chapter 6 Atomic Structure and Chemical Bonds

section 1 Why do atoms combine?

Before You Read

Think of a rock. How would you describe it? Now think of a balloon. How is a balloon different from a rock?

_____

_____

What You'll Learn

- how electrons are arranged in an atom
- the amount of energy electrons have
- how the periodic table is organized

Read to Learn

Mark the Text

Highlight As you read highlight important sentences and terms. When you are finished reading, review what you have highlighted.

Atomic Structure

You might be surprised to learn that all matter contains mostly empty space. Even solids like rocks and metals have empty space. How can this be? Although there might be little or no space between atoms, there is a lot of empty space within each atom.

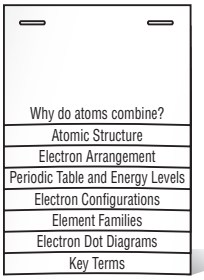
At the center of an atom is the nucleus. It contains protons and neutrons. The rest of the atom is empty except for electrons. Electrons are extremely small compared to the nucleus. The **electron cloud** is the space around the nucleus where the electrons travel. However, the exact location of any one electron cannot be determined and their paths are not well-defined, as shown in the figure.

Imagine that the nucleus of an atom is the size of a penny. Electrons would be smaller than grains of dust. The electron cloud would go out as far as 20 football fields.

FOLDABLES™

A Organize Information

Make the following layered book Foldable using four sheets of notebook paper to help you organize information about atoms.



Where in the electron cloud are electrons?

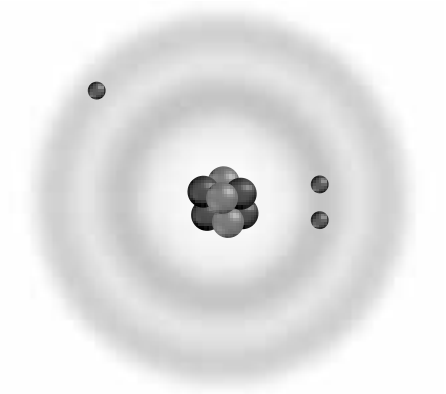
You might think that electrons are like the planets that circle the Sun, but they are not. Planets travel in predictable orbits. You can tell exactly where a planet will be at any time. This is not true for electrons. Although electrons do travel in predictable areas, it is impossible to tell exactly where any one electron will be at any time. So, scientists use a mathematical model to predict where an electron might be.

What makes the atoms of elements different?

The atoms of every element are different. Each element has a certain number of protons, neutrons, and electrons in its atoms. The number of protons is always the same as the number of electrons in neutral atoms. The figure shows a two-dimensional model of the electron structure of a lithium atom. A neutral lithium atom has three protons and four neutrons in its nucleus. Three electrons move around its nucleus.

Picture This

1. **Identify** Circle the electrons in the figure.



Electron Arrangement

You know that different elements have different numbers of electrons. The way electrons are arranged in the electron cloud is also different for different elements. The physical and chemical properties of an element can be different, depending on the number of electrons and how they are arranged.

What are energy levels?

Reading Check

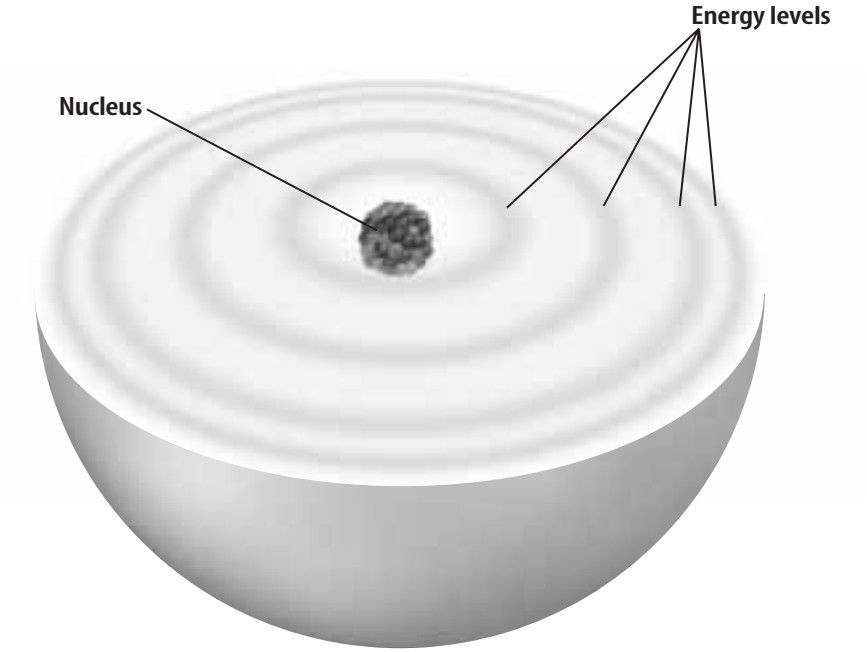
2. **Define** What are energy levels in an atom?

_____

_____

_____

Electrons move in the electron cloud in an atom. Some electrons are closer to the nucleus than others. So, electrons can be in different areas. **Energy levels** are the different areas for electrons in an atom. The figure at the top of the next page shows a model of what energy levels might look like in an atom. The dark bands in the diagram represent the energy levels. Each level has a different amount of energy.



Picture This

3. **Label** energy level one on the model of the atom.

How many electrons are in an energy level?

Each energy level can hold only a certain number of electrons. Energy levels farther away from the nucleus can hold more electrons. Energy levels close to the nucleus hold fewer electrons. Energy level one, the closest to the nucleus, can hold one or two electrons. Energy level two can hold up to eight electrons. Energy level three can hold up to 18 electrons. Energy level four can hold up to 32 electrons.

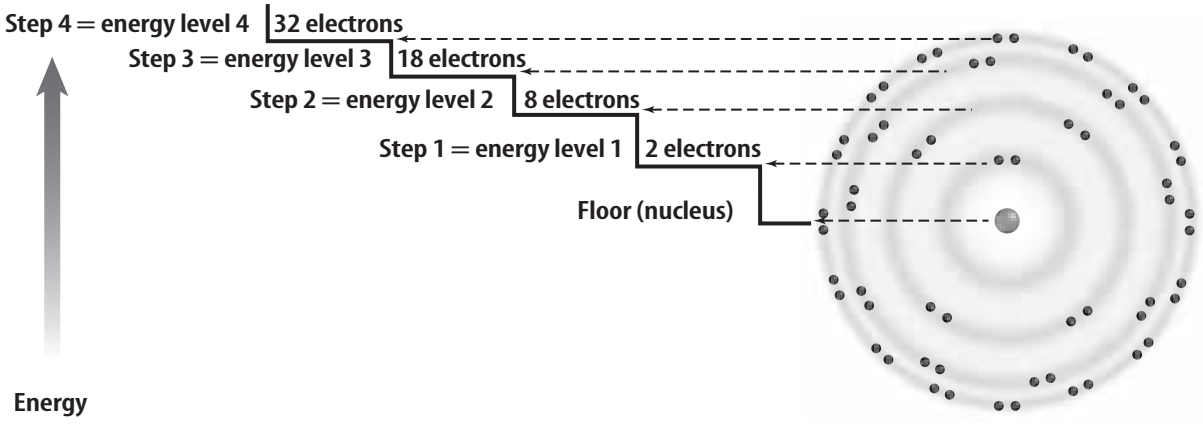
Picture This

4. **Apply** Chlorine has 17 electrons. What is the highest energy level in which you would find electrons in a chlorine atom?

_____

How can energy levels be represented?

Look at the stairway in the figure below. This stairway shows the maximum number of electrons each energy level can hold. The electrons in each energy level have different amounts of energy.



Applying Math

5. **Calculate** Use the formula $2n^2$. How many electrons could energy level five have? Show your work.

Which levels have the most energy?

Energy level one electrons are closest to the nucleus. They have the least energy. Electrons in energy level two have more energy. They are on the second stair step. The electrons farthest from the nucleus have the highest amount of energy. They are easiest to remove. To find the number of electrons an energy level can hold, use the formula $2n^2$, where n is the number of the energy level.

If the electrons in the highest energy level have the highest energy, why are they easiest to remove? Remember that electrons are negatively charged. The nucleus is positively charged because it contains protons. The farther the electrons are from the nucleus, the less they are attracted to it. So, it takes less energy to remove an electron in a higher energy level. It takes more energy to remove an electron in a lower energy level.

Periodic Table and Energy Levels

The periodic table has a lot of data about the elements. You can use it to understand energy levels, too. Remember that the atomic number of an element is the number of protons in an atom of the element. The number of protons is equal to the number of electrons in a neutral atom. So, you can look at the atomic number of an element and find how many protons and electrons it has. For example, oxygen is atomic number 8. This means that oxygen has eight protons in its nucleus and eight electrons.

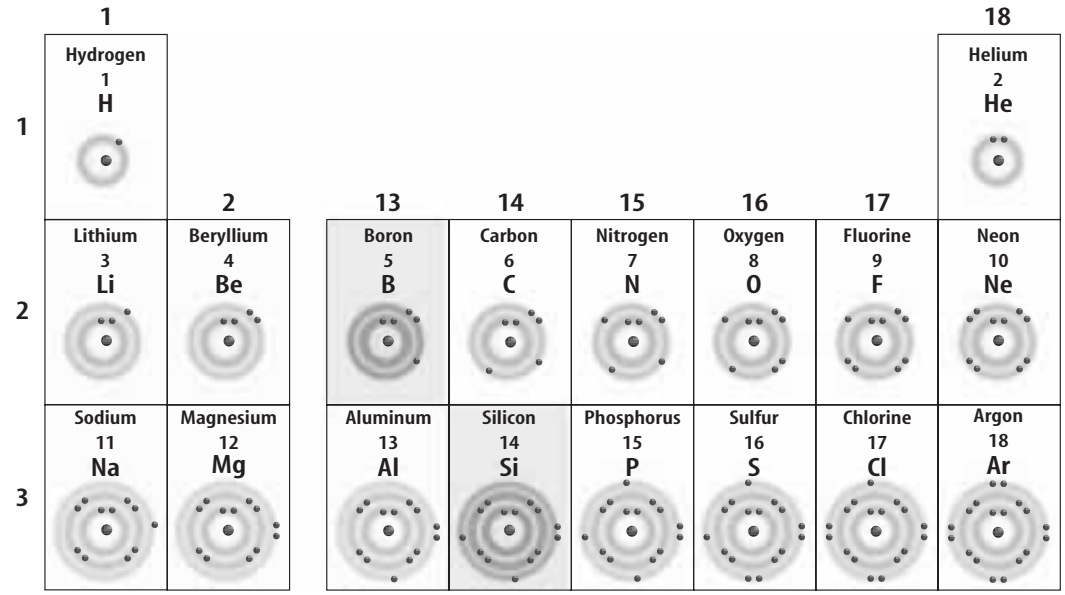
Reading Check

6. **Explain** What is the atomic number?

Electron Configurations

In the periodic table, the elements are arranged in a certain order. Part of the periodic table is shown on the next page. Look at the horizontal rows, or periods. The number of electrons in a neutral atom of each element increases by one from left to right in each period.

First Period In the first period, hydrogen has one electron and helium has two. The first energy level can hold two electrons, so helium's outer energy level is complete. Atoms with a complete outer energy level are stable and do not combine easily with other elements. So, helium is stable.



Second Period In the second period, or row, lithium has three electrons. Two electrons fill energy level one. This leaves only one electron for energy level two. Energy level two can hold up to eight electrons. Look at each element to the right of lithium. The electrons begin to fill energy level two. On the right side of the periodic table, neon has a total of 10 electrons. Two are in energy level one. Eight are in energy level two. Because the outer energy level of neon is complete, neon is a stable element.

Third Period In the third period, the electrons begin filling energy level three. On the right side, argon has eight electrons in energy level three. Is it full? No, energy level three can hold 18 electrons. An atom with exactly eight electrons in its outer energy level is stable. Argon is a stable element. Each period in the periodic table ends with a stable element.

Element Families

Each column in the periodic table is an element group, or family. The first element family begins with lithium. Hydrogen is separate from the first family. The elements in each family have the same number of electrons in their outer energy level. So the members of each element family have similar chemical properties.

Dmitri Mendeleev, a Russian chemist, noticed this repeating pattern of properties. In 1869, he created his first periodic table of elements using this pattern. Mendeleev's table is much like the one used today.

Picture This

7. Identify Circle all of the elements that have three electrons in their outer energy level.

Reading Check

8. Determine What is true about elements in a family?

What are noble gases?

Look at the periodic table on the previous page. Find neon. Notice that neon and the elements below it have eight electrons in their outer energy levels. These are very stable elements. They do not combine easily with other elements.

Helium does not have eight electrons, but its outer energy level is complete because energy level 1 can hold only two electrons. So, helium is also stable. The Group 18 elements are called noble gases. The noble gases are the most stable elements.

Reading Check

9. Identify Except for helium, how many electrons do noble gases have in their outer energy levels?

How are noble gases used?

Noble gases are useful because they are so stable. Lightbulbs have noble gases to keep the filaments from reacting with air. Noble gases also are used to make colored lights in signs. If an electric current passes through the noble gases, they glow with different colors. Neon makes orange-red, argon makes lavender, and helium makes a yellow-white light.

What are halogens?

The elements in Group 17 are called halogens. Look at the elements in Group 17 in the periodic table on the previous page. Notice that their outer energy levels have seven electrons. If they gain one electron, they become stable. The halogens are very reactive.

Fluorine is the most reactive halogen because its outer energy level is closest to the nucleus. The other halogens get less reactive as their outer energy levels get farther away from the nucleus. So, chlorine in period 3 is less reactive than fluorine in period 2.

Think it Over

10. Infer Think about the electrons in the outer energy levels of halogens and alkali metals. Why do you think that halogens and alkali metals would react very well with each other?

What are alkali metals?

Look at the elements lithium and sodium in the periodic table on the previous page. Except for hydrogen, the elements in this group are called alkali metals. Alkali metals have one electron in their outer energy levels. When these elements react, this one electron in the outer energy level is removed.

Remember that it is easier to remove electrons that are farther away from the nucleus because less energy is needed. Elements at the bottom of the group give up the one electron in their outer energy levels more easily than those at the top. The elements toward the bottom of this group are more reactive. For example, sodium in period 3 is more reactive than lithium in period 2. This is the opposite of the halogens.

Electron Dot Diagrams

You have read that the properties of an element depend on the number of electrons in its outer energy level. That's why chemists often make models of atoms showing only the electrons in the outer energy level. These models are called electron dot diagrams. An **electron dot diagram** is the chemical symbol for an element surrounded by as many dots as there are electrons in its outer energy level.

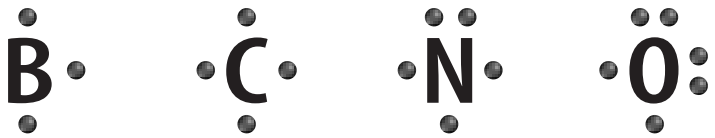
Why not draw dots for all of the electrons in an atom? You could do that. But for some elements, you would have to draw a lot of dots. For example, iodine has 53 electrons. So, you would have to draw 53 dots. What really matters is the number of electrons in the outer energy level. These are the electrons that determine how an element can react. Iodine has seven electrons in the outer energy level. Drawing seven dots is easier than drawing 53 dots.

Reading Check

11. Explain What does the number of electrons in the outer energy level of an atom show?

How do you write electron dot diagrams?

How many dots do you draw? Where do you put them? First, you need to know how many electrons are in the outer energy level. You can use the periodic table to find out. To make the diagram, write the symbol for the element. For boron, you write the letter B. Boron has three electrons in its outer energy level. So, you need to draw three dots. Start by making one dot above the letter B. Next, go clockwise and draw a dot to the right of the B. Then, draw a dot below the B. If there are more electrons, keep drawing dots clockwise around the symbol. If there are more than four electrons, draw dots in pairs. The diagram below shows electron dot diagrams for boron, carbon, nitrogen, and oxygen.



Picture This

12. Identify How many electrons does oxygen have in its outer energy level?

How do you use electron dot diagrams?

You can use electron dot diagrams to show how atoms bond with each other. A **chemical bond** is the force that holds two atoms together. Chemical bonds hold atoms together like glue holds things together. Atoms bond with other atoms in ways that make each atom more stable. That means the outer energy levels of bonded atoms becomes like those of the noble gases.

After You Read

Mini Glossary

chemical bond: the force that holds two atoms together

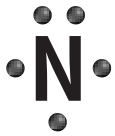
electron cloud: the space around the nucleus where the electrons travel

electron dot diagram: the chemical symbol for an element surrounded by as many dots as there are electrons in its outer energy level

energy levels: the different areas for electrons in an atom

1. Review the terms and their definitions in the Mini Glossary. Where in an atom are the energy levels located? Answer in a complete sentence.

2. Below is the electron dot diagram for nitrogen and the symbol P for the element phosphorus. Both nitrogen and phosphorus are in Group 15 on the periodic table. Complete the electron dot diagram for phosphorus.



P

3. Look at the dot diagrams above. What do nitrogen and phosphorus have in common?

4. At the beginning of the section, you were asked to highlight important sentences and terms as you read. How did highlighting help you learn about electrons in an atom?

End of Section

ScienceOnline Visit **ips.msscience.com** to access your textbook, interactive games, and projects to help you learn more about how atoms combine.

chapter 6

Atomic Structure and Chemical Bonds

section 2 How Elements Bond

Before You Read

What does it mean when two things are bonded? What are some things you might use to bond two items?

_____

_____

What You'll Learn

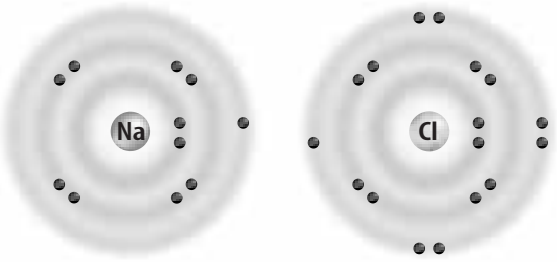
- about ionic and covalent bonds
- about compounds and molecules
- polar and nonpolar covalent bonds
- chemical shorthand

Read to Learn

Ionic Bonds—Loss and Gain

Elements that join by chemical bonds do not fall apart easily. Atoms form bonds by using the electrons in their outer energy levels. Elements can bond in four different ways—they can lose electrons, gain electrons, pool electrons, or share electrons with another element.

Lose Electrons Sodium chloride forms when sodium and chlorine atoms bond as shown below. Sodium is a soft, silvery metal. It is a member of the alkali metal family. It reacts violently when added to water or chlorine. Sodium is so reactive because it has only one electron in its outer energy level. Removing this one electron empties the outer energy level. What is left is the completed energy level below it. Sodium is now stable, like neon. Remember, neon is a stable noble gas.



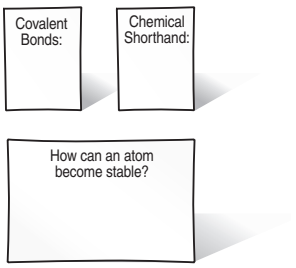
Sodium Chlorine

Study Coach

Create a Quiz As you read the section, write quiz questions about the main ideas and vocabulary terms. When you finish reading, answer your quiz questions.

FOLDABLES™

Find Main Ideas Make the following Foldable out of notebook paper. Make quarter-sheets and a half-sheet to list the main ideas on covalent bonds, chemical shorthand, and how atoms become stable.



Gain Electrons Chlorine bonds in the opposite way. It gains an electron. Chlorine has seven electrons in its outer energy level. It gains an electron to have a complete outer energy level. When this happens, chlorine becomes stable. It then has the same number of electrons as the noble gas argon.

What are ions?

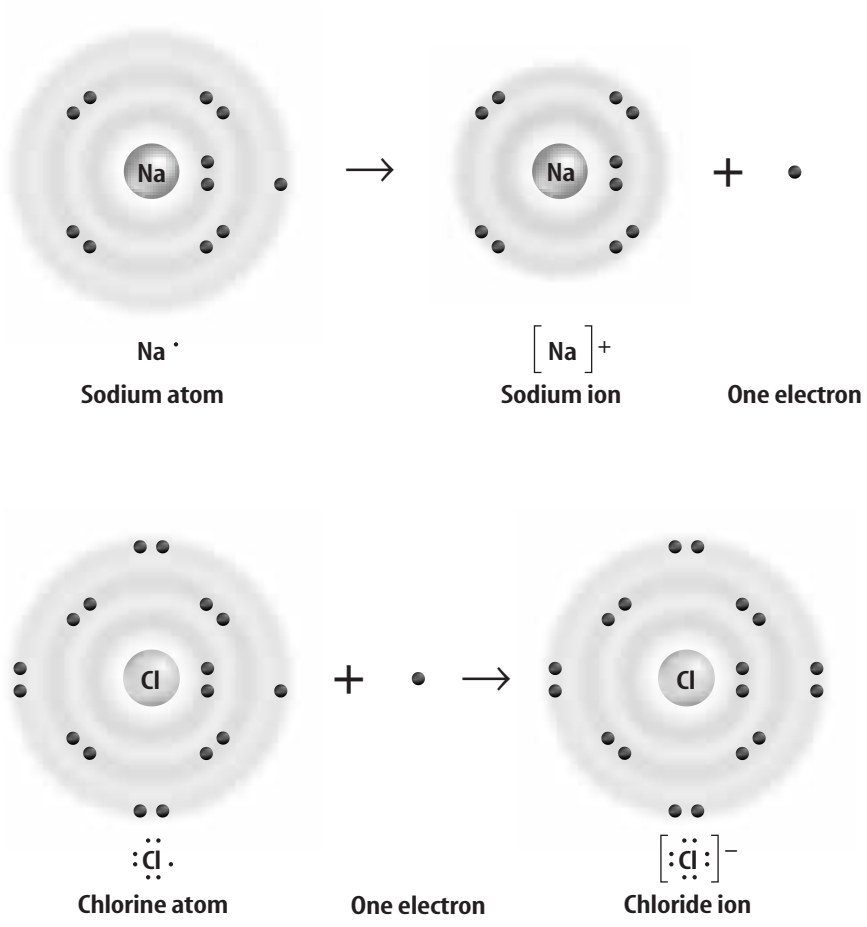
When a sodium atom loses an electron, it becomes more stable. But, the atom has one fewer electron than protons. This changes the balance of electric charge. The atom becomes a positively charged ion. When a chlorine atom gains an electron, it has one more electron than protons. This makes the chlorine atom a negatively charged ion. An **ion** (I ahn) is an atom that is no longer neutral because it has gained or lost an electron. The figure below shows how sodium ions (Na^+) and chloride ions (Cl^-) are formed.

Reading Check

1. **Describe** Which of the following does not describe an ion: positive, negative, or neutral?

_____

How Ions Form



Picture This

2. **Draw and Label** A sodium atom loses an electron and becomes positively charged. Circle the electron in the sodium atom (Na) that is taken away. A chlorine atom gains an electron and becomes negatively charged. Circle the electron in the chloride ion (Cl–) that is gained.

How do ions form bonds?

Positive sodium ions and negative chloride ions are strongly attracted to each other. An **ionic bond** is the attraction that holds negative ions and positive ions close together.

The figure below shows how sodium and chloride ions form an ionic bond. The compound sodium chloride, or table salt, is formed. A **compound** is a pure substance that has two or more elements that are chemically bonded.

Sodium ion | Chloride ion | Sodium Chloride

Can elements gain or lose 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 to have a completed outer energy level. The symbol for a magnesium ion is Mg^{2+}. The 2+ shows that the ion has lost two electrons.

One Ionic Bond When magnesium loses its two electrons, the electrons could be gained by an oxygen atom. Oxygen needs to gain two electrons to become stable. So, a magnesium ion, Mg^{2+}, and an oxide ion, O^{2-}, can form an ionic bond to make magnesium oxide (MgO). The 2+ charge of the magnesium ion and the 2− charge of the oxide ion balance each other.

Two Ionic Bonds A single magnesium ion (Mg^{2+}) also can bond with two chlorine ions (Cl^-). The 2+ charge of the magnesium ion is balanced by the two negative charges of the two chlorine ions. Each chlorine ion gains one electron. This ionic bond between magnesium and chlorine forms the compound magnesium chloride ($MgCl_2$).

Metallic Bonding—Pooling

In the examples above, a metal formed ionic bonds with nonmetals. Metals can form bonds with other metal atoms, but in a different way.

Picture This

3. Use a Diagram In the first dot diagram, notice the dot next to the symbol for sodium, Na. Draw an arrow from that dot to the place in the dot diagram for chlorine, Cl, where it will be located in sodium chloride.

Reading Check

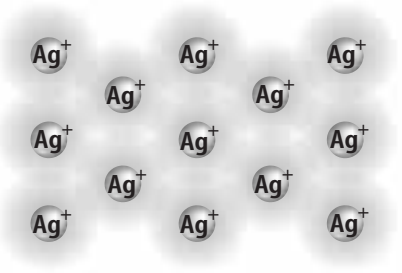
4. Explain In magnesium chloride, what balances the 2+ charge of the magnesium ion?

_____

_____

How do metals bond?

In metal atoms, the electrons are not held tightly to the outer energy levels of the atoms. Instead, they move freely among all the metal ions. These moving electrons form a pool of shared electrons. The figure below is an example of a pool of electrons in the metal silver. **Metallic bonds** form when metal atoms share their pooled electrons.



What are some properties of metals?

Metallic bonds cause metals to have special properties. The pooled electrons let the atoms slide past each other to stretch and not break. So, metals can be hammered into sheets without breaking. They can also be drawn into wires without breaking. Metallic bonds also let metals conduct electricity well. An electric current in solids is a flow of electrons. The outer electrons in metal atoms move easily from one atom to the next to conduct electric current.

Covalent Bonds—Sharing

Some atoms don't gain or lose electrons very easily. For example, carbon has six total electrons. Four of these electrons are in the outer energy level. To be more stable, carbon would either have to gain four electrons or lose four. Losing or gaining four electrons would take a lot of energy. But, carbon can form a bond by sharing electrons.

What is a covalent bond?

Atoms of many elements become more stable by sharing electrons. A **covalent** (koh VAY luhnt) **bond** is a chemical bond that forms between nonmetal atoms when they share electrons. 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 is stable some of the time. Compounds held together with covalent bonds are called molecular compounds.

Picture This

5. **Describe** How would you describe the outer electrons of the silver atoms—attached to certain atoms or free?

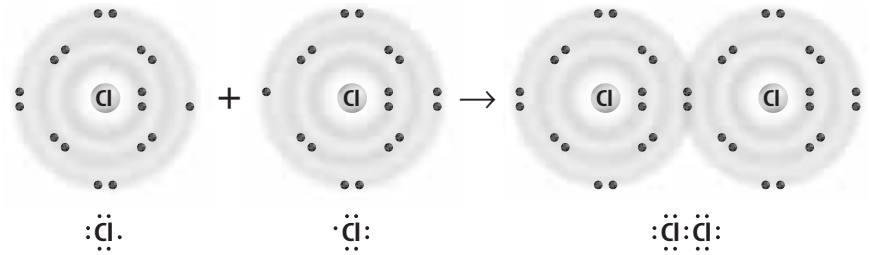
_____

Reading Check

6. **Explain** What type of atoms share electrons on a covalent bond?

_____

Neutral Particles The atoms in a covalent bond form a neutral particle. The particle is neutral because it has the same number of positive and negative charges. A **molecule** (MAH lih kyewl) is the neutral particle formed when atoms share electrons. A molecule is the basic unit of a molecular compound. The figure below shows how molecules form by sharing electrons. Notice in the figure that none of the atoms are ions. That's because no electrons are gained or lost when a molecule forms. Solids that are crystals, such as sodium chloride, are not called molecules, because their basic units are ions, not molecules.



Chlorine atom Chlorine atom Chlorine molecule

Picture This

7. Evaluate Look at the figure. How many electrons are shared between the two chlorine atoms in a chlorine molecule?

_____

What are double and triple bonds?

Sometimes an atom shares more than one electron with another atom. Look at the molecule of carbon dioxide shown below. Each oxygen atom shares two electrons with the carbon atom. The carbon atom shares two of its electrons with each oxygen atom. When two pairs of electrons form a covalent bond, it is called a double bond. A triple bond happens when three pairs of electrons are shared in a covalent bond. The nitrogen molecule in the figure below is an example of a triple bond.

Carbon atom Oxygen atoms Carbon dioxide molecule

Nitrogen atoms Nitrogen molecule

Picture This

8. Interpret Scientific Illustrations How many pairs of electrons are shared between the nitrogen atoms in the triple bond of the nitrogen molecule?

_____

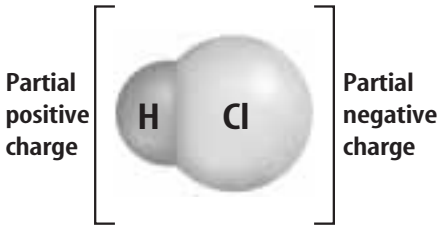
Polar and Nonpolar Molecules

Atoms in a covalent bond don't always share electrons equally. Some atoms have a greater attraction for electrons than others do. For example, hydrogen and chlorine can form a covalent bond. But, chlorine attracts electrons more strongly than hydrogen does. So, the shared electron pair spends more time around the chlorine atom than the hydrogen atom.

Since the electron pair spends more time around the chlorine atom, this end of the molecule has a slight negative charge. The hydrogen end of the molecule has a slight positive charge. This happens because the hydrogen atom is without its electron most of the time. A **polar bond** is a bond in which electrons are shared unevenly. The figure below shows an example of a polar bond.

Picture This

9. Use Models How would you describe the sharing of the electrons in the hydrogen chloride molecule—even or uneven?

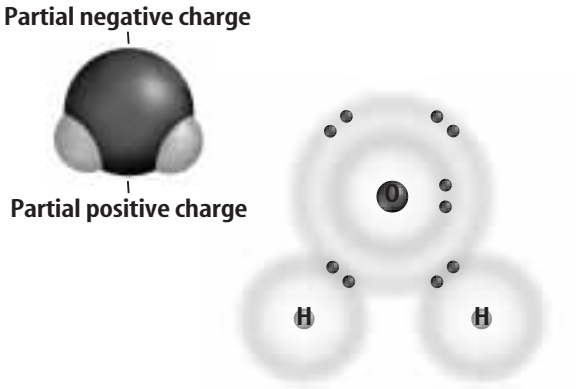


What makes water molecules polar?

Water molecules form when hydrogen and oxygen share electrons. Water molecules are polar because the electrons are shared unevenly. The oxygen atom has a greater share of the electrons than the hydrogen atom. Look at the figure below. Water molecules can be attracted to positive and negative charges because they are polar. Many of the physical properties of water are due to the fact that the molecule is polar. Molecules that do not have uneven charges are called nonpolar molecules. An example of a nonpolar bond is the triple bond in a nitrogen molecule.

Think it Over

10. Explain Water molecules attract each other because they are polar. Many water molecules are attracted to many other water molecules. Explain which charges are attracted to each other.



Chemical Shorthand

In medieval times, alchemists (AL kuh mists) were the first to study chemistry. The alchemists learned about the properties of some elements. They used symbols to represent elements and chemical processes. Scientists today use symbols, too. The table below shows both ancient and modern symbols for some elements. The periodic table includes the symbol for each element. The symbols are usually one or two letters. Often, the symbol is the first letter of the name for the element. For example, the symbol for oxygen is O. Sometimes, the name for the element in another language is used. For example, the symbol for potassium is K. The Latin word for potassium is kalium.

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

What are chemical formulas?

Symbols and numbers are used to show the elements in compounds. A **chemical formula** is a set of chemical symbols and numbers that shows which elements are in a compound and how many atoms of each element are in it. For example, two hydrogen atoms in a covalent bond are represented by the chemical formula H_2. The H stands for hydrogen. The subscript 2 tells you that there are two hydrogen atoms. A subscript is a number that is written a little below a line of text. Another example of a chemical formula is H_2O, or water. The formula tells you there are two hydrogen atoms and one oxygen atom in a water molecule. Notice that when symbols don't have a subscript, like the O in H_2O, there is only one atom.

Picture This

11. Determine Which is probably most easily understood by people today, the ancient symbols or the modern symbols?

_____

Reading Check

12. Infer What does a chemical formula tell you about a compound?

_____

_____

_____

_____

After You Read

Mini Glossary

chemical formula: a set of chemical symbols and numbers that shows which elements are in a compound and how many atoms of each element are in it

compound: a pure substance that has two or more elements that are chemically bonded

covalent (koh VAY luhnt) bond: a chemical bond that forms between atoms when they share electrons

ion (I ahn): an atom that is no longer neutral because it has gained or lost an electron

ionic bond: attraction that holds negative ions and positive ions close together

metallic bond: a chemical bond that forms when metal atoms share their pooled electrons

molecule (MAH lih kyewl): a neutral particle formed when atoms share electrons

polar bond: a bond in which electrons are shared unevenly

1. Review the terms and their definitions in the Mini Glossary. Choose two terms that describe different kinds of chemical bonds and write a sentence or two that tells how they are different.

2. Fill in the table below to summarize what you learned in this section about chemical bonds.

Chemical Bonds		
Type of Bond	**Reaction**	**Example**
Ionic bond	**A negative ion and a positive ion come together.**	
Metallic bond		
Covalent bond		**hydrogen, water**
Polar bond		

End of Section

ScienceOnline Visit **ips.msscience.com** to access your textbook, interactive games, and projects to help you learn more about how elements bond.