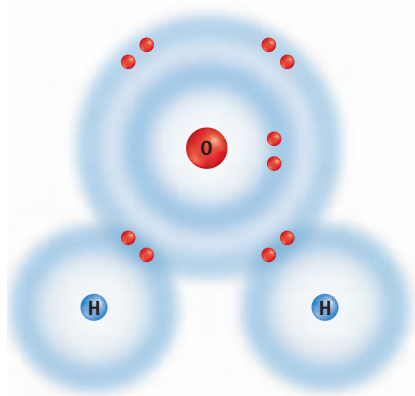


Figure 6 In water, hydrogen contributes one electron and oxygen contributes the other to each hydrogen-oxygen bond. The atoms share those electrons instead of giving them up.

Stability Is Reached Sodium had only one electron in its outer energy level, which it lost to combine with chlorine in sodium chloride. However, look back to the next, outermost energy level of sodium. This is now the new outer energy level, and it is stable with eight electrons. When the outer electron of sodium is removed, a complete inner energy level is revealed and now becomes the new outer energy level. Sodium and chlorine are stable now because of the exchange of an electron.

In the compound water, each hydrogen atom needs one electron to fill its outer energy level. The oxygen atom needs two electrons for its outer level to be stable with eight electrons. Hydrogen and oxygen become stable and form bonds in a different way than sodium and chlorine. Instead of gaining or losing electrons, they share them. **Figure 6** shows how hydrogen and oxygen share electrons to achieve a more stable arrangement of electrons.

When atoms gain, lose, or share electrons, an attraction forms between the atoms, pulling them together to form a compound. This attraction is called a chemical bond. A **chemical bond** is the force that holds atoms together in a compound. In Section 2 you will learn how these chemical bonds are formed.

section 1 review

Summary

Combined Elements

- When elements combine, the new compound has unique properties that are different from the original properties of the elements.

Formulas

- Chemical symbols and numbers are shorthand for the elements and their amounts in chemical formulas.

Atomic Stability

- The elements of Group 18, the noble gases, rarely combine with other elements.
- Electron dot diagrams show the electrons in the outer energy level of an atom.
- Most atoms need eight electrons to complete their outer energy level.
- Atoms form chemical bonds in three separate different ways to complete their outer energy levels.
- A chemical bond is the force that holds atoms together in a compound.

Self Check

- Compare and contrast** the properties of the individual elements that combine to make salt with the compound salt.
- Identify** what the formula BaF_2 tells you about this compound.
- Identify** the forces that hold atoms and molecules together at the atomic level. Give an example of how these forces are involved in a chemical reaction.
- Explain** why some elements are stable on their own while others are more stable in compounds.
- Describe** why chemical bonding occurs. Give two examples of how bonds can form.
- Think Critically** The label on a box of cleanser states that it contains CH_3COOH . What elements are in this compound? How many atoms of each element can be found in a unit of CH_3COOH ?

Applying Math

- Use Percentages** Given that the molecular weight of $\text{Mg}(\text{OH})_2$, magnesium hydroxide, is 58.32 g, what percentage of this compound is oxygen?



Atomic Trading Cards

Perhaps you have seen or collected trading cards for famous athletes. Usually each card has a picture of the athlete on one side with important statistics related to the sport on the back. Atoms can also be identified by their properties and statistics.

Real-World Question

How can a visible model show how energy levels fill when atoms combine?

Goals

- **Display** the electrons of elements according to their energy levels.
- **Compare and classify** elements according to their outer energy levels.

Materials

4-in $\times$ 6-in index cards
periodic table

Procedure

1. Get an assigned element from the teacher. Write the following information for your element on your index card: name, symbol, group number, atomic number, atomic mass, metal/nonmetal/metalloid.
2. On the other side of your index cards, show the number of protons and neutrons in the nucleus (e.g. $6p$ for six protons and $6n$ for six neutrons for carbon.)
3. Draw circles around the nucleus to represent the energy levels of your element. The number of circles you will need is the same as the row the element is in on the periodic table.



4. Draw dots on each circle to represent the electrons in each energy level. Remember, elements in row one become stable with two outer electrons while levels two and three become stable with eight electrons.
5. Look at the picture side only of four or five of your classmates' cards. Determine which element they have and to which group it belongs.

Conclude and Apply

1. As you classify the elements according to their group number, what pattern do you see in the number of electrons in the outer energy level?
2. Atoms that give up electrons combine with atoms that gain electrons in order to form compounds. In your Science Journal, predict some pairs of elements that would combine in this way.

Communicating Your Data

Make a graph that relates the groups to the number of electrons in their outer energy level. **For more help, refer to the Science Skill Handbook.**

Types of Bonds

Reading Guide

What You'll Learn

- **Describe** ionic bonds and covalent bonds.
- **Identify** the particles produced by ionic bonding and by covalent bonding.
- **Distinguish** between a nonpolar covalent bond and a polar covalent bond.

Why It's Important

Bond type determines how compounds mix and interact with other compounds.



Review Vocabulary

atom: the smallest piece of matter that still retains the property of the element

New Vocabulary

- ion
- ionic bond
- covalent bond
- molecule
- polar molecule
- nonpolar molecule

Figure 7 Goiter, an enlargement of the thyroid gland in the neck, can be caused by iodine deficiency.



Gain or Loss of Electrons

When you participate in a sport you might talk about gaining or losing an advantage. To gain an advantage, you want to have a better time than your opponent. It is important that you keep practicing because you don't want to lose that advantage. Gaining or losing an advantage happens as you try to meet a standard for your sport.

Atoms, too, lose or gain to meet a standard—a stable energy level. They do not lose or gain an advantage. Instead, they lose or gain electrons. An atom that has lost or gained electrons is called an ion. An **ion** is a charged particle because it now has either more or fewer electrons than protons. The positive and negative charges are not balanced. It is the electric forces between oppositely charged particles, such as ions, that hold compounds together.

Some of the most common compounds are made by the loss and gain of just one electron. These compounds contain an element from Group 1 on the periodic table and an element from Group 17. Some examples are sodium chloride, commonly known as table salt; sodium fluoride, an anticavity ingredient in some toothpastes; and potassium iodide, an ingredient in iodized salt.



Why do people need iodine? A lack of iodine causes a wide range of problems in the human body. The most obvious is an enlarged thyroid gland, as shown in **Figure 7**, but the problems can include mental retardation, neurological disorders, and physical problems.

A Bond Forms What happens when potassium and iodine atoms come together? A neutral atom of potassium has one electron in its outer level. This is not a stable outer energy level. When potassium forms a compound with iodine, potassium loses one electron from its fourth level, and the third level becomes a complete outer level. However, the atom is no longer neutral. The potassium atom has become an ion. When a potassium atom loses an electron, the atom becomes positively charged because there is one electron less in the atom than there are protons in the nucleus. The $1+$ charge is shown as a superscript written after the element's symbol, K^+ , to indicate its charge. *Superscript* means “written above.”

The iodine atom in this reaction undergoes change, as well. An iodine atom has seven electrons in its outer energy level. Recall that a stable outer energy level contains eight electrons. During the reaction with potassium, the iodine atom gains an electron, leaving its outer energy level with eight electrons. This atom is no longer neutral because it gained an extra negative particle. It now has a charge of $1-$ and is called an iodide ion, written as I^- . The compound formed between potassium and iodine is called potassium iodide. The dot diagrams for the process are shown in **Figure 8**.



Reading Check

What part of an ion's symbol indicates its charge?

Another way to look at the electron in the outer shell of a potassium atom is as an advertisement to other atoms saying, “Available: One electron to lend.” The iodine atom would have the message, “Wanted: One electron to borrow.” When the two atoms get together, each becomes a stable ion. Notice that the resulting compound has a neutral charge because the positive and negative charges of the ions cancel each other.



Muscle Development

Ions are important in many processes in your body. The movement of muscles is just one of these processes. Muscle movement would be impossible without the movement of ions in and out of nerve cells.

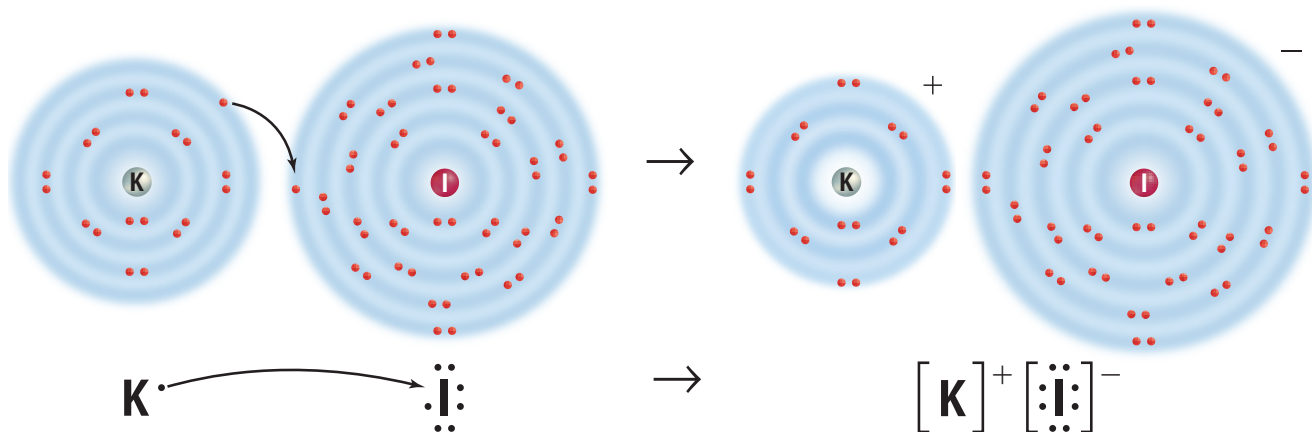


Figure 8 Potassium and iodine must perform a transfer of one electron. Potassium and iodine end up with stable outer energy levels.



Topic: Ionic Bonds

Visit gpscience.com for Web links to information about ionic bonding.

Activity Find out what a valence electron is and how it applies to an ionic bond.

The Ionic Bond

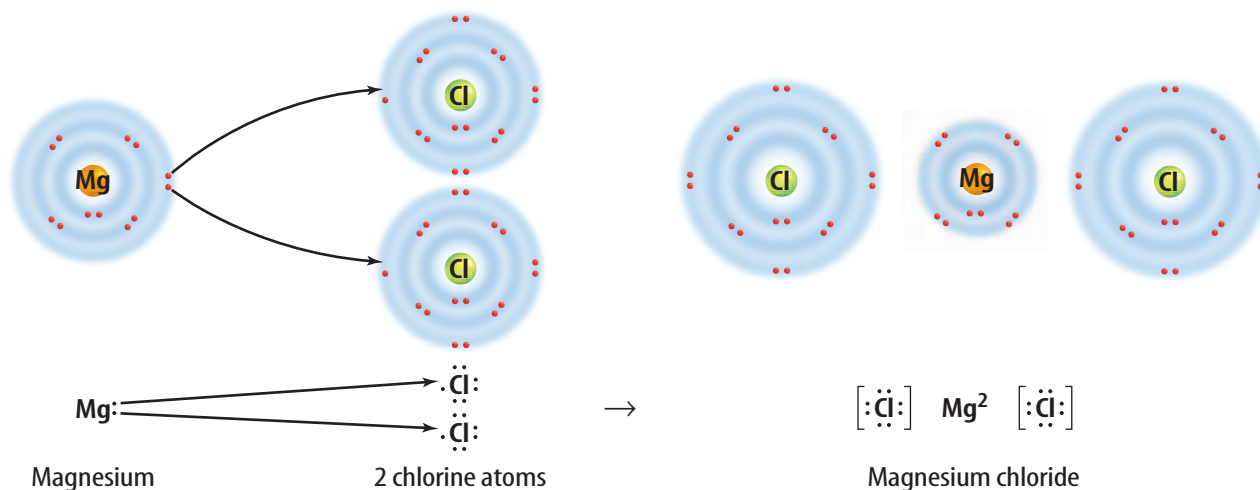
When ions attract in this way, a bond is formed. An **ionic bond** is the force of attraction between the opposite charges of the ions in an ionic compound. In an ionic bond, a transfer of electrons takes place. If an element loses electrons, one or more elements must gain an equal number of electrons to maintain the neutral charge of the compound.

Now that you have seen how an ionic bond forms when one electron is involved, see how it works when more than one is involved. The formation of magnesium chloride, MgCl_2 , is another example of ionic bonding. When magnesium reacts with chlorine, a magnesium atom loses two electrons and becomes a positively charged ion, Mg^{2+} . At the same time, two chlorine atoms gain one electron each and become negatively charged chloride ions, Cl^- . In this case, a magnesium atom has two electrons to lend, but a single chlorine atom needs to borrow only one electron. Therefore, it takes two chlorine atoms, as shown in **Figure 9**, to take the two electrons from the magnesium ion.

Zero Net Charge The result of this bond is a neutral compound. The compound as a whole is neutral because the sum of the charges on the ions is zero. The positive charge of the magnesium ion is exactly equal to the negative charge of the two chloride ions. In other words, when atoms form an ionic compound, their electrons are shifted to other atoms, but the overall number of protons and electrons of the combined atoms remains equal and unchanged. Therefore, the compound is neutral.

Ionic bonds usually are formed by bonding between metals and nonmetals. Looking at the periodic table, you will see that the elements that bond ionically are often across the table from each other. Ionic compounds are often crystalline solids with high melting points.

Figure 9 A magnesium atom gives an electron to each of two chlorine atoms to form MgCl_2 .



Sharing Electrons

Some atoms of nonmetals are unlikely to lose or gain electrons. For example, the elements in Group 14 of the periodic table have four electrons in their outer levels. They would have to either gain or lose four electrons in order to have a stable outer level. The loss of this many electrons takes a great deal of energy. Each time an electron is removed, the nucleus holds the remaining electrons even more tightly. Therefore, these atoms become more chemically stable by sharing electrons, rather than by losing or gaining electrons.

The attraction that forms between atoms when they share electrons is known as a **covalent bond**. A neutral particle that forms as a result of electron sharing is called a **molecule** as shown in **Figure 10**.

Single Covalent Bonds A single covalent bond is made up of two shared electrons. Usually, one of the shared electrons comes from one atom in the bond and the other comes from the other atom in the bond. A water molecule contains two single bonds. In each bond, a hydrogen atom contributes one electron to the bond and the oxygen atom contributes the other. The two electrons are shared, forming a single bond. The result of this type of bonding is a stable outer energy level for each atom in the molecule. Each hydrogen atom is stable with two electrons, and the oxygen atom is stable with eight outer energy level electrons.

Multiple Bonds A covalent bond also can contain more than one pair of electrons. An example of this is the bond in nitrogen (N_2), shown in **Figure 11**. A nitrogen atom has five electrons in its outer energy level and needs to gain three electrons to become stable. It does this by sharing its three electrons with another nitrogen atom. The other nitrogen atom also shares its three electrons. When each atom contributes three electrons to the bond, the bond contains six electrons, or three pairs of electrons. Each pair of electrons represents a bond. Therefore, three pairs of electrons represent three bonds, or a triple bond. Each nitrogen atom is stable with eight electrons in its outer energy level. In a similar way, a bond that contains two shared pairs of electrons is a double bond. Carbon dioxide is an example of a molecule with double bonds.

Covalent bonds form between nonmetallic elements. These elements are close together in the upper right-hand corner of the periodic table. Many covalent compounds are liquids or gases at room temperature.

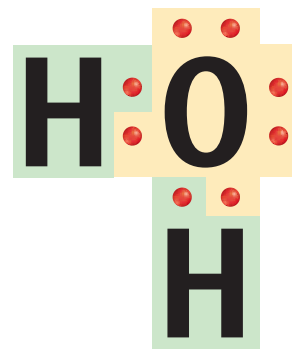


Figure 10 Each of the pairs of electrons between the two hydrogens and the oxygen is shared as each atom contributes one electron to the pair to make the bond.



Figure 11 The dot diagram shows that the two nitrogen atoms in nitrogen gas share six electrons. **Explain** which of these gases would require the most energy to react with another element to form a compound, H_2 or N_2 .

Mini LAB

Observing Bond Type

Procedure

1. Turn on the faucet to produce a thin **stream of water**.
2. Rub an inflated **balloon** with **wool or fur**.
3. Bring the balloon near the stream of water, and describe what you see.

Analysis

1. Explain your observations.
2. Relate the attraction between the balloon and the water to the attraction between the north and south poles of two magnets. Why might water act like a magnet?



Unequal Sharing Electrons are not always shared equally between atoms in a covalent bond. The strength of the attraction of each atom to its electrons is related to the size of the atom, the charge of the nucleus, and the total number of electrons the atom contains. Part of the strength of attraction has to do with how far away from the nucleus the electron being shared is. For example, a magnet has a stronger pull when it is right next to a piece of metal rather than several centimeters away. The other part of the strength of attraction has to do with the size of the positive charge in the nucleus. Using a magnet as an example again, a strong magnet will hold the metal more firmly than a weak magnet.

One example of this unequal sharing is found in a molecule of hydrogen chloride, HCl. In water, HCl is hydrochloric acid, which is used in laboratories, in industry to clean metal, and is found in your stomach where it digests food. Chlorine atoms have a stronger attraction for electrons than hydrogen atoms do. As a result, the electrons shared in hydrogen chloride will spend more time near the chlorine atom than near the hydrogen atom, as shown in **Figure 12**. The chlorine atom has a partial negative charge represented by a lower case Greek symbol delta followed by a negative superscript, δ^- . The hydrogen atom has a partial positive charge represented by a δ^+ .

Tug-of-War You might think of the bond as the rope in a tug-of-war, and the shared electrons as the knot in the center of the rope. **Figure 13** illustrates this concept. Each atom in the molecule attracts the electrons that they share. However, sometimes the atoms aren't the same size. The same thing happens in tug-of-war. Sometimes one team is larger or has stronger participants than the other.

When this is true, the knot in the middle of the rope ends up closer to the stronger team. Similarly, the electrons being shared in a molecule are held more closely to the atoms with the stronger pull or larger nucleus.

Figure 12 The chlorine atom exerts the greater pull on the electrons in hydrogen chloride which forms hydrochloric acid in water.

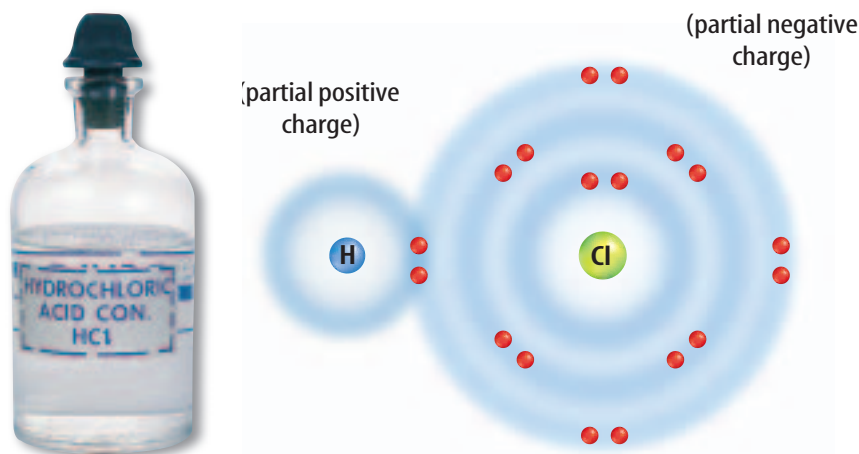
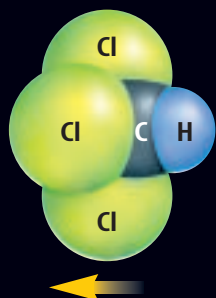
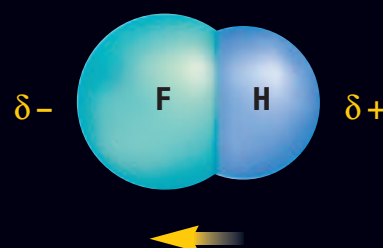


Figure 13

When playing tug-of-war, if there are more—or stronger—team members on one end of the rope than the other, there is an unequal balance of power. The stronger team can pull harder on the rope and has the advantage. A similar situation exists in polar molecules, in which electrons are attracted more strongly by one type of atom in the molecule than another. Because of this unequal sharing of electrons, polar molecules have a slightly negative end and a slightly positive end, as shown below.



CHLOROFORM In a molecule of chloroform (CHCl_3), or trichloromethane (tri klor oh ME thayn), the three chlorine atoms attract electrons more strongly than the hydrogen atom does, creating a partial negative charge on the chlorine end of the molecule and a partial positive charge on the hydrogen end. This polar molecule is a clear, sweet-smelling liquid once widely used as an anesthetic in human and veterinary surgery.



HYDROGEN FLUORIDE Hydrogen and fluorine react to form hydrogen fluoride (HF). In an HF molecule, the two atoms are bound together by a pair of electrons, one contributed by each atom. But the electrons are not shared equally because the fluorine atom attracts them more strongly than the hydrogen atom does. The result is a polar molecule with a slightly positive charge near the hydrogen end and a slightly negative charge near the fluorine end.

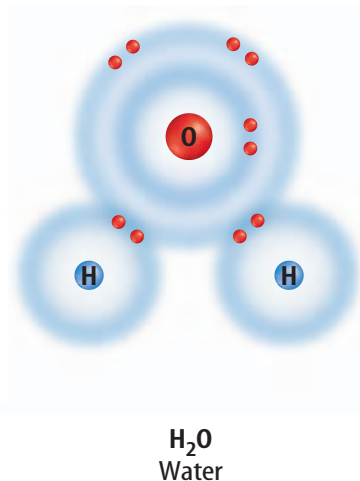


Figure 14 The polarity of water is responsible for many of its unique properties.

Polar or Nonpolar? For the molecule involved in this electron tug-of-war, there is another consequence. Again, look at the molecule of hydrogen chloride. This unequal sharing of electrons gives each chlorine atom a slight negative charge and each hydrogen atom a slight positive charge. The atom holding the electron more closely always will have a slightly negative charge. The charge is balanced but not equally distributed. This type of molecule is called polar. The term *polar* means “having opposite ends.” A **polar molecule** is one that has a slightly positive end and a slightly negative end although the overall molecule is neutral. Water is an example of a polar molecule, as shown in **Figure 14**.

Reading Check What is a polar molecule?

Two atoms that are exactly alike can share their electrons equally, forming a nonpolar molecule. A **nonpolar molecule** is one in which electrons are shared equally in bonds. Such a molecule does not have oppositely charged ends. This is true of molecules made from two identical atoms or molecules that are symmetric, such as CCl_4 .

section 2 review

Summary

Gain or Loss of Electrons

- An ion is a charged particle that has either fewer or more electrons than protons, resulting in a negative or positive charge.

Ionic Bond

- An ionic bond is the force or attraction between opposite charges of ions in an ionic bond.
- An ionic compound is neutral because the sum of the ion charges is zero.

Sharing Electrons

- Some atoms, like those in Group 4, share electrons instead of losing or gaining them.
- Covalent bonds can form single, double, or triple bonds.
- In a polar molecule the electrons are shared unequally in the bond. This results in slightly charged ends.
- Electrons are shared equally in a nonpolar molecule.

Self Check

1. **Explain** why an atom makes an ionic bond only with certain other atoms.
2. **Compare and contrast** the possession of electrons in ionic and covalent bonds.
3. **Name** the types of particles formed by covalent bonds.
4. **Think Critically** From the following list of symbols, choose two elements that are likely to form an ionic bond: O, Ne, S, Ca, K. Next, select two elements that would likely form a covalent bond. Explain.
5. **Concept Map** Using the following terms, make a network-tree concept map of chemical bonding: *ionic, covalent, ions, positive ions, negative ions, molecules, polar, and nonpolar*.

Applying Math

6. **Solve One-Step Equations** Aluminum oxide, Al_2O_3 , can be produced during space shuttle launches. Show that the sum of the positive and negative charges in a unit of Al_2O_3 equals zero.

Writing Formulas and Naming Compounds

Reading Guide

What You'll Learn

- **Explain** how to determine oxidation numbers.
- **Write** formulas and names for ionic compounds.
- **Write** formulas and names for covalent compounds.

Why It's Important

The name and the formula convey information about the compound.



Review Vocabulary

anion: a negatively charged ion

New Vocabulary

- binary compound
- oxidation number
- polyatomic ion
- hydrate

Binary Ionic Compounds

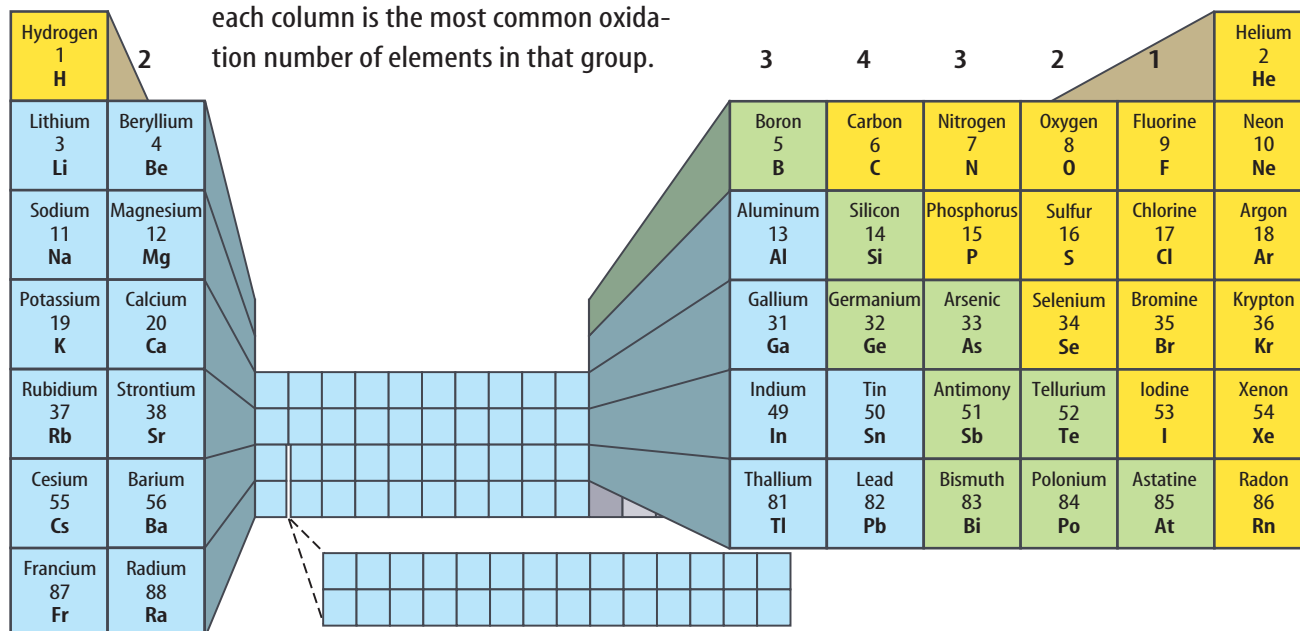
Does the table in **Figure 15** look like it has anything to do with chemistry? It is an early table of the elements made by alchemists—scientists who tried to make gold from other elements. The alchemist used symbols like these to write the formulas of substances. The first formulas of compounds you will write are for binary ionic compounds. A **binary compound** is one that is composed of two elements. Potassium iodide, the salt additive discussed in Section 2, is a binary ionic compound. However, before you can write a formula, you must have all the needed information at your fingertips. What will you need to know?

Are electrons gained or lost? You need to know which elements are involved and what number of electrons they lose, gain, or share in order to become stable. How can you determine this? Section 1 discussed the relationship between an element's position on the periodic table and the number of electrons it gains or loses. This is called the **oxidation number** of an element. An oxidation number tells you how many electrons an atom has gained, lost, or shared to become stable.

For ionic compounds the oxidation number is the same as the charge on the ion. For example, a sodium ion has a charge of $1+$ and an oxidation number of $1+$. A chloride ion has a charge of $1-$ and an oxidation number of $1-$.

Figure 15 This old chart of the elements used pictorial symbols to represent elements.

	MINERA	METALLA	MINERALIA	SALIA	DECOMPOSITA	TERRA
I	MINERA					
II	METALLA					
III	MINERALIA					
IV	SALIA					
V	DECOMPOSITA					
VI	TERRA					



Oxidation Numbers The numbers with positive or negative signs in **Figure 16** are the oxidation numbers for the elements in the columns below them. Notice how they fit with the periodic table groupings.

The elements in **Table 2** can have more than one oxidation number. When naming these compounds, the oxidation number is expressed in the name with a roman numeral. For example, the oxidation number of iron in iron(III) oxide is 3+.

Table 2 Special Ions

Name	Oxidation Number
Copper (I)	1+
Copper (II)	2+
Iron (II)	2+
Iron (III)	3+
Chromium (II)	2+
Chromium (III)	3+
Lead (II)	2+
Lead (IV)	4+

Compounds Are Neutral When writing formulas it is important to remember that although the individual ions in a compound carry charges, the compound itself is neutral. A formula must have the right number of positive ions and the right number of negative ions so the charges balance. For example, sodium chloride is made up of a sodium ion with a $1+$ charge and a chloride ion with a $1-$ charge. One of each ion put together makes a neutral compound with the formula NaCl.

However, what if you have a compound like calcium fluoride? A calcium ion has a charge of $2+$ and a fluoride ion has a charge of $1-$. In this case you need to have two fluoride ions for every calcium ion in order for the charges to cancel and the compound to be neutral with the formula CaF_2 .

Some compounds require more figuring. Aluminum oxide contains an ion with a 3+ charge and an ion with a 2- charge. You must find the least common multiple of 3 and 2 in order to determine how many of each ion you need. You need two aluminum ions and three oxygen ions in order to have a 6+ charge and a 6- charge and therefore, the neutral compound Al_2O_3 .

Writing Formulas After you've learned how to find the oxidation numbers and their least common multiple, you can write formulas for ionic compounds by using the following rules in this order.

1. Write the symbol of the element or polyatomic ion (ions containing more than one atom) that has the positive oxidation number or charge. Hydrogen, the ammonium ion (NH_4^+), and all metals have positive oxidation numbers.
2. Write the symbol of the element or polyatomic ion with the negative oxidation number. Nonmetals other than hydrogen and polyatomic ions other than NH_4^+ have negative oxidation numbers.
3. The charge (without the sign) of one ion becomes the subscript of the other ion. Reduce the subscripts to the smallest whole numbers that retain the ratio of ions.



Lime The use of compounds to enrich yield of crops has been developed through the ages. Farmers must sometimes add lime, which is calcium oxide, to soil in their fields. What is the formula of calcium oxide?

Applying Math

DETERMINING A CHEMICAL FORMULA What is the formula for lithium nitride?

IDENTIFY known values

Identify the known values:

Symbol and oxidation number of the positive element:

Lithium $\xrightarrow{\text{means}}$ Li^{1+}

Symbol and oxidation number of the negative element:

Nitrogen $\xrightarrow{\text{means}}$ N^{3-}

SOLVE the problem

The charge (without the sign) of one ion becomes the subscript of the other:

Li^{1+} N^{3-} $\xrightarrow{\text{means}}$ Li_3N_1 or Li_3N

Reduce the subscripts to the smallest whole numbers that retain the ratios of ions.

CHECK the answer

Does your answer seem reasonable? Check your answer by determining if your compound is neutral.

Practice Problems

1. What is the formula for lead (IV) phosphide?
2. What is the formula for iron (III) oxide?

For more practice problems go to page 834, and visit gpscience.com/extra_problems.

Table 3 Elements in Binary Compounds

Element	-ide Name
Oxygen	oxide
Phosphorus	phosphide
Nitrogen	nitride
Sulfur	sulfide

Writing Names You can name a binary ionic compound from its formula by using these rules.

1. Write the name of the positive ion.
2. Using **Table 2**, check to see if the positive ion is capable of forming more than one oxidation number. If it is, determine the oxidation number of the ion from the formula of the compound. To do this, keep in mind that the overall charge of the compound is zero and the negative ion has only one possible charge. Write the charge of the positive ion using roman numerals in parentheses after the ion's name. If the ion has only one possible oxidation number, proceed to step 3.
3. Write the root name of the negative ion. The root is the first part of the element's name. For chlorine the root is *chlor-*. For oxygen it is *ox-*.
4. Add the ending *-ide* to the root. **Table 3** lists several elements and their *-ide* counterparts. For example, BaF_2 is named barium fluoride.

Subscripts do not become part of the name for ionic compounds. However, subscripts can be used to help determine the charges of these metals that have more than one positive charge.

Applying Science

Can you name binary ionic compounds?

What would a chemist name the compound CuCl ?

Identifying the Problem

There are four simple steps in naming binary ionic compounds.

1. Write the name of the positive ion in the compound. In CuCl , the name of the positive ion is copper.
2. Check **Table 2** to determine if copper is one of the elements that can have more than one oxidation number. Looking at **Table 2**, you can see that copper can have a $1+$ or a $2+$ oxidation number. You need to determine which to use. Looking at the compound, you see that there is one copper atom and one chlorine atom. You know that

the overall charge of the compound is zero and that chlorine only forms a $1-$ ion. For the charge of the compound to be zero, the charge of the copper ion must be $1+$. Write this charge using roman numerals in parentheses after the element's name, copper (I).

3. Write the root name of the negative ion. The negative ion is chlorine and its root is *chlor-*.
4. Add the ending *-ide* to the root, chloride.
5. The full name of the compound CuCl is copper (I) chloride.

Solving the Problem

1. What is the name of CuO ?
2. What is the name of AlCl_3 ?

Compounds with Complex Ions

Not all compounds are binary. Baking soda—used in cooking, as a medicine, and for brushing your teeth—has the formula NaHCO_3 . This is an example of an ionic compound that is not binary. Some compounds, including baking soda, are composed of more than two elements. They contain polyatomic ions. The prefix *poly-* means “many,” so the term *polyatomic* means “having many atoms.” A **polyatomic ion** is a positively or negatively charged, covalently bonded group of atoms. So the polyatomic ion as a whole contains two or more elements. The polyatomic ion in baking soda is the bicarbonate or hydrogen carbonate ion, HCO_3^- .

Writing Names Table 4 lists several polyatomic ions. To name a compound that contains one of these ions, first write the name of the positive ion. Use Table 4 to find the name of a polyatomic ion. Then write the name of the negative ion. For example, K_2SO_4 is potassium sulfate. What is the name of $\text{Sr}(\text{OH})_2$? Begin by writing the name of the positive ion, strontium. Then find the name of the polyatomic ion, OH^- . Table 4 lists it as hydroxide. Thus the name is strontium hydroxide.

Writing Formulas To write formulas for these compounds, follow the rules for binary compounds, with one addition. When more than one polyatomic ion is needed, write parentheses around the polyatomic ion before adding the subscript. How would you write the formula of barium chlorate?

First, identify the symbol of the positive ion. Barium has a symbol of Ba and forms a $2+$ ion, Ba^{2+} . Next, identify the negative chlorate ion. Table 4 shows that it is ClO_3^- . Finally, you need to balance the charges of the ions to make the compound neutral. It will take two chlorate ions with a $1-$ charge to balance the $2+$ charge of the barium ion. Because the chlorate ion is polyatomic, you use parentheses before adding the subscript. Therefore, the formula is $\text{Ba}(\text{ClO}_3)_2$. Another example of naming complex compounds is shown in Figure 17.

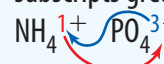
Table 4 Polyatomic Ions

Charge	Name	Formula
1+	ammonium	NH_4^+
1−	acetate chlorate hydroxide nitrate	$\text{C}_2\text{H}_3\text{O}_2^-$ ClO_3^- OH^- NO_3^-
2−	carbonate sulfate	CO_3^{2-} SO_4^{2-}
3−	phosphate	PO_4^{3-}

Figure 17 Naming Complex Compounds

How would a scientist write the chemical formula for ammonium phosphate?

To write the formula, answer the following questions:

- What is the positive ion and its charge?
The positive ion is NH_4^{1+} and its charge $1+$.
- What is the negative ion and its charge?
The negative ion is PO_4^{3-} and its charge $3-$.
- Balance the charges to make the compound neutral.
 - three NH_4^{1+} ions ($+3$) balances one PO_4^{3-} ($3-$) or
 - The charge of one ion (without the sign) becomes the subscript of the other. Add parentheses for subscripts greater than one.

 $\text{NH}_4^{1+} \text{PO}_4^{3-}$ gives $(\text{NH}_4)_3\text{PO}_4$

The chemical formula for ammonium phosphate is $(\text{NH}_4)_3\text{PO}_4$.



Making a Hydrate

Procedure



1. Mix 150 mL of **plaster of paris** with 75 mL of **water** in a small **bowl**.
2. Let the plaster dry overnight and take the hardened plaster out of the bowl.
3. Lightly tap the plaster with a **rubber hammer**.
4. Heat the plaster with a **hair dryer** on the hottest setting and observe.
5. Place towel over the sample then lightly tap the plaster with the hammer after heating it.

Analysis

1. What happened to the plaster when you tapped it before and after heating it?
2. What did you observe happening to the plaster as you heated it? Explain.

Compounds with Added Water

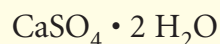
Some ionic compounds have water molecules as part of their structure. These compounds are called hydrates. A **hydrate** is a compound that has water chemically attached to its ions and written into its chemical formula.

Common Hydrates The term *hydrate* comes from a word that means “water.” When a solution of cobalt chloride evaporates, pink crystals that contain six water molecules for each unit of cobalt chloride are formed. The formula for this compound is $\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$ and is called cobalt chloride hexahydrate.

You can remove water from these crystals by heating them. The resulting blue compound is called anhydrous, which means “without water.” When anhydrous (blue) CoCl_2 is exposed to water, even from the air, it will revert back to its hydrated state.

The plaster of paris shown in **Figure 18** also forms a hydrate when water is added. It becomes calcium sulfate dihydrate, which is also known as gypsum. The water that was added to the powder became a part of the compound.

When writing a formula that contains a hydrate, the number is shown after a “•”. Following the number 2 is the formula for water as shown below.



Naming Binary Covalent Compounds

Covalent compounds are those formed between elements that are nonmetals. Some pairs of nonmetals can form more than one compound with each other. For example, nitrogen and oxygen can form N_2O , NO , NO_2 , and N_2O_5 . In the system you have learned so far, each of these compounds would be called nitrogen oxide. You would not know from that name what the composition of the compound is.

Figure 18 The presence of water changes this powder into a material that can be used to create art.

Identify the formula for this powder prior to the addition of water.



Using Prefixes Scientists use the Greek prefixes in **Table 5** to indicate how many atoms of each element are in a binary covalent compound. The nitrogen and oxygen compounds N_2O , NO , NO_2 , and N_2O_5 would be named dinitrogen oxide, nitrogen oxide, nitrogen dioxide, and dinitrogen pentoxide. Notice that the last vowel of the prefix is dropped when the second element begins with a vowel as in pentoxide. Often the prefix *mono-* is omitted, although it is used for emphasis in some cases. Carbon monoxide is one example.



Reading Check

What prefix would be used for seven atoms of one element in a covalent compound?

These same prefixes are used when naming the hydrates previously discussed. The main ionic compound is named the regular way, but the number of water molecules in the hydrate is indicated by the Greek prefix.

You have learned how to write formulas of binary ionic compounds and of compounds containing polyatomic ions. Using oxidation numbers to write formulas, you can predict the ratio in which atoms of elements might combine to form compounds. You also have seen how hydrates have water molecules as part of their structures and formulas. Finally, you saw how to use prefixes in naming binary covalent compounds. As you continue to study, you will see many uses of formulas.

Table 5 Prefixes for Covalent Compounds

Number of Atoms	Prefix
1	<i>mono-</i>
2	<i>di-</i>
3	<i>tri-</i>
4	<i>tetra-</i>
5	<i>penta-</i>
6	<i>hexa-</i>
7	<i>hepta-</i>
8	<i>octa-</i>

section 3 review

Summary

Binary Ionic Compounds

- A binary compound is one composed of two elements.
- The oxidation number tells how many electrons an atom has gained, lost, or shared to become stable.
- The net charge of a compound is zero.

Compounds with Complex Ions

- A polyatomic ion is a positively or negatively charged, covalently bonded group of atoms.
- A hydrate is a compound that has water chemically attached to its ions.
- Greek prefixes are used to indicate how many atoms of each element are in a binary covalent compound.

Self Check

1. **Use Formulas** Write formulas for the following compounds: potassium iodide, magnesium hydroxide, aluminum sulfate, and chlorine heptoxide.
2. **Use Formulas** Write the names of these compounds: KCl , Cr_2O_3 , $\text{Ba}(\text{ClO}_3)_2$, NH_4Cl , and PCl_3 .
3. **Name** $\text{Mg}_3(\text{PO}_4)_2 \cdot 4\text{H}_2\text{O}$, and write the formula for calcium nitrate trihydrate.
4. **Think Critically** Explain why sodium and potassium will or will not react to form a bond with each other.

Applying Math

5. **Solve One-Step Equations** The overall charge on the polyatomic sulfate ion, found in some acids, is 2^- . Its formula is SO_4^{2-} . If the oxygen ion has a 2^- oxidation number, determine the oxidation number of sulfur in this polyatomic ion.

Become a Bond Breaker

Goals

- **Observe** the effect of heat on melting points of selected substances.
- **Design** an experiment that allows you to make some inferences that relate ease of melting and forces of attraction between particles of a substance.

Possible Materials

small samples of crushed ice, table salt, and sugar
wire test-tube holder
test tubes
laboratory burner
stopwatch

Safety Precautions



WARNING: Keep a safe distance from the open flame of the lab burner. Wear proper eye protection. Do not continue heating beyond 5 min.

Real-World Question

The basic structural units of ionic compounds are ions. For covalent substances, molecules make up the basic units. By using controlled heat to melt substances, you can test various compounds to rate the attractive forces between their basic units. Would a substance that is difficult to melt have strong forces or weak forces holding its basic units together? How do the attractive forces between ions compare to the attractive forces between molecules?

Form a Hypothesis

Based on what you know about ions and molecules, state a hypothesis about which generally would have stronger attractions between their structural units.

Test Your Hypothesis

Make a Plan

1. As a group, agree upon and write a hypothesis statement.
2. As a group, write a detailed list of steps that are needed to test your hypothesis. Determine what your control will be.



Using Scientific Methods

3. As you heat materials in a test tube, what variables are held constant?
4. How will you time the heating of the individual substances?
5. Will you run any tests more than one time?
6. Make a list of materials that you will need to complete your experiment.
7. **Design** a data table in your Science Journal to record your observations.
8. Make sure your teacher approves your plan before you start.

Follow Your Plan

1. Carry out the experiment exactly as planned.
2. While you are observing the heating of each substance, think about the movement of the particles. Which particles are held together by ionic bonds? Which are made up of covalent molecules? How does that affect their movement?
3. Be sure to write down exactly how long it takes to melt each tested substance.



Analyze Your Data

1. **Compare** your results with those of other groups in the class.
2. **Classify** your tested substances as more likely ionic or covalent.
3. Which substances are generally more difficult to melt?
4. Did you have a control in this experiment? Variables?

Conclude and Apply

1. **Think Critically** How did the results of your experiment support or disprove your hypothesis?
2. **Infer** Sugar is known as a polar covalent compound. Knowing this, infer from your results how polarity affects melting point.

Communicating Your Data

Make a chart showing your results and pointing out ways to distinguish between the different kinds of bonds.

A Sticky Subject

In 1942, a research team was working on creating a new kind of glass. The group was working with some cyanoacrylate monomers (si uh noh A kruh layt • MAH nuh muhrz) which showed promise, but there was a problem that kept coming up. Everything the monomers touched stuck to everything else!

Cyanoacrylate is the chemical name for instant, super-type glues. The researcher was so focused on finding a different type of glass that at the time nobody recognized an important new adhesive. Not until a few years later.

In 1952, a member of the research team, working on new materials for jet plane canopies, made a similar complaint. The ethyl cyanoacrylate they were working with again made everything stick together. This time, the insight stuck to the scientists like, well, like GLUE! “I began gluing everything I could lay

my hands on—glass plates, rubber stoppers, metal spatulas, wood, paper, plastic. Everything stuck to everything, almost instantly, and



Super-type glues make it possible to perfectly repair broken objects.

with bonds I could not break apart,” recalls the head of the research group.

Stick to It

Most adhesives, commonly called glues, are long chains of bonded molecules called polymers. Cyanoacrylate, however, exists as monomers—single molecules with double bonds. And it stays that way until it hits anything with moisture in it—like air. Yes, even the small amount of moisture in air and on the surfaces of most materials is enough to dissolve the double bonds in the monomers of cyanoacrylate, making them join together in long chains. The chains bond to surfaces as they polymerize.

The discovery of cyanoacrylates had an immediate impact on the automobile and airplane industries. And it soon “held” a spot in almost every household toolbox. Since the 1990s, however, cyanoacrylate glues are also finding a place in the doctor’s office. A doctor can apply a thin layer of instant glue instead of putting stitches in a cut. This specially made medical glue was approved by the U.S. Food and Drug Administration in 1998.



Take Note Visit a store and make a table of different kinds of glues. List their common names, their chemical names, what they are made of, how long it takes them to set, and the types of surfaces for which they are recommended. Note any safety precautions.

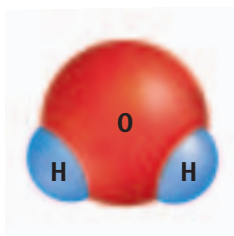
Science online

For more information, visit
gpscience.com/oops

Reviewing Main Ideas

Section 1 Stability in Bonding

1. The properties of compounds are generally different from the properties of the elements they contain.
2. A chemical formula for a compound indicates the composition of a unit of the compound. This model of a water molecule shows the shape of the molecule and the relative size of the atoms.
3. Chemical bonding occurs because atoms of most elements become more stable by gaining, losing, or sharing electrons in order to obtain a stable outer energy level.



3. The unequal sharing of electrons produces compounds that contain polar bonds, and the equal sharing of electrons produces nonpolar compounds.

Section 3 Writing Formulas and Naming Compounds

1. An oxidation number indicates how many electrons an atom has gained, lost, or shared when bonding with other atoms.
2. In the formula of an ionic compound, the element or ion with the positive oxidation number is written first, followed by the one with the negative oxidation number.
3. The name of a binary compound is derived from the names of the two elements that compose the compound. Salt is an example of a binary compound.

Section 2 Types of Bonds

1. Ionic bonds between atoms are formed by the attraction between ions. Covalent bonds are formed by the sharing of electrons. Below is an example of an ionically bonded compound.



2. Ionic bonding occurs between charged particles called ions and produces ionic compounds. Covalent bonding produces units called molecules and occurs between nonmetallic elements.



4. A hydrate is a compound that has water chemically attached to its ions and written into its formula.
5. Greek prefixes are used in the names of covalent compounds. These indicate the number of each atom present.

FOLDABLES™ Use the Foldable that you made at the beginning of this chapter to help you review chemical bonds.

Using Vocabulary

binary compound p.615	ionic bond p.610
chemical bond p.606	molecule p.611
chemical formula p.603	nonpolar molecule p.614
covalent bond p.611	oxidation number p.615
hydrate p.620	polar molecule p.614
ion p.608	polyatomic ion p.619

Match each phrase with a vocabulary word.

- a charged group of atoms
- a compound composed of two elements
- a molecule with partially charged areas
- a positively or negatively charged particle
- a chemical bond between oppositely charged ions
- a bond formed from shared electrons
- crystalline substance that contains water
- a particle made of covalently bonded atoms
- shows an element's combining ability
- tells which elements are in a compound and their ratios.

Checking Concepts

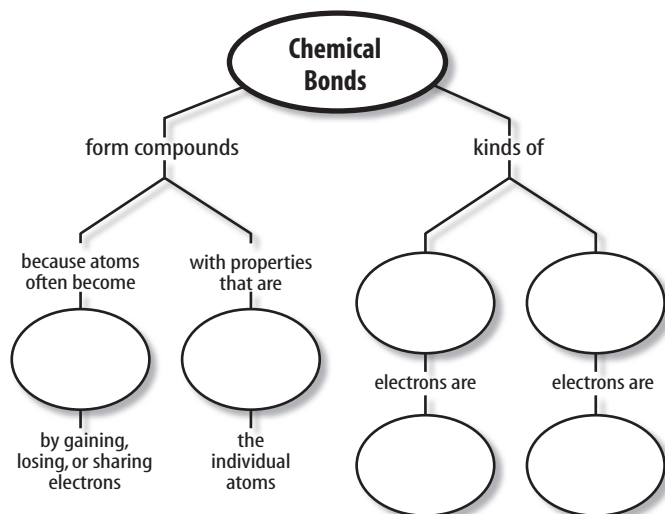
Choose the word or phrase that best answers the question.

- Which elements are least likely to react with other elements?
A) metals C) nonmetals
B) noble gases D) transition elements
- What is the name of CuO?
A) copper oxide
B) copper(I) oxide
C) copper(II) oxide
D) copper(III) oxide

- Which of the following formulas represents a nonpolar molecule?
A) N_2 C) NaCl
B) H_2O D) HCl
- How many electrons are in the outer energy level of Group 17 elements?
A) 1 C) 17
B) 2 D) 7
- Which is a binary ionic compound?
A) O_2 C) H_2SO_4
B) NaF D) $Cu(NO_3)_2$
- Which of these is an example of an anhydrous compound?
A) H_2O C) $CuSO_4 \cdot 5H_2O$
B) $CaSO_4$ D) $CaSO_4 \cdot 2H_2O$
- Which of the following is an atom that has gained an electron?
A) negative ion C) polar molecule
B) positive ion D) nonpolar molecule
- Which of these is an example of a covalent compound?
A) sodium chloride C) calcium chloride
B) calcium fluoride D) sulfur dioxide

Interpreting Graphics

- Copy and complete this concept map.



20. Write the name and formula for the compound illustrated to the right.



Use the table below to answer question 21.

Which compounds exist?	
Formula	Possible Compounds
SF ₆	AlF ₆ or TeF ₆
K ₂ SO ₄	Na ₂ SO ₄ or Ba ₂ SO ₄
CO ₂	CCl ₂ or CS ₂
CaCO ₃	OCO ₃ or BaCO ₃

21. Elements from one family (vertical column) of the periodic table generally combine with elements from another family and polyatomic ions in the same ratio. For example, one calcium atom combines with two chlorine atoms to give CaCl₂ (calcium chloride) as it does with two fluorine atoms to give CaF₂ (calcium fluoride). Using a periodic table as a guide, predict which of the two compounds on the right side of the table above is more likely to exist based upon the formula on the left side.

Thinking Critically

22. **Draw** Anhydrous magnesium chloride is used to make wood fireproof. Draw a dot diagram of magnesium chloride.
23. **Use Formulas** Artificial diamonds are made using thallium carbonate. If thallium has an oxidation number of 1+, what is the formula for the compound?
24. **Compare and contrast** polar and nonpolar molecules.

25. **Write** Baking soda, which is sodium hydrogen carbonate, and vinegar, which contains hydrogen acetate, can be used as household cleaners. Write the chemical formulas for these two compounds.

26. **Draw Conclusions** Ammonia gas and water react to form household ammonia, which contains NH₄⁺ and OH⁻ ions. The formula for water is H₂O, what is the formula for ammonia gas?

27. **Draw Conclusions** The name of a compound called copper (II) sulfate is written on a bottle. What is the charge of the copper ion? What is the charge of the sulfate ion?

28. **Explain** what electric forces between oppositely charged electrons and protons have to do with chemical reactions.

29. **Name Compounds** Write the chemical name for the following compounds:

- A) Fe₂S₃ C) Ca(PO₄)₂
 B) Cu(ClO₃)₂ D) (NH₄)₂SO₄

30. **Model** One common form of phosphorus, white phosphorus, has the formula P₄ and is formed by four covalently bonded phosphorus atoms. Make a model of this molecule, showing that all four atoms are now chemically stable.

Applying Math

31. **Oxidation Number** What is the oxidation number of Fe in the compound Fe₂S₃?

- A) 1⁺ C) 3⁺
 B) 2⁺ D) 4⁺

32. **Chemical Formulas** Write the chemical formulas for the following compounds:

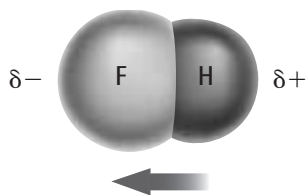
- A) potassium chloride
 B) calcium carbonate
 C) copper sulfate
 D) sodium oxide

Part 1 Multiple Choice

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

- Which element is NOT part of the compound NH_4NO_3 ?
 A. nitrogen C. oxygen
 B. nickel D. hydrogen
- When an atom is chemically stable, how many electrons are in its outer energy level?
 A. 0 C. 4
 B. 7 D. 8

Use the figure below to answer questions 3 and 4.



- What type of bond holds the atoms of this molecule together?
 A. covalent C. triple
 B. ionic D. double
- Which statement about this molecule is TRUE?
 A. This is a nonpolar molecule.
 B. The electrons are shared equally in the bonds of this molecule.
 C. This molecule does not have oppositely charged ends.
 D. This is a polar molecule.

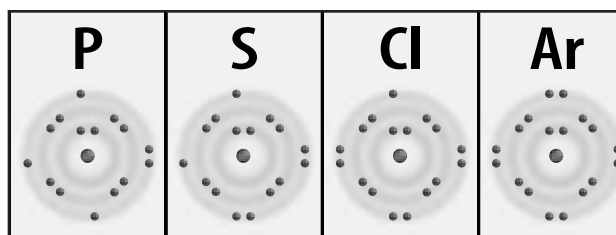
Test-Taking Tip

Comprehension Be sure you understand the question before you read the answer choices. Make special note of words like NOT or EXCEPT. Read and consider all the answer choices before you mark your answer sheet.

Question 1 Try to identify each of the elements in the compound before reading the answer choices.

- What do the group 7A elements become when they react with group 1A elements?
 A. negative ions C. positive ions
 B. neutral D. polyatomic ions

Use the illustration below to answer questions 6–8.

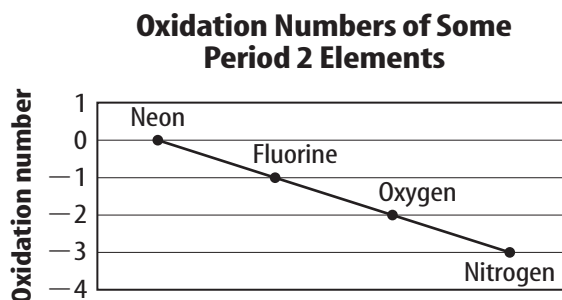


- Which element is least likely to form an ionic bond with sodium?
 A. phosphorous C. chlorine
 B. sulfur D. argon
- How many electrons are required to complete the outer energy level of a phosphorous atom?
 A. 1 C. 3
 B. 2 D. 4
- How many electrons are in an argon atom?
 A. 8 C. 18
 B. 10 D. 26
- What is the oxidation number of sodium in the compound Na_3PO_4 ?
 A. -1 C. -3
 B. +3 D. +1
- What is the name of $\text{KC}_2\text{H}_3\text{O}_2$?
 A. potassium carbide
 B. potassium acetate
 C. potassium hydroxide
 D. potassium oxide
- What is the chemical formula for lead (II) oxide?
 A. PbO C. PbO_2
 B. Pb_2O D. Pb_2O_2

Part 2 Short Response/Grid In

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

Use the illustration below to answer questions 12 and 13.



12. Describe the trend in the oxidation numbers of these period 2 elements.
13. Compare the oxidation numbers of nitrogen and fluorine. Why do they differ?
14. Draw electron dot diagrams for carbon and hydrogen. Draw a dot diagram for methane, CH_4 , one of many compounds formed by these two elements.
15. Give several examples of ionic compounds. What are two properties often shared by these substances?
16. A compound has the formula $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$. Identify and define this type of compound. Using the appropriate prefix, write its name.
17. What information is given in a chemical formula?
18. The bonding of atoms and molecules is the result of oppositely charged electrons and protons being held together by electric forces within the atom. Using this information, explain the bonding of NaCl .

Part 3 Open Ended

Record your answers on a sheet of paper.

Use the illustration below to answer questions 19 and 20.



19. Describe the bond holding the nitrogen atoms together in this molecule.
20. Nitrogen occurs naturally as a diatomic molecule because N_2 molecules are more stable than nitrogen atoms. H_2 , O_2 , F_2 , Cl_2 , Br_2 , and I_2 are other diatomic molecules. Draw dot diagrams for three of these molecules.
21. Explain why elements in Group 4A, which have four electrons in the outer energy level, are unlikely to lose all of the electrons in the outer energy level.
22. What factors affect how strongly an atom is attracted to its electrons?
23. Create a chart which compares the properties of polar and nonpolar molecules. Your chart should include several examples of each type of molecule.
24. Scientists have created a compound which combines xenon and fluorine. Why is this compound so unusual and difficult to create? Why is fluorine a good choice for scientists attempting to form a compound with xenon?
25. What is the difference between nitrogen oxide and dinitrogen pentoxide? Why are prefixes used in this situation?
26. KCl is an example of ionic bonding. HCl is an example of covalent bonding. Describe the difference in the bonds in terms of electrons and outer energy levels.