

Chemical Bonds

Together, holding hands, these sky divers are a stable group instead of separately falling objects. A chemical bond between elements is similar. Atoms combine when the compound formed is more stable than the separate atoms. Like the circle of sky divers, the compounds formed have properties unlike those found in the separate elements. In this chapter, you will read about how chemical bonds form and learn how to write chemical formulas and equations.

What do you think?

Science Journal Look at the picture below with a classmate. Discuss what you think this might be or what is happening. Here's a hint: *Bonds are forming to make something that you can sprinkle on popcorn.* Write your answer or best guess in your Science Journal.



EXPLORE ACTIVITY

You have probably noticed how the liquids in oil and vinegar salad dressings will not stay mixed after the bottle is shaken. Why do some liquids such as water and rubbing alcohol mix together, but others like oil and water do not? The compounds that make up the liquids are different. Some, like water and rubbing alcohol, can attract each other. Others, like water and oil, do not. In this chapter, these different types of compounds will be discussed further.

Separating liquids

1. Pour 20 mL of water into a 100 mL graduated cylinder.
2. Pour 20 mL of vegetable oil into the same cylinder. Vigorously swirl the two liquids together, and observe for several minutes.
3. Add two drops of food dye and observe.
4. After several minutes, slowly pour 30 mL of rubbing alcohol into the cylinder.
5. Add two more drops of food dye and observe.

Observe

In your Science Journal, write a paragraph describing how the different liquids reacted to each other.



FOLDABLES Reading & Study Skills

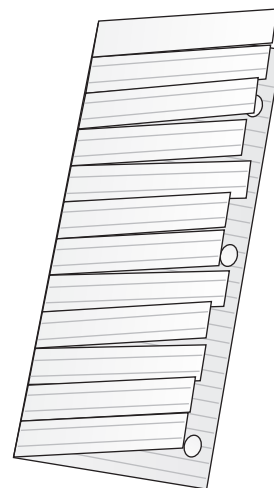


Before You Read

Making a Chemical Formula Study Fold

Make the following Foldable to help you identify chemical formulas from this chapter.

1. Place a sheet of notebook paper in front of you so the short side is at the top and the holes are on the right side. Fold the paper in half from the left side to the right side.
2. Through the top thickness of paper, cut along every third line from the outside edge to the centerfold, forming tabs as shown.
3. Before you read the chapter, collect ten chemical formulas and write them on the front of the tabs. As you read the chapter, write what compound the formula represents under the tabs.



Stability in Bonding

As You Read

What You'll Learn

- **Describe** how a compound differs from its component elements.
- **Explain** what a chemical formula represents.
- **State** a reason why chemical bonding occurs.

Vocabulary

chemical formula
chemically stable
chemical bond

Why It's Important

Understanding why atoms form compounds depends on knowing how an atom can become stable.

Combined Elements

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

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

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

Figure 1

The difference between the copper metal and the copper compound formed on the Statue of Liberty is striking. A new compound has formed.



New Properties One interesting observation you will make is that the compound formed when elements combine often has properties that aren't anything like those of the individual elements. Sodium chloride, for example, shown in **Figure 2**, is a compound made from the elements sodium and chlorine. Sodium is a shiny, soft, silvery metal that reacts violently with water. Chlorine is a poisonous greenish-yellow gas. Would you have guessed that these elements combine to make ordinary table salt?



Figure 2 Sodium is a soft, silvery metal that combines with chlorine, a greenish-yellow gas, to form sodium chloride, which is a white crystalline solid. How are the properties of table salt different from those of sodium and chlorine?

Formulas

The chemical symbols Na and Cl represent the elements sodium and chlorine. When written as NaCl, the symbols make up a formula, or chemical shorthand, for the compound sodium chloride. A **chemical formula** tells what elements a compound contains and the exact number of the atoms of each element in a unit of that compound. The compound that you are probably most familiar with is H₂O, more commonly known as water.

This formula contains the symbols H for the element hydrogen and O for the element oxygen. Notice the subscript number 2 written after the H for hydrogen. *Subscript* means “written below.” A subscript written after a symbol tells how many atoms of that element are in a unit of the compound. If a symbol has no subscript, the unit contains only one atom of that element. A unit of H₂O contains two hydrogen atoms and one oxygen atom.

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

Table 1 Some Familiar Compounds

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

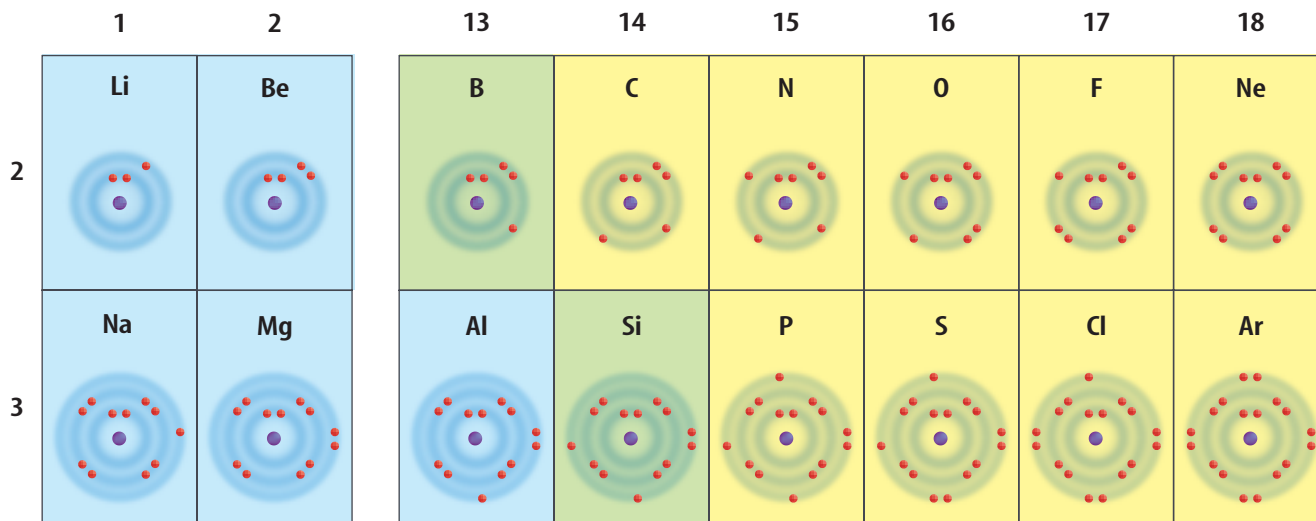
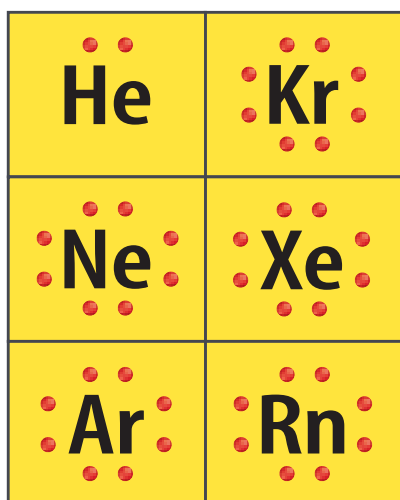


Figure 3
The number of electrons in each group's outer level increases across the table until the noble gases in Group 18 have a complete outer energy level.

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



Atomic Stability

Why do atoms form compounds? Atoms combine when the compound formed is more stable than the separate atoms. The periodic table on the inside back cover of your book lists 115 elements, most of which can combine with other elements. However, the six noble gases in Group 18 seldom form compounds. Why is this so? Atoms of noble gases are unusually stable. Compounds of these atoms rarely form because they are almost always less stable than the original atoms.

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

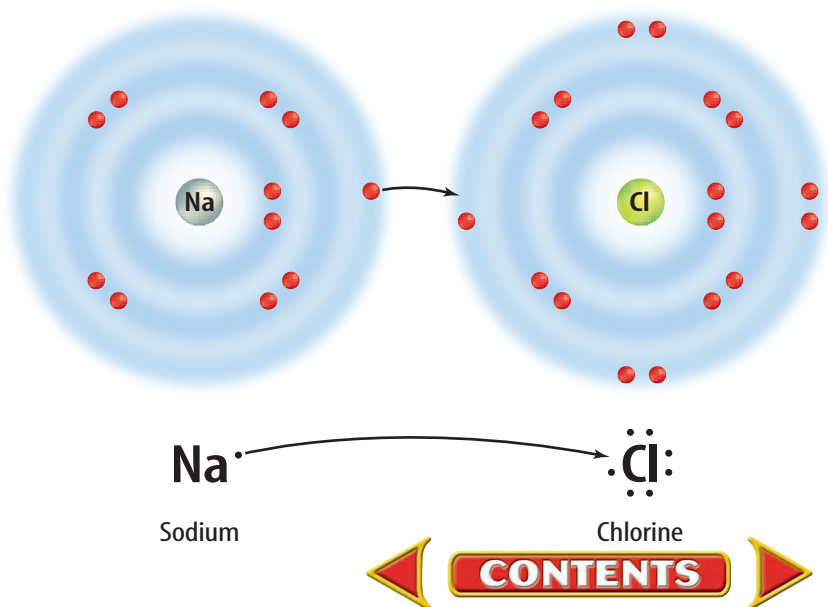
What makes the noble gases more stable than other elements? An atom is **chemically stable** when its outer energy level is complete. Recall that the outer energy levels of helium and hydrogen are stable with two electrons. The outer energy levels of all the other elements are stable when they contain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

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

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

When you look at the elements in Groups 13 through 17, you see that each of them falls short of having a stable energy level. Each group contains too few electrons for a stable level of eight electrons. The elements are not stable because of it and commonly form compounds.

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



SCIENCE Online 

Research Visit the Glencoe Science Web site at science.glencoe.com for more information about using dot diagrams to represent outer energy level electrons. Communicate to your class what you learn.



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

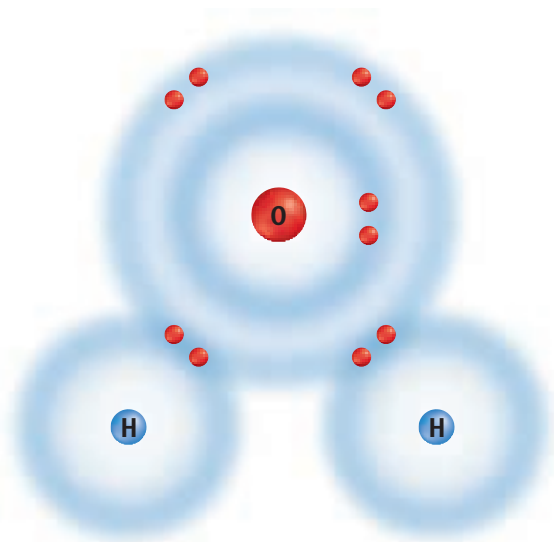


Figure 6
In water, hydrogen contributes one electron and oxygen contributes the other to each hydrogen-oxygen bond. The atoms share those electrons instead of giving them up.

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

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

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

Reading Check *What is a chemical bond?*

Section 1 Assessment

- Describe what happens to the properties of elements when atoms form compounds.
- What does the formula BaF_2 tell you about this compound?
- Why are some elements stable on their own while others are more stable in compounds?
- In what ways can a chemical bond form?
- Think Critically** The label on a box of cleanser states that it contains $\text{HC}_2\text{H}_3\text{O}_2$. What elements are in this compound? How many atoms of each element can be found in a unit of $\text{HC}_2\text{H}_3\text{O}_2$?

Skill Builder Activities

- Making and Using Tables** The compounds in **Table 1** that contain carbon are classified as organic, and the others are classified as inorganic. Reorganize the contents of the table using these groups. **For more help, refer to the Science Skill Handbook.**
- Communicating** A chemical bond is not something you can touch or observe easily. Using the concepts of electron arrangements, energy, and stability, write a paragraph in your Science Journal describing a chemical bond. **For more help, refer to the Science Skill Handbook.**

Activity

Atomic Trading Cards

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

What You'll Investigate

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

Materials

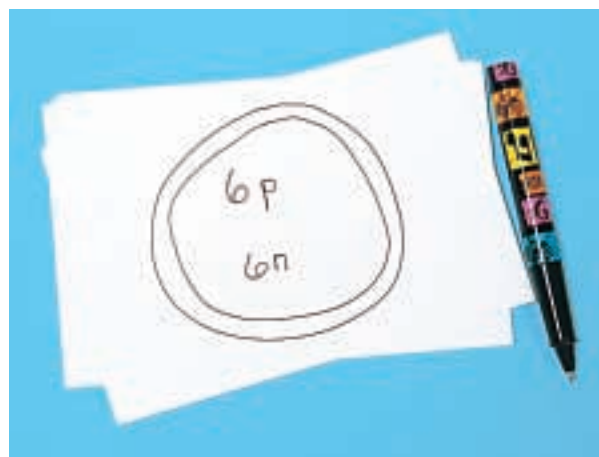
4 × 6 inch index cards
periodic table

Goals

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

Procedure

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



level one can hold two electrons and levels two and three can hold eight electrons.

5. Look at the picture side only of four or five of your classmates' cards. Determine which element they have and to which group it belongs.

Conclude and Apply

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

Communicating

Your Data

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

Types of Bonds

As You Read

What You'll Learn

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

Vocabulary

ion	polar molecule
ionic bond	nonpolar molecule
molecule	covalent bond

Why It's Important

Bond type determines other properties of the compound.

Figure 7

Goiter, a condition that causes an enlargement of the thyroid gland in the neck, is caused by iodine deficiency.



Gain or Loss of Electrons

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

Atoms, too, lose or gain to meet a standard—a stable energy level. They do not lose or gain an advantage. Instead, they lose or gain electrons. An atom that has lost or gained electrons is called an ion. An **ion** is a charged particle because it now has either more or fewer electrons than protons. The positive and negative charges are not balanced.

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



Health

INTEGRATION

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

Adding iodine to salt is as easy as spraying it with potassium iodide. However, even though the solution is relatively simple, more countries have iodine deficiency problems than do not. Much progress has been made in the movement to solve this problem, and the work continues.

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

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

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

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

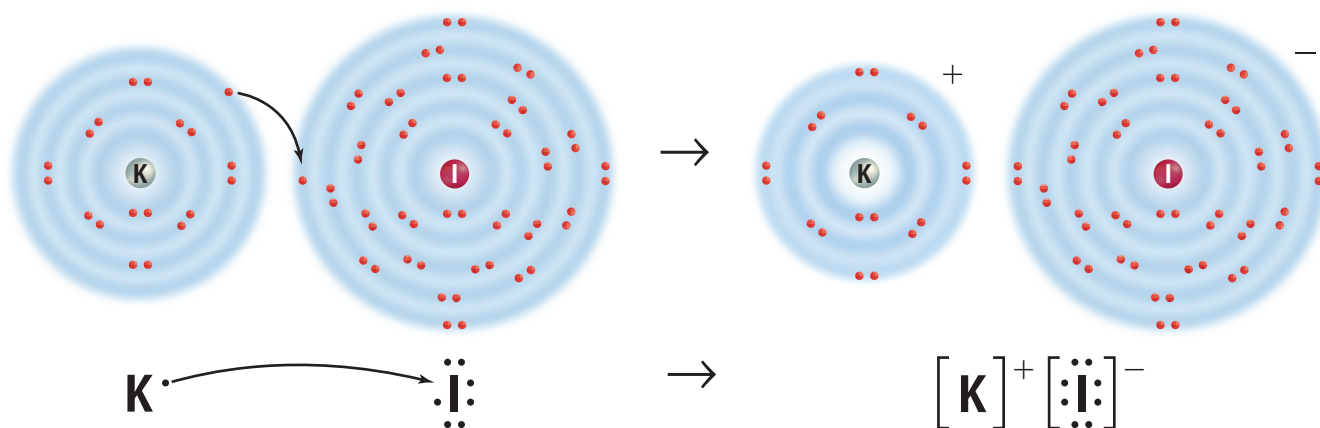


Life Science

INTEGRATION

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

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



Sharing Electrons

Some atoms of nonmetals are unlikely to lose or gain electrons. For example, the elements in Group 4 of the periodic table have four electrons in their outer level. They would have to either gain or lose four electrons in order to have a stable outer level. The loss of this many electrons takes a great deal of energy. Each time an electron is removed, the nucleus holds the remaining electrons even more tightly. Therefore, these atoms become more chemically stable by sharing electrons, rather than by losing or gaining electrons.

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

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

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

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

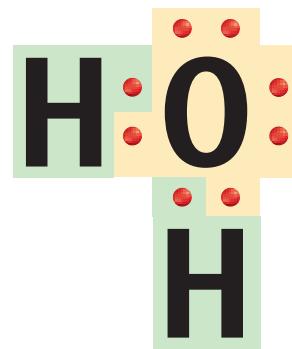


Figure 10
Each of the pairs of electrons between the two hydrogens and the oxygen is shared as each atom contributes one electron to the pair to make the bond.

Figure 11
The dot diagram shows that the two nitrogen atoms in nitrogen gas share six electrons.

TRY AT HOME

Mini LAB

Observing Bond Type

Procedure

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

Analysis

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

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

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

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

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

Figure 12

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

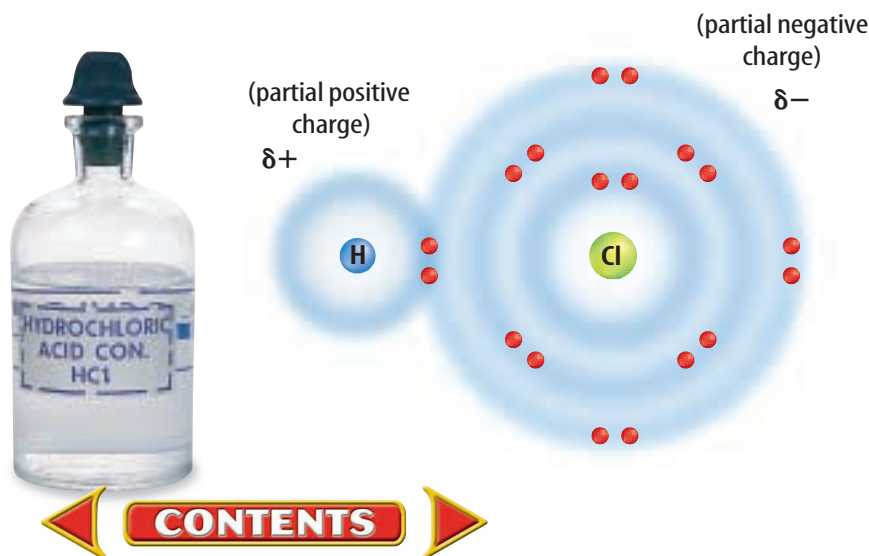
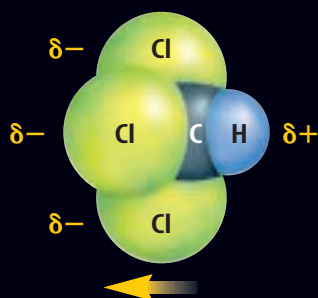
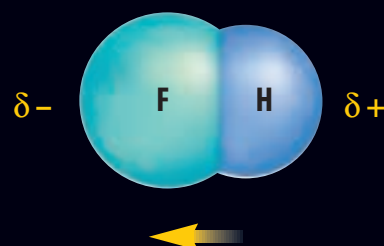


Figure 13

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



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



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

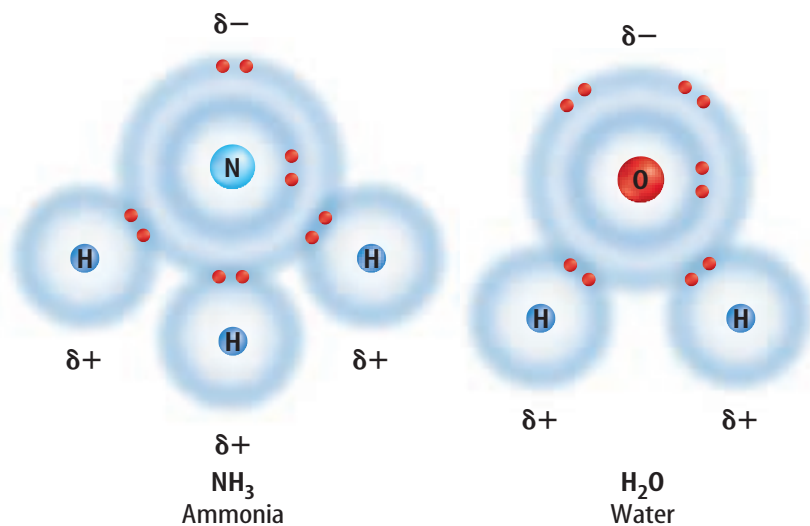


Figure 14

A model of the ammonia molecule illustrates the charge difference as the nitrogen holds the electron more closely. The polarity of water is responsible for many of its unique properties.

polar. The term *polar* means “having opposite ends.” A **polar molecule** is one that has a slightly positive end and a slightly negative end although the overall molecule is neutral. Ammonia and water are examples of a polar molecule, as shown in **Figure 14**.

Reading Check What is a polar molecule?

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

Section 2 Assessment

1. Why does an atom make an ionic bond only with certain other atoms?
2. Compare the possession of electrons in ionic and covalent bonds.
3. What types of particles are formed by covalent bonds?
4. What is the difference between polar and nonpolar molecules?
5. **Think Critically** From the following list of symbols, choose two elements that are likely to form an ionic bond: O, Ne, S, Ca, K. Next, select two elements that would likely form a covalent bond. Explain.

Skill Builder Activities

6. **Concept Mapping** Using the following terms, make a network tree concept map of chemical bonding: *ionic, covalent, ions, positive ions, negative ions, molecules, polar, and nonpolar*. For more help, refer to the **Science Skill Handbook**.
7. **Solving One-Step Equations** Aluminum oxide, Al_2O_3 , can be produced during space shuttle launches. Show that the sum of the positive and negative charges in a unit of Al_2O_3 equals zero. For more help, refer to the **Math Skill Handbook**.

Writing Formulas and Naming Compounds

Symbols and Shorthand

Does the table in **Figure 15** look like it has anything to do with chemistry? It is an early table of the elements made by alchemists—scientists who tried to make gold from other elements. The alchemist used symbols like these to write the formulas of substances like silver tarnish. The modern chemist uses symbols from the modern periodic table and writes the formula Ag_2S . When you get to the end of this section, you, too, will name compounds and write their formulas.

Binary Ionic Compounds

The first formulas of compounds you will write are for binary ionic compounds. A **binary compound** is one that is composed of two elements. Potassium iodide, the salt additive discussed in Section 2, is a binary ionic compound. However, before you can write a formula, you must have all the needed information at your fingertips. What will you need to know?

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

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

As You Read

What You'll Learn

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

Vocabulary

binary compound polyatomic ion
oxidation number hydrate

Why It's Important

The name and formula of a compound convey information about the compound.

Figure 15

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

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

Figure 16
The number at the top of each column is the most common oxidation number of elements in that Group.

1+												0					
Hydrogen 1 H	2+											3+	4+	5+	2-	1-	Helium 2 He
Lithium 3 Li	Beryllium 4 Be											Boron 5 B	Carbon 6 C	Nitrogen 7 N	Oxygen 8 O	Fluorine 9 F	Neon 10 Ne
Sodium 11 Na	Magnesium 12 Mg											Aluminum 13 Al	Silicon 14 Si	Phosphorus 15 P	Sulfur 16 S	Chlorine 17 Cl	Argon 18 Ar
Potassium 19 K	Calcium 20 Ca											Gallium 31 Ga	Germanium 32 Ge	Arsenic 33 As	Selenium 34 Se	Bromine 35 Br	Krypton 36 Kr
Rubidium 37 Rb	Strontium 38 Sr											Indium 49 In	Tin 50 Sn	Antimony 51 Sb	Tellurium 52 Te	Iodine 53 I	Xenon 54 Xe
Cesium 55 Cs	Barium 56 Ba											Thallium 81 Tl	Lead 82 Pb	Bismuth 83 Bi	Polonium 84 Po	Astatine 85 At	Radon 86 Rn
Francium 87 Fr	Radium 88 Ra																

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

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

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

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

However, what if you have a compound like calcium fluoride? A calcium ion has a charge of 2+ and a fluoride ion has a charge of 1-. In this case you need to have two fluoride ions for every calcium ion in order for the charges to cancel and the compound to be neutral with the formula CaF₂.

Some compounds require more figuring. Aluminum oxide contains an ion with a 3+ charge and an ion with a 2- charge. You must find the least common multiple of 3 and 2 in order to determine how many of each ion you need. You need two aluminum ions and three oxygen ions in order to have a 6+ charge and a 6- charge and therefore, the neutral compound Al₂O₃.

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

1. Write the symbol of the element or polyatomic ion (ions containing more than one atom) that has the positive oxidation number or charge. Hydrogen, the ammonium ion (NH_4^+) and all metals have positive oxidation numbers.
2. Write the symbol of the element or polyatomic ion with the negative oxidation number. Nonmetals other than hydrogen and polyatomic ions other than NH_4^+ have negative oxidation numbers.
3. Use subscripts next to each ion so that the sum of the charges of all the ions in the formula is zero.



Earth Science INTEGRATION

Farmers must sometimes add lime, which is calcium oxide, to soil in their fields. What is the formula of calcium oxide?

Math Skills Activity

Writing Formulas

Example Problem

What is the formula for lithium nitride?

Solution

1 *This is what you know:*

Write the symbol and oxidation number of the positive element:

Lithium (Li) = 1+

Write the symbol and oxidation number of the negative element:

Nitrogen (N) = 3-

Least common multiple = 3

2 *This is what you need to do:*

Add subscripts so that the sum of the oxidation numbers is zero

$3 \text{ Li} = (3)(1+) = 3+$

$1 \text{ N} = 3-$

Complete the formula: Li_3N

Check your answer by multiplying each subscript by the oxidation number and compare.

Li_3 gives $(3)(1+) = 3+$.

N gives $(1)(3-) = 3-$ and $(3+) + (3-) = 0$.

Practice Problem

What is the formula for lead(IV) phosphide?

For more help, refer to the **Math Skill Handbook**.

Table 3 Elements in Binary Compounds

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

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

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

Notice that the subscripts of the positive and negative ion are not part of the name of the compound except when the positive ion has more than one possible charge.

Problem-Solving Activity

Can you name binary ionic compounds?

What would a chemist name the compound CuCl ?

Identifying the problem

There are four simple steps in naming binary ionic compounds.

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

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

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

Solving the Problem

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

Compounds with Complex Ions

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

Table 4 Polyatomic Ions

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

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

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

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



Figure 17
This humidity predictor uses cobalt chloride.

Mini LAB

Making a Hydrate

Procedure



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

Analysis

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

Compounds with Added Water

Have you seen weather predictors made from blue paper that turns pink in humid air? **Figure 17** shows an example of these humidity detectors. What properties allow this change? Some ionic compounds have water molecules as part of their structure. These compounds are called hydrates. A **hydrate** is a compound that has water chemically attached to its ions.

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

You can remove water from these crystals by heating them. The resulting blue compound is called anhydrous, which means “without water.” If you apply this anhydrous compound to paper, the paper will gain water molecules easily. How will this blue paper react to the presence of water vapor?

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

Naming Binary Covalent Compounds

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

Figure 18

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



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

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

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

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

Table 5 Prefixes for Covalent Compounds

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

Section 3 Assessment

1. What compounds can be formed from element X , with oxidation numbers $3+$ and $5+$, and element Z , with oxidation numbers $2-$ and $3-$? Write their formulas.
2. Write formulas for the following compounds: *potassium iodide*, *magnesium hydroxide*, *aluminum sulfate*, and *chlorine heptoxide*.
3. Write the names of these compounds: KCl , Cr_2O_3 , $\text{Ba}(\text{ClO}_3)_2$, NH_4Cl , and PCl_3 .
4. Name $\text{Mg}_3(\text{PO}_4)_2 \cdot 4\text{H}_2\text{O}$, and write the formula for calcium nitrate trihydrate.
5. **Think Critically** Explain why sodium and potassium will or will not form a bond.

Skill Builder Activities

6. **Testing a Hypothesis** Design an experiment to distinguish between crystals that are hydrates and those that are not. Include crystals of iron(II) chloride, crystals of copper(II) nitrate, and crystals of sucrose. **For more help, refer to the Science Skill Handbook.**
7. **Solving One-Step Equations** The overall charge on the polyatomic sulfate ion, found in some acids, is $2-$. Its formula is SO_4^{2-} . If the oxygen ion has a $2-$ oxidation number, determine the oxidation number of sulfur in this polyatomic ion. **For more help, refer to the Math Skill Handbook.**

Activity

Design Your Own Experiment

Become a Bond Breaker

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



Recognize the Problem

How do the attractive forces between ions compare to the attractive forces between molecules?

Form a Hypothesis

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

Goals

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

Possible Materials

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

Safety Precautions



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



Test Your Hypothesis

Plan

1. As a group, agree upon and write a hypothesis statement.
2. As a group, write a detailed list of steps that are needed to test your hypothesis. Determine what your control will be.
3. As you heat materials in a test tube, what variables are held constant?
4. How will you time the heating of the individual substances?
5. Will you run any tests more than one time?
6. Make a list of materials that you will need to complete your experiment.
7. **Design** a data table in your Science Journal to record your observations.
8. Make sure your teacher approves your plan before you start.

Do

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



Analyze Your Data

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

Draw Conclusions

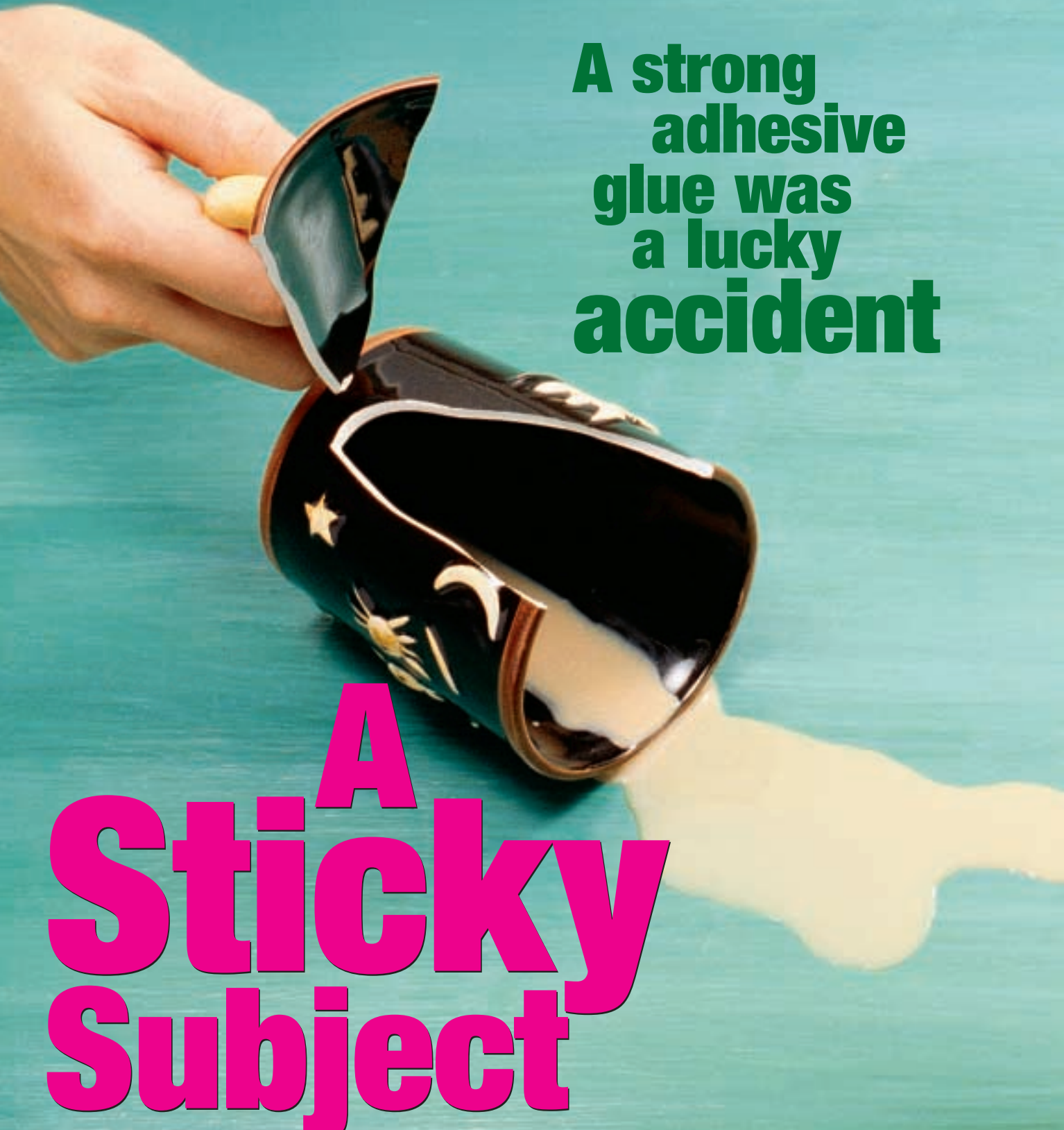
1. How did the results of your experiment support or disprove your hypothesis?
2. Sugar is known as a polar covalent compound. Knowing this, infer from your results how polarity affects melting point.

Communicating Your Data

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

Oops! Accidents in SCIENCE

SOMETIMES GREAT DISCOVERIES HAPPEN BY ACCIDENT!

A hand is shown holding a broken piece of a black ceramic mug. The mug has a white interior and a yellow star pattern. A yellow liquid spill is visible on the teal surface below the mug. The background is a solid teal color.

**A strong
adhesive
glue was
a lucky
accident**

A Sticky Subject

596

◀ CONTENTS ▶

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

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



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

In 1952, a member of the research team, working on new materials for jet plane canopies, made a similar complaint. The ethyl cyanoacrylate they were working with again made everything stick together. This time, the insight stuck to the scientists like, well, like GLUE! “I began gluing everything I could lay my hands on—glass plates, rubber stoppers, metal spatulas, wood, paper, plastic.

Everything stuck to everything, almost instantly, and with bonds I could not break apart,” recalls the head of the research group.

Stick to It

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

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

Cyanoacrylates are also used in dental and eye surgery and to stop bleeding in internal organs.



The repaired mug is ready for use.

CLICK HERE

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

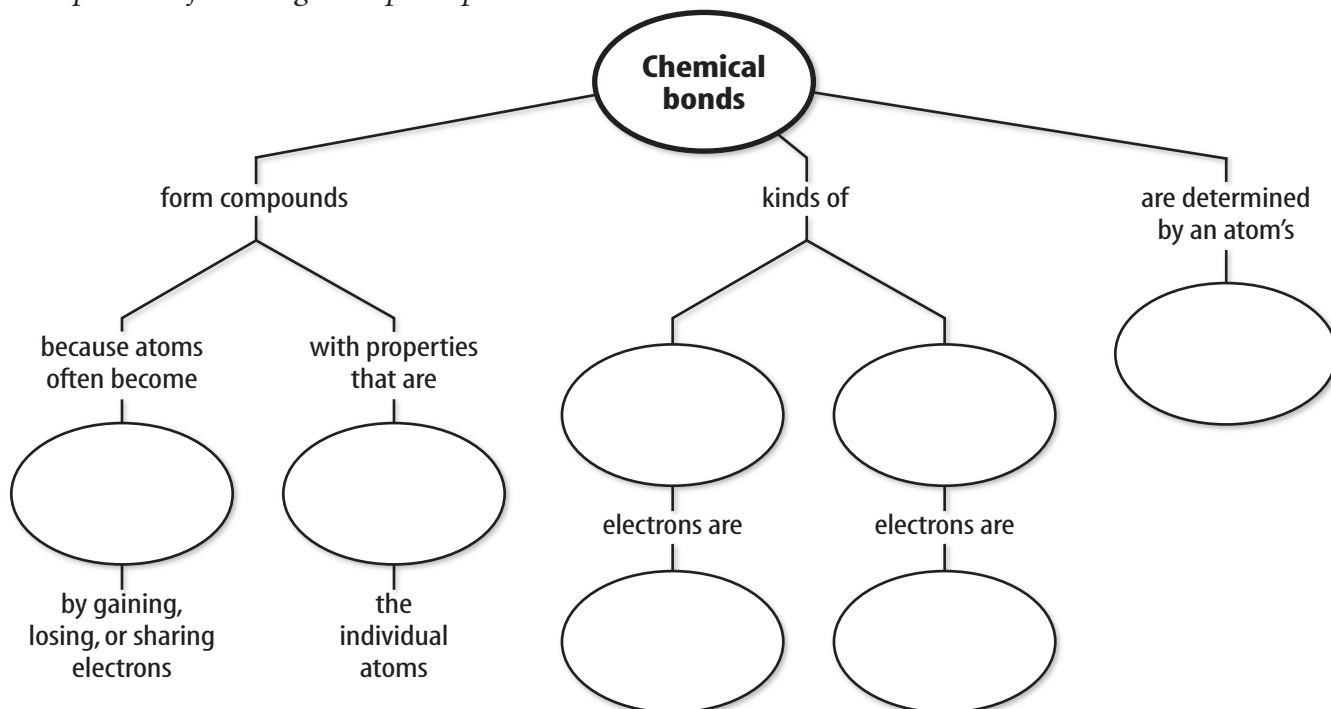
CONTENTS

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Visualizing Main Ideas

Complete the following concept map.



Vocabulary Review

Vocabulary Words

- | | |
|----------------------|----------------------|
| a. binary compound | h. ionic bond |
| b. chemical bond | i. molecule |
| c. chemical formula | j. nonpolar molecule |
| d. chemically stable | k. oxidation number |
| e. covalent bond | l. polar molecule |
| f. hydrate | m. polyatomic ion |
| g. ion | |

Using Vocabulary

Match each phrase with a vocabulary word.

- a charged group of atoms
- a compound composed of two elements
- a molecule with partially charged ends
- a positively or negatively charged atom
- a chemical bond between oppositely charged ions
- a bond formed from shared electrons
- crystalline substance that contains water
- outer energy level is filled with electrons
- shows an element's combining ability
- tells which elements are in a compound and their ratios



Study Tip

Read the chapters before you go over them in class. Being familiar with the material before your teacher explains it gives you a better understanding and provides you with a good opportunity to ask questions.

Chapter 19 Assessment

Checking Concepts

Choose the word or phrase that best answers the question.

- Which elements are least likely to react with other elements?
A) metals C) nonmetals
B) noble gases D) transition elements
- What is the oxidation number of Fe in the compound Fe_2S_3 ?
A) 1^+ C) 3^+
B) 2^+ D) 4^+
- What is the name of CuO ?
A) copper oxide
B) copper(I) oxide
C) copper(II) oxide
D) copper(III) oxide
- What is the formula for copper(II) chlorate?
A) CuClO_3 C) $\text{Cu}(\text{ClO}_3)_2$
B) CuCl D) CuCl_2
- Which of the following formulas represents a nonpolar molecule?
A) N_2 C) NaCl
B) H_2O D) HCl
- How many electrons are in the outer energy level of Group 17 elements?
A) 1 C) 17
B) 2 D) 7
- Which is a binary ionic compound?
A) O_2 C) H_2SO_4
B) NaF D) $\text{Cu}(\text{NO}_3)_2$
- Which of these is an example of an anhydrous compound?
A) H_2O C) $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$
B) CaSO_4 D) $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$
- Which of the following is an atom that has gained an electron?
A) negative ion C) polar molecule
B) positive ion D) nonpolar molecule

- Which of these is an example of a covalent compound?

A) sodium chloride C) calcium chloride
B) calcium fluoride D) sulfur dioxide

Thinking Critically

- Anhydrous magnesium chloride is used to make wood fireproof. Draw a dot diagram of magnesium chloride.
- Baking soda, which is sodium hydrogen carbonate, and vinegar, which contains hydrogen acetate, can be used as household cleaners. Write the chemical formulas for these two compounds.
- Artificial diamonds are made using thallium carbonate. If thallium has an oxidation number of 1^+ , what is the formula for the compound?
- The formula for a compound that composes kidney stones is $\text{Ca}_3(\text{PO}_4)_2$. What is the chemical name of this compound?
- Ammonium sulfate is used as a fertilizer. What is its chemical formula?

Developing Skills

- Comparing and Contrasting** Compare and contrast polar and nonpolar molecules.
- Interpreting Scientific Illustrations** Write the name and formula for the compound illustrated to the right.



- Drawing Conclusions**

Ammonia gas and water react to form household ammonia, which contains NH_4^+ and OH^- ions. If the formula for water is H_2O , what is the formula for ammonia gas?

19. Predicting Elements from one family (vertical row) of the periodic table generally combine with elements from another family and polyatomic ions in the same ratio. For example, one calcium atom combines with two chlorine atoms to give CaCl_2 (calcium chloride) as it does with two fluorine atoms to give CaF_2 (calcium fluoride). For each formula in the table below, using a periodic table as a guide, predict which of the two compounds on the right side of the table is more likely to exist.

Which compounds exist?	
Formula	Possible Compounds
SF_6	AlF_6 or TeF_6
K_2SO_4	Na_2SO_4 or Ba_2SO_4
CO_2	CCl_2 or CS_2
CaCO_3	OCO_3 or BaCO_3

Performance Assessment

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

21. Model One common form of phosphorus, white phosphorus, has the formula P_4 and is formed by four covalently bonded phosphorus atoms. Make a model of this molecule, showing that all four atoms are now chemically stable.

TECHNOLOGY

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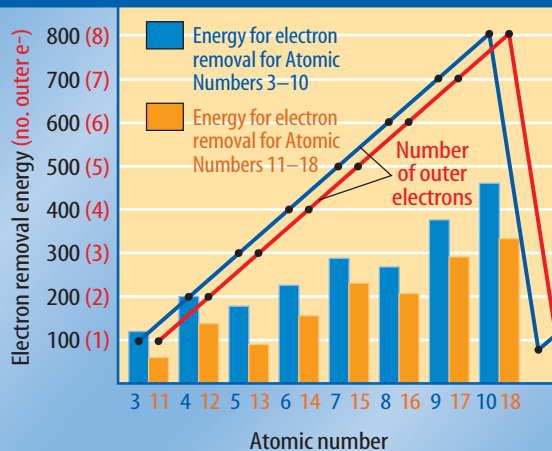
CONTENTS



Test Practice

Cindy constructed a graph of ionization energy, which is the energy required to remove one electron and also the number of outer electrons an atom has in relation to its atomic number. Her finished graphs are shown in the diagram below.

Electron Removal Energy v. Atomic Number



Study the diagram and answer the following questions.

- A reasonable hypothesis based on these data is that as the number of outer electrons increases, the _____.
 - energy required to remove one electron decreases
 - energy required to remove one electron increases
 - atomic number decreases
 - potential to form ions increases
- The noble gases have full outer energy levels. Which atomic numbers on the graph represent noble gases?

F) 3 and 11	H) 9 and 17
G) 7 and 15	J) 10 and 18

Reading Comprehension

Read the passage. Then read each question that follows the passage. Decide which is the best answer to each question.

Mendeleev and the Periodic Table

By 1860, scientists had discovered a total of 63 chemical elements. Dmitri Mendeleev, a Russian chemist, thought that there had to be some order among the elements.

He made a card for each element. On the card, he listed the physical and chemical properties of the element, such as atomic mass, density, color, and melting point. He also wrote each element's combining power, or its ability to form compounds with other elements.

When he arranged the cards in order of increasing atomic mass, Mendeleev noticed that the elements followed a periodic, or repeating, pattern. Every seven cards, the properties repeated. He placed each group of seven cards in rows, one under another so that the elements in a column, or group, had similar chemical and physical properties.

In a few places, Mendeleev had to move his cards one space to the left or right to follow the pattern. This left a few empty spaces. He predicted that these spaces would be filled with elements that were unknown. He even predicted the properties of the unknown elements. Fifteen years later, three new elements were discovered and placed in the empty spaces of the Periodic Table. Their physical and chemical properties agreed with Mendeleev's predictions.

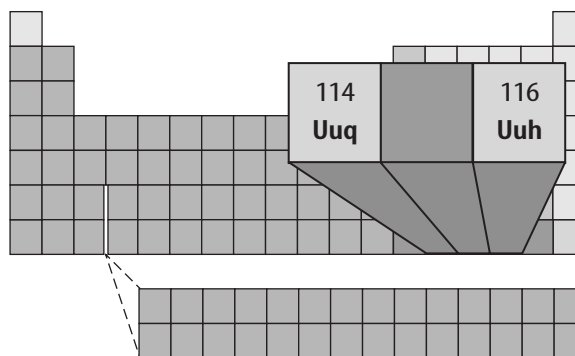
Today there are more than 100 known elements. An extra column has been added for the noble gases, a group of elements not known to exist in Mendeleev's time. Members of this group almost never combine with other

elements. As new elements are discovered or are made artificially, scientists can place them in their proper place on the Periodic Table thanks to Mendeleev.

Test-Taking Tip

To answer questions about sequence of events, make a time line of what happened in each paragraph of the passage.

All elements can be organized according to their physical and chemical properties.

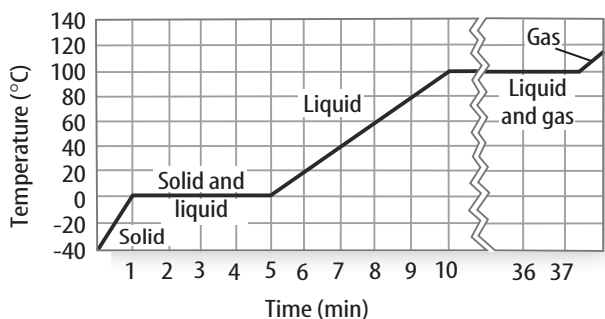


- Which of the following occurred FIRST in the passage?
 - Three new elements were discovered fifteen years after Mendeleev developed the Periodic Table.
 - The noble gases were discovered and placed in the Periodic Table.
 - Mendeleev predicted properties of the unknown elements.
 - New elements were made in the laboratory and then placed in the Periodic Table.
- The word artificially in this passage means _____.
 - unnaturally
 - artistically
 - atomically
 - radioactively

Reasoning and Skills

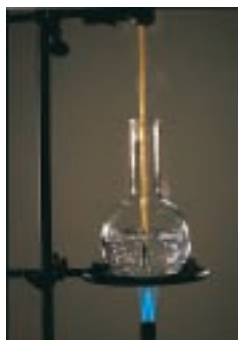
Read each question and choose the best answer.

Changes in States of Matter



- The graph shows the change in temperature as ice is heated until it changes completely to gas. How much higher than the starting temperature is the boiling point?
A) 40°C **C)** 140°C
B) 100°C **D)** 180°C

Test-Taking Tip Boiling point is the flat section of the graph where liquid changes to gas.



- What is being measured in the illustration?
F) boiling point **H)** density
G) melting point **J)** flammability

Test-Taking Tip Think about what you might be measuring when you use a thermometer in a liquid that you are heating.

Selected Properties of Selected Pure Substances

Substance	Melting Point (°C)	Boiling Point (°C)	Color
Aluminum	660.4	2,519	silver metallic
Argon	-189.2	-185.7	colorless
Mercury	-38.8	356.6	silver metallic
Water	0	100	colorless

- Room temperature is about 20°C. In the table, which substance is a solid at room temperature?
A) aluminum
B) argon
C) mercury
D) water

Test-Taking Tip Remember that negative temperatures are below zero.

Read this question carefully before writing your answer on a separate sheet of paper.

- The density of pure water is 1.00 g/cm³. Since ice floats on water, we know that the density of ice is *less* than that of water. Design an experiment to determine the density of an ice cube. List all the necessary steps.
 (Volume = Length × Width × Height;
 Density = Mass / Volume)

Test-Taking Tip Make sure to consider all the information provided in the question.