

# How Are Billiards & Bottles Connected?



**B**illiards, a popular table game of the 1800s, used balls carved from ivory. In the 1860s, an ivory shortage prompted one billiard-ball manufacturer to offer a reward of \$10,000 to anyone who could come up with a suitable substitute. In an attempt to win the prize, an inventor combined certain organic compounds, put them into a mold, and subjected them to heat and pressure. The result was a hard, shiny lump that sparked a major new industry—the plastics industry. By the mid-1900s, chemists had invented many different kinds of moldable plastic. Today, plastic is made into countless products—everything from car parts to soda bottles.

**unit** **projects**

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Projects include:

- **History** Construct a ceramics time line by exploring the history of ceramics and the way they meet advanced technological needs.
- **Career** Develop trivia cards on the life of Freidrich August Kekule, a chemist and theorist.
- **Model** Develop an original use for a new material, design “blueprints,” conduct a patent search, and present your idea to fellow class scientists.



*Recycling Plastics* investigates the history of plastics, the seven classes of plastics, their chemistry, and how they can be recycled. Become a more active, aware, and responsible citizen.

**BIG Idea**

Elements can be classified into three main types—metals, nonmetals, and metalloids.

**19.1 Metals**

**MAIN Idea** Metals are located on the left side of the periodic table and are generally shiny, good conductors, malleable, and ductile.

**19.2 Nonmetals**

**MAIN Idea** Nonmetals are located on the right side of the periodic table and are generally dull, poor conductors, and brittle.

**19.3 Mixed Groups**

**MAIN Idea** Some groups on the periodic table contain metalloids—elements that share some properties of both metals and nonmetals.

**Stress and the Elements**

It takes a combination of metals, nonmetals, and metalloids to construct an airplane and have a viable aircraft. It is necessary to understand the properties of each element and how they will work with each other.

**Science Journal**

Describe what some of the key elements are (which might be found in this picture) and the properties of these elements that make them so crucial.

# Elements and Their Properties



# Start-Up Activities



## Observe Colorful Clues

It is the distinct physical properties of each element that make it so that one element can be identified from another. In this lab, you will observe how the heated atoms of some elements absorb energy and then in a short time release the absorbed energy, which you see as colored light.



1. Wearing gloves and using tongs, carefully hold a clean paper clip in the hottest part of a lab burner flame for 45 seconds.
2. Dip the hot paper clip into a solution of copper(II) sulfate.
3. Using the tongs with the same paper clip, repeat step 1, observing any color change.
4. Repeat all three steps using solutions of strontium chloride and sodium chloride with clean tongs and new paper clips.
5. **Think Critically** Which element—chlorine or strontium—was responsible for the color observed when strontium chloride was placed in the flame? How do you know? Devise a plan to determine whether copper or sulfate was responsible for the color in step 2.

## FOLDABLES™ Study Organizer

**Groups** Make the following Foldable to help classify and organize elements into groups based on their common features.

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



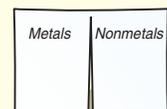
**STEP 2** **Fold** in half from side to side with the fold at the top.



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



**STEP 4** **Turn** the paper horizontally and **label** the tabs *Metals* and *Nonmetals* as shown.



**Illustrate and Label** Before reading the chapter, list all of the metal and nonmetal elements you know under the appropriate tab. As you read the chapter, check your list and make changes as needed.



Preview this chapter's content and activities at [gpscience.com](http://gpscience.com)

# Metals

## Reading Guide

### What You'll Learn

- **Describe** the properties of a typical metal.
- **Identify** the alkali metals and alkaline earth metals.
- **Differentiate** among three groups of transition elements.

### Why It's Important

Metals are a part of your everyday life—from electric cords to the cars you ride in.

### Review Vocabulary

**element:** substance with atoms that are all alike

### New Vocabulary

- metal
- malleable
- ductile
- metallic bonding
- radioactive element
- transition element

**Figure 1** The various properties of metals make them useful.



Metals, like the one shown, can be hammered into thin sheets.

**Explain** one use for a sheet of metal.



Metals can be drawn into wires, like the wire that is being used here.

**Describe** what this property of metals is called.

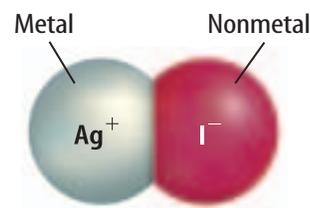
## Properties of Metals

The first metal used about 6,000 years ago was gold. The use of copper and silver followed a few thousand years later. Then came tin and iron. Aluminum wasn't refined until the 1800s because it must go through a much more complicated refining process that earlier civilizations had not yet developed.

In the periodic table, metals are elements found to the left of the stair-step line. In the table on the inside back cover of your book, the metal element blocks are colored blue. **Metals** usually have common properties—they are good conductors of heat and electricity, and all but one are solid at room temperature. Mercury is the only metal that is not a solid at room temperature.

Metals also reflect light. This is a property called luster. Metals are **malleable** (MAL yuh bul), which means they can be hammered or rolled into sheets, as shown in **Figure 1**. Metals are also **ductile**, which means they can be drawn into wires like the ones shown in **Figure 1**. These properties make metals suitable for use in objects ranging from eyeglass frames to computers to building structures.

**Ionic Bonding in Metals** The atoms of metals generally have one to three electrons in their outer energy levels. In chemical reactions, metals tend to give up electrons easily because of the strength of charge of the protons in the nucleus. When metals combine with nonmetals, the atoms of the metals tend to lose electrons to the atoms of nonmetals, forming ionic bonds, as shown in **Figure 2**. Both metals and nonmetals become more chemically stable when they form ions. They take on the electron structure of the nearest noble gas.



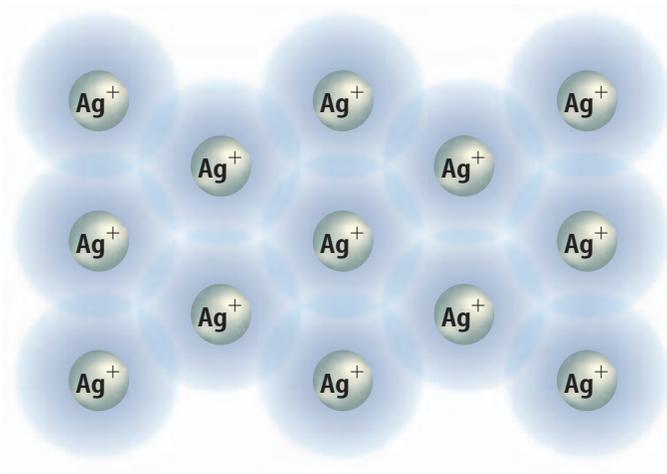
**Figure 2** Metals can form ionic bonds with nonmetals.

**Metallic Bonding** Another type of bonding, neither ionic nor covalent, occurs among the atoms in a metal. In **metallic bonding**, positively charged metallic ions are surrounded by a cloud of electrons. Outer-level electrons are not held tightly to the nucleus of an atom. Rather, the electrons move freely among many positively charged ions. As shown in **Figure 3**, the electrons form a cloud around the ions of the metal.

The idea of metallic bonding explains many of the properties of metals. For example, when a metal is hammered into a sheet or drawn into a wire, it does not break because the ions are in layers that slide past one another without losing their attraction to the electron cloud. Metals are also good conductors of electricity because the outer-level electrons are weakly held.

 **Reading Check** *Why do metals conduct electricity?*

Look at the periodic table inside the back cover of your book. How many of the elements in the table are classified as metals? All of the blue-shaded boxes represent metals. Except for hydrogen, all the elements in Groups 1 through 12 are metals, as well as the elements under the stair-step line in Groups 13 through 15. You will learn more about metals in some of these groups throughout this chapter.



**Figure 3** In metallic bonding, the electrons represented by the cloud are not attached to any one silver ion. This allows them to move and conduct electricity.



## The Alkaline Earth Metals

The alkaline earth metals make up Group 2 of the periodic table. Like most metals, these metals are shiny, malleable, and ductile. They are also similar to alkali metals in that they combine so readily with other elements that they are not found as free elements in nature. Each atom of an alkaline earth metal has two electrons in its outer energy level. These electrons are given up when an alkaline earth metal combines with a nonmetal. As a result, the alkaline earth metal becomes a positively charged ion in a compound such as calcium fluoride,  $\text{CaF}_2$ .

**Fireworks and Other Uses** Magnesium metal is one of the metals used to produce the brilliant white color in fireworks like the ones in **Figure 5**. Compounds of strontium produce the bright red flashes. Magnesium's lightness and strength account for its use in cars, planes, and spacecraft. Magnesium also is used in compounds to make such things as household ladders and baseball and softball bats. Most life on Earth depends upon chlorophyll, a magnesium compound that enables plants to make food. Marble statues and some countertops are made of the calcium compound calcium carbonate.

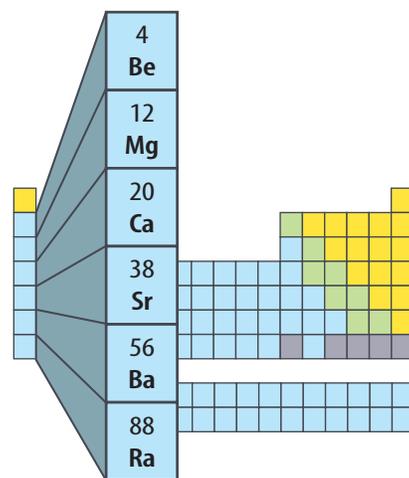
**The Alkaline Earth Metals and Your Body** Calcium is seldom used as a free metal, but its compounds are needed for life. You may take a vitamin with calcium. Calcium phosphate in your bones helps make them strong.



The barium compound  $\text{BaSO}_4$  is used to diagnose some digestive disorders because it absorbs X-ray radiation well. First, the patient swallows a barium compound. Next, an X ray is taken while the barium compound is going through the digestive tract. A doctor can then see where the barium is in the body. In this way, doctors can diagnose internal abnormalities in the body.

Radium, the last element in Group 2, is radioactive and is found associated with uranium. It was once used to treat cancers. Today, other radioactive elements that are more readily available are replacing radium in cancer therapy.

The Alkaline Earth Metals



**Figure 5** Alkaline earth metals make spectacular fireworks.



## Mini LAB

### Discovering What's in Cereal

#### Procedure

1. Tape a small, strong magnet to a pencil at the eraser end.
2. Place some dry, fortified, cold cereal in a plastic bag.
3. Thoroughly crush the cereal.
4. Pour the crushed cereal into a deep bowl and cover it with water.
5. Stir the mixture for about 10 min with your pencil/magnet. Stir slowly for the last minute.
6. Remove the magnet and examine it carefully. Record your observations.

#### Analysis

1. What common element is attracted to your magnet?
2. Why is this element added to the cereal?



A simplified periodic table with a callout box highlighting the transition elements. The callout box contains the following information:

26	27	28
Fe	Co	Ni

## Transition Elements

A titanium bike frame and a glowing tungsten lightbulb filament are examples of objects made from transition elements. **Transition elements** are those elements in Groups 3 through 12 in the periodic table. They are called transition elements because they are considered to be elements in transition between Groups 1 and 2 and Groups 13 through 18. Look at the periodic table inside the back cover of your book. Which elements do you think of as being typical metals? Transition elements are the most familiar because they often occur in nature as uncombined elements, unlike Group 1 and Group 2 metals which are less stable.

Transition elements often form colored compounds. The gems in **Figure 6** show brightly colored compounds containing chromium. Cadmium yellow and cobalt blue paints are made from compounds of transition elements. However, cadmium and cobalt paints are so toxic that their use is limited.

**Iron, Cobalt, and Nickel** The first elements in Groups 8, 9, and 10—iron, cobalt, and nickel—form a unique cluster of transition elements. These three sometimes are called the iron triad. All three elements are used in the process to create steel and other metal mixtures.

Iron—the main component of steel—is the most widely used of all metals. It is the second most abundant metallic element in Earth's crust after aluminum. Other metals are added to steel to give it various characteristics. Some steels contain cobalt or nickel. Nickel is added to some metals to give them strength. Also, nickel is used to give a shiny, protective coating to other metals.



**Figure 6** The colors of the ruby and emerald are due to the transition element chromium.

**Figure 7** The coinage metals have many uses.



Because gold and silver are so expensive, copper is more common in coins.

Silver is used in compounds to make photographic materials.

**Copper, Silver, and Gold** The main metals in the objects in **Figure 7** are copper, silver, and gold—the three elements in Group 11. Because they are so stable and malleable and can be found as free elements in nature, these metals were once used widely to make coins. For this reason, they are known as the coinage metals. Because they are so expensive, silver and gold rarely are used in coins anymore. The United States stopped using gold in the production of its coins in 1933 and silver in 1964. Most coins now are made of nickel and copper.

Copper often is used in electrical wiring because of its superior ability to conduct electricity and its relatively low cost. Can you imagine a world without photographs and movies? Silver iodide and silver bromide break down when exposed to light, producing an image on paper. Consequently, these compounds are used to make photographic film and paper. Silver and gold are used in jewelry because of their attractive color, relative softness, resistance to corrosion, and rarity.

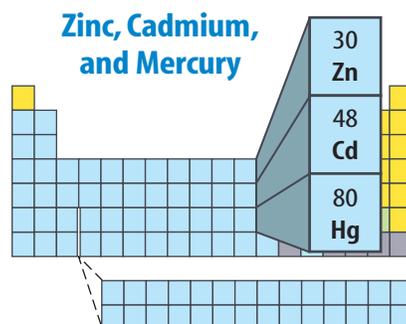
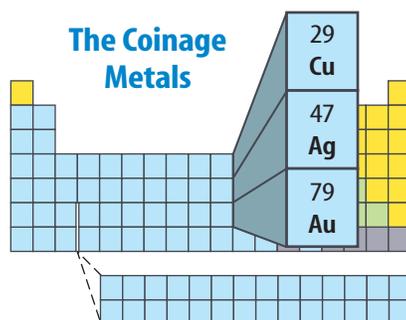


Gold frequently is used in jewelry.

**Reading Check** *Why does gold's relative softness make it a good choice for jewelry?*

**Zinc, Cadmium, and Mercury** Zinc, cadmium, and mercury are found in Group 12 of the periodic table. Zinc combines with oxygen in the air to form a thin, protective coating of zinc oxide on its surface. Zinc and cadmium often are used to coat, or plate, other metals such as iron because of this protective quality. Cadmium is used also in rechargeable batteries.

Mercury is a silvery, liquid metal—the only metal that is a liquid at room temperature. It is used in thermometers, thermostats, switches, and batteries. Mercury is poisonous and can accumulate in the body. People have died of mercury poisoning after eating fish that lived in mercury-contaminated water.





## Metals in the Crust

Earth's hardened outer layer, called the crust, contains many compounds and a few uncombined metals such as gold and copper. Metals must be mined and separated from their ores, as shown in **Figure 9**.

Most of the world's platinum is found in South Africa. Chromium is important because it is used to harden steel, to manufacture stainless steel, and to form other alloys. The United States imports most of its chromium from South Africa, the Philippines, and Turkey.



**Figure 9** Copper is mined in the United States at the Bingham Canyon Copper Mine in Utah.

**Ores: Minerals and Mixtures** Metals in Earth's crust that combined with other elements are found as ores. Most ores consist of a metal compound, or mineral, within a mixture of clay or rock. After an ore is mined from Earth's crust, the rock is separated from the mineral. Then the mineral often is converted to another physical form. This step usually involves heat and is called roasting. Finally, the metal is refined into a pure form. Later it can be alloyed with other metals.

Removing the waste rock can be expensive. If the cost of removing the waste rock becomes greater than the value of the desired material, the mineral no longer is classified as an ore.

### section 1 review

#### Summary

##### Properties of Metals

- Metals tend to form ionic and metallic bonds due to low numbers of electrons in their outer energy level.

##### Alkali and Alkaline Earth Metals

- Elements in Group 1 are called alkali metals.
- Elements in Group 2 are called alkaline earth metals.

##### Transition Elements and Inner Transition Metals

- Transition elements are elements in Groups 3–12 in the periodic table.
- Inner transition metals fit in the periodic table between Groups 3 and 4 in periods 6 and 7.

#### Self Check

1. **Describe** how to test palladium to see if it is a metal.
2. **Explain** how arrangement of the iron triad differs from arrangements of coinage metals.
3. **Identify** how metallic bonds differ from ionic and covalent bonds.
4. **Think Critically** If  $X$  stands for a metal, how can you tell from the following formulas— $XCl$  and  $XCl_2$ —which compound contains an alkali metal and which contains an alkaline earth metal?

#### Applying Math

5. **Use Percentages** Pennies used to be made of copper and zinc, and weighed 3.11 g. Today, pennies are made of copper-plated zinc, and weighs 2.5 g. A new penny weighs what percent of an old penny?

# Nonmetals

## Reading Guide

### What You'll Learn

- **Recognize** hydrogen as a non-metal.
- **Compare and contrast** properties of the halogens.
- **Describe** properties and uses of the noble gases.

### Why It's Important

Nonmetals are not only all around you, they are an essential part of your body.

### Review Vocabulary

**molecule:** neutral particle formed when atoms share electrons

### New Vocabulary

- nonmetal
- diatomic molecule
- salt
- sublimation

## Properties of Nonmetals

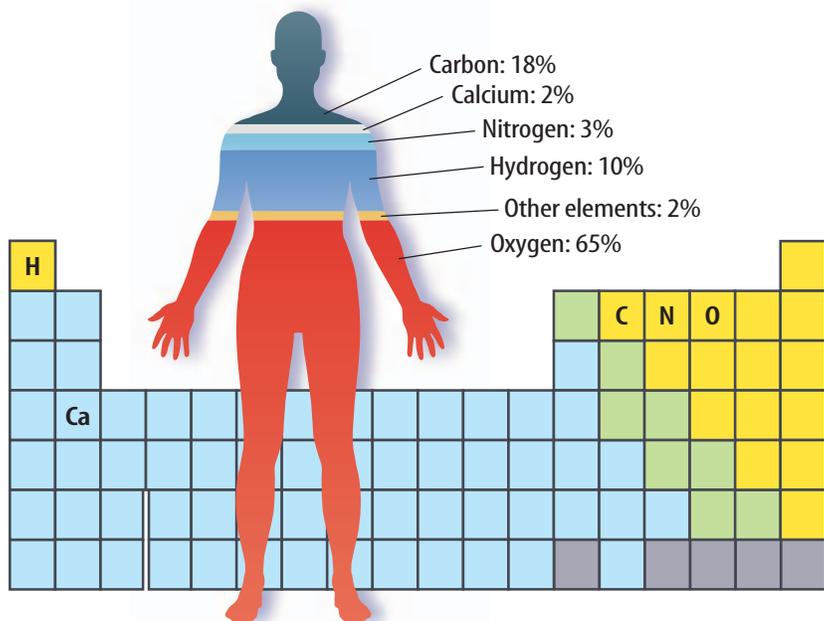
Most of your body's mass is made of oxygen, carbon, hydrogen, and nitrogen, as shown in **Figure 10**. Calcium, a metal, and other elements make up the remaining four percent of your body's mass. Phosphorus, sulfur, and chlorine are among these other elements found in your body. These elements are classified as nonmetals. **Nonmetals** are elements that usually are gases or brittle solids at room temperature. Because solid nonmetals are brittle or powdery, they are not malleable or ductile. Most non-

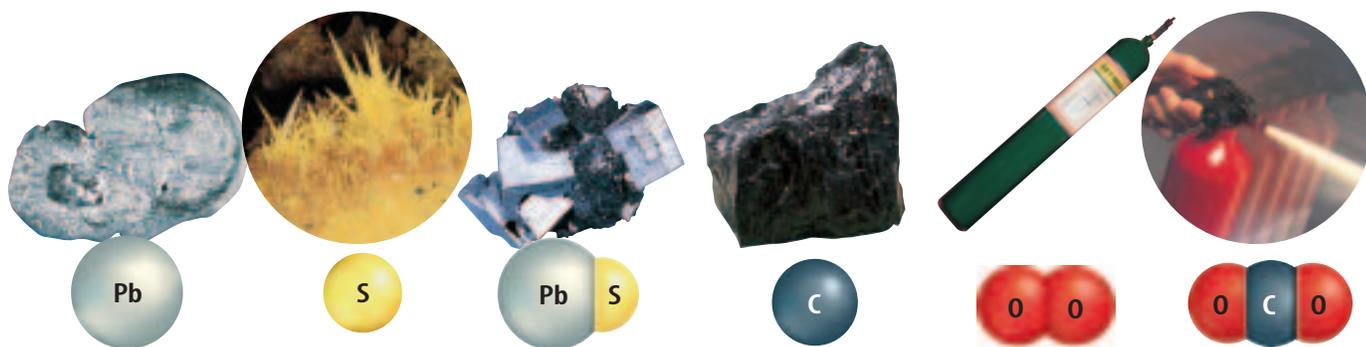
metals do not conduct heat or electricity well, and generally they are not shiny.

In the periodic table, all nonmetals except hydrogen are found at the right of the stair-step line. On the table in the inside back cover of your book, the nonmetal element blocks are colored yellow. The noble gases, Group 18, make up the only group of elements that are all nonmetals. Group 17 elements, except for astatine, are also nonmetals. Other nonmetals, found in Groups 13 through 16, will be discussed later.

**Figure 10** As a percentage of mass, humans are made up of mostly nonmetals.

### Elements in the Human Body





Lead and sulfur bond ionically to form lead sulfide,  $\text{PbS}$ , also known as galena.

Carbon and oxygen can bond covalently to form carbon dioxide,  $\text{CO}_2$ .

**Bonding in Nonmetals** The electrons in most nonmetals are strongly attracted to the nucleus of the atom. So, as a group, nonmetals are poor conductors of heat and electricity.

Most nonmetals can form ionic and covalent compounds. Examples of these two kinds of compounds are shown in **Figure 11**.

When nonmetals gain electrons from metals, the nonmetals become negative ions in ionic compounds. An example of such an ionic compound is potassium iodide,  $\text{KI}$ , which often is added to table salt.  $\text{KI}$  is formed from the nonmetal iodine and the metal potassium. When bonded with other nonmetals, atoms of nonmetals usually share electrons to form covalent compounds. An example is ammonia,  $\text{NH}_3$ , the strong, unpleasant-smelling compound you notice when you open a bottle of some household cleaners.

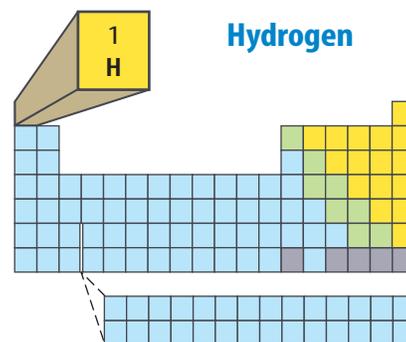
## Hydrogen

If you could count all the atoms in the universe, you would find that about 90 percent of them are hydrogen. Most hydrogen on Earth is found in the compound water. The word *hydrogen* is derived from the Greek term for “water forming.” When water is broken down into its elements, hydrogen becomes a gas made up of diatomic molecules. A **diatomic molecule** consists of two atoms of the same element in a covalent bond.

Hydrogen is highly reactive. A hydrogen atom has a single electron, which the atom shares when it combines with other nonmetals. For example, hydrogen burns in oxygen to form water,  $\text{H}_2\text{O}$ , in which hydrogen shares electrons with oxygen.

Hydrogen can gain an electron when it combines with alkali and alkaline earth metals. The compounds formed are hydrides, such as sodium hydride,  $\text{NaH}$ .

**Figure 11** Nonmetals form ionic bonds with metals and covalent bonds with other nonmetals.



**Reading Check** What is a diatomic molecule?

## The Halogens

9	F
17	Cl
35	Br
53	I
85	At

## The Halogens

Halogen lights contain small amounts of bromine or iodine. These elements, as well as fluorine, chlorine, and astatine, are called halogens and are in Group 17. They are very reactive in their elemental form, and their compounds have many uses. As shown in **Figure 12**, fluorides are added to toothpastes and to city water systems to prevent tooth decay, and chlorine compounds are added to water to disinfect it.

Because an atom of a halogen has seven electrons in its outer energy level, only one electron is needed to complete this energy level. If a halogen gains an electron from a metal, an ionic compound, called a **salt**, is formed. An example of this is NaCl. In the gaseous state, the halogens form reactive diatomic covalent molecules and can be identified by their distinctive colors. Chlorine is greenish yellow, bromine is reddish orange, and iodine is violet.

Fluorine is the most chemically active of all elements. Hydrofluoric acid, a mixture of hydrogen fluoride and water, is used to etch glass and to frost the inner surfaces of lightbulbs and is also used in the fabrication of semiconductors.



### Identifying Chlorine Compounds in Your Water

#### Procedure



1. In three labeled test tubes, obtain 2 mL of chlorine standard solution, distilled water, and drinking water.
2. Carefully add five drops of silver nitrate solution to each and stir. **WARNING:** Avoid contact with the silver nitrate solution. Silver nitrate is a corrosive liquid that can stain skin and clothes.

#### Analysis

1. Which solution will definitely show a presence of chlorine? How did this result compare to the result with distilled water?
2. Which result most resembled your drinking water?

**Figure 12** The halogens have many uses.

Chlorine compounds are used in pools to disinfect the water.



Fluoride compounds are used in toothpaste to prevent tooth decay.





**Figure 13** This ocean-salt recovery site uses evaporation to separate the halogen compounds from the water so the salts can be refined further.

**Uses of Halogens** The odor you sometimes smell near a swimming pool is chlorine. Chlorine compounds are used to disinfect water. Chlorine, the most abundant halogen, is obtained from seawater at ocean-salt recovery sites like the one in **Figure 13**. Household and industrial bleaches used to whiten flour, clothing, and paper also contain chlorine compounds.

Bromine, the only nonmetal that is a liquid at room temperature, also is extracted from compounds in seawater. Other bromine compounds are used as dyes in cosmetics.

Iodine, a shiny purple-gray solid at room temperature, is obtained from seawater. When heated, iodine changes directly to a purple vapor. The process of a solid changing directly to a vapor without forming a liquid is called **sublimation**, as shown in **Figure 14**. Iodine is essential in your diet for the production of the hormone thyroxin and to prevent goiter, an enlarging of the thyroid gland in the neck.

 **Reading Check** *What is sublimation?*

Astatine is the last member of Group 17. It is radioactive and rare, but has many properties similar to those of the other halogens. There are no known uses due to its rarity.



### **Chlorofluorocarbons**

Compounds called chlorofluorocarbons are used in refrigeration systems. If released, these compounds destroy ozone in the atmosphere. The ozone protects you from some of the harmful rays from the Sun. Find the advantages and disadvantages of these compounds. Write your answer in your Science Journal.



**Figure 14** Frozen carbon dioxide, or dry ice, is used to make inexpensive, visible gas for theatrical productions. The carbon dioxide is brought out as a solid, then it sublimates as shown here.

## Noble Gases

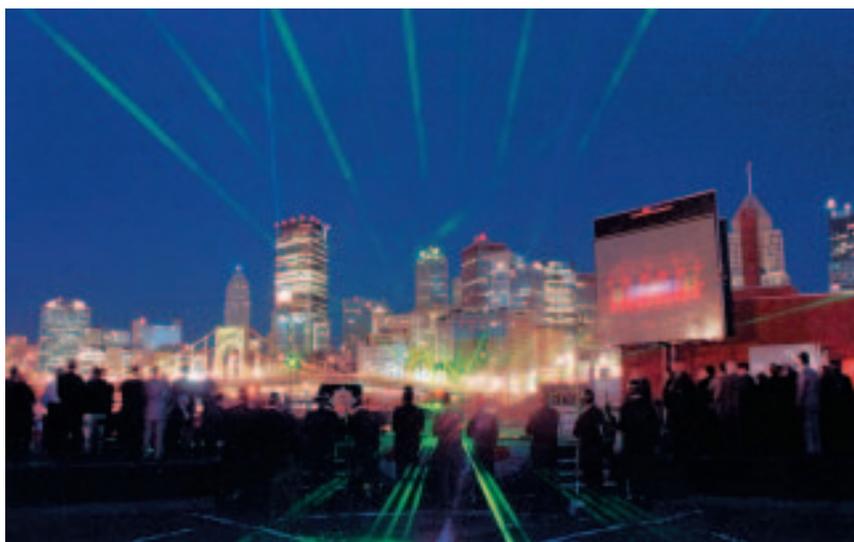
2	He
10	Ne
18	Ar
36	Kr
54	Xe
86	Rn

## The Noble Gases

The noble gases exist as isolated atoms. They are stable because their outermost energy levels are full. No naturally occurring noble gas compounds are known, but several compounds of xenon and krypton with fluorine have been created in a laboratory.

The stability of noble gases is what makes them useful. In addition, the light weight of helium makes it useful in lighter-than-air blimps and balloons. Neon and argon are used in “neon lights” for advertising. Argon and krypton are used in electric lightbulbs to produce light in lasers, as seen in **Figure 15**.

**Figure 15** Noble gases are used to produce spectacular laser light shows.



### section 2 review

#### Summary

##### Properties of Nonmetals

- Nonmetals usually are gases or brittle solids that are not shiny and do not conduct heat or electricity.

##### Hydrogen

- Hydrogen makes up 90 percent of the atoms in the universe and is highly reactive.

##### Halogens

- Halogens are in Group 17 and are highly reactive in their elemental form.

##### The Noble Gases

- Noble gases exist only as isolated atoms because their outer energy levels are full.

#### Self Check

1. **Describe** two ways in which hydrogen combines with other elements.
2. **Rank** the following nonmetals from lowest number of electrons in the outer level to highest:  $Cl$ ,  $H^+$ ,  $He$ ,  $H$ .
3. **Explain** how solid nonmetals are different from solid metals.
4. **Describe** how you can tell that a gas is a halogen.
5. **Think Critically** What is the process of a solid changing directly into a vapor? Which element undergoes this process at room temperature?

#### Applying Math

6. **Interpret data** by identifying the nonmetal with its oxidation number in these compounds:  $MgO$ ,  $NaH$ ,  $AlBr_3$ , and  $FeS$ .

## What Type is it?

Suppose you want an element for a certain use. You might be able to use a metal but not a nonmetal. In this lab, you will test several metals and nonmetals and compare their properties.

### Real-World Question

How can you use properties to distinguish metals from nonmetals?

#### Goals

- **Observe** physical properties.
- **Test** the malleability of the materials.
- **Identify** electrical conductivity in the given materials.

#### Materials

samples of C, Mg, Al, S, and Sn  
 conductivity tester  
 spatula  
 dishes for the samples  
 small hammer  
 paper towels

#### Safety Precautions



### Procedure

1. **Prepare** a table in your Science Journal like the one shown above.
2. **Observe** and record the appearance of each element sample. Include its physical state, color, and whether it is shiny or dull.
3. Remove a small sample of one of the elements. Gently tap the sample with a hammer. The sample is malleable if it flattens when tapped and brittle if it shatters. Clean the hammer between testing using a paper towel.

#### Observing Properties

Element	Appearance	Malleable or Brittle	Electrical Conductivity	Shiny or Dull
Carbon				
Magnesium	Do not write in this book.			
Aluminum				
Sulfur				
Tin				

4. Repeat step 3 for each sample.
5. Test the conductivity of each element by touching the electrodes of the conductivity tester to a sample. If the bulb lights, the element conducts electricity.

### Conclude and Apply

1. **Compare and Contrast** Locate each element you used on the periodic table. Compare your results with what you would expect from an element in that location.
2. **Explain** Locate palladium, Pd, on the periodic table. Use the results you obtained during the activity to predict some of the properties of palladium.

### Communicating Your Data

Compare your results with those of other students. For more help, refer to the **Science Skill Handbook**.

# Mixed Groups

## Reading Guide

### What You'll Learn

- **Distinguish** among metals, nonmetals, and metalloids.
- **Describe** the nature of allotropes.
- **Recognize** the significance of differences in crystal structure in carbon.
- **Understand** the importance of synthetic elements.

### Why It's Important

The elements in mixed groups affect your life every day, because they are in everything from the computer you use to the air you breathe.

### Review Vocabulary

**substance:** element or compound that cannot be broken down into simpler components

### New Vocabulary

- metalloid
- allotrope
- semiconductor
- transuranium element

### The Boron Group

5	B
13	Al
31	Ga
49	In
81	Tl

**Figure 16** Aluminum is used frequently in the construction of airplanes because it is light and strong.



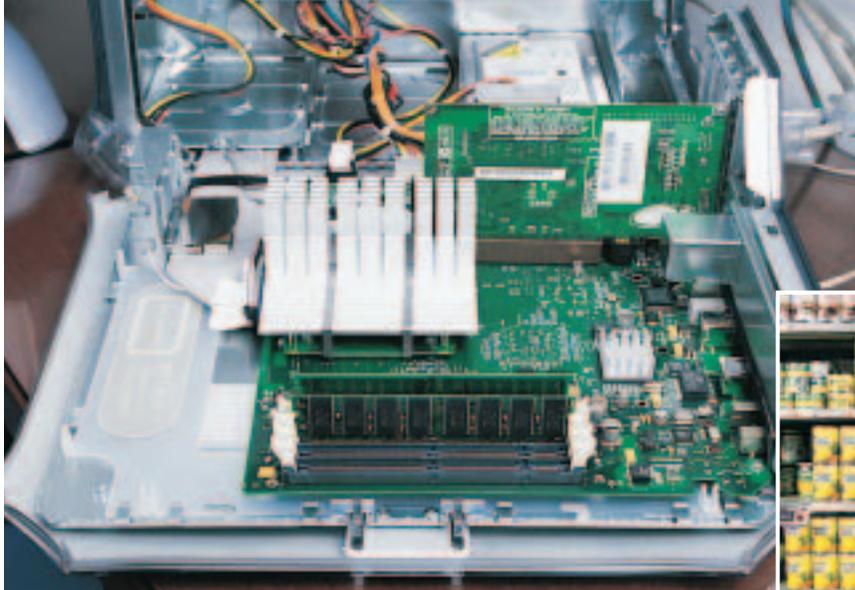
## Properties of Metalloids

Can an element be a metal and a nonmetal? In a sense, some elements called metalloids are. Metalloids share unusual characteristics. **Metalloids** can form ionic and covalent bonds with other elements and can have metallic and nonmetallic properties. Some metalloids can conduct electricity better than most nonmetals, but not as well as some metals, giving them the name semiconductor. With the exception of aluminum, the metalloids are the elements in the periodic table that are located along the stair-step line. The mixed groups—13, 14, 15, 16, and 17—contain metals, nonmetals, and metalloids.

## The Boron Group

Boron, a metalloid, is the first element in Group 13. If you look around your home, you might find two compounds of boron. One of these is borax, which is used in some laundry products to soften water. The other is boric acid, a mild antiseptic. Boron also is used as a grinding material and as boranes, which are compounds used for jet and rocket fuel.

Aluminum, a metal in Group 13, is the most abundant metal in Earth's crust. It is used in soft-drink cans, foil wrap, cooking pans, and as siding. Aluminum is strong and light and is used in the construction of airplanes such as the one in **Figure 16**.



Silicon is used to make the chips that allow this computer to run.

**Figure 17** Elements in Group 14 have many uses.



These tin cans are made of steel with a tin coating.

## The Carbon Group

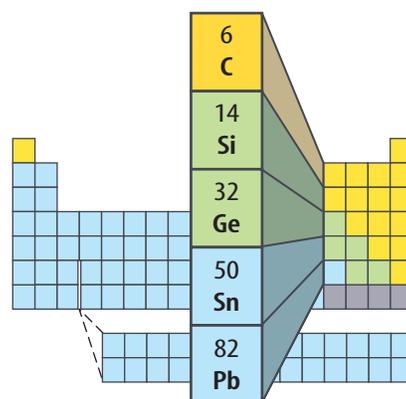
Each element in Group 14, the carbon family, has four electrons in its outer energy level, but this is where much of the similarity ends. Carbon is a nonmetal, silicon and germanium are metalloids, and tin and lead are metals. Carbon occurs as an element in coal and as a compound in oil, natural gas, and foods. Carbon in these materials can combine with oxygen to produce carbon dioxide,  $\text{CO}_2$ . In the presence of sunlight, plants utilize  $\text{CO}_2$  to make food. Carbon compounds, many of which are essential to life, can be found in you and all around you. All organic compounds contain carbon, but not all carbon compounds are organic.

Silicon is second only to oxygen in abundance in Earth's crust. Most silicon is found in sand,  $\text{SiO}_2$ , and almost all rocks and soil. The crystal structure of silicon dioxide is similar to the structure of diamond. Silicon occurs as two allotropes. **Allotropes**, which are different forms of the same element, have different molecular structures. One allotrope of silicon is a hard, gray substance, and the other is a brown powder.

### Reading Check *What are allotropes?*

Silicon is the main component in **semiconductors**—elements that conduct an electric current under certain conditions. Many of the electronics that you use every day, like the computer in **Figure 17**, need semiconductors to run. Germanium, the other metalloid in the carbon group, is used along with silicon in making semiconductors. Tin is used to coat other metals to prevent corrosion, like the tin cans in **Figure 17**. Tin also is combined with other metals to produce bronze and pewter. Lead was used widely in paint at one time, but because it is toxic, lead no longer is used.

### The Carbon Group



**Topic:**

**Buckminsterfullerene**

Visit [gpscience.com](http://gpscience.com) for Web links to information about this compound.

**Activity** Research this compound and describe some of the qualities that make it unique.

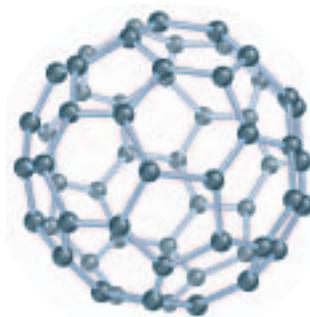
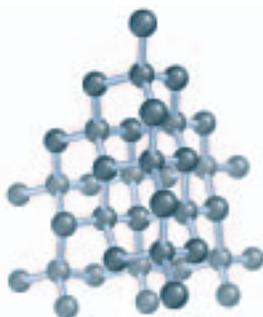
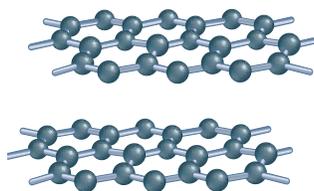
**Figure 18** Three allotropes of carbon are depicted here. **Identify** the geometric shapes that make up each allotrope.

**Allotropes of Carbon** What do the diamond in a diamond ring and the graphite in your pencil have in common? They are both carbon. Diamond, graphite, and buckminsterfullerene, shown in **Figure 18**, are allotropes of an element.

A diamond is clear and extremely hard. In a diamond, each carbon atom is bonded to four other carbon atoms at the vertices, or corner points, of a tetrahedron. In turn, many tetrahedrons join together to form a giant molecule in which the atoms are held tightly in a strong crystalline structure. This structure accounts for the hardness of diamond.

Graphite is a black powder that consists of hexagonal layers of carbon atoms. In the hexagons, each carbon atom is bonded to three other carbon atoms. The fourth electron of each atom is bonded weakly to the layer next to it. This structure allows the layers to slide easily past one another, making graphite an excellent lubricant. In the mid-1980s, a new allotrope of carbon called buckminsterfullerene was discovered. This soccer-ball-shaped molecule, informally called a buckyball, was named after the architect-engineer R. Buckminster Fuller, who designed structures with similar shapes.

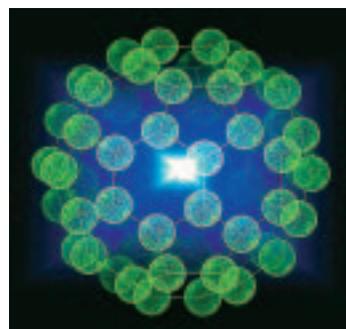
In 1991, scientists were able to use the buckyballs to synthesize extremely thin, graphitelike tubes. These tubes, called nanotubes, are about 1 billionth of a meter in diameter. That means you could stack tens of thousands of nanotubes just to get the thickness of one piece of paper. Nanotubes might be used someday to make computers that are smaller and faster and to make strong building materials.



Graphite



Diamond



Buckminsterfullerene

## The Nitrogen Group

The nitrogen family makes up Group 15. Each element has five electrons in its outer energy level. These elements tend to share electrons and to form covalent compounds with other elements. Nitrogen often is used to make nitrates (which are compounds that contain the nitrate ion,  $\text{NO}_3^-$ ) and ammonia,  $\text{NH}_3$ , both of which are used in fertilizers. Nitrogen is the fourth most abundant element in your body. Each breath you take is about 80 percent gaseous nitrogen in the form of diatomic molecules,  $\text{N}_2$ . Yet you and other animals and plants can't use nitrogen in its diatomic form. The nitrogen must be combined into compounds, such as amino acids.

The Nitrogen Group

7 N
15 P
33 As
51 Sb
83 Bi

## CIRCLE GRAPHS

**Use Circle Graphs** Oxygen, the predominant element in Earth's crust, makes up approximately 46.6 percent of the crust. If you were to show this information on a circle graph, how many degrees would represent oxygen?

- This is what you know:**

% oxygen = 46.6%  
total degrees in a circle =  $360^\circ$
- This is what you need to find:** degrees of a circle that represent 46.6%
- Use this formula:**

$$\frac{\% \text{ oxygen}}{\% \text{ total}} = \frac{\text{degrees oxygen}}{\text{degrees total}}$$
- Rearrange the equation and substitute:**

$$\text{degrees oxygen} = \frac{\% \text{ oxygen} \times \text{degrees total}}{\% \text{ total}}$$

$$\text{degrees oxygen} = \frac{46.6\% \times 360^\circ}{100\%}$$

$$\text{degrees oxygen} = 167.76^\circ, \text{ rounded to } 168^\circ$$
- Determine the units:**

$$\text{degrees} = \frac{\text{percent}}{\text{percent}} \times \text{degrees}$$

**Answer:** In a circle graph, the number of degrees 46.6% of oxygen would represent is  $168^\circ$ .

ScienceOnline

For more practice problems, go to page 834, and visit [gpscience.com/extra\\_problems](http://gpscience.com/extra_problems).

### Practice Problems

- The percentages of remaining elements in Earth's crust are: silicon, 27.7; aluminum, 8.1; iron, 5.0; calcium, 3.6; sodium, 2.8; potassium, 2.6; magnesium, 2.1; and other elements, 1.5. Find the number of degrees in a circle each percentage would represent.
- Challenge** Create a circle graph of the elements in Earth's crust.

**Uses of the Nitrogen Group** Phosphorus is a nonmetal that has three allotropes. Phosphorous compounds can be used for many things from water softeners to fertilizers, match heads, and even in fine china. Antimony is a metalloid, and bismuth is a metal. Both elements are used with other metals to lower their melting points. Because of this property, the metal in automatic fire-sprinkler heads contains bismuth.

 **Reading Check** Why is bismuth used in fire-sprinkler heads?

**The Oxygen Group**

8	O
16	S
34	Se
52	Te
84	Po

## The Oxygen Group

Group 16 on the periodic table is the oxygen group. You can live for only a short time without oxygen, which makes up about 21 percent of air. Oxygen, a nonmetal, exists in the air as diatomic molecules,  $O_2$ . During electrical storms, some oxygen molecules,  $O_2$ , change into ozone molecules,  $O_3$ . Oxygen also has several uses in compound form, including the one shown at left in **Figure 19**.

Nearly all living things on Earth need  $O_2$  for respiration. Living things also depend on a layer of  $O_3$  around Earth for protection from some of the Sun's radiation.

The second element in the oxygen group is sulfur. Sulfur is a nonmetal that exists in several allotropic forms. It exists as different-shaped crystals and as a noncrystalline solid. Sulfur combines with metals to form sulfides of such distinctive colors that they are used as pigments in paints.

The nonmetal selenium and two metalloids—tellurium and polonium—are the other Group 16 elements. Selenium is the most common of these three. This element is one of several that you need in trace amounts in your diet. Many multivitamins contain this nonmetal as an ingredient. But selenium is toxic if too much of it gets into your system. Selenium also is used in photocopiers like the one in **Figure 19**.

**Figure 19** Group 16 compounds have a variety of uses.

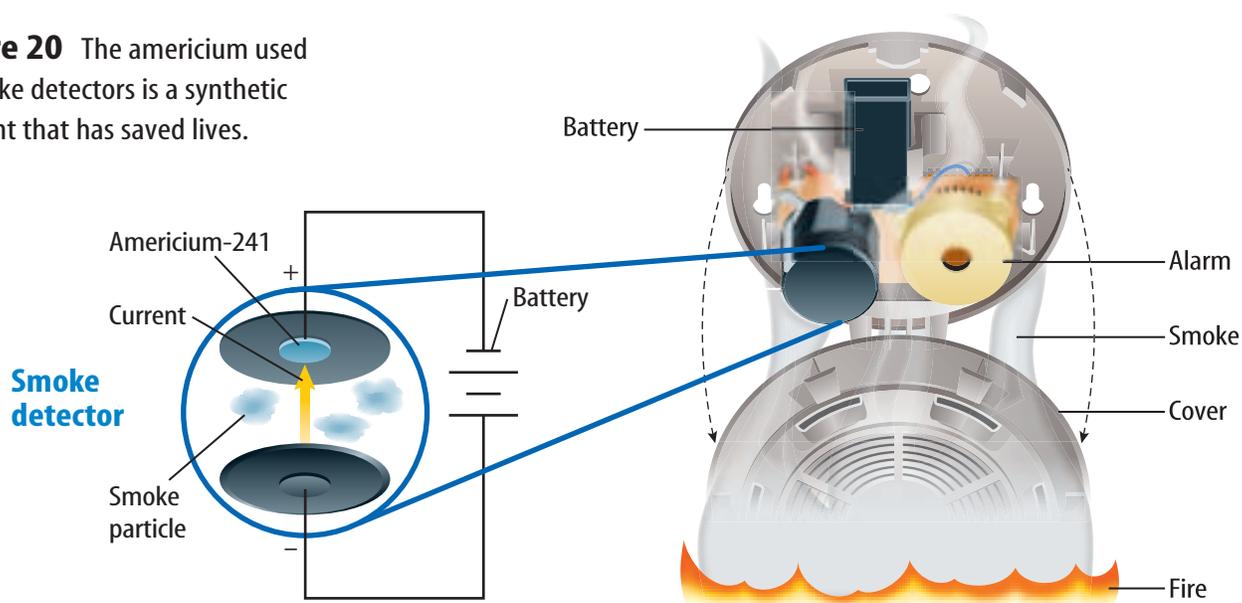
Solutions of hydrogen peroxide,  $H_2O_2$ , are used to clean minor wounds.



Selenium is used in xerography to make photocopiers.



**Figure 20** The americium used in smoke detectors is a synthetic element that has saved lives.

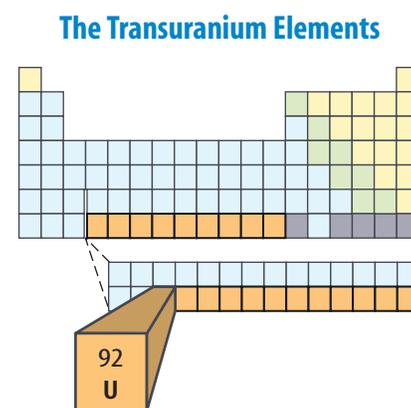


## Synthetic Elements

If you made something that always fell apart, you might think you were not successful. However, nuclear scientists are learning to do just that. By smashing existing elements with particles accelerated in a heavy ion accelerator, they have been successful in creating elements not typically found on Earth. Except for technetium 43 and promethium 61, each synthetic element has more than 92 protons.

Bombarding uranium with neutrons can make neptunium, element 93. Half of the synthesized atoms of neptunium disintegrate in about two days. This may not sound useful, but when neptunium atoms disintegrate, they form plutonium. This highly toxic element has been produced in control rods of nuclear reactors and is used in bombs. Plutonium also can be changed to americium, element 95. This element is used in home smoke detectors such as the one in **Figure 20**. In smoke detectors, a small amount of americium emits charged particles. An electric plate in the smoke detector attracts some of these charged particles. When a lot of smoke is in the air, it interferes with the electric current, which immediately sets off the alarm in the smoke detector.

**Transuranium Elements** Elements having more than 92 protons, the atomic number of uranium, are called **transuranium elements**. These elements do not belong exclusively to the metal, nonmetal, or metalloid group. These are the elements toward the bottom of the periodic table. Some are in the actinide series, and some are on the bottom row of the main periodic table. All of the transuranium elements are synthetic and unstable, and many of them disintegrate quickly.



**Figure 21**

**S**ome elements, such as gold, silver, tin, carbon, copper, and lead, have been known and used for thousands of years. Most others were discovered much more recently. Even at the time of the American Revolution in 1776, only 24 elements were known. The timeline below shows the dates of discovery of selected elements, ancient and modern.

**Au - GOLD**  
Prized since the Stone Age



**Ag - SILVER**  
Found in tombs dating to 4000 B.C.



**A.D. 1774**  
**Cl - CHLORINE**  
Pale green, toxic gas

**A.D. 1700**

**1817**  
**Cd - CADMIUM**  
Used to color yellow and red paint



**A.D. 1800**

**1825**  
**Al - ALUMINUM**  
Most abundant element in Earth's crust



**1868**  
**He - HELIUM**  
Lighter-than-air gas used to fill balloons



**1898**  
**Ne - NEON**  
Glowes when electricity flows through it

**1898**  
**Po - POLONIUM and Ra - RADIUM**  
Radioactive elements discovered by Marie and Pierre Curie



**A.D. 1900**

**1900**  
**Rn - RADON**  
Radioactive gas that may cause cancer



**1952**  
**Es - EINSTEINIUM**  
Radioactive gas named after Albert Einstein

**1981–1996**  
**Bh - BOHRIUM, Ds - DARMSTADTIUM**  
Elements isolated by a heavy ion accelerator such as the UNILAC, below



**A.D. 2000**

**Why make elements?** Figure 21 shows when some of the elements were discovered throughout history. The processes used to discover these elements have varied widely. The most recently discovered elements are synthetic. By studying how the synthesized elements form and disintegrate, you can gain an understanding of the forces holding the nucleus together. When these atoms disintegrate, they are said to be radioactive.

Radioactive elements can be useful. For example, technetium's radioactivity makes it ideal for many medical applications. At this time, many of the synthetic elements last only small fractions of seconds after they are constructed and can be made only in small amounts. However, the value of applications that might be discovered easily could offset their costs.

**Seeking Stability** Element 114, discovered in 1999, appears to be much more stable than most synthetic elements of its size. It lasted for 30 s before it broke apart. This may not seem like long, but it lasts 100,000 times longer than an atom of element 112. Perhaps this special combination of 114 protons and 175 neutrons allows the nucleus to hold together despite the enormous repulsion between the protons.

In the 1960s, scientists theorized that stable synthetic elements exist. Finding one might help scientists understand how the forces inside the atom work. Perhaps someday you'll read about some of the everyday uses this discovery has brought.



**Topic: Synthetic Elements**

Visit [gpscience.com](http://gpscience.com) for Web links to information and an online update about synthetic elements.

**Activity** Find what some of the latest developments are in synthetic elements. Collect information on the one that interests you most and explain what you think is the most intriguing property of this element.

section **3** review

**Summary**

**Properties of Metalloids**

- Metalloids are elements that can form ionic and covalent bonds with other elements and can have metallic and nonmetallic properties.

**Carbon Group**

- The elements in Group 14 have four electrons in their outer energy levels.

**Nitrogen Group**

- The elements in Group 15 tend to share electrons and form covalent bonds.

**Synthetic Elements**

- Synthetic elements are elements that are not typically found on Earth.
- By synthesizing elements, scientists may understand how the forces inside the atom work.

**Self Check**

1. **Explain** why Groups 14 and 15 are better representatives of mixed groups than Groups 13 and Group 16.
2. **Describe** how allotropes of silicon differ in appearance.
3. **Explain** how an element is classified as a transuranium element.
4. **Describe** what type of structure a diamond has. How would you build a model of this?
5. **Think Critically** Graphite and a diamond are both made of the element carbon. Why is graphite a lubricant and diamond the hardest gem known?

**Applying Math**

6. **Calculate** Element 114 lasted 30s before falling apart. It lasted 100,000 times longer than element 112. How long did element 112 last?

# Slippery Carbon

## Goals

- **Make a model** that will demonstrate the molecular structure of graphite.
- **Compare and contrast** the strength of the different bonds in graphite.
- **Infer** the relationship between bonding and physical properties.

## Possible Materials

thin spaghetti  
small gumdrops  
thin polystyrene sheets  
flat cardboard  
scissors

## Safety Precautions



Use care when working with scissors and uncooked spaghetti.

## Real-World Question

Often, a lubricant is needed when two metals touch each other. For example, a sticky lock sometimes works better with the addition of a small amount of graphite. What gives this allotrope of carbon the slippery property of a lubricant? Why do certain arrangements of atoms in a material cause the material to feel slippery?



## Form a Hypothesis

Based on your understanding of how carbon atoms bond, form a hypothesis about the relationship of graphite's molecular structure to its physical properties.



## ▶ Test Your Hypothesis

### Make A Plan

1. As a group, agree upon a logical hypothesis statement.
2. As a group, sequence and list the steps you need to take to test your hypothesis. Be specific, describing exactly what you will do at each step to make a model of the types of bonding present in graphite.
3. Remember from **Figure 18** that graphite consists of rings of six carbons bonded in a flat hexagon. These rings are bonded to each other. In addition, the flat rings in one layer are weakly attached to other flat layers.
4. List possible materials you plan to use.
5. Read over the experiment to make sure that all steps are in logical order.
6. Will your model be constructed with materials that show weak and strong attractions?



### Follow Your Plan

1. Make sure your teacher approves your plan before you start.
2. Have you selected materials to use in your model that demonstrate weak and strong attractions? Carry out the experiment as planned.
3. Once your model has been constructed, list any observations that you make and include a sketch in your Science Journal.

## ▶ Analyze Your Data

1. **Compare** your model with designs and results of other groups.
2. How does your model illustrate two types of attractions found in the graphite structure?
3. How does the bonding of graphite that you explored in the lab explain graphite's lubricating properties? Write your answer in your Science Journal.

## ▶ Conclude and Apply

1. **Describe** the results you obtained from your experiment. Did the results support your hypothesis?
2. **Describe** why graphite makes a good lubricant.
3. **Explain** what kinds of bonds you think a diamond has.

### Communicating Your Data

**Explain** to a friend why graphite makes a good lubricant and how the two types of bonds make a difference.

# The GAS that glows



A neon sign in the making. Workers carefully twist the light tubes into different shapes.

## Neon has made the world a more colorful place

“Nothing in the world gave a glow such as we had seen.” With these words, two British chemists recorded their discovery of neon in 1898. Neon is a noble gas that emits a spectacular red-orange glow when an electric current is passed through it. It also makes up a tiny portion of the air we breathe.

But neon’s presence remained undetected until a technology called spectroscopy allowed the chemists to view that “blaze of crimson light” in their lab—a light that soon lit up the world in fantastical ways.

### Signs of Change

Pink flamingos, cowboys on bucking broncos, deep-sea fish afloat in the air—neon signs make any building or billboard come alive in a kaleidoscope of colors. Barely a decade after neon was discovered, a chemist developed the

first neon sign. The chemist took the air out of a glass tube and replaced it with neon gas. When the gas was jolted with electricity, it glowed like a fiery sunset. The chemist sold the light to a barber, who hung it over his storefront. By the 1920s, neon lights were used to advertise everything from cars to diners.

When a touch of mercury is added to neon, it glows a tropical blue. The other colors seen in “neon lights” actually come from other noble gases. Krypton, for instance, glows yellow. Xenon shines like a bluish-white star.

### Other Uses for Neon

The vivid light emitted by neon can penetrate the densest fog, making it a natural choice for airplane beacons. Neon also is used to manufacture lasers and television tubes. Neon definitely helps light up our lives!

**Identify** As a group, brainstorm a new product or business, then design a neon sign to advertise your idea. See if other groups can correctly guess what your sign represents.

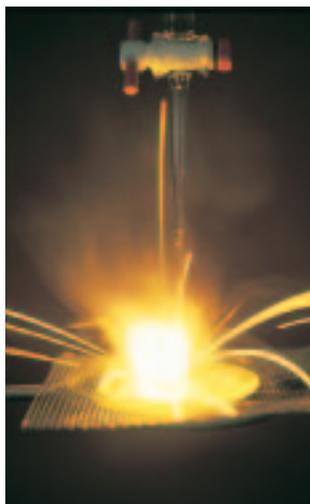
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For more information, visit  
[gpscience.com/time](http://gpscience.com/time)

## Reviewing Main Ideas

**Section 1 Metals**

1. A typical metal is a hard, shiny solid that, due to metallic bonding, is malleable, ductile, and a good conductor.
2. Groups 1 and 2 are the alkali and alkaline earth metals, which have some similar and some contrasting properties.
3. The iron triad, the coinage metals, and the elements in Group 12 are examples of transition elements.
4. The lanthanides and actinides have atomic numbers 58 through 71 and 90 through 103, respectively.

**Section 2 Nonmetals**

1. Nonmetals can be brittle and dull. They are also poor conductors of electricity.
2. As a typical nonmetal, hydrogen is a gas that forms compounds by sharing electrons with other nonmetals and by forming ionic bonds with metals.
3. All the halogens, Group 17, have seven outer electrons and form covalent and ionic compounds, but each halogen has some properties that are unlike each of the others in the group.

4. The noble gases, Group 18, are elements whose properties and uses are related to their chemical stability.

**Section 3 Mixed Groups**

1. Groups 13 through 16 include metals, nonmetals, and metalloids.



2. Allotropes are forms of the same element having different molecular structures.
3. The properties of three forms of carbon—graphite, diamond, and buckminsterfullerene—depend upon the differences in their crystal structures.
4. All synthetic elements are short-lived. Except for technetium-43 and promethium-61, they have atomic numbers greater than 92 and are referred to as transuranium elements. These elements are found toward the bottom of the periodic table.

**FOLDABLES™** Use the Foldable that you made at the beginning of this chapter to help you review elements and their properties.

**Using Vocabulary**

- |                         |                           |
|-------------------------|---------------------------|
| allotrope p.585         | radioactive element p.572 |
| diatomic molecule p.579 | salt p.580                |
| ductile p.570           | semiconductor p.585       |
| malleable p.570         | sublimation p.581         |
| metal p.570             | transition element p.574  |
| metallic bonding p.571  | transuranium element      |
| metalloid p.584         | p.589                     |
| nonmetal p.578          |                           |

Complete each sentence with the correct vocabulary word(s).

- The \_\_\_\_\_ are located to the left of the stair-step line on the periodic table.
- Different structural forms of the same element are called \_\_\_\_\_.
- Positively charged ions are surrounded by freely moving electrons in \_\_\_\_\_.
- A(n) \_\_\_\_\_ is a molecule comprised of two atoms.
- The \_\_\_\_\_ are in Groups 3 through 12 on the periodic table.

**Checking Concepts**

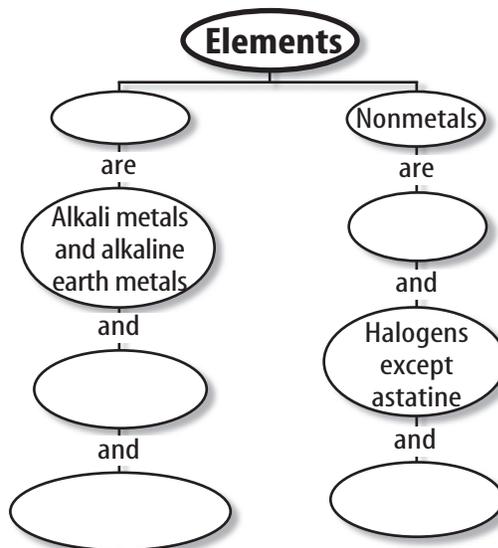
Choose the word or phrase that best answers the question.

- When magnesium and fluorine react, what type of bond is formed?  
 A) metallic                      C) covalent  
 B) ionic                              D) diatomic
- What type of bond is found in a piece of pure gold?  
 A) metallic                      C) covalent  
 B) ionic                              D) diatomic
- Because electrons move freely in metals, which property describes metals?  
 A) brittle                              C) dull  
 B) hard                                  D) conductors

- Which set of elements makes up the most reactive group of all metals?  
 A) iron triad  
 B) coinage metals  
 C) alkali metals  
 D) alkaline earth metals
- Which element is the most reactive of all nonmetals?  
 A) fluorine                      C) hydrogen  
 B) uranium                      D) oxygen
- Which element is always found in nature combined with other elements?  
 A) copper                              C) magnesium  
 B) gold                                  D) silver
- Which elements are least reactive?  
 A) metals                              C) noble gases  
 B) halogens                          D) actinides
- What element is formed when neptunium disintegrates?  
 A) ytterbium                      C) americium  
 B) promethium                      D) plutonium

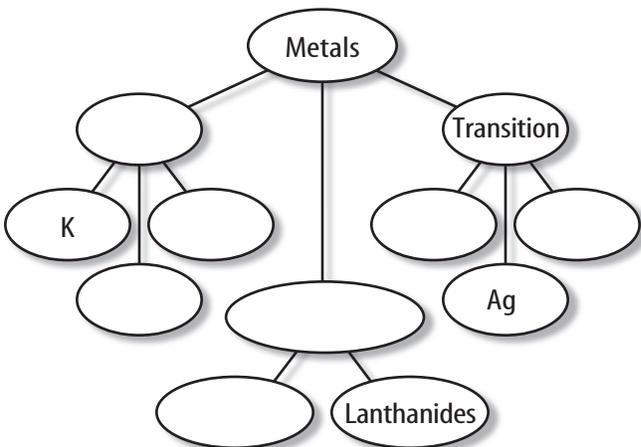
**Interpreting Graphics**

- Copy and complete the concept map using the following: *transition elements, hydrogen, metals, inner transition metals, noble gases.*



## Thinking Critically

15. **Concept Map** Copy and complete the concept map using the following: *Na, Fe, Actinides, Hg, Ba, Alkali, and Inner transition.*



16. **Make and Use Tables** Use the periodic table to classify each of the following as a lanthanide or actinide: californium, europium, cerium, nobelium, terbium, and uranium.
17. **Explain** why mercury is rarely used in thermometers that take body temperatures.
18. **Explain** The density of hydrogen is lower than air and can be used to fill balloons. Why is helium used instead of hydrogen?
19. **Explain** Copper is a good choice for use in electrical wiring. What type of elements would not work well for this purpose? Why?
20. **Explain** why various silver compounds are used in photography.
21. **Describe** Like selenium, chromium is poisonous but is needed in trace amounts in your diet. How would you apply this information in order to use vitamin and mineral pills safely?

22. **Compare and Contrast** Explain why aluminum is a metal and carbon is not.
23. **Explain** What is metallic bonding? Explain how this affects conductivity.
24. **Describe** the geometric shapes of the carbon allotropes.

## Applying Math

Use the following table to answer question 25.

Gas Analysis

Gas	Volume %
CO	6.8
H <sub>2</sub>	47.3
CH <sub>4</sub>	33.9
CO <sub>2</sub>	2.2
N <sub>2</sub>	6
Other	3.8

25. **Interpret Data** When coke-oven gas is burned in an industrial process, several gases are produced in the reaction. If 385 grams of coke-oven gas are consumed in this reaction, how many grams of CH<sub>4</sub> (methane) are produced?
26. **Use Percentage** Chloroform has the chemical formula, CHCl<sub>3</sub>, and a molecular weight of 119.39 g. What is the percentage of Cl (chlorine) present in this compound?
27. **Use Numbers** Calculate the molecular weight of gallium bromide (GaBr<sub>3</sub>).

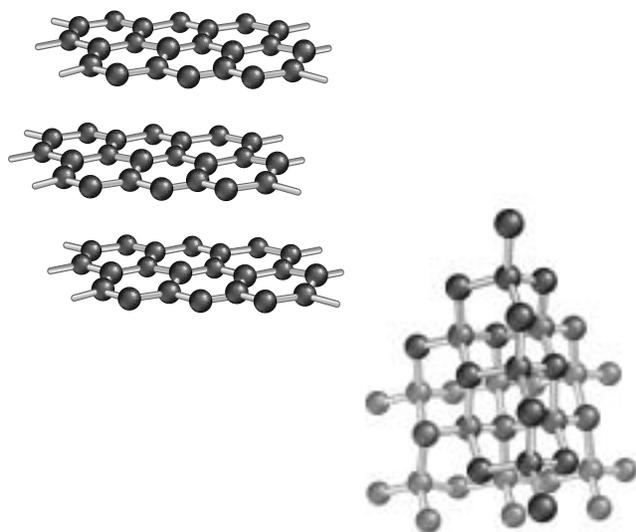


## Part 2 Short Response/Grid In

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

- Define the general properties of metals which make them useful and versatile materials.
- Use the electron configuration of the elements sodium and potassium to explain why these elements do not occur in nature in elemental form.

Use the illustrations below to answer questions 11 and 12.



- Define the term *allotrope*, and identify these allotropes of carbon.
- Compare the structures of these carbon allotropes and relate the structures to the properties of these materials.
- Describe some unique properties of hydrogen.
- Identify and describe the uses of some of the halogens obtained from seawater.
- Compare the two types of bonds which nonmetals can form.

## Part 3 Open Ended

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

- Recent Federal Drug Administration statements advise limiting consumption of tuna and salmon. Which transitional element is the source of the problem? Explain why this element poses a potential risk.
- Use the properties of metallic bonds to explain why metal hammered into sheets does not break, as well as why metals conduct electricity.
- Based on its electron configuration and position in the periodic table, explain why fluorine is the most chemically active of all elements.

Use the illustration below to answer question 19.



- Identify the gas which enables this blimp to remain suspended in the atmosphere. Why would it be dangerous to use hydrogen for this purpose?
- Explain the importance of organisms that convert nitrogen from its diatomic form into other compounds.