section 2

How Elements Bond

as you read

What You'll Learn

- **Compare and contrast** ionic and covalent bonds.
- **Distinguish** between compounds and molecules.
- **Identify** the difference between polar and nonpolar covalent bonds.
- **Interpret** chemical shorthand.

Why It's Important

Chemical bonds join the atoms in the materials you use every day.

Review Vocabulary

electron: a negatively charged particle that exists in an electron cloud around an atom's nucleus

New Vocabulary

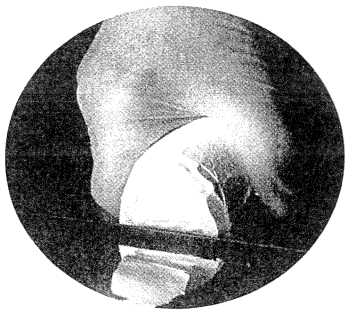
- ion
- ionic bond
- compound
- metallic bond
- covalent bond
- molecule
- polar bond
- chemical formula

Ionic Bonds—Loss and Gain

When you put together the pieces of a jigsaw puzzle, they stay together only as long as you wish. When you pick up the completed puzzle, it falls apart. When elements are joined by chemical bonds, they do not readily fall apart. What would happen if suddenly the salt you were shaking on your fries separated into sodium and chlorine? Atoms form bonds with other atoms using the electrons in their outer energy levels. They have four ways to do this—by losing electrons, by gaining electrons, by pooling electrons, or by sharing electrons with another element.

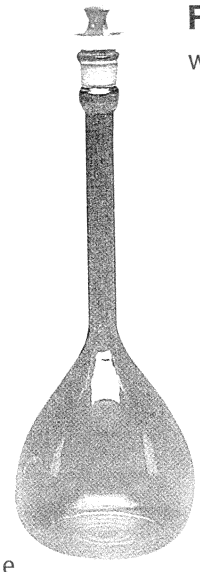
Sodium is a soft, silvery metal as shown in **Figure 11.** It can react violently when added to water or to chlorine. What makes sodium so reactive? If you look at a diagram of its energy levels below, you will see that sodium has only one electron in its outer level. Removing this electron empties this level and leaves the completed level below. By removing one electron, sodium's electron configuration becomes the same as that of the stable noble gas neon.

Chlorine forms bonds in a way that is the opposite of sodium—it gains an electron. When chlorine accepts an electron, its electron configuration becomes the same as that of the noble gas argon.



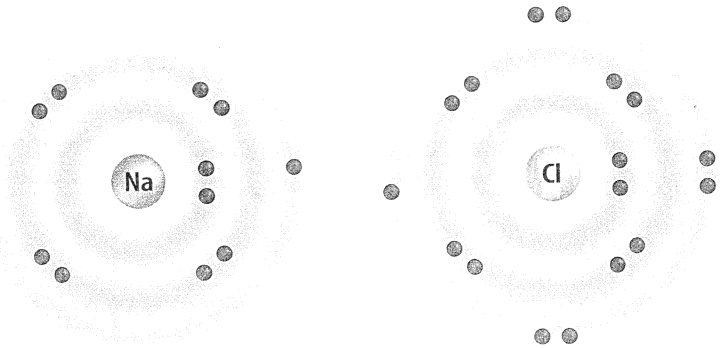
Sodium

Sodium is a silvery metal that can be cut with a knife. Chlorine is a greenish, poisonous gas.



Chlorine

Figure 11 Sodium and chlorine react, forming white crystalline sodium chloride.



Sodium atom

Chlorine atom

If chlorine receives an electron from sodium, both atoms will become stable and a bond will form.

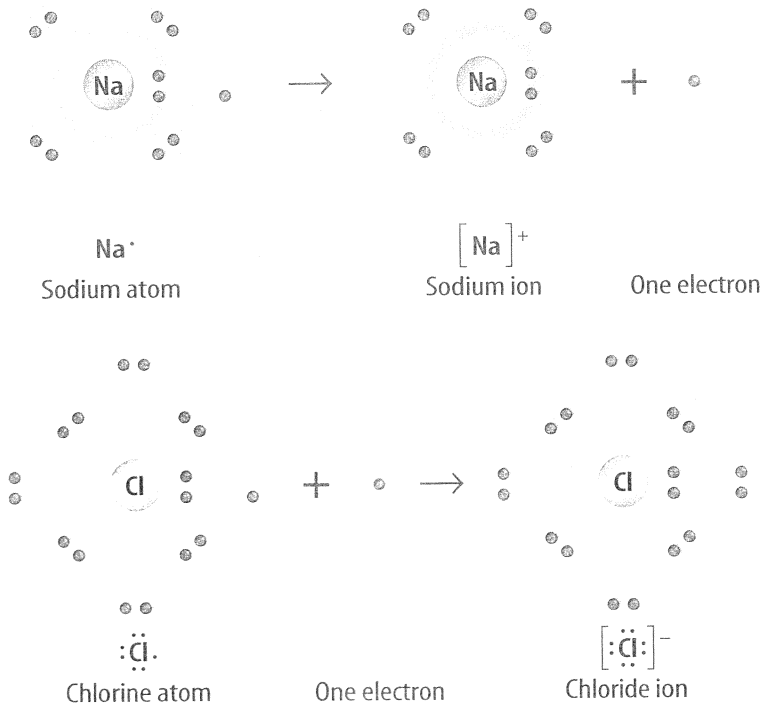


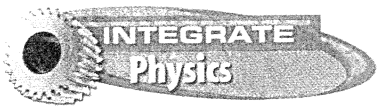
Figure 12 Ions form when elements lose or gain electrons. When sodium comes into contact with chlorine, an electron is transferred from the sodium atom to the chlorine atom. Na becomes a Na^+ ion. Cl becomes a Cl^- ion.

Ions—A Question of Balance As you just learned, a sodium atom loses an electron and becomes more stable. But something else happens also. By losing an electron, the balance of electric charges changes. Sodium becomes a positively charged ion because there is now one fewer electron than there are protons in the nucleus. In contrast, chlorine becomes an ion by gaining an electron. It becomes negatively charged because there is one more electron than there are protons in the nucleus.

An atom that is no longer neutral because it has lost or gained an electron is called an **ion** (I ahn). A sodium ion is represented by the symbol Na^+ and a chloride ion is represented by the symbol Cl^-. **Figure 12** shows how each atom becomes an ion.

Bond Formation The positive sodium ion and the negative chloride ion are strongly attracted to each other. This attraction, which holds the ions close together, is a type of chemical bond called an **ionic bond.** In **Figure 13,** sodium and chloride ions form an ionic bond. The compound sodium chloride, or table salt, is formed. A **compound** is a pure substance containing two or more elements that are chemically bonded.

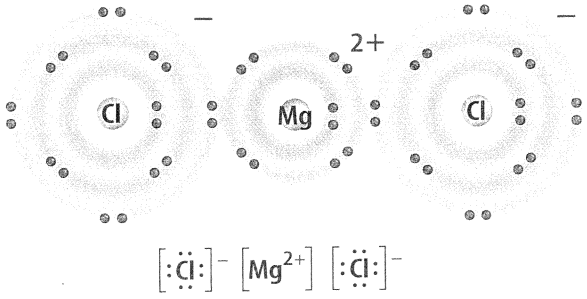
Figure 13 An ionic bond forms between atoms of opposite charges. **Describe** *how an atom becomes positive or negative.*



Ions When ions dissolve in water, they separate. Because of their positive and negative charges, the ions can conduct an electric current. If wires are placed in such a solution and the ends of the wires are connected to a battery, the positive ions move toward the negative terminal and the negative ions move toward the positive terminal. This flow of ions completes the circuit.

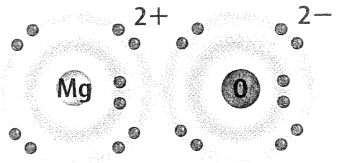
Figure 14 Magnesium has two electrons in its outer energy level.

If one electron is lost to each of two chlorine atoms, magnesium chloride forms.



$[:\ddot{Cl}:]^-$ $[Mg^{2+}]$ $[:\ddot{Cl}:]^-$

Magnesium chloride



$[Mg^{2+}]$ $[O^{2-}]$

Magnesium oxide

If both electrons are lost to one oxygen atom, magnesium oxide forms.

Determine *the electron arrangement for magnesium sulfide and calcium oxide.*

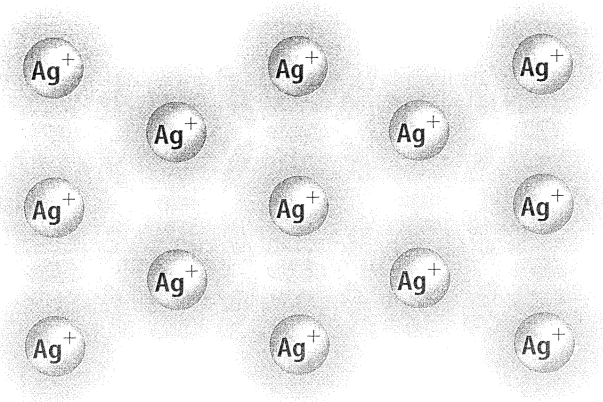
More Gains and Losses You have seen what happens when elements gain or lose one electron, but can elements lose or gain more than one electron? The element magnesium, Mg, in Group 2 has two electrons in its outer energy level. Magnesium can lose these two electrons and achieve a completed energy level. These two electrons can be gained by two chlorine atoms. As shown in **Figure 14,** a single magnesium ion represented by the symbol Mg^{2+} and two chloride ions are generated. The two negatively charged chloride ions are attracted to the positively charged magnesium ion forming ionic bonds. As a result of these bonds, the compound magnesium chloride ($MgCl_2$) is produced.

Some atoms, such as oxygen, need to gain two electrons to achieve stability. The two electrons released by one magnesium atom could be gained by a single atom of oxygen. When this happens, magnesium oxide (MgO) is formed, as shown in **Figure 14.** Oxygen can form similar compounds with any positive ion from Group 2.

Metallic Bonding—Pooling

You have just seen how metal atoms form ionic bonds with atoms of nonmetals. Metals can form bonds with other metal atoms, but in a different way. In a metal, the electrons in the outer energy levels of the atoms are not held tightly to individual atoms. Instead, they move freely among all the ions in the metal, forming a shared pool of electrons, as shown in **Figure 15. Metallic bonds** form when metal atoms share their pooled electrons. This bonding affects the properties of metals. For example, when a metal is hammered into sheets or drawn into a wire, it does not break. Instead, layers of atoms slide over one another. The pooled electrons tend to hold the atoms together. Metallic bonding also is the reason that metals conduct electricity well. The outer electrons in metal atoms readily move from one atom to the next to transmit current.

Figure 15 In metallic bonding, the outer electrons of the silver atoms are not attached to any one silver atom. This allows them to move and conduct electricity.



Covalent Bonds—Sharing

Some atoms are unlikely to lose or gain electrons because the number of electrons in their outer levels makes this difficult. For example, carbon has six protons and six electrons. Four of the six electrons are in its outer energy level. To obtain a more stable structure, carbon would either have to gain or lose four electrons. This is difficult because gaining and losing so many electrons takes so much energy. The alternative is sharing electrons.

The Covalent Bond Atoms of many elements become more stable by sharing electrons. The chemical bond that forms between nonmetal atoms when they share electrons is called a **covalent** (koh VAY luhnt) **bond.** Shared electrons are attracted to the nuclei of both atoms. They move back and forth between the outer energy levels of each atom in the covalent bond. So, each atom has a stable outer energy level some of the time. Covalently bonded compounds are called molecular compounds.

Reading Check *How do atoms form covalent bonds?*

The atoms in a covalent bond form a neutral particle, which contains the same numbers of positive and negative charges. The neutral particle formed when atoms share electrons is called a **molecule** (MAH lih kyewl). A molecule is the basic unit of a molecular compound. You can see how molecules form by sharing electrons in **Figure 16.** Notice that no ions are involved because no electrons are gained or lost. Crystalline solids, such as sodium chloride, are not referred to as molecules, because their basic units are ions, not molecules.

Mini LAB

Constructing a Model of Methane

Procedure

1. Using **circles of colored paper** to represent protons, neutrons, and electrons, build paper models of one carbon atom and four hydrogen atoms.
2. Use your models of atoms to construct a molecule of methane by forming covalent bonds. The methane molecule has four hydrogen atoms chemically bonded to one carbon atom.

Analysis

1. In the methane molecule, do the carbon and hydrogen atoms have the same arrangement of electrons as two noble gas elements? Explain your answer.
2. Does the methane molecule have a charge?

Try at Home

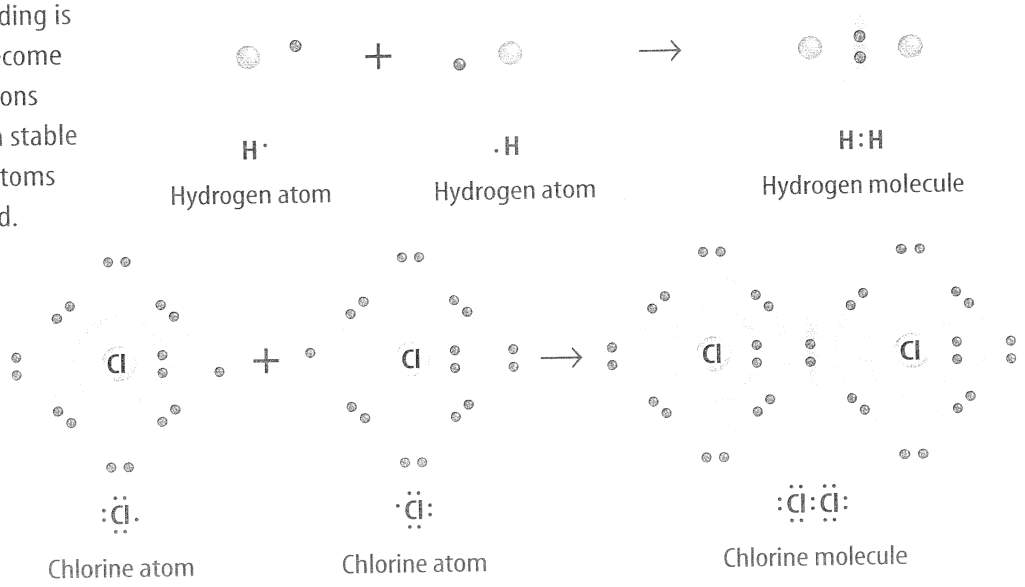


Figure 16 Covalent bonding is another way that atoms become more stable. Sharing electrons allows each atom to have a stable outer energy level. These atoms form a single covalent bond.

Figure 17 An atom can also form a covalent bond by sharing two or three electrons.

Carbon atom — Oxygen atoms — Carbon dioxide molecule

In carbon dioxide, carbon shares two electrons with each of two oxygen atoms forming two double bonds. Each oxygen atom shares two electrons with the carbon atom.

Nitrogen atoms — Nitrogen molecule

Each nitrogen atom shares three electrons in forming a triple bond.

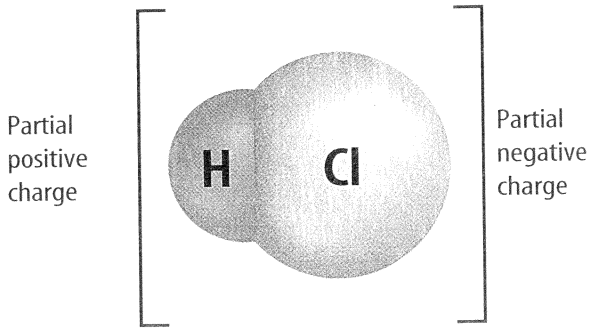
Double and Triple Bonds Sometimes an atom shares more than one electron with another atom. In the molecule carbon dioxide, shown in **Figure 17,** each of the oxygen atoms shares two electrons with the carbon atom. The carbon atom shares two of its electrons with each oxygen atom. When two pairs of electrons are involved in a covalent bond, the bond is called a double bond. **Figure 17** also shows the sharing of three pairs of electrons between two nitrogen atoms in the nitrogen molecule. When three pairs of electrons are shared by two atoms, the bond is called a triple bond.

Reading Check *How many pairs of electrons are shared in a double bond?*

Polar and Nonpolar Molecules

You have seen how atoms can share electrons and that they become more stable by doing so, but do they always share electrons equally? The answer is no. Some atoms have a greater attraction for electrons than others do. Chlorine, for example, attracts electrons more strongly than hydrogen does. When a covalent bond forms between hydrogen and chlorine, the shared pair of electrons tends to spend more time near the chlorine atom than the hydrogen atom.

Figure 18 Hydrogen chloride is a polar covalent molecule.



This unequal sharing makes one side of the bond more negative than the other, like poles on a battery. This is shown in **Figure 18.** Such bonds are called polar bonds. A **polar bond** is a bond in which electrons are shared unevenly. The bonds between the oxygen atom and hydrogen atoms in the water molecule are another example of polar bonds.

The Polar Water Molecule Water molecules form when hydrogen and oxygen share electrons. **Figure 19** shows how this sharing is unequal. The oxygen atom has a greater share of the electrons in each bond—the oxygen end of a water molecule has a slight negative charge and the hydrogen end has a slight positive charge. Because of this, water is said to be polar—having two opposite ends or poles like a magnet.

When they are exposed to a negative charge, the water molecules line up like magnets with their positive ends facing the negative charge. You can see how they are drawn to the negative charge on the balloon in **Figure 19.** Water molecules also are attracted to each other. This attraction between water molecules accounts for many of the physical properties of water.

Molecules that do not have these uneven charges are called nonpolar molecules. Because each element differs slightly in its ability to attract electrons, the only completely nonpolar bonds are bonds between atoms of the same element. One example of a nonpolar bond is the triple bond in the nitrogen molecule.

Like ionic compounds, some molecular compounds can form crystals, in which the basic unit is a molecule. Often you can see the pattern of the units in the shape of ionic and molecular crystals, as shown in **Figure 20.**

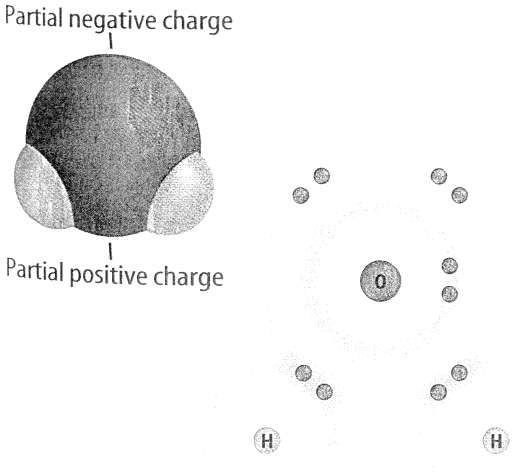
Science Online

Topic: Polar Molecules

Visit for Web links to information about soaps and detergents.

Activity Oil and water are not soluble in one another. However, if you add a few grams of a liquid dish detergent, the oil will become soluble in the water. Instead of two layers, there will be only one. Explain why soap can help the oil become soluble in water.

Figure 19 Two hydrogen atoms share electrons with one oxygen atom, but the sharing is unequal. The electrons are more likely to be closer to the oxygen than the hydrogens. The space-saving model shows how the charges are separated or polarized. **Define** *the term* polar.



The positive ends of the water molecules are attracted to the negatively charged balloon, causing the stream of water to bend.