



Atomic Structure and Chemical Bonds

chapter preview

sections

1 Why do atoms combine?

2 How Elements Bond

Lab Ionic Compounds

Lab Atomic Structure



Virtual Labs How can you tell which elements form chemical bonds?

The Noble Family

Blimps, city lights, and billboards, all have something in common—they use gases that are members of the same element family. In this chapter, you'll learn about the unique properties of element families. You'll also learn how electrons can be lost, gained, and shared by atoms to form chemical bonds.

Science Journal Write a sentence comparing household glue to chemical bonds.

Start-Up Activities



Model the Energy of Electrons

It's time to clean out your room—again. Where do all these things come from? Some are made of cloth and some of wood. The books are made of paper and an endless array of things are made of plastic. Fewer than 100 different kinds of naturally occurring elements are found on Earth. They combine to make all these different substances. What makes elements form chemical bonds with other elements? The answer is in their electrons.

1. Pick up a paper clip with a magnet. Touch that paper clip to another paper clip and pick it up.
2. Continue picking up paper clips this way until you have a strand of them and no more will attach.
3. Then, gently pull off the paper clips one by one.
4. **Think Critically** In your Science Journal, discuss which paper clip was easiest to remove and which was hardest. Was the clip that was easiest to remove closer to or farther from the magnet?

FOLDABLES™ Study Organizer

Chemical Bonds Make the following Foldable to help you classify information by diagramming ideas about chemical bonds.

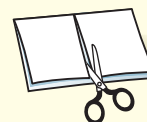
STEP 1 **Fold** a vertical sheet of paper in half from top to bottom.



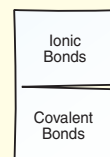
STEP 2 **Fold** in half from side to side with the fold at the top.



STEP 3 **Unfold** the paper once. **Cut** only the fold of the top flap to make two tabs.



STEP 4 **Turn** the paper vertically and **label** the tabs as shown.



Summarize As you read the chapter, identify the main ideas of bonding under the appropriate tabs. After you have read the chapter, explain the difference between polar covalent bonds and covalent bonds on the inside portion of your Foldable.



Preview this chapter's content and activities at blue.msscience.com



Why do atoms combine?

as you read

What You'll Learn

- **Identify** how electrons are arranged in an atom.
- **Compare** the relative amounts of energy of electrons in an atom.
- **Compare** how the arrangement of electrons in an atom is related to its place in the periodic table.

Why It's Important

Chemical reactions take place all around you.



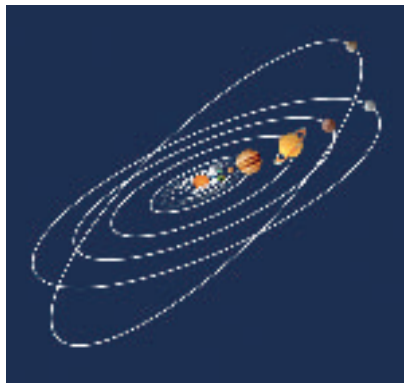
Review Vocabulary

atom: the smallest part of an element that keeps all the properties of that element

New Vocabulary

- electron cloud
- energy level
- electron dot diagram
- chemical bond

Figure 1 You can compare and contrast electrons with planets.



Planets travel in well-defined paths.

Atomic Structure

When you look at your desk, you probably see it as something solid. You might be surprised to learn that all matter, even solids like wood and metal contain mostly empty space. How can this be? The answer is that although there might be little or no space between atoms, a lot of empty space lies within each atom.

At the center of every atom is a nucleus containing protons and neutrons. This nucleus represents most of the atom's mass. The rest of the atom is empty except for the atom's electrons, which are extremely small compared with the nucleus. Although the exact location of any one electron cannot be determined, the atom's electrons travel in an area of space around the nucleus called the **electron cloud**.

To visualize an atom, picture the nucleus as the size of a penny. In this case, electrons would be smaller than grains of dust and the electron cloud would extend outward as far as 20 football fields.

Electrons You might think that electrons resemble planets circling the Sun, but they are very different, as you can see in **Figure 1**. First, planets have no charges, but the nucleus of an atom has a positive charge and electrons have negative charges.

Second, planets travel in predictable orbits—you can calculate exactly where one will be at any time. This is not true for electrons. Although electrons do travel in predictable areas, it is impossible to calculate the exact position of any one electron. Instead scientists use a model that predicts where an electron is most likely to be.



Electrons travel around the nucleus. However, their paths are not well-defined.



Element Structure Each element has a different atomic structure consisting of a specific number of protons, neutrons, and electrons. The number of protons and electrons is always the same for a neutral atom of a given element. **Figure 2** shows a two-dimensional model of the electron structure of a lithium atom, which has three protons and four neutrons in its nucleus, and three electrons moving around its nucleus.

Electron Arrangement

The number and arrangement of electrons in the electron cloud of an atom are responsible for many of the physical and chemical properties of that element.

Electron Energy Although all the electrons in an atom are somewhere in the electron cloud, some electrons are closer to the nucleus than others. The different areas for an electron in an atom are called **energy levels**. **Figure 3** shows a model of what these energy levels might look like. Each level represents a different amount of energy.

Number of Electrons Each energy level can hold a maximum number of electrons. The farther an energy level is from the nucleus, the more electrons it can hold. The first energy level, energy level 1, can hold one or two electrons, the second, energy level 2, can hold up to eight, the third can hold up to 18, and the fourth energy level can hold a maximum of 32 electrons.

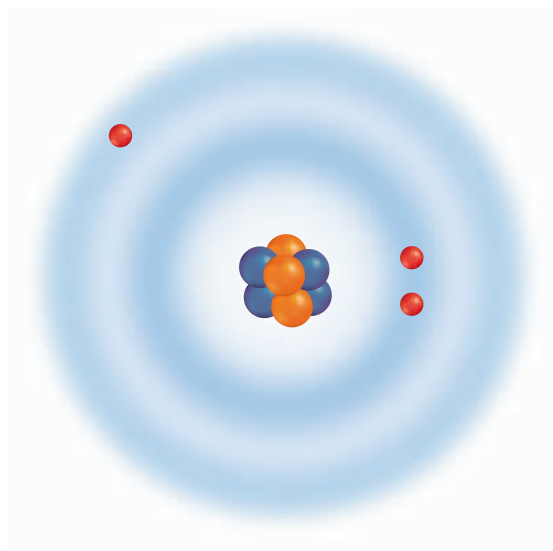


Figure 2 This neutral lithium atom has three positively charged protons, three negatively charged electrons, and four neutral neutrons.

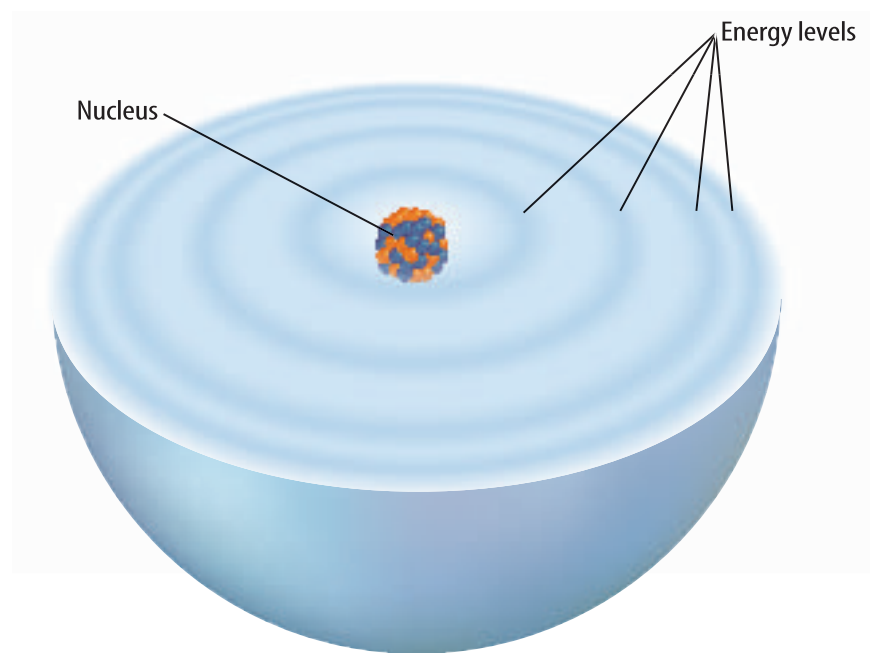


Figure 3 Electrons travel in three dimensions around the nucleus of an atom. The dark bands in this diagram show the energy levels where electrons are most likely to be found. **Identify** the energy level that can hold the most electrons.

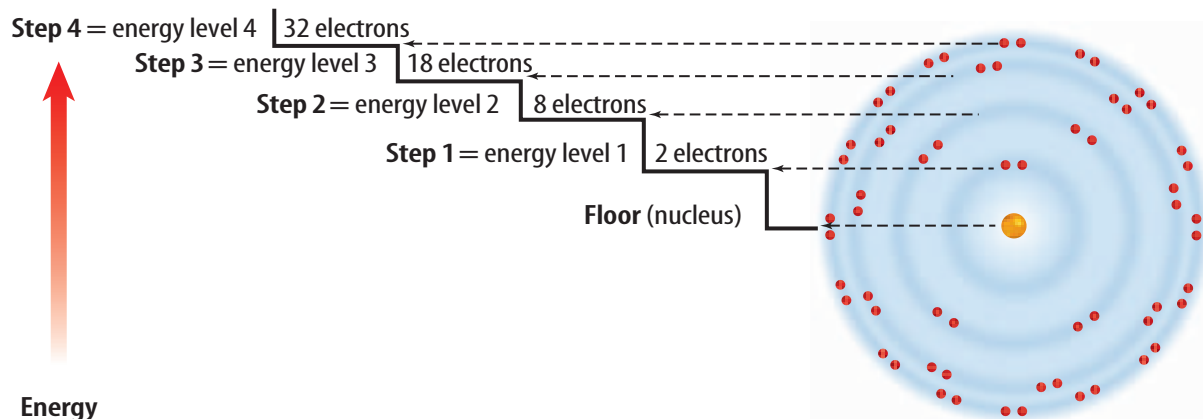


Figure 4 The farther an energy level is from the nucleus, the more electrons it can hold.

Identify the energy level with the least energy and the energy level with the most energy.

Energy Steps The stairway, shown in **Figure 4**, is a model that shows the maximum number of electrons each energy level can hold in the electron cloud. Think of the nucleus as being at floor level. Electrons within an atom have different amounts of energy, represented by energy levels. These energy levels are represented by the stairsteps in **Figure 4**. Electrons in the level closest to the nucleus have the lowest amount of energy and are said to be in energy level one. Electrons farthest from the nucleus have the highest amount of energy and are the easiest to remove. To determine the maximum number of electrons that can occupy an energy level, use the formula, $2n^2$, where n equals the number of the energy level.

Recall the Launch Lab at the beginning of the chapter. It took more energy to remove the paper clip that was closest to the magnet than it took to remove the one that was farthest away. That's because the closer a paper clip was to the magnet, the stronger the magnet's attractive force was on the clip. Similarly, the closer a negatively charged electron is to the positively charged nucleus, the more strongly it is attracted to the nucleus. Therefore, removing electrons that are close to the nucleus takes more energy than removing those that are farther away from the nucleus.



Reading Check

What determines the amount of energy an electron has?



Topic: Electrons

Visit blue.msscience.com for Web links to information about electrons and their history.

Activity Research why scientists cannot locate the exact positions of an electron.

Periodic Table and Energy Levels

The periodic table includes a lot of data about the elements and can be used to understand the energy levels also. Look at the horizontal rows, or periods, in the portion of the table shown in **Figure 5**. Recall that the atomic number for each element is the same as the number of protons in that element and that the number of protons equals the number of electrons because an atom is electrically neutral. Therefore, you can determine the number of electrons in an atom by looking at the atomic number written above each element symbol.



Electron Configurations

If you look at the periodic table shown in **Figure 5**, you can see that the elements are arranged in a specific order. The number of electrons in a neutral atom of the element increases by one from left to right across a period. For example, the first period consists of hydrogen with one electron and helium with two electrons in energy level one. Recall from **Figure 4** that energy level one can hold up to two electrons. Therefore, helium's outer energy level is complete. Atoms with a complete outer energy level are stable. Therefore, helium is stable.



Reading Check

What term is given to the rows of the periodic table?

The second period begins with lithium, which has three electrons—two in energy level one and one in energy level two. Lithium has one electron in its outer energy level. To the right of lithium is beryllium with two outer-level electrons, boron with three, and so on until you reach neon with eight.











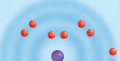
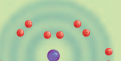
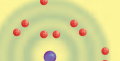
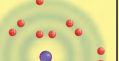
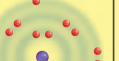
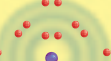
Look again at **Figure 4**. You'll see that energy level two can hold up to eight electrons. Not only does neon have a complete outer energy level, but also this configuration of exactly eight electrons in an outer energy level is stable. Therefore, neon is stable. The third period elements fill their outer energy levels in the same manner, ending with argon. Although energy level three can hold up to 18 electrons, argon has eight electrons in its outer energy level—a stable configuration. Each period in the periodic table ends with a stable element.



Nobel Prize Winner

Ahmed H. Zewail is a professor of chemistry and physics and the director of the Laboratory for Molecular Sciences at the California Institute of Technology. He was awarded the 1999 Nobel Prize in Chemistry for his research. Zewail and his research team use lasers to record the making and breaking of chemical bonds.

Figure 5 This portion of the periodic table shows the electron configurations of some elements. Count the electrons in each element and notice how the number increases across a period.

1							18
Hydrogen 1 H							Helium 2 He
							
2	2						
Lithium 3 Li	Beryllium 4 Be						
							
3		13	14	15	16	17	
		Boron 5 B	Carbon 6 C	Nitrogen 7 N	Oxygen 8 O	Fluorine 9 F	Neon 10 Ne
							
		Aluminum 13 Al	Silicon 14 Si	Phosphorus 15 P	Sulfur 16 S	Chlorine 17 Cl	Argon 18 Ar
							

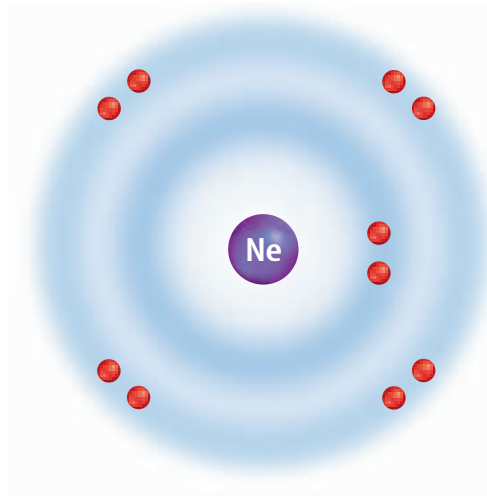
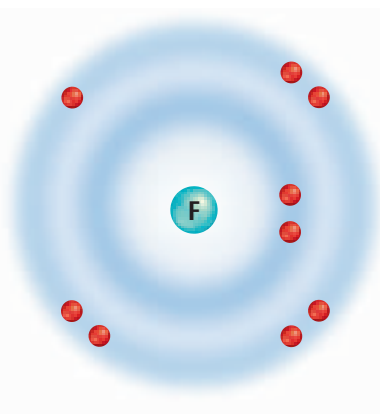


Figure 6 The noble gases are stable elements because their outer energy levels are complete or have a stable configuration of eight electrons like neon shown here.

Figure 7 The halogen element fluorine has seven electrons in its outer energy level.

Determine how many electrons the halogen family member bromine has in its outer energy level.



Element Families

Elements can be divided into groups, or families. Each column of the periodic table in **Figure 5** contains one element family. Hydrogen is usually considered separately, so the first element family begins with lithium and sodium in the first column. The second family starts with beryllium and magnesium in the second column, and so on. Just as human family members often have similar looks and traits, members of element families have similar chemical properties because they have the same number of electrons in their outer energy levels.

It was the repeating pattern of properties that gave Russian chemist Dmitri Mendeleev the idea for his first periodic table in 1869. While listening to his family play music, he noticed how the melody repeated with increasing complexity. He saw a similar repeating pattern in the elements and immediately wrote down a version of the periodic table that looks much as it does today.

Noble Gases Look at the structure of neon in **Figure 6**. Neon and the elements below it in Group 18 have eight electrons in their outer energy levels. Their energy levels are stable, so they do not combine easily with other elements. Helium, with two electrons in its lone energy level, is also stable. At one time these elements were thought to be completely unreactive, and therefore became known as the inert gases. When chemists learned that some of these gases can react, their name was changed to noble gases. They are still the most stable element group.

This stability makes possible one widespread use of the noble gases—to protect filaments in lightbulbs. Another use of noble gases is to produce colored light in signs. If an electric current is passed through them they emit light of various colors—orange-red from neon, lavender from argon, and yellowish-white from helium.

Halogens The elements in Group 17 are called the halogens. A model of the element fluorine in period 2 is shown in **Figure 7**. Like all members of this family, fluorine needs one electron to obtain a stable outer energy level. The easier it is for a halogen to gain this electron to form a bond, the more reactive it is. Fluorine is the most reactive of the halogens because its outer energy level is closest to the nucleus. The reactivity of the halogens decreases down the group as the outer energy levels of each element's atoms get farther from the nucleus. Therefore, bromine in period 4 is less reactive than fluorine in period 2.



Alkali Metals Look at the element family in Group 1 on the periodic table at the back of this book, called the alkali metals. The first members of this family, lithium and sodium, have one electron in their outer energy levels. You can see in **Figure 8** that potassium also has one electron in its outer level. Therefore, you can predict that the next family member, rubidium, does also. These electron arrangements are what determines how these metals react.



Reading Check

How many electrons do the alkali metals have in their outer energy levels?

The alkali metals form compounds that are similar to each other. Alkali metals each have one outer energy level electron. It is this electron that is removed when alkali metals react. The easier it is to remove an electron, the more reactive the atom is. Unlike halogens, the reactivities of alkali metals increase down the group; that is, elements in the higher numbered periods are more reactive than elements in the lower numbered periods. This is because their outer energy levels are farther from the nucleus. Less energy is needed to remove an electron from an energy level that is farther from the nucleus than to remove one from an energy level that is closer to the nucleus. For this reason, cesium in period 6 loses an electron more readily and is more reactive than sodium in period 3.

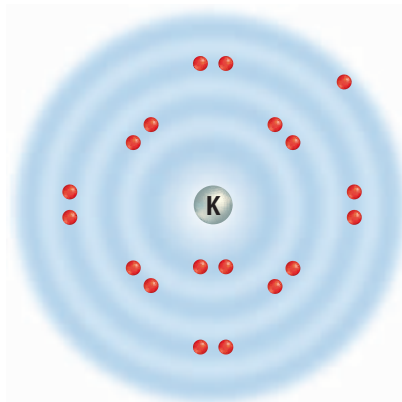


Figure 8 Potassium, like lithium and sodium, has only one electron in its outer level.

Applying Science

How does the periodic table help you identify properties of elements?

The periodic table displays information about the atomic structure of the elements. This information includes the properties, such as the energy level, of the elements. Can you identify an element if you are given information about its energy level? Use your ability to interpret the periodic table to find out.

Identifying the Problem

Recall that elements in a group in the periodic table contain the same number of electrons in their outer levels. The number of electrons increases by one from left to right across a period. Refer to **Figure 5**. Can you identify an

unknown element or the group a known element belongs to?

Solving the Problem

1. An unknown element in Group 2 has a total number of 12 electrons and two electrons in its outer level. What is it?
2. Name the element that has eight electrons, six of which are in its outer level.
3. Silicon has a total of 14 electrons, four electrons in its outer level, and three energy levels. What group does silicon belong to?
4. Three elements have the same number of electrons in their outer energy levels. One is oxygen. Using the periodic table, what might the other two be?



Mini LAB

Drawing Electron Dot Diagrams

Procedure

1. Draw a periodic table that includes the first 18 elements—the elements from hydrogen through argon. Make each block a 3-cm square.
2. Fill in each block with the electron dot diagram of the element.

Analysis

1. What do you observe about the electron dot diagram of the elements in the same group?
2. Describe any changes you observe in the electron dot diagrams across a period.

Electron Dot Diagrams

You have read that the number of electrons in the outer energy level of an atom determines many of the chemical properties of the atom. Because these electrons are so important in determining the chemical properties of atoms, it can be helpful to make a model of an atom that shows only the outer electrons. A model like this can be used to show what happens to these electrons during reactions.

Drawing pictures of the energy levels and electrons in them takes time, especially when a large number of electrons are present. If you want to see how atoms of one element will react, it is handy to have an easier way to represent the atoms and the electrons in their outer energy levels. You can do this with electron dot diagrams. An **electron dot diagram** is the symbol for the element surrounded by as many dots as there are electrons in its outer energy level. Only the outer energy level electrons are shown because these are what determine how an element can react.

How to Write Them How do you know how many dots to make? For Groups 1 and 2, and 13–18, you can use the periodic table or the portion of it shown in **Figure 5**. Group 1 has one outer electron. Group 2 has two. Group 13 has three, Group 14, four, and so on to Group 18. All members of Group 18 have stable outer energy levels. From neon down, they have eight electrons. Helium has only two electrons, because that is all that its single energy level can hold.

The dots are written in pairs on four sides of the element symbol. Start by writing one dot on the top of the element symbol, then work your way around, adding dots to the right, bottom, and left. Add a fifth dot to the top to make a pair. Continue in this manner until you reach eight dots to complete the level.

The process can be demonstrated by writing the electron dot diagram for the element nitrogen. First, write N—the element symbol for nitrogen. Then, find nitrogen in the periodic table and see what group it is in. It's in Group 15, so it has five electrons in its outer energy level. The completed electron dot diagram for nitrogen can be seen in **Figure 9**.

The electron dot diagram for iodine can be drawn the same way. The completed diagram is shown on the right in **Figure 9**.

Figure 9 Electron dot diagrams show only the electrons in the outer energy level.

Explain why only the outer energy level electrons are shown.

Nitrogen contains five electrons in its outer energy level.



Iodine contains seven electrons in its outer energy level.





Figure 10 Some models are made by gluing pieces together. The glue that holds elements together in a chemical compound is the chemical bond.

Using Dot Diagrams Now that you know how to write electron dot diagrams for elements, you can use them to show how atoms bond with each other. A **chemical bond** is the force that holds two atoms together. Chemical bonds unite atoms in a compound much as glue unites the pieces of the model in **Figure 10**. Atoms bond with other atoms in such a way that each atom becomes more stable. That is, their outer energy levels will resemble those of the noble gases.

 **Reading Check** What is a chemical bond?

section 1 review

Summary

Atom Structure

- At the center of the atom is the nucleus.
- Electrons exist in an area called the electron cloud.
- Electrons have a negative charge.

Electron Arrangement

- The different regions for an electron in an atom are called energy levels.
- Each energy level can hold a maximum number of electrons.

The Periodic Table

- The number of electrons is equal to the atomic number.
- The number of electrons in a neutral atom increases by one from left to right across a period.

Self Check

1. **Determine** how many electrons nitrogen has in its outer energy level. How many does bromine have?
2. **Solve** for the number of electrons that oxygen has in its first energy level. Second energy level?
3. **Identify** which electrons in oxygen have more energy, those in the first energy level or those in the second.
4. **Think Critically** Atoms in a group of elements increase in size as you move down the columns in the periodic table. Explain why this is so.

Applying Math

5. **Solve One-Step Equations** You can calculate the maximum number of electrons each energy level can hold using the formula $2n^2$. Calculate the number of electrons in the first five energy levels where n equals the number of energy levels.



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 | ● covalent bond |
| ● ionic bond | ● molecule |
| ● compound | ● polar bond |
| ● metallic bond | ● chemical formula |

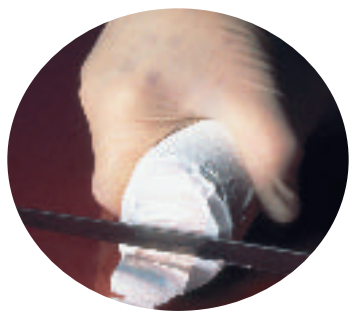
Ionic Bonds—Loss and Gain

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.

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

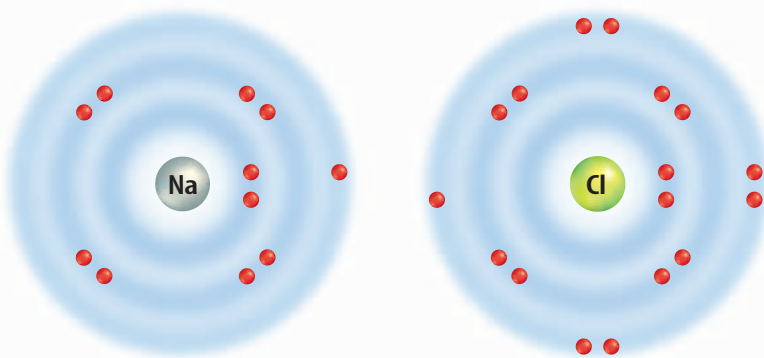


Sodium

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



Chlorine



Their electronic structures show why they react.

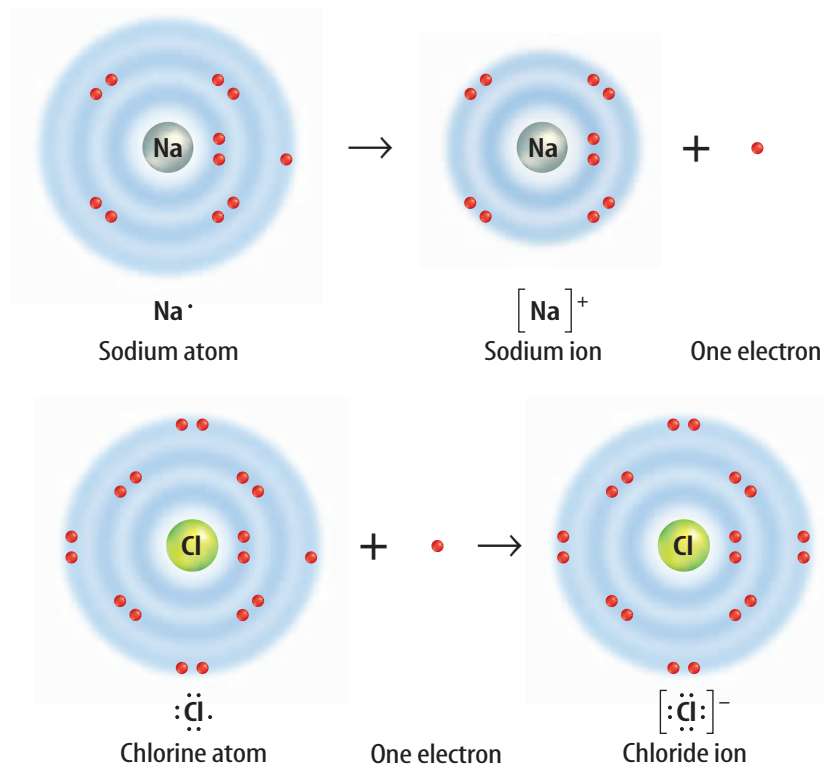


Figure 12 Ions form when elements lose or gain electrons. When sodium comes into contact with chlorine, an electron is transferred from the sodium atom to the chlorine atom. Na becomes a Na^+ ion. Cl becomes a Cl^- ion.



Ions 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.

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.

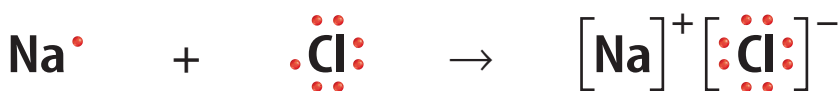
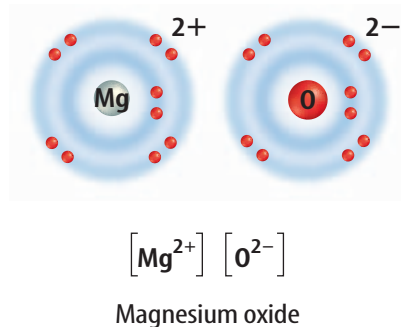
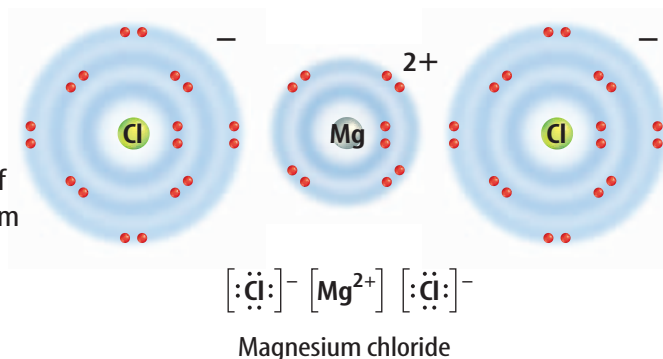


Figure 13 An ionic bond forms between atoms of opposite charges. **Describe** how an atom becomes positive or negative.



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.



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

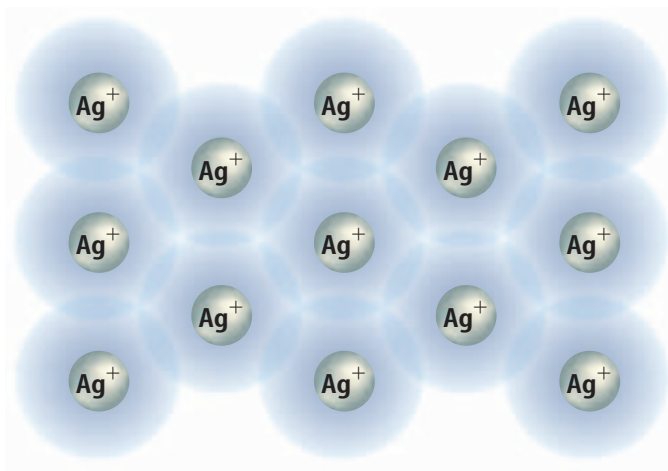
Determine the electron arrangement for magnesium sulfide and calcium oxide.

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

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.



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.



Covalent Bonds—Sharing

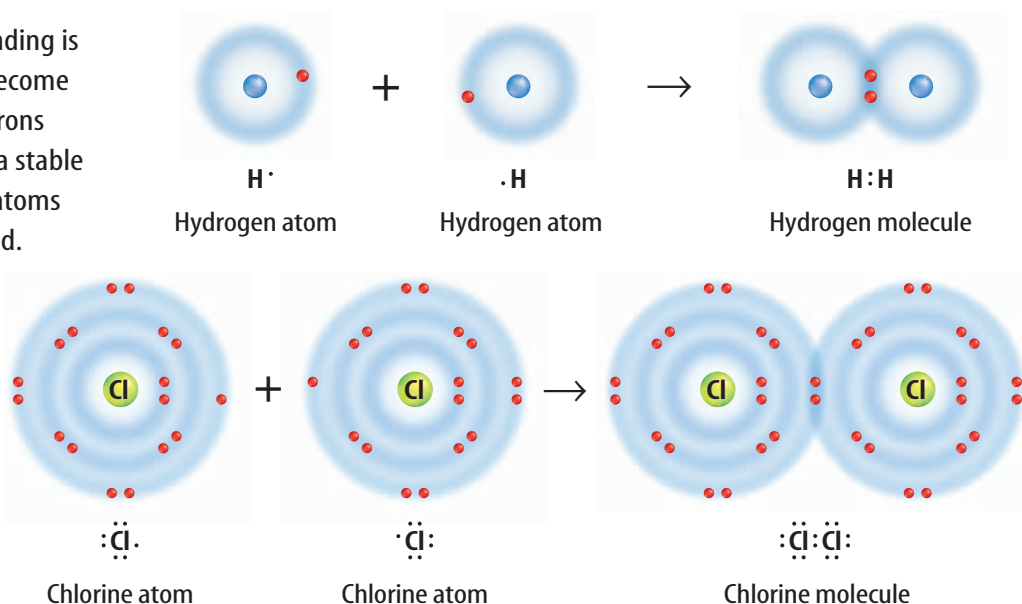
Some atoms are unlikely to lose or gain electrons because the number of electrons in their outer levels makes this difficult. For example, carbon has six protons and six electrons. Four of the six electrons are in its outer energy level. To obtain a more stable structure, carbon would either have to 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.

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.



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.

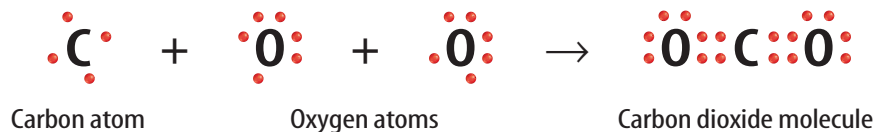
Analysis

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?





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



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.



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.

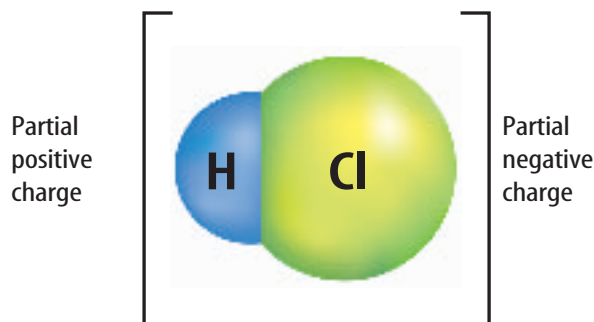
 **Reading Check** How many pairs of electrons are shared in a double bond?

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.

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.

Figure 18 Hydrogen chloride is a polar covalent molecule.





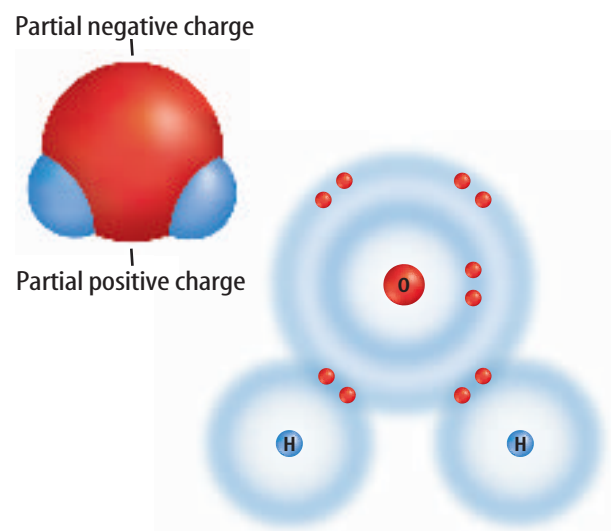
The Polar Water Molecule Water molecules form when hydrogen and oxygen share electrons. **Figure 19** shows how this sharing is unequal. The oxygen atom has a greater share of the electrons in each bond—the oxygen end of a water molecule has a slight negative charge and the hydrogen end has a slight 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**.

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.



Scienceonline

Topic: Polar Molecules

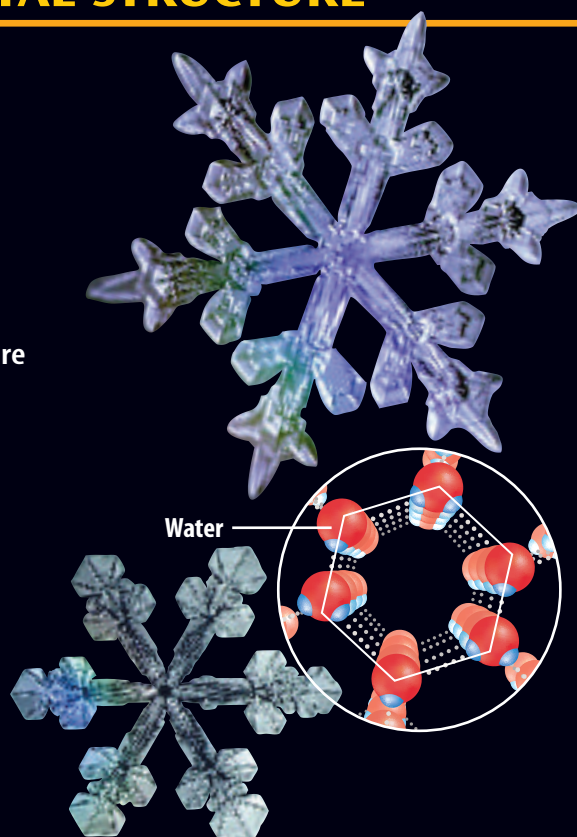
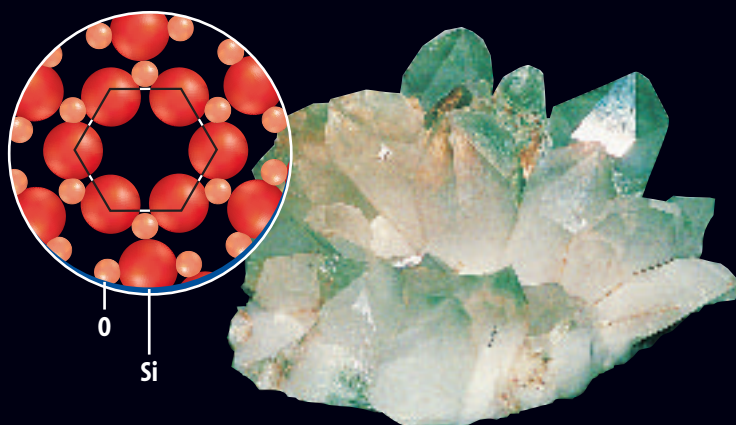
Visit blue.msscience.com for Web links to information about soaps and detergents.

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.

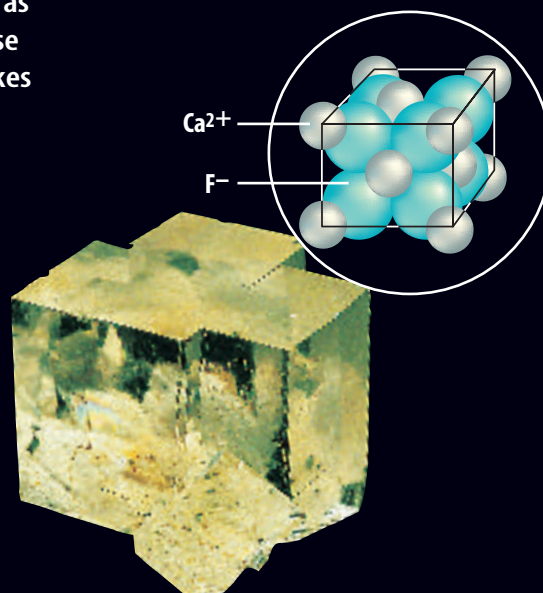
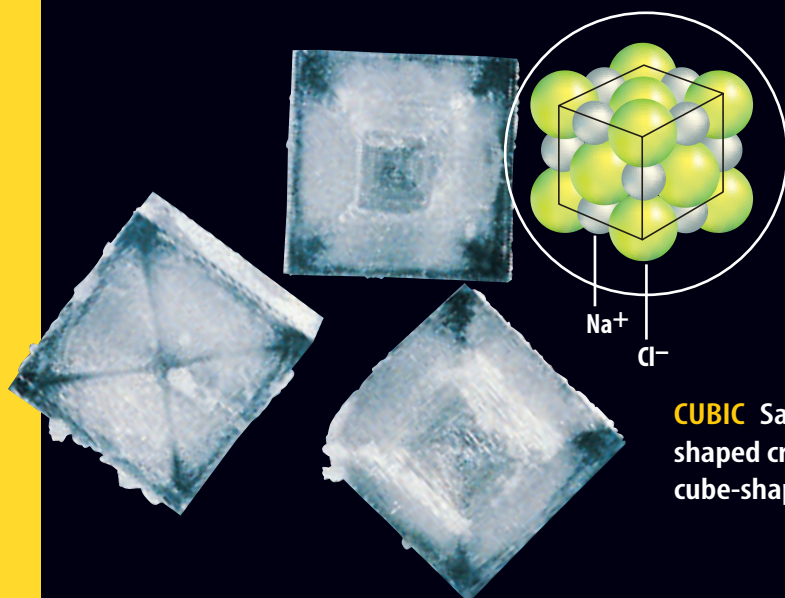


Figure 20

Many solids exist as crystals. Whether tiny grains of table salt or big, chunky blocks of quartz you might find rock hunting, a crystal's shape is often a reflection of the arrangement of its particles. Knowing a solid's crystal structure helps researchers understand its physical properties. Some crystals with cubic and hexagonal shapes are shown here.



HEXAGONAL Quartz crystals, above, are six sided, just as a snowflake, above right, has six points. This is because the molecules that make up both quartz and snowflakes arrange themselves into hexagonal patterns.



CUBIC Salt, left, and fluorite, above, form cube-shaped crystals. This shape is a reflection of the cube-shaped arrangement of the ions in the crystal.



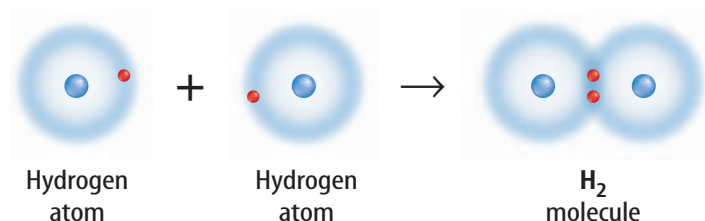
Chemical Shorthand

In medieval times, alchemists (AL kuh mists) were the first to explore the world of chemistry. Although many of them believed in magic and mystical transformations, alchemists did learn much about the properties of some elements. They even used symbols to represent them in chemical processes, some of which are shown in **Figure 21**.

	Sulfur	Iron	Zinc	Silver	Mercury	Lead
Ancient						
Modern	S	Fe	Zn	Ag	Hg	Pb

Symbols for Atoms Modern chemists use symbols to represent elements, too. These symbols can be understood by chemists everywhere. Each element is represented by a one letter-, two letter-, or three-letter symbol. Many symbols are the first letters of the element's name, such as H for hydrogen and C for carbon. Others are the first letters of the element's name in another language, such as K for potassium, which stands for kalium, the Latin word for potassium.

Symbols for Compounds Compounds can be described using element symbols and numbers. For example, **Figure 22** shows how two hydrogen atoms join together in a covalent bond. The resulting hydrogen molecule is represented by the symbol H_2 . The small 2 after the H in the formula is called a subscript. *Sub* means "below" and *script* means "write," so a subscript is a number that is written a little below a line of text. The subscript 2 means that two atoms of hydrogen are in the molecule.



The subscript 2 after the H indicates that the hydrogen molecule contains two atoms of hydrogen.

The formula for ammonia, NH_3 , tells you that the ratio is one nitrogen atom to three hydrogen atoms.

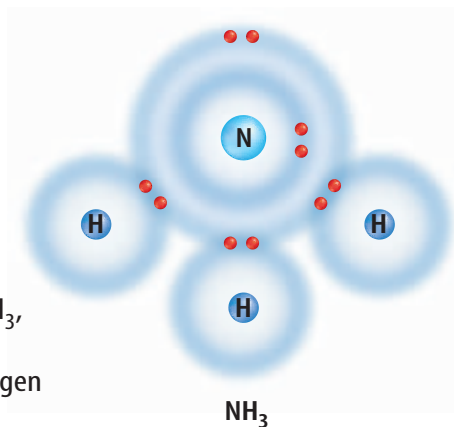


Figure 21 Alchemists used elaborate symbols to describe elements and processes. Modern chemical symbols are letters that can be understood all over the world.

Figure 22 Chemical formulas show you the kind and number of atoms in a molecule.

Describe the term subscript.

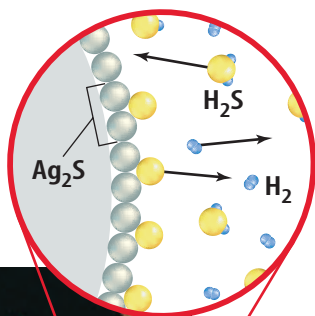


Figure 23 Silver tarnish is the compound silver sulfide, Ag_2S . The formula shows that two silver atoms are combined with one sulfur atom.

Chemical Formulas A **chemical formula** is a combination of chemical symbols and numbers that shows which elements are present in a compound and how many atoms of each element are present. When no subscript is shown, the number of atoms is understood to be one.



Reading Check

What is a chemical formula and what does it tell you about a compound?

Now that you understand chemical formulas, you can look back at the other chemical compounds shown earlier in this chapter, and write their chemical formulas. A water molecule contains one oxygen atom and two hydrogen atoms, so its formula is H_2O . Ammonia, shown in **Figure 22**, is a covalent compound that contains one nitrogen atom and three hydrogen atoms. Its chemical formula is NH_3 .

The black tarnish that forms on silver, shown in **Figure 23**, is a compound made up of the elements silver and sulfur in the proportion of two atoms of silver to one atom of sulfur. If alchemists knew the composition of silver tarnish, how might they have written a formula for the compound? The modern formula for silver tarnish is Ag_2S . The formula tells you that it is a compound that contains two silver atoms and one sulfur atom.

section 2 review

Summary

Four Types of Bonds

- Ionic bond is the attraction that holds ions close together.
- Metallic bonds form when metal atoms pool their electrons.
- Covalent bonds form when atoms share electrons.
- A polar covalent bond is a bond in which electrons are shared unevenly.

Chemical Shorthand

- Compounds can be described by using element symbols and numbers.
- A chemical formula is a combination of element symbols and numbers.

Self Check

1. **Determine** Use the periodic table to decide whether lithium forms a positive or negative ion. Does fluorine form a positive or negative ion? Write the formula for the compound formed from these two elements.
2. **Compare and contrast** polar and nonpolar bonds.
3. **Explain** how a chemical formula indicates the ratio of elements in a compound.
4. **Think Critically** Silicon has four electrons in its outer energy level. What type of bond is silicon most likely to form with other elements? Explain.

Applying Skills

5. **Predict** what type of bonds that will form between the following pairs of atoms: carbon and oxygen, potassium and bromine, fluorine and fluorine.

IONIC COMPOUNDS

Metals in Groups 1 and 2 often lose electrons and form positive ions. Nonmetals in Groups 16 and 17 often gain electrons and become negative ions. How can compounds form between these four groups of elements?

Real-World Question

How do different atoms combine with each other to form compounds?

Goals

- **Construct** models of electron gain and loss.
- **Determine** formulas for the ions and compounds that form when electrons are gained or lost.

Materials

paper (8 different colors)
tacks (2 different colors)
corrugated cardboard
scissors

Safety Precautions



Procedure

1. Cut colored-paper disks 7 cm in diameter to represent the elements Li, S, Mg, O, Ca, Cl, Na, and I. Label each disk with one symbol.
2. Lay circles representing the atoms Li and S side by side on cardboard.
3. Choose colored thumbtacks to represent the outer electrons of each atom. Place the tacks evenly around the disks to represent the outer electron levels of the elements.
4. Move electrons from the metal atom to the nonmetal atom so that both elements



achieve noble gas arrangements of eight outer electrons. If needed, cut additional paper disks to add more atoms of one element.

5. Write the formula for each ion and the compound formed when you shift electrons.
6. Repeat steps 2 through 6 to combine Mg and O, Ca and Cl, and Na and I.

Conclude and Apply

1. **Draw** electron dot diagrams for all of the ions produced.
2. **Identify** the noble gas elements having the same electron arrangements as the ions you made in this lab.
3. **Analyze Results** Why did you have to use more than one atom in some cases? Why couldn't you take more electrons from one metal atom or add extra ones to a nonmetal atom?

Communicating Your Data

Compare your compounds and dot diagrams with those of other students in your class. **For more help, refer to the Science Skill Handbook.**

Atomic Structure

Goals

- **Design** a model of a chosen element.
- **Observe** the models made by others in the class and identify the elements they represent.

Possible Materials

magnetic board
rubber magnetic strips
candy-coated chocolates
scissors
paper
marker
coins

Safety Precautions



WARNING: *Never eat any food in the laboratory. Wash hands thoroughly.*

Real-World Question

As more information has become known about the structure of the atom, scientists have developed new models. Making your own model and studying the models of others will help you learn how protons, neutrons, and electrons are arranged in an atom. Can an element be identified based on a model that shows the arrangement of the protons, neutrons, and electrons of an atom? How will your group construct a model of an element that others will be able to identify?

Make A Model

1. Choose an element from periods 2 or 3 of the periodic table. How can you determine the number of protons, neutrons, and electrons in an atom given the atom's mass number?
2. How can you show the difference between protons and neutrons? What materials will you use to represent the electrons of the atom? How will you represent the nucleus?



Using Scientific Methods

3. How will you model the arrangement of electrons in the atom? Will the atom have a charge? Is it possible to identify an atom by the number of protons it has?
4. Make sure your teacher approves your plan before you proceed.

Test Your Model

1. **Construct** your model. Then record your observations in your Science Journal and include a sketch.
2. **Construct** another model of a different element.
3. **Observe** the models made by your classmates. Identify the elements they represent.

Analyze Your Data

1. **State** what elements you identified using your classmates' models.
2. **Identify** which particles always are present in equal numbers in a neutral atom.
3. **Predict** what would happen to the charge of an atom if one of the electrons were removed.
4. **Describe** what happens to the charge of an atom if two electrons are added. What happens to the charge of an atom if one proton and one electron are removed?
5. **Compare and contrast** your model with the electron cloud model of the atom. How is your model similar? How is it different?

Conclude and Apply

1. **Define** the minimum amount of information that you need to know in order to identify an atom of an element.
2. **Explain** If you made models of the isotopes boron-10 and boron-11, how would these models be different?

Communicating Your Data

Compare your models with those of other students. Discuss any differences you find among the models.



"Baring the Atom's Mother Heart"

from *Selu: Seeking the Corn-Mother's Wisdom*

by Marilou Awiakta



Author Marilou Awiakta was raised near Oak Ridge National Laboratory, a nuclear research laboratory in Tennessee where her father worked. She is of Cherokee and Irish descent. This essay resulted from conversations the author had with writer Alice Walker. It details the author's concern with nuclear technology.

"What is the atom, Mother? Will it hurt us?"

I was nine years old. It was December 1945. Four months earlier, in the heat of an August morning—Hiroshima. Destruction. Death. Power beyond belief, released from something invisible¹. Without knowing its name, I'd already felt the atoms' power in another form...

"What is the atom, Mother? Will it hurt us?"

"It can be used to hurt everybody, Marilou. It killed thousands² of people in Hiroshima and Nagasaki. But the atom itself. . . ? It's invisible, the smallest bit of matter. And it's in everything. Your hand, my dress, the milk you're drinking—. . .

. . . Mother already had taught me that beyond surface differences, everything is [connected]. It seemed natural for the atom to be part of this connection. At school, when I was introduced to Einstein's theory of relativity—that energy and matter are one—I accepted the concept easily.

1 I can't see

2 10,500

Understanding Literature

Refrain Refrains are emotionally charged words or phrases that are repeated throughout a literary work and can serve a number of purposes. In this work, the refrain is when the author asks, "What is the atom, Mother? Will it hurt us?" Do you think the refrain helps the reader understand the importance of the atom?

Respond to the Reading

1. How did the author's mother explain the atom to her?
2. Is this a positive or negative explanation of the atom?
3. **Linking Science and Writing** Write a short poem about some element you learned about in this chapter.



Nuclear fission, or splitting atoms, is the breakdown of an atom's nucleus. It occurs when a particle, such as a neutron, strikes the nucleus of a uranium atom, splitting the nucleus into two fragments, called fission fragments, and releasing two or three neutrons. These released neutrons ultimately cause a chain reaction by splitting more nuclei and releasing more neutrons. When it is uncontrolled, this chain reaction results in a devastating explosion.

Reviewing Main Ideas

Section 1 Why do atoms combine?

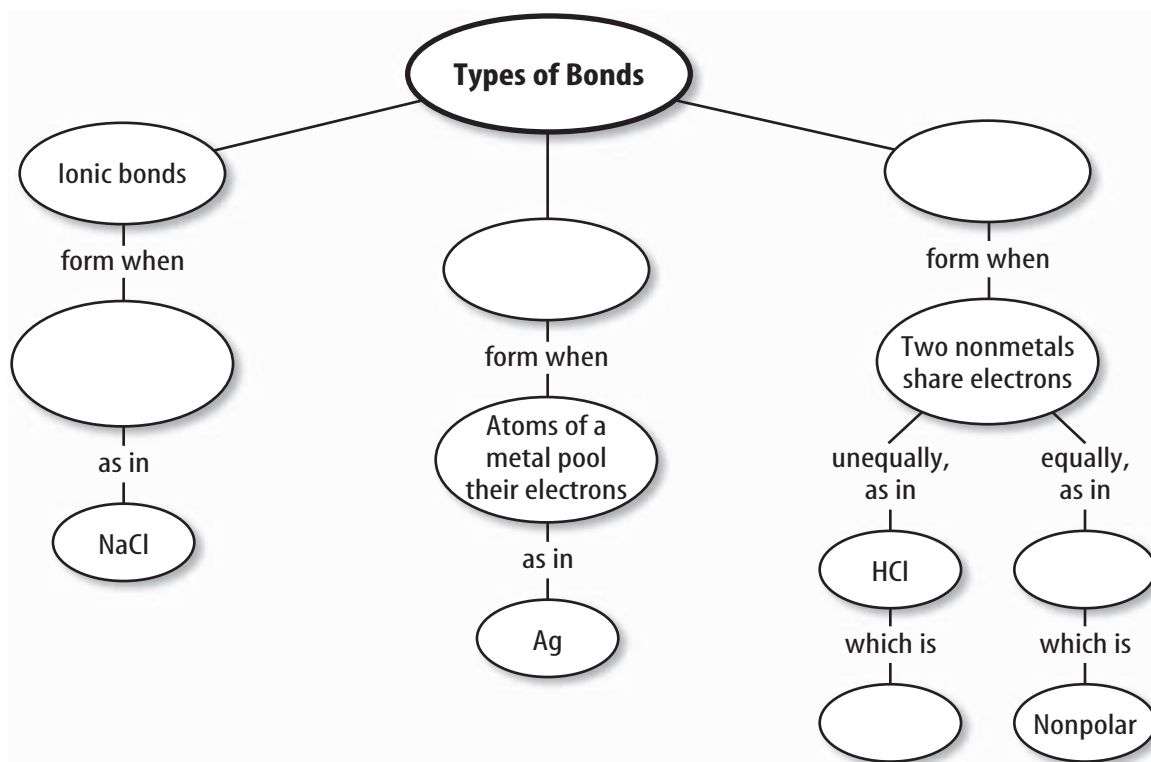
1. The electrons in the electron cloud of an atom are arranged in energy levels.
2. Each energy level can hold a specific number of electrons.
3. The periodic table supplies a great deal of information about the elements.
4. The number of electrons in an atom increases across each period of the periodic table.
5. The noble gas elements are stable because their outer energy levels are stable.
6. Electron dot diagrams show the electrons in the outer energy level of an atom.

Section 2 How Elements Bond

1. An atom can become stable by gaining, losing, or sharing electrons so that its outer energy level is full.
2. Ionic bonds form when a metal atom loses one or more electrons and a nonmetal atom gains one or more electrons.
3. Covalent bonds are created when two or more nonmetal atoms share electrons.
4. The unequal sharing of electrons results in a polar covalent bond.
5. A chemical formula indicates the kind and number of atoms in a compound.

Visualizing Main Ideas

Copy and complete the following concept map on types of bonds.



Using Vocabulary

chemical bond p. 471	energy level p. 465
chemical formula p. 480	ion p. 473
compound p. 473	ionic bond p. 473
covalent bond p. 475	metallic bond p. 474
electron cloud p. 464	molecule p. 475
electron dot diagram p. 470	polar bond p. 476

Distinguish between the terms in each of the following pairs.

- ion—molecule
- molecule—compound
- electron dot diagram—ion
- chemical formula—molecule
- ionic bond—covalent bond
- electron cloud—electron dot diagram
- covalent bond—polar bond
- compound—formula
- metallic bond—ionic bond

Checking Concepts

Choose the word or phrase that best answers the question.

- Which of the following is a covalently bonded molecule?
A) Cl_2 C) Ne
B) air D) salt
- What is the number of the group in which the elements have a stable outer energy level?
A) 1 C) 16
B) 13 D) 18
- Which term describes the units that make up substances formed by ionic bonding?
A) ions C) acids
B) molecules D) atoms

- Which of the following describes what is represented by the symbol Cl^- ?
A) an ionic compound
B) a polar molecule
C) a negative ion
D) a positive ion
- What happens to electrons in the formation of a polar covalent bond?
A) They are lost.
B) They are gained.
C) They are shared equally.
D) They are shared unequally.
- Which of the following compounds is unlikely to contain ionic bonds?
A) NaF C) LiCl
B) CO D) MgBr_2
- Which term describes the units that make up compounds with covalent bonds?
A) ions C) salts
B) molecules D) acids
- In the chemical formula CO_2 , the subscript 2 shows which of the following?
A) There are two oxygen ions.
B) There are two oxygen atoms.
C) There are two CO_2 molecules.
D) There are two CO_2 compounds.

Use the figure below to answer question 18.

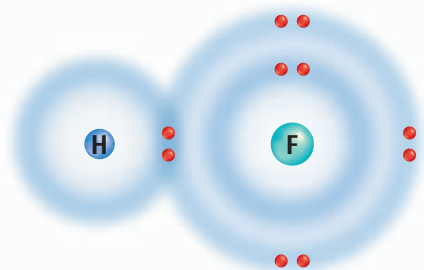


- Which is NOT true about the molecule H_2O ?
A) It contains two hydrogen atoms.
B) It contains one oxygen atom.
C) It is a polar covalent compound.
D) It is an ionic compound.

Thinking Critically

- 19. Explain** why Groups 1 and 2 form many compounds with Groups 16 and 17.

Use the illustration below to answer questions 20 and 21.



- 20. Explain** what type of bond is shown here.
- 21. Predict** In the HF molecule above, predict if the electrons are shared equally or unequally between the two atoms. Where do the electrons spend more of their time?

- 22. Analyze** When salt dissolves in water, the sodium and chloride ions separate. Explain why this might occur.

- 23. Interpret Data** Both cesium, in period 6, and lithium, in period 2, are in the alkali metals family. Cesium is more reactive. Explain this using the energy step diagram in Figure 4.

- 24. Explain** Use the fact that water is a polar molecule to explain why water has a much higher boiling point than other molecules of its size.

- 25. Predict** If equal masses of CuCl and CuCl₂ decompose into their components—copper and chlorine—predict which compound will yield more copper. Explain.

- 26. Concept Map** Draw a concept map starting with the term *Chemical Bond* and use all the vocabulary words.

- 27. Recognize Cause and Effect** A helium atom has only two electrons. Why does helium behave as a noble gas?

- 28. Draw a Conclusion** A sample of an element can be drawn easily into wire and conducts electricity well. What kind of bonds can you conclude are present?

Performance Activities

- 29. Display** Make a display featuring one of the element families described in this chapter. Include electronic structures, electron dot diagrams, and some compounds they form.

Applying Math

Use the table below to answer question 30.

Formulas of Compounds		
Compound	Number of Metal Atoms	Number of Nonmetal Atoms
Cu ₂ O		
Al ₂ S ₃	Do not write in this book.	
NaF		
PbCl ₄		

- 30. Make and Use Tables** Fill in the second column of the table with the number of metal atoms in one unit of the compound. Fill in the third column with the number of atoms of the nonmetal in one unit.

- 31. Molecules** What are the percentages of each atom for this molecule, K₂CO₃?

- 32. Ionic Compounds** Lithium, as a positive ion, is written as Li¹⁺. Nitrogen, as a negative ion, is written as N³⁻. In order for the molecule to be neutral, the plus and minus charges have to equal zero. How many lithium atoms are needed to make the charges equal to zero?

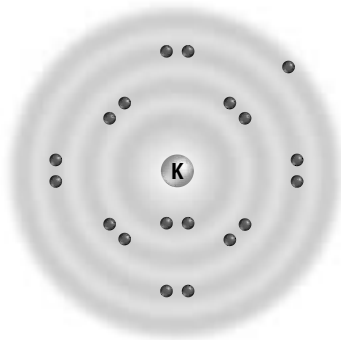
- 33. Energy Levels** Calculate the maximum number of electrons in energy level 6.

Part 1 Multiple Choice

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

1. Sodium combines with fluorine to produce sodium fluoride (NaF), an active ingredient in toothpaste. In this form, sodium has the electron configuration of which other element?
- neon
 - magnesium
 - lithium
 - chlorine

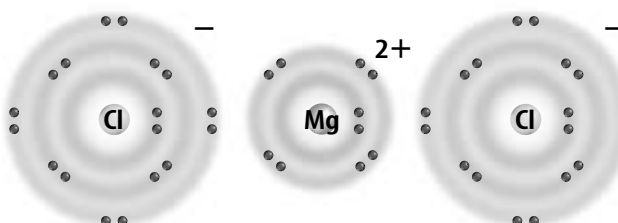
Use the illustration below to answer questions 2 and 3.



2. The illustration above shows the electron configuration for potassium. How many electrons does potassium need to gain or lose to become stable?
- gain 1
 - gain 2
 - lose 1
 - lose 2
3. Potassium belongs to the Group 1 family of elements on the periodic table. What is the name of this group?
- halogens
 - alkali metals
 - noble gases
 - alkaline metals

4. What type of bond connects the atoms in a molecule of nitrogen gas (N_2)?
- ionic
 - single
 - double
 - triple

Use the illustration below to answer questions 5 and 6.



Magnesium chloride

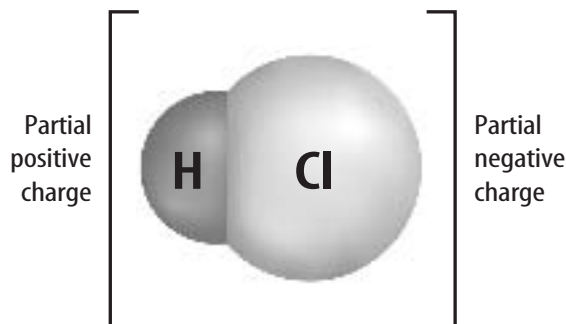
5. The illustration above shows the electron distribution for magnesium chloride. Which of the following is the correct way to write the formula for magnesium chloride?
- Mg_2Cl
 - $MgCl_2$
 - $MgCl$
 - Mg_2Cl_2
6. Which of the following terms best describes the type of bonding in magnesium chloride?
- ionic
 - pooling
 - metallic
 - covalent
7. What is the maximum number of electrons in the third energy level?
- 8
 - 16
 - 18
 - 24

Part 2 Short Response/Grid In

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

8. What is an electron cloud?
9. Explain what is wrong with the following statement: All covalent bonds between atoms are polar to some degree because each element differs slightly in its ability to attract electrons. Give an example to support your answer.

Use the illustration below to answer questions 10 and 11.



10. The illustration above shows how hydrogen and chlorine combine to form a polar molecule. Explain why the bond is polar.
11. What is the electron dot diagram for the molecule in the illustration?
12. What is the name of the family of elements in Group 17 of the periodic table?
13. Name two ways that electrons around a nucleus are different from planets circling the Sun.
14. Which family of elements used to be known as inert gases? Why was the name changed?

Test-Taking Tip

Take Your Time Stay focused during the test and don't rush, even if you notice that other students are finishing the test early.

Part 3 Open Ended

Record your answers on a sheet of paper.

15. Scientific experiments frequently require an oxygen-free environment. Such experiments often are performed in containers flooded with argon gas. Describe the arrangement of electrons in an argon atom. Why is argon often a good choice for these experiments?
16. Which group of elements is called the halogen elements? Describe their electron configurations and discuss their reactivity. Name two elements that belong to this group.
17. What is an ionic bond? Describe how sodium chloride forms an ionic bond.
18. Explain metallic bonding. What are some ways this affects the properties of metals?
19. Explain why polar molecules exist, but polar ionic compounds do not exist.

Use the illustration below to answer questions 20 and 21.



20. Explain what is happening in the photograph above. What would happen if the balloon briefly touched the water?
21. Draw a model showing the electron distribution for a water molecule. Explain how the position of the electrons causes the effect shown in your illustration.