Chapter 4

# Elements and the Periodic Table

## CALIFORNIA Standards Preview

**S 8.3 Each of the more than 100 elements of matter has distinct properties and a distinct atomic structure. All forms of matter are composed of one or more of the elements. As a basis for understanding this concept:**

a. Students know the structure of the atom and know it is composed of protons, neutrons, and electrons.

**S 8.7 The organization of the periodic table is based on the properties of the elements and reflects the structure of atoms. As a basis for understanding this concept:**

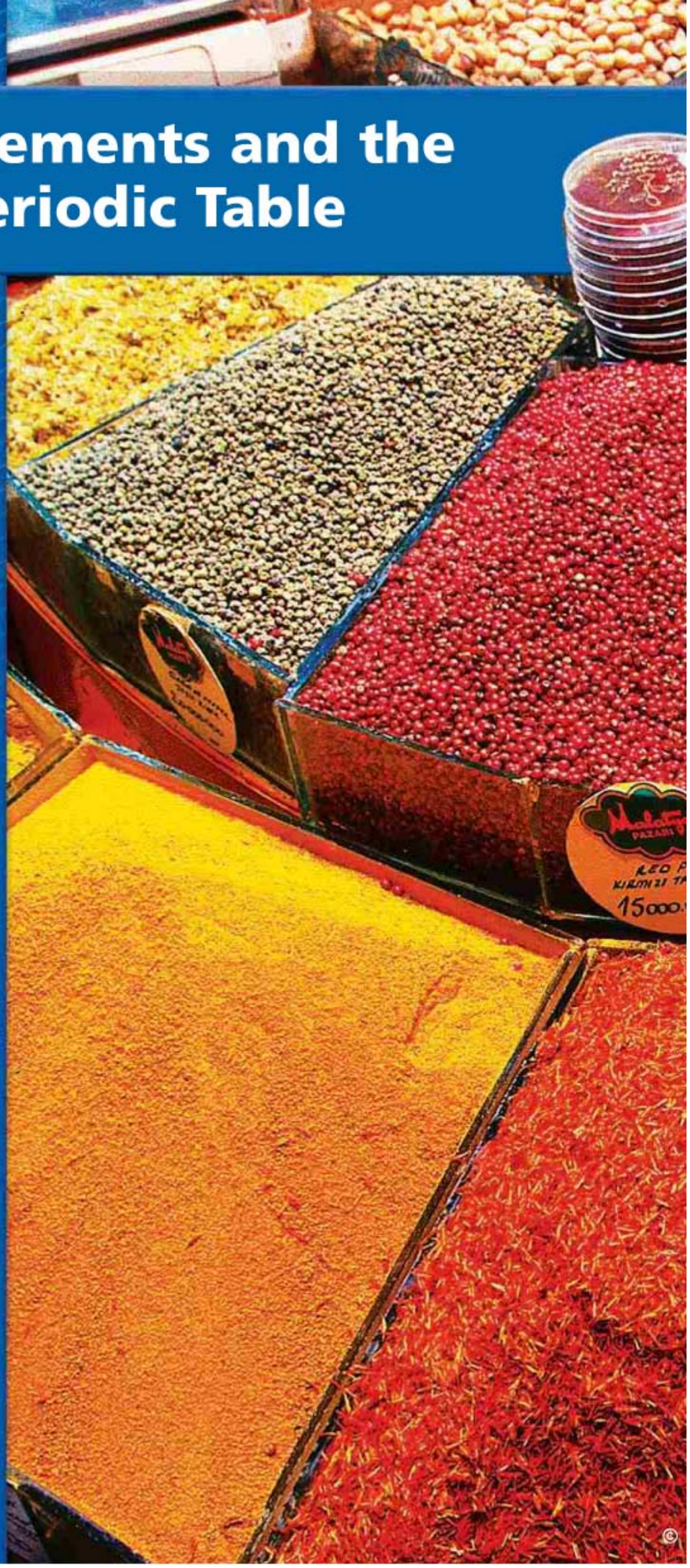
a. Students know how to identify regions corresponding to metals, nonmetals, and inert gases.

b. Students know each element has a specific number of protons in the nucleus (the atomic number) and each isotope of the element has a different but specific number of neutrons in the nucleus.

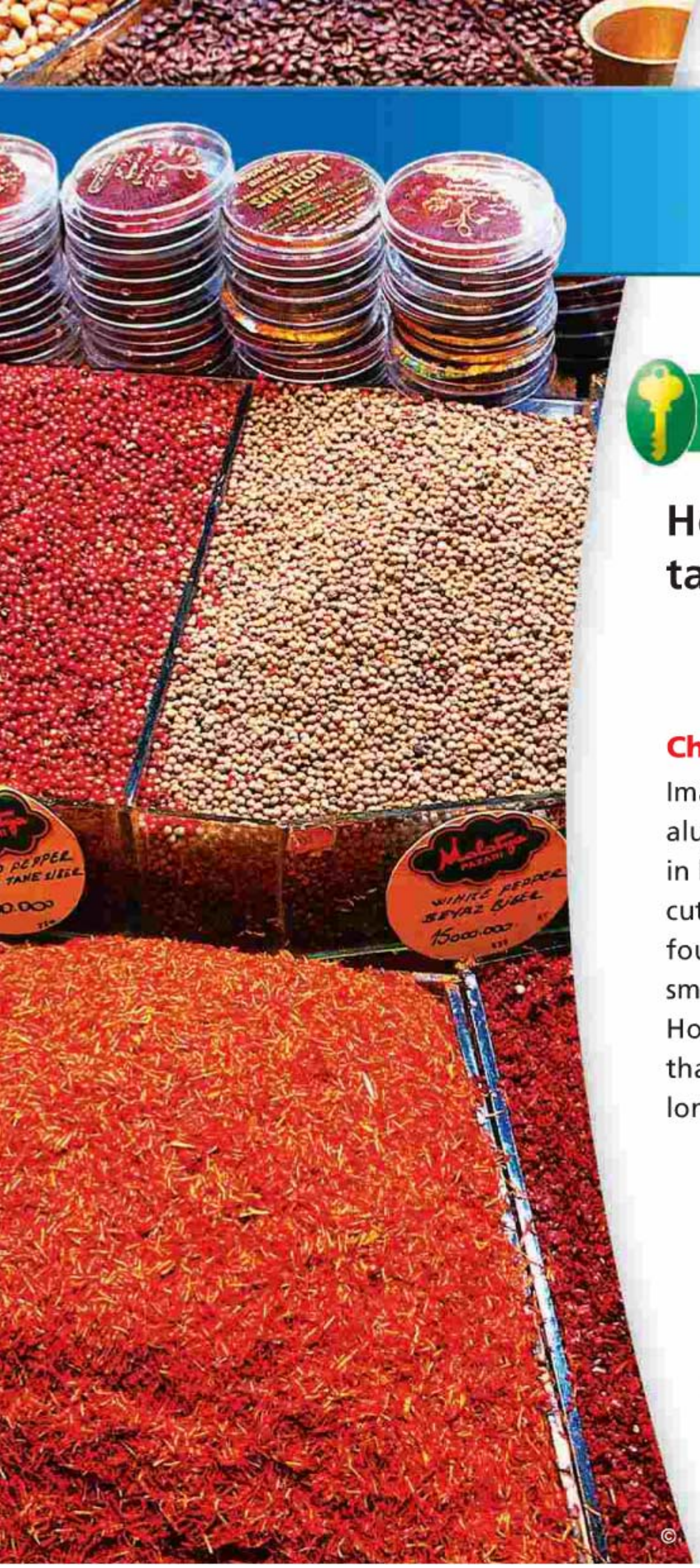
c. Students know substances can be classified by their properties, including their melting temperature, density, hardness, and thermal and electrical conductivity.

**S 8.9 Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other three strands, students should develop their own questions and perform investigations. Students will:**

c. Distinguish between variable and controlled parameters on a test.



Like the spices in this bazaar, elements can be organized by their properties.



**Video Preview**

**Discovery Channel School**

*Elements and the Periodic Table*

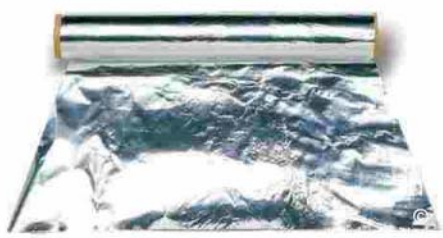
Focus on the **BIG Idea**

S 8.7

## How is the periodic table organized?

### Check What You Know

Imagine you have a piece of aluminum foil, and you cut it in half. If each of these pieces is cut in half a second, third, and fourth time, the pieces become smaller but are still aluminum. How small must a piece be so that at the next cut it will no longer be aluminum?



# Build Science Vocabulary

**The images shown here represent some of the key terms in this chapter. You can use this vocabulary skill to help you understand the meaning of some key terms in this chapter.**

Vocabulary Skill

## Greek Word Origins

Many science words come to English from ancient Greek. For example, the word *autograph* comes from the Greek word *auto* meaning "self" and *graph* meaning "written." Therefore, an *autograph* is one's name written in one's own handwriting.

| auto | + | graph | = | autograph |
|---|---|---|---|---|
| self | | written | | written in one's own handwriting |

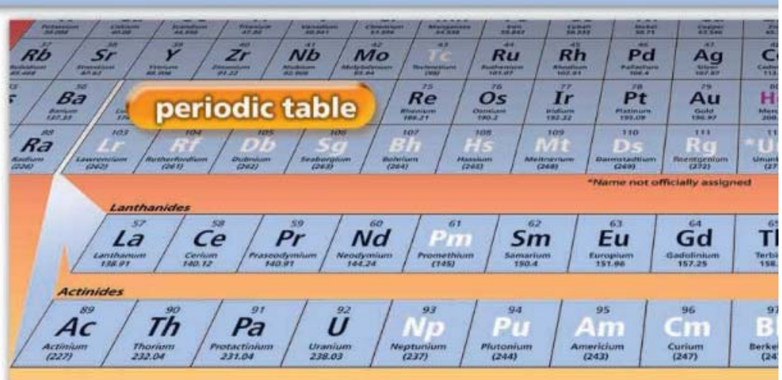
Learn these Greek origins to help you remember the key terms.

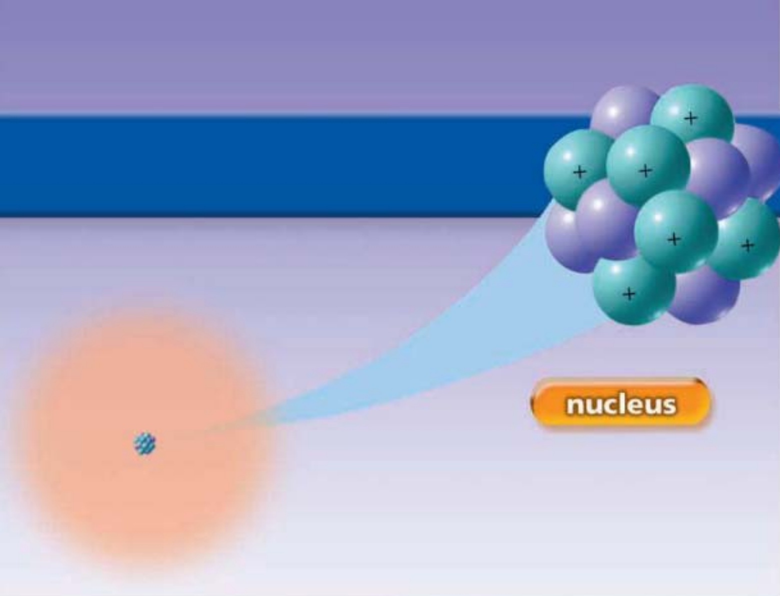
| Greek Origin | Meaning | Key Words |
|---|---|---|
| *alpha* | First letter of the Greek alphabet | Alpha particle |
| *atomos* | Cannot be cut; indivisible | Atom, atomic number, atomic mass |
| *beta* | Second letter of the Greek alphabet | Beta particle |
| *di* | Two, double | Diatomic molecule |
| *gamma* | Third letter of the Greek alphabet | Gamma radiation |
| *hals* | Salt, relating to salt | Halogen |

## Apply It!

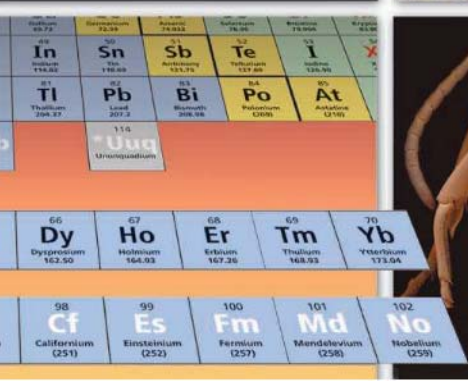
Review the Greek origins and meanings in the chart. What is the meaning of the prefix *di-* in *diatomic*? Predict the meaning of *diatomic molecule*. Revise your definition as needed.

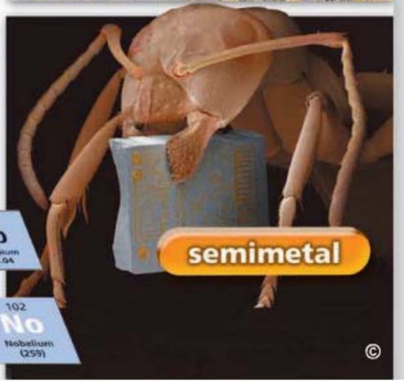
Look for words with these Greek origins as you read the chapter.






# Chapter 4 Vocabulary

## Section 1 (page 124)

atom
electron
nucleus
proton
energy level
neutron
atomic number
isotope
mass number

## Section 2 (page 131)

atomic mass
periodic table
period
group
chemical symbol

## Section 3 (page 138)

metal
malleable
ductile
thermal conductivity
electrical conductivity
reactivity
corrosion
alkali metal
alkaline earth metal
transition metal
particle accelerator

## Section 4 (page 148)

nonmetal
diatomic molecule
halogen
inert gas
semimetal
semiconductor

## Section 5 (page 158)

radioactive decay
radioactivity
alpha particle
beta particle
gamma radiation
tracer

Interactive Textbook

**Build Science Vocabulary *Online***

**Visit:** PHSchool.com
**Web Code:** cxj-1040

# How to Read Science

## Reading Skill

### Preview Visuals

Before you read the science text, it's important to take the time to preview the visuals. Visuals are photographs, graphs, tables, diagrams, and illustrations. Visuals contain important information that helps you understand the content. Follow these steps to preview visuals.

- Read the title.
- Read the labels and captions.
- Ask yourself questions about the visuals to give yourself a purpose for reading.

Preview the periodic table in Figure 14 of this chapter. Use a graphic organizer to ask questions about the table.

**Figure 14: Periodic Table of the Elements**

| |
|---|
| **Q.** Why are most of the squares in the table tinted blue? |
| **A.** |
| **Q.** Why do the symbols for some elements appear in red? |
| **A.** |
| **Q.** Why are two rows of elements listed below the main table? |
| **A.** |

### Apply It!

Copy the graphic organizer into your notebook. Answer the questions as you learn more about the periodic table. Preview the visuals for Sections 2 and 3, and create graphic organizers.

Lab zone

# Standards Investigation

S 8.7.c

## Survey Properties of Metals

Chemists have a system for organizing the elements. There are more than 100 elements, and as you will learn in this chapter, about 80 of them are classified as metals. In this investigation, you will examine more closely the physical and chemical properties of metals.

### Your Goal

To survey the properties of several samples of metallic elements

To complete the investigation, you must

- interpret what the periodic table tells you about your samples
- design and conduct experiments that will allow you to test at least three properties of your metals
- compare and contrast the properties of your sample metals
- follow the safety guidelines in Appendix A

### Plan It!

Study the periodic table to determine which elements are metals. Brainstorm with your classmates about the properties of metals. What properties allow you to recognize a metal? How do you think metals differ from nonmetals? Your teacher will assign samples of metals to your group. You will be observing their properties in this investigation.

# Section 1 Introduction to Atoms

## CALIFORNIA Standards Focus

**S 8.3.a** Students know the structure of the atom and know it is composed of protons, neutrons, and electrons.

**S 8.7.b** Students know each element has a specific number of protons in the nucleus (the atomic number) and each isotope of the element has a different but specific number of neutrons in the nucleus.

- How did atomic theory develop and change?
- What is the modern model of the atom?

### Key Terms

- atom
- electron
- nucleus
- proton
- energy level
- neutron
- atomic number
- isotope
- mass number

## Lab zone Standards Warm-Up

### What's in the Box?

1. Your teacher will give you a sealed box that contains an object. Without opening the box, move the box around to find out as much as you can about the object.
2. Make a list of your observations about the object. For example, does the object slide or roll? Is it heavy or light? Is it soft or hard? Is the object round or flat?
3. Think about familiar objects that could give you clues about what's inside the box.

**Think It Over**

**Inferring** Make a sketch showing what you think the object looks like. Tell how you inferred the properties of the object from indirect observations.

Glance at the painting below and you see people enjoying an afternoon in the park. Now look closely at the circled detail of the painting. There you'll discover that the artist used thousands of small spots of color to create these images of people and the park.

Are you surprised that such a rich painting can be created from lots of small spots? Matter is like that, too. The properties of matter that you can observe result from the properties of tiny objects that you cannot see. As you learned earlier, the tiny objects that make up all matter are atoms.

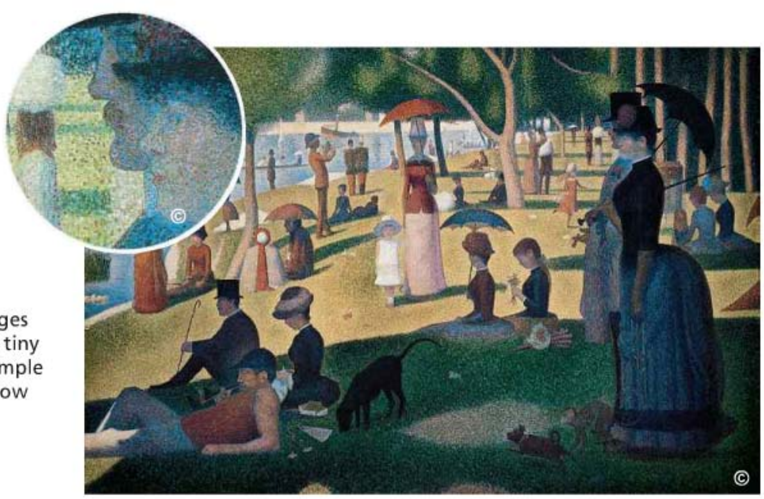


**FIGURE 1**
***Sunday Afternoon on the Island of La Grande Jatte***
This painting by artist Georges Seurat, which is made from tiny dots of paint, gives you a simple model for thinking about how matter is made of atoms.

## Development of Atomic Theory

If you could look into an atom, what might you see? Figuring out what atoms are made of hasn't been easy. Because atoms are so small, studying them is a bit like trying to solve the mystery of the sealed box in the Standards Warm-Up activity. Ideas about the shape and structure of atoms have changed many times.

The first people to think about the nature of matter were the ancient Greeks. Around the year 430 B.C., a Greek philosopher named Democritus proposed the idea that matter is formed of small pieces that could not be cut into smaller parts. He used the word *atomos*, which means "uncuttable," for these smallest possible pieces. In modern terms, an **atom** is the smallest particle of an element.

The ancient Greeks did not prove the existence of atoms because they did not do experiments. In science, ideas are just ideas unless they can be tested. The idea of atoms began to develop again in the 1600s. This time, however, people did do experiments. As a result, atomic theory began to take shape. **Atomic theory grew as a series of models that developed from experimental evidence. As more evidence was collected, the theory and models were revised.**

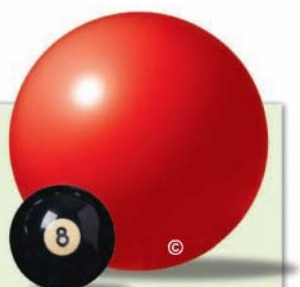
**Dalton's Atomic Theory** Using evidence from many experiments, John Dalton, an English chemist, inferred that atoms had certain characteristics. He began to propose an atomic theory and model for atoms. The main ideas of Dalton's theory are summarized in Figure 2. With only a few changes, Dalton's atomic theory is still accepted today.

**Reading Checkpoint** What is the modern definition of an atom?

**Go Online** PHSchool.com

**For:** More on atomic structure
**Visit:** PHSchool.com
**Web Code:** cgd-2011

FIGURE 2
**Dalton Model**
Dalton thought that atoms were like smooth, hard balls that could not be broken into smaller pieces.




**Summary of Dalton's Ideas**

- All elements are composed of atoms that cannot be divided.
- All atoms of the same element are exactly alike and have the same mass. Atoms of different elements are different and have different masses.
- An atom of one element cannot be changed into an atom of a different element. Atoms cannot be created or destroyed in any chemical change, only rearranged.
- Every compound is composed of atoms of different elements, combined in a specific ratio.

**FIGURE 3**
**Thomson's Model**
Thomson suggested that atoms had negatively charged electrons embedded in a positive sphere.

## Thomson's Model

Through a series of experiments around the start of the twentieth century, scientists discovered that atoms are made of even smaller parts. In 1897, another English scientist, J. J. Thomson, found that atoms contain negatively charged particles. Yet, scientists knew that atoms themselves had no electrical charge. So, Thomson reasoned, atoms must also contain some sort of positive charge.

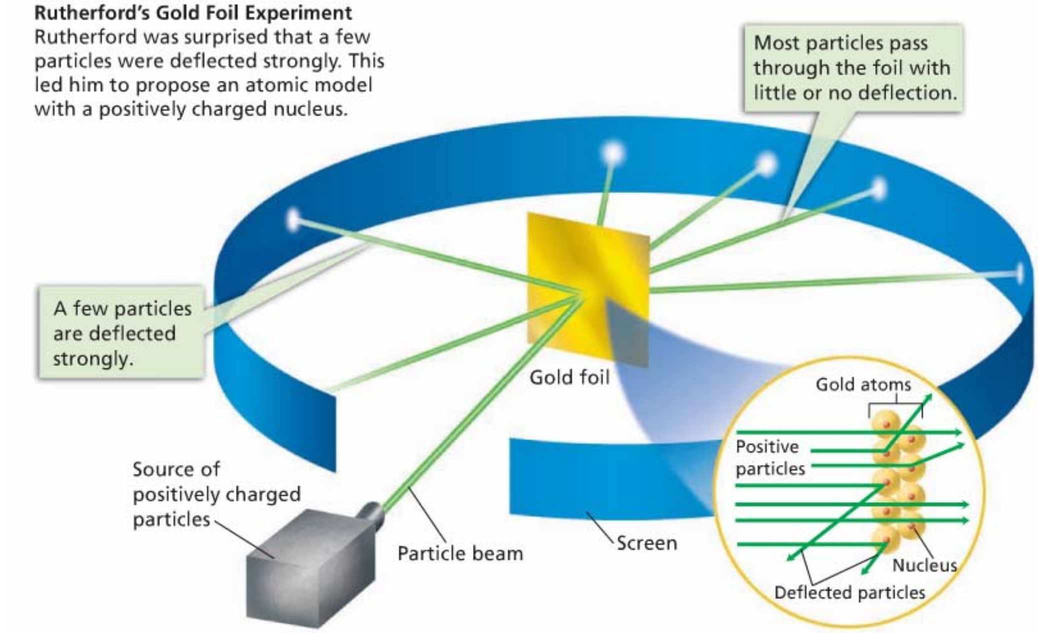
Thomson proposed a model like the one in Figure 3. He described an atom that consisted of negative charges scattered throughout a ball of positive charge—something like raisins or berries in a muffin. The negatively charged particles later became known as **electrons.**

**Reading Checkpoint** **Where were the electrons located in Thomson's model of an atom?**

## Rutherford's Model

In 1911, one of Thomson's students, Ernest Rutherford, found evidence that countered Thomson's model. In an experiment diagrammed in Figure 4, Rutherford's research team aimed a beam of positively charged particles at a thin sheet of gold foil. They predicted that, if Thomson's model were correct, the charged particles would pass right through the foil in a straight line. The gold atoms would not have enough positive charge in any one region to strongly repel the charged particles.

**FIGURE 4**
**Rutherford's Gold Foil Experiment**
Rutherford was surprised that a few particles were deflected strongly. This led him to propose an atomic model with a positively charged nucleus.



Rutherford's team observed that most of the particles passed through the foil undisturbed, as expected. But, to their surprise, a few particles were deflected strongly. Since like charges repel each other, Rutherford inferred that an atom's positive charge must be clustered in a tiny region in its center, called the **nucleus** (NOO klee us). (The plural of *nucleus* is *nuclei.*) Any particle that was deflected strongly had been repelled by a gold atom's nucleus.

Scientists knew from other experiments that electrons had almost no mass. Therefore, they reasoned that nearly all of an atom's mass must also be located in the tiny, positively charged nucleus. In Rutherford's atomic model, the atom was mostly empty space with electrons moving around the nucleus in that space. Later research suggested that the nucleus was made of one or more positively charged particles. Rutherford called the positively charged particles in an atom's nucleus **protons.**

**Bohr's Model** In 1913, Niels Bohr, a Danish scientist, revised the atomic model. Bohr showed that electrons could have only specific amounts of energy, leading them to move in certain orbits. The orbits in Bohr's model resemble planets orbiting the sun or the layers of an onion, as shown in Figure 6.

**Cloud Model** In the 1920s, the atomic model changed again. Scientists determined that electrons do not orbit the nucleus like planets. Instead, electrons can be anywhere in a cloudlike region around the nucleus. The "cloud" is a visual model. It symbolizes where electrons are likely to be found. An electron's movement is related to its **energy level,** or the specific amount of energy it has. Electrons of different energy levels are likely to be found in different places. The energy of each electron keeps it in motion around the positive nucleus to which it is attracted.

**FIGURE 5**
**Rutherford's Model**
According to Rutherford's model, an atom was mostly empty space.
**Making Models** *How is a fruit with a pit at its center a simple model for Rutherford's idea?*

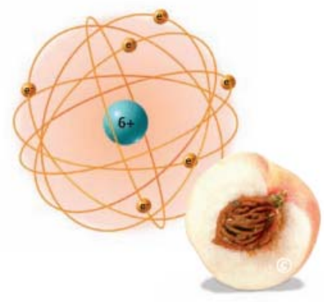
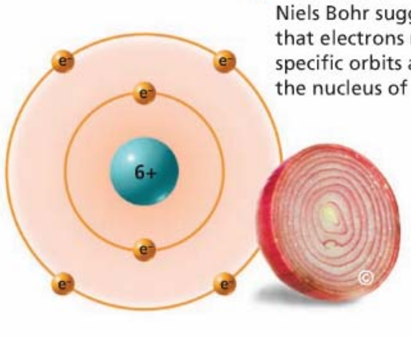
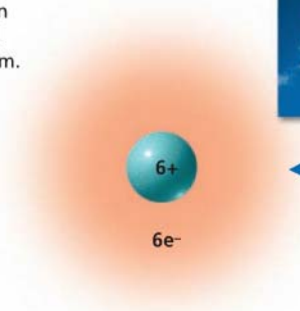



**FIGURE 6**
## Later Atomic Models
Through the first part of the twentieth century, atomic models continued to change.

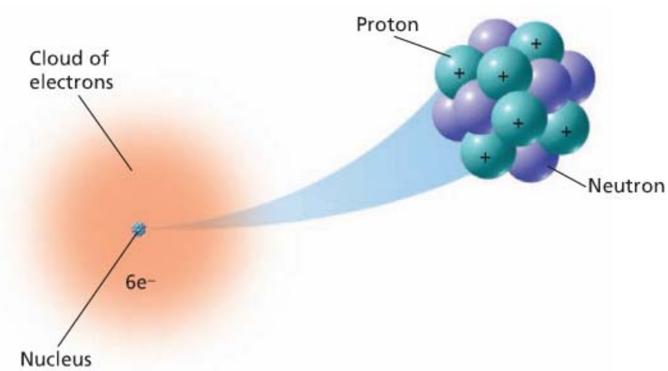



**Bohr Model**
Niels Bohr suggested that electrons move in specific orbits around the nucleus of an atom.




**Cloud Model**
According to the cloud model, electrons move rapidly in every direction around the nucleus.

FIGURE 7
**Modern Model of an Atom**
This model of a carbon atom consists of positively charged protons and neutral neutrons in a nucleus that is surrounded by a cloud of negatively charged electrons.
**Relating Cause and Effect** *What effect do the neutrons in the nucleus have on the atom's electric charge? Explain.*




**Lab zone Try This Activity**

### How Far Away?

1. On a piece of paper, make a small circle no bigger than a dime. The circle represents the nucleus of an atom.
2. Measure the diameter of the circle in centimeters.
3. Now predict where the outer edge of this model atom would be. For example, would the outer edge be within the edges of the paper? Your desk? The classroom? The school building?

**Calculating** The diameter of an actual atom can be 100,000 times that of its nucleus. Calculate the diameter of your model atom. How close was your prediction in Step 3 to your calculation? (*Hint:* To understand the scale of your answer, change the units of measurement from centimeters to meters.)

## The Modern Atomic Model

In 1932, English scientist James Chadwick discovered another particle in the nucleus of atoms. This new particle, called a **neutron**, was hard to detect because it has no electric charge. A neutron has nearly the same mass as a proton.

Chadwick's discovery led to an adjustment in the atomic model. This model, pictured in Figure 7, has not changed much since the 1930s. The modern atomic model describes the atom as mostly empty space. **At the center of the atom is a tiny, massive nucleus containing protons and neutrons. Surrounding the nucleus is a cloudlike region of moving electrons.** New research continues to provide data that support this model. These data also confirm many of the earlier inferences made by scientists who helped advance atomic theory.

**Particle Charges** Look closely at Figure 7. Protons are shown in the diagram by a plus sign (+), and electrons are shown by the symbol $e^-$. If you count the number of protons, you'll see there are six—the same as the number of electrons. In an atom, the number of protons equals the number of electrons. As a result, the positive charge from the protons equals the negative charge from the electrons. The charges balance, making the atom neutral. In contrast, the number of neutrons in an atom does not have to equal the number of protons. Neutrons don't affect the charge of an atom because they have no charge.

**Reading Checkpoint** **Where are the electrons located in the modern model of an atom?**

**Particles in an Atom**

| Particle | Symbol | Charge | Relative Mass (amu) | Model |
|---|---|---|---|---|
| Proton | $p^+$ | 1+ | 1 |  |
| Neutron | n | 0 | 1 |  |
| Electron | $e^-$ | 1– | $\frac{1}{1,836}$ |  |

**FIGURE 8**
An atom is composed of positively charged protons, neutral neutrons, and negatively charged electrons. Protons and neutrons are about equal in mass. An electron has about 1/2,000 the mass of a proton or neutron.

**Comparing Particle Masses** Although electrons may balance protons charge-for-charge, they can't compare when it comes to mass. It takes almost 2,000 electrons to equal the mass of just one proton. A proton and a neutron are about equal in mass. Together, the protons and neutrons make up nearly all the mass of an atom.

Figure 8 compares the charges and masses of the three atomic particles. Atoms are too small to be described easily by everyday units of mass, such as grams or kilograms. Sometimes scientists use units known as atomic mass units (amu). A proton or a neutron has a mass equal to about one amu.

**Scale and Size of Atoms** Looking back at the modern atomic model (Figure 7), you may see that most of an atom's volume is the space in which the electrons move. In contrast, the nucleus seems tiny. But no image can be drawn in a book that would show how small the nucleus really is compared to an entire atom. To picture the scale of an atom, imagine that the nucleus were the size of an eraser on a pencil. If you put this "nucleus" on the pitcher's mound of a baseball stadium, the electrons could be as far away as the top row of seats!

Atoms are amazingly small. The tiniest visible speck of dust may contain 10 million billion atoms. Because they are so small, atoms are hard to study. Today's powerful microscopes can give a glimpse of atoms, as shown in Figure 9. But they do not show the structure of atoms. Models, such as those shown in this book, are helpful in learning more about atoms.

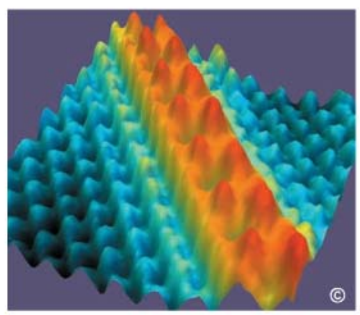


**FIGURE 9**
**Imaging Atoms**
This image was made by a scanning tunneling microscope. It shows a zigzag chain of cesium atoms (red) on a background of gallium and arsenic atoms (blue). The colors were added to the image.

**Atomic Number** Every atom of a given element has the same number of protons. For example, the nucleus of every carbon atom has 6 protons. Every oxygen atom has 8 protons, and every iron atom has 26 protons. The number of protons in the nucleus of an atom is the **atomic number** of that atom's element. The definition of an element is based on its atomic number. Atoms with different atomic numbers are atoms of different elements. Carbon's atomic number is 6. Oxygen has an atomic number of 8. Iron has an atomic number of 26.

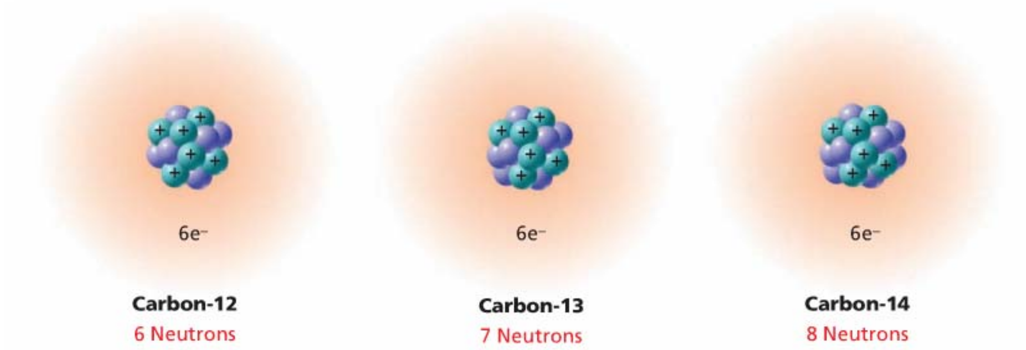



**FIGURE 10**
**Isotopes**
Atoms of all isotopes of carbon contain 6 protons and 6 electrons, but they differ in their number of neutrons. Carbon-12 is the most common isotope.
**Interpreting Diagrams** *Which isotope of carbon has the largest mass number?*

**Isotopes and Mass Number** Although the number of protons is fixed for a particular element, the same is not true for the number of neutrons in the nucleus. Atoms of the same element that have different numbers of neutrons are called **isotopes** (EYE suh tohps). Three carbon isotopes are illustrated in Figure 10. Each carbon atom has 6 protons and 6 electrons. But the number of neutrons is 6, 7, or 8. An isotope is identified by its **mass number,** which is the sum of the protons and neutrons in the nucleus of an atom. The most common isotope of carbon has a mass number of 12 (6 protons + 6 neutrons), and may be written as "carbon-12." Two other isotopes are carbon-13 and carbon-14. Despite their different mass numbers, all three carbon isotopes react the same way chemically.

Hydrogen also has three isotopes. All hydrogen atoms have one proton in the nucleus. The most common isotope is hydrogen-1 (1 proton + 0 neutrons). The others are hydrogen-2 (1 proton + 1 neutron) and hydrogen-3 (1 proton + 2 neutrons). Hydrogen-2 is called deuterium. Hydrogen-3 is called tritium.

## Section 1 Assessment

S 8.3.a, 8.7.b,
E-LA: Reading 8.1.2

**Vocabulary Skill** **Greek Word Origins** Use what you know about the Greek word *atomos* to explain the meaning of *atom.*

### Reviewing Key Concepts

HINT **1. a. Reviewing** Why did atomic theory change with time?

HINT **b. Describing** Describe Bohr's model of the atom. What specific information did Bohr contribute to scientists' understanding of the atom?

HINT **c. Comparing and Contrasting** How is the modern atomic model different from Bohr's model?

HINT **2. a. Reviewing** What are the three main particles in the modern model of an atom?

**b. Explaining** What is atomic number? How is it used to distinguish one element from another? HINT

**c. Applying Concepts** The atomic number of nitrogen is 7. How many protons, neutrons, and electrons make up an atom of nitrogen-15? HINT

### Lab zone At-Home Activity

**Modeling Atoms** Build a three-dimensional model of an atom using materials such as beads, cotton, and clay. Show the model to your family, and explain what makes atoms of different elements different from one another.

# Section 2 Organizing the Elements

**CALIFORNIA Standards Focus**

**S 8.7.a** Students know how to identify regions corresponding to metals, nonmetals, and inert gases.

- How did Mendeleev discover the pattern that led to the periodic table?
- How are the elements organized in the modern periodic table?

## Key Terms

- atomic mass
- periodic table
- period
- group
- chemical symbol

## Lab zone Standards Warm-Up

### Which Is Easier?

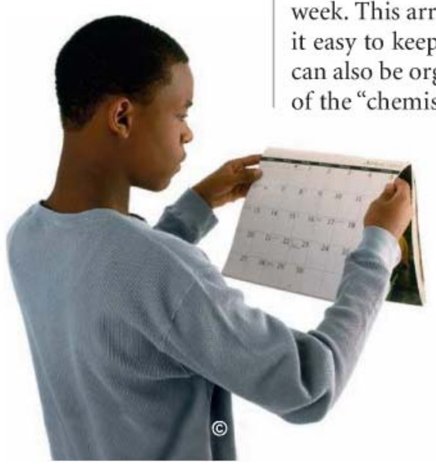
1. Make 4 sets of 10 paper squares, using a different color for each set. Number the squares in each set from 1 through 10.
2. Place all of the squares on a flat surface, numbered side up. Don't arrange them in order.
3. Ask your partner to think of a way of arranging the squares that makes it easy to find a square of a particular color and number. Have your partner describe to you how the squares should be organized.
4. Working together, arrange the squares according to the organization scheme devised by your partner.
5. Trade places with your partner and repeat Steps 2 through 4. Try to think of a different organization scheme than the one devised by your partner.

**Think It Over**

**Drawing Conclusions** Compare the different ways that you and your classmates organized the squares. Were some schemes more organized than others? Explain.

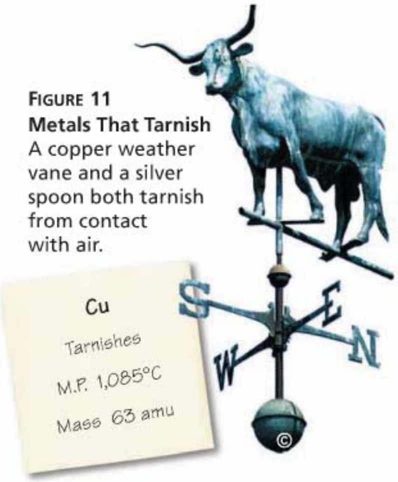
You wake up, jump out of bed, and start to get dressed for school. Then you ask yourself a question: Is there school today? To find out, you check the calendar. There's no school today because it's Saturday.

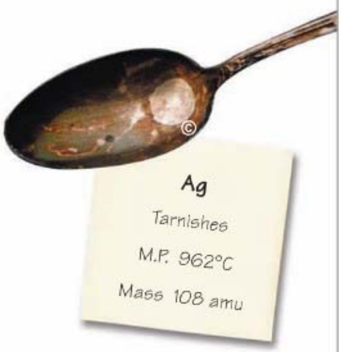
The calendar arranges the days of the month into horizontal periods called weeks and vertical groups called days of the week. This arrangement follows a repeating pattern that makes it easy to keep track of which day it is. The chemical elements can also be organized into something like a calendar. The name of the "chemists' calendar" is the periodic table.



A calendar organizes the days of the week into a useful, repeating pattern.

**FIGURE 11**
**Metals That Tarnish**
A copper weather vane and a silver spoon both tarnish from contact with air.




# Mendeleev's Periodic Table

By 1869, a total of 63 elements had been discovered. A few were gases. Two were liquids. Most were solid metals. Some reacted explosively. Others reacted more slowly. Scientists wondered if the properties of elements followed a pattern. A Russian scientist, Dmitri Mendeleev (men duh LAY ef), discovered a set of patterns that applied to all the elements.

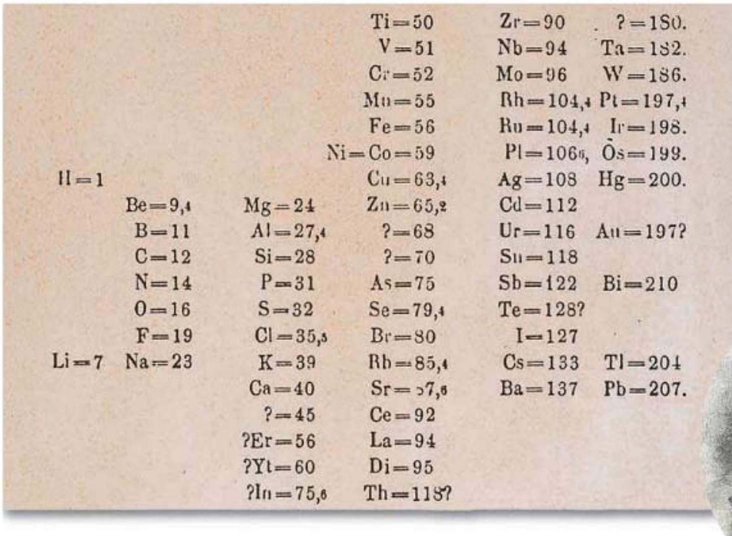
**Patterns of Properties** Mendeleev knew that some elements have similar chemical and physical properties. For example, both fluorine and chlorine are gases that irritate the lungs and form similar compounds. Silver and copper, shown in Figure 11, are both shiny metals that tarnish if exposed to air. Mendeleev thought these similarities were important clues to a hidden pattern.

To find that pattern, Mendeleev wrote each element's melting point (M.P.), density, and color on individual cards. He also included the element's atomic mass. The **atomic mass** is the average mass of all the isotopes of an element. Mendeleev then tried arranging the cards in various ways.

**Mendeleev noticed that a pattern of properties appeared when he arranged the elements in order of increasing atomic mass.** For example, when the 63 known elements were arranged in this order, lithium (Li) came in second, sodium (Na) came in ninth, and potassium (K) came in sixteenth. Each of these elements reacted with water in the same way. So, Mendeleev lined up the cards for these elements to form their own group. He did the same with other similar elements. Group by group, Mendeleev constructed the first periodic table. A **periodic table** is an arrangement of elements showing the repeating pattern of their properties. (The word *periodic* means "in a regular, repeated pattern.")

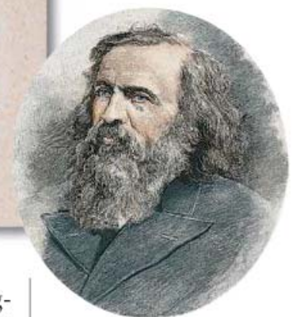
**Reading Checkpoint** What properties do silver and copper share?

**FIGURE 12**
**Metals That React With Water**
Lithium and sodium both react with water. **Interpreting Photographs** *Which metal reacts more vigorously with water?*



| | | | | | |
|---|---|---|---|---|---|
| | | | Ti=50 | Zr=90 | ?=180. |
| | | | V=51 | Nb=94 | Ta=182. |
| | | | Cr=52 | Mo=96 | W=186. |
| | | | Mn=55 | Rh=104,4 | Pt=197,4 |
| | | | Fe=56 | Ru=104,4 | Ir=198. |
| | | | Ni=Co=59 | Pl=106,6 | Os=199. |
| H=1 | | | Cu=63,4 | Ag=108 | Hg=200. |
| | Be=9,4 | Mg=24 | Zn=65,2 | Cd=112 | |
| | B=11 | Al=27,4 | ?=68 | Ur=116 | Au=197? |
| | C=12 | Si=28 | ?=70 | Sn=118 | |
| | N=14 | P=31 | As=75 | Sb=122 | Bi=210 |
| | O=16 | S=32 | Se=79,4 | Te=128? | |
| | F=19 | Cl=35,5 | Br=80 | I=127 | |
| Li=7 | Na=23 | K=39 | Rb=85,4 | Cs=133 | Tl=204 |
| | | Ca=40 | Sr=87,6 | Ba=137 | Pb=207. |
| | | ?=45 | Ce=92 | | |
| | | ?Er=56 | La=94 | | |
| | | ?Yt=60 | Di=95 | | |
| | | ?In=75,6 | Th=118? | | |

**FIGURE 13**
**Mendeleev's Periodic Table**
When Mendeleev published his first periodic table, he left question marks in some places. Based on the properties and atomic masses of surrounding elements, he predicted that new elements with specific properties would be discovered.



**Predicting New Elements** Mendeleev found that arranging the known elements strictly by increasing atomic mass did not always group similar elements together. So, he moved a few of his element cards into groups where the elements did have similar properties. After arranging all 63 elements, three blank spaces were left. Mendeleev predicted that the blank spaces would be filled by elements that had not yet been discovered. He even predicted the properties of those new elements.

In 1869, Mendeleev published his periodic table. It looked something like the one shown in Figure 13. Within 16 years, chemists discovered the three missing elements—scandium, gallium, and germanium. Their properties are close to those that Mendeleev had predicted.

## The Modern Periodic Table

The periodic table changed as scientists discovered new elements and learned more about atomic structure. The modern periodic table contains more than 100 elements. It is also organized differently from Mendeleev's table. In the modern periodic table, the elements are arranged in order of increasing atomic number. Recall that the atomic number of an element equals the number of protons in an atom of that element.

The modern periodic table appears on the next two pages. **The properties of an element can be predicted from its location on the periodic table.** This predictability is the reason that the periodic table is so useful to chemists.

Video Field Trip
Discovery Channel School
***Elements and the Periodic Table***

FIGURE 14

## Periodic Table of the Elements

The modern periodic table includes over 100 elements. Many of the properties of an element can be predicted by its position in the table.

**Go Online** *active art*
**For:** Periodic Table activity
**Visit:** PHSchool.com
**Web Code:** cgp-1032

**Key**

| | |
|---|---|
| C | Solid |
| Br | Liquid |
| H | Gas |
| Tc | Not found in nature |

**Symbol**
One- or two-letter symbols identify most elements. Some periodic tables also list the names of the elements.

| Period | Group 1 | Group 2 | Group 3 | Group 4 | Group 5 | Group 6 | Group 7 | Group 8 | Group 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 H Hydrogen 1.0079 | | | | | | | | |
| 2 | 3 Li Lithium 6.941 | 4 Be Beryllium 9.0122 | | | | | | | |
| 3 | 11 Na Sodium 22.990 | 12 Mg Magnesium 24.305 | | | | | | | |
| 4 | 19 K Potassium 39.098 | 20 Ca Calcium 40.08 | 21 Sc Scandium 44.956 | 22 Ti Titanium 47.90 | 23 V Vanadium 50.941 | 24 Cr Chromium 51.996 | 25 Mn Manganese 54.938 | 26 Fe Iron 55.847 | 27 Co Cobalt 58.933 |
| 5 | 37 Rb Rubidium 85.468 | 38 Sr Strontium 87.62 | 39 Y Yttrium 88.906 | 40 Zr Zirconium 91.22 | 41 Nb Niobium 92.906 | 42 Mo Molybdenum 95.94 | 43 Tc Technetium (98) | 44 Ru Ruthenium 101.07 | 45 Rh Rhodium 102.91 |
| 6 | 55 Cs Cesium 132.91 | 56 Ba Barium 137.33 | 71 Lu Lutetium 174.97 | 72 Hf Hafnium 178.49 | 73 Ta Tantalum 180.95 | 74 W Tungsten 183.85 | 75 Re Rhenium 186.21 | 76 Os Osmium 190.2 | 77 Ir Iridium 192.22 |
| 7 | 87 Fr Francium (223) | 88 Ra Radium (226) | 103 Lr Lawrencium (262) | 104 Rf Rutherfordium (261) | 105 Db Dubnium (262) | 106 Sg Seaborgium (263) | 107 Bh Bohrium (264) | 108 Hs Hassium (265) | 109 Mt Meitnerium (268) |

**Lanthanides**

| | | | | | |
|---|---|---|---|---|---|
| 57 La Lanthanum 138.91 | 58 Ce Cerium 140.12 | 59 Pr Praseodymium 140.91 | 60 Nd Neodymium 144.24 | 61 Pm Promethium (145) | 62 Sm Samarium 150.4 |

**Actinides**

| | | | | | |
|---|---|---|---|---|---|
| 89 Ac Actinium (227) | 90 Th Thorium 232.04 | 91 Pa Protactinium 231.04 | 92 U Uranium 238.03 | 93 Np Neptunium (237) | 94 Pu Plutonium (244) |

The lanthanides and the actinides are placed off the table to save space and to make the rest of the table easier to read. Follow the blue shading to see how they fit in the table.

**Key**

- Metal
- Semimetal
- Nonmetal
- Inert gas
- Properties not established

**Atomic Mass**
Atomic mass is the average mass of an element's atoms. Atomic masses in parentheses are those of the most stable isotope.

**Atomic Number**
The atomic number is the number of protons in an atom's nucleus.

Many periodic tables include a zigzag line that separates the metals from the nonmetals.

| 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 2 He Helium 4.0026 |
| | | | 5 B Boron 10.81 | 6 C Carbon 12.011 | 7 N Nitrogen 14.007 | 8 O Oxygen 15.999 | 9 F Fluorine 18.998 | 10 Ne Neon 20.179 |
| | | | 13 Al Aluminum 26.982 | 14 Si Silicon 28.086 | 15 P Phosphorus 30.974 | 16 S Sulfur 32.06 | 17 Cl Chlorine 35.453 | 18 Ar Argon 39.948 |
| 28 Ni Nickel 58.71 | 29 Cu Copper 63.546 | 30 Zn Zinc 65.38 | 31 Ga Gallium 69.72 | 32 Ge Germanium 72.59 | 33 As Arsenic 74.922 | 34 Se Selenium 78.96 | 35 Br Bromine 79.904 | 36 Kr Krypton 83.80 |
| 46 Pd Palladium 106.4 | 47 Ag Silver 107.87 | 48 Cd Cadmium 112.41 | 49 In Indium 114.82 | 50 Sn Tin 118.69 | 51 Sb Antimony 121.75 | 52 Te Tellurium 127.60 | 53 I Iodine 126.90 | 54 Xe Xenon 131.30 |
| 78 Pt Platinum 195.09 | 79 Au Gold 196.97 | 80 Hg Mercury 200.59 | 81 Tl Thallium 204.37 | 82 Pb Lead 207.2 | 83 Bi Bismuth 208.98 | 84 Po Polonium (209) | 85 At Astatine (210) | 86 Rn Radon (222) |
| 110 Ds Darmstadtium (269) | 111 Rg Roentgenium (272) | 112 *Uub Ununbium (277) | | 114 *Uuq Ununquadium | | | | |

*Name not officially assigned

(Atomic masses in parentheses are those of the most stable isotope.)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 63 Eu Europium 151.96 | 64 Gd Gadolinium 157.25 | 65 Tb Terbium 158.93 | 66 Dy Dysprosium 162.50 | 67 Ho Holmium 164.93 | 68 Er Erbium 167.26 | 69 Tm Thulium 168.93 | 70 Yb Ytterbium 173.04 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 95 Am Americium (243) | 96 Cm Curium (247) | 97 Bk Berkelium (247) | 98 Cf Californium (251) | 99 Es Einsteinium (252) | 100 Fm Fermium (257) | 101 Md Mendelevium (258) | 102 No Nobelium (259) |

## Lab zone Skills Activity

### Classifying

Choose any ten elements and assign them letters from *A* to *J*. On an index card for each element, write the letter for the element and list some of its properties. You may list properties that you learn about in this chapter or properties presented in another reference source.

Exchange cards with a classmate. Can you identify each element? Can you identify elements that have similar properties? Which properties are most helpful in identifying elements?

**Classes of Elements** Look at Figure 14 on the previous two pages, starting at the upper left with hydrogen (H). Notice that the atomic numbers increase from left to right. You may also notice that the table is color-coded. Each color-coded region corresponds to a different class of elements—metals, semimetals, nonmetals, and inert gases.

**Periods** The periodic table is organized in horizontal rows called **periods.** A period contains a series of different elements. From left to right, the properties of the elements change in a pattern. Metals are shown on the left of the table, with the most reactive metals on the far left. Nonmetals are located on the right, with the most reactive next to the inert gases on the far right. Semimetals are found between the metals and nonmetals. This pattern is repeated in each period. Typically, the atoms of elements increase in mass from left to right, and elements in lower rows are more massive than those in the upper rows.

The periodic table contains seven periods. Period 1 has two elements. Periods 2 and 3 each have 8 elements. Periods 4 and 5 each have 18 elements. Period 6 has 32 elements. Notice that some of the elements in Periods 6 and 7 are placed off the table to save space. These elements are the lanthanides and actinides.

**Groups** The vertical columns of the periodic table are called **groups.** A group—also known as a family—consists of elements with similar characteristics. For example, the elements in Group 1 react violently with water, while the elements in Group 2 react with water slowly or not at all. Group 17 elements react violently with Group 1 elements, but Group 18 elements rarely react at all.

The lanthanides and the actinides do not belong in the 18 groups labeled in Figure 14. Figure 15 shows a different form of the periodic table. It includes the lanthanides and actinides where they would fit, according to their atomic numbers. Because this form of the table is so wide, it is difficult to fit in a book unless you show only the elements' symbols.

**Reading Checkpoint** **How many periods does the periodic table contain?**

**FIGURE 15**
**An Expanded Periodic Table**
If the lanthanides and actinides were placed within the body of the periodic table, they would increase the number of groups to 32.

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | H | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | He |
| 2 | Li | Be | | | | | | | | | | | | | | | | | | | | | | | | | B | C | N | O | F | Ne |
| 3 | Na | Mg | | | | | | | | | | | | | | | | | | | | | | | | | Al | Si | P | S | Cl | Ar |
| 4 | K | Ca | | | | | | | | | | | | | | | Sc | Ti | V | Cr | Mn | Fe | Co | Ni | Cu | Zn | Ga | Ge | As | Se | Br | Kr |
| 5 | Rb | Sr | | | | | | | | | | | | | | | Y | Zr | Nb | Mo | Tc | Ru | Rh | Pd | Ag | Cd | In | Sn | Sb | Te | I | Xe |
| 6 | Cs | Ba | La | Ce | Pr | Nd | Pm | Sm | Eu | Gd | Tb | Dy | Ho | Er | Tm | Yb | Lu | Hf | Ta | W | Re | Os | Ir | Pt | Au | Hg | Tl | Pb | Bi | Po | At | Rn |
| 7 | Fr | Ra | Ac | Th | Pa | U | Np | Pu | Am | Cm | Bk | Cf | Es | Fm | Md | No | Lr | Rf | Db | Sg | Bh | Hs | Mt | Ds | Rg | Uub | | Uuq | | | | |

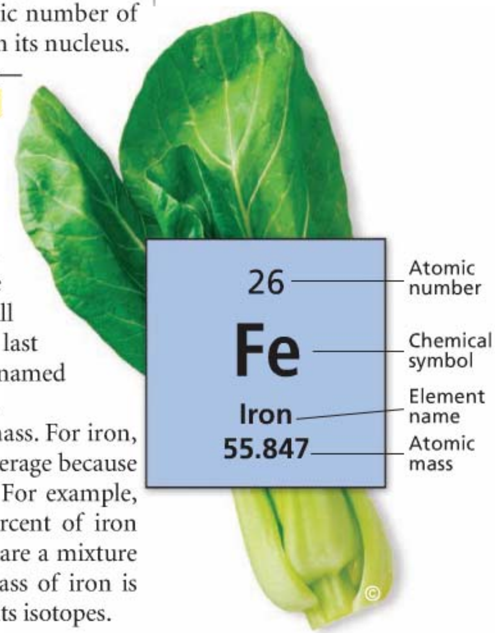
**Reading The Data** In the periodic table, there is one square for each element. **In this book, each square in the periodic table lists four pieces of information: an element's atomic number, chemical symbol, name, and atomic mass.**

Iron (Fe) is the element located in Group 8, Period 4 of the periodic table. You can see the square for iron reproduced in Figure 16. The first piece of information in the square is the number 26, the atomic number of iron. An atomic number of 26 tells you that every iron atom has 26 protons in its nucleus.

Just below the atomic number are the letters Fe—the chemical symbol for iron. A **chemical symbol** is a representation of an element usually consisting of one or two letters. Often, a chemical symbol is an abbreviation of the element's English name. For example, the symbol for zinc is Zn, and the symbol for calcium is Ca. Other symbols are abbreviations of Latin names. For example, the Latin name of iron is *ferrum*, so its symbol is Fe. Still other elements have names derived from the last names of scientists. For example, Curium (Cm) is named after the French scientists Pierre and Marie Curie.

The last number in the square is the atomic mass. For iron, this value is 55.847 amu. The atomic mass is an average because most elements consist of a mixture of isotopes. For example, iron is a mixture of four isotopes. About 92 percent of iron atoms are iron-56 (having 30 neutrons). The rest are a mixture of iron-54, iron-57, and iron-58. The atomic mass of iron is determined from the combined percentages of all its isotopes.

**FIGURE 16**
**Iron**
Iron has an atomic number of 26 and an atomic mass of 55.847 amu. Bok choy, shown below, is a leafy vegetable rich in iron.
**Inferring** *How many protons does an iron atom contain?*




## Section 2 Assessment

S 8.7.a, E-LA: Reading 8.2.0, Writing 8.2.4

**Target Reading Skill** **Preview Visuals** Review your graphic organizer for Figure 14. How did you answer your questions?

**Reviewing Key Concepts**

1. a. **Reviewing** In what order did Mendeleev arrange the elements in his periodic table?
   b. **Explaining** What pattern did Mendeleev discover when he arranged the elements?
   c. **Interpreting Tables** What elements did Mendeleev group with lithium in his periodic table?
2. a. **Listing** What information is listed in an element's square in the periodic table?
   b. **Comparing and Contrasting** Describe two differences between Mendeleev's periodic table and the modern periodic table.
   c. **Interpreting Tables** What element has 47 protons in its nucleus?

### Writing in Science

**Advertisement** Write an advertisement that you could use to sell copies of Mendeleev's periodic table to chemists in 1869. Remember: chemists in 1869 have never seen such a table.

Section 3

# Metals

CALIFORNIA Standards Focus

**S 8.7.a** Students know how to identify regions corresponding to metals, nonmetals, and inert gases.

**S 8.7.c** Students know substances can be classified by their properties, including their melting temperature, density, hardness, and thermal and electrical conductivity.

- What are the physical properties of metals?
- How does the reactivity of metals change across the periodic table?
- How are synthetic elements produced?

**Key Terms**

- metal
- malleable
- ductile
- thermal conductivity
- electrical conductivity
- reactivity
- corrosion
- alkali metal
- alkaline earth metal
- transition metal
- particle accelerator

Lab zone **Standards Warm-Up**

### Why Use Aluminum?

1. Examine several objects made from aluminum, including a can, a disposable pie plate, heavy-duty aluminum foil, foil-covered wrapping paper, and aluminum wire.
2. Compare the shape, thickness, and general appearance of the objects.
3. Observe what happens if you try to bend and unbend each object.
4. For what purpose is each object used?

**Think It Over**

**Inferring** Use your observations to list as many properties of aluminum as you can. Based on your list of properties, infer why aluminum was used to make each object. Explain your answer.

It's hard to imagine modern life without metals. The cars you ride in are made of steel, which is mostly iron. Airplanes are covered in aluminum. A penny is coated with copper. Copper wires carry electric current to lamps, stereos, and computers.

## Properties of Metals

Substances can be classified by their properties, including melting temperature, density, hardness, and thermal and electrical conductivity. **Metals** are elements that are good conductors of electric current and heat. They also tend to be shiny and bendable—like copper wire, for instance. The majority of elements in the periodic table are metals.

**Physical Properties** **The physical properties of metals include luster, malleability, ductility, and conductivity.** A **malleable** (MAL ee uh bul) material is one that can be hammered or rolled into flat sheets or other shapes. A **ductile** material is one that can be pulled out, or drawn, into a long wire. Copper is both malleable and ductile. It can be made into thin sheets or drawn into wires.

**Thermal conductivity** is the ability of an object to transfer heat. The ability of an object to transfer electric current is **electrical conductivity**. Most metals are good thermal conductors and electrical conductors. In addition, some metals are magnetic. For example, iron (Fe), cobalt (Co), and nickel (Ni) are attracted to magnets and can be made into magnets. Most metals are also solids at room temperature. However, one metal—mercury (Hg)—is a liquid at room temperature.

**Chemical Properties** The ease and speed with which a substance reacts with other substances is called its **reactivity.** Metals usually react by losing electrons to other atoms. Some metals are very reactive. For example, sodium (Na) reacts strongly when exposed to air or water. To prevent it from reacting, sodium must be stored under oil in sealed containers. By comparison, gold (Au) and platinum (Pt) are very unreactive metals.

The reactivities of other metals fall somewhere between those of sodium and gold. Iron, for example, reacts slowly with oxygen in the air, forming iron oxide, or rust. If iron is not protected by paint or plated with another metal, it will slowly turn to reddish-brown rust. The gradual wearing away of a metal due to a chemical reaction is called **corrosion.**

**Reading Checkpoint** What are three physical properties of metals?

FIGURE 17
**Properties of Metals**
Metals have certain physical and chemical properties. **Classifying** *Categorize each of the properties of metals that are shown as either physical or chemical.*

**Magnetism ▲**
Some metals are attracted to magnets.

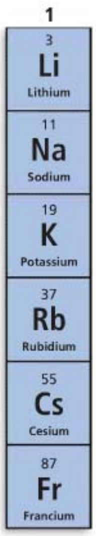
**▼ Malleability**
Gold can be pounded into coins.

**Reactivity ►**
This iron chain is coated with rust after being exposed to air.

◀ Potassium is highly reactive with air, so it is stored in oil.

Bananas are a good source of potassium in a healthful diet. ▶

▲ The reactions of some compounds containing potassium help get fireworks off the ground.



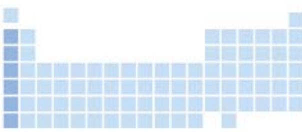



FIGURE 18

**Alkali Metals**

Potassium is an alkali metal. **Making Generalizations** *What characteristics do other Group 1 elements share with potassium?*

## Metals in the Periodic Table

The metals in a group, or family, have similar properties, and these family properties change gradually as you move across the table. **The reactivity of metals tends to decrease as you move from left to right across the periodic table.**

**Alkali Metals** The metals in Group 1, from lithium to francium, are called the **alkali metals.** Alkali metals, listed in Figure 18, react with other elements by losing one electron. These metals are so reactive that they are never found as uncombined elements in nature. Instead, they are found only in compounds. In the laboratory, scientists have been able to isolate alkali metals from their compounds. As pure, uncombined elements, some of the alkali metals are shiny and so soft that you can cut them with a plastic knife.

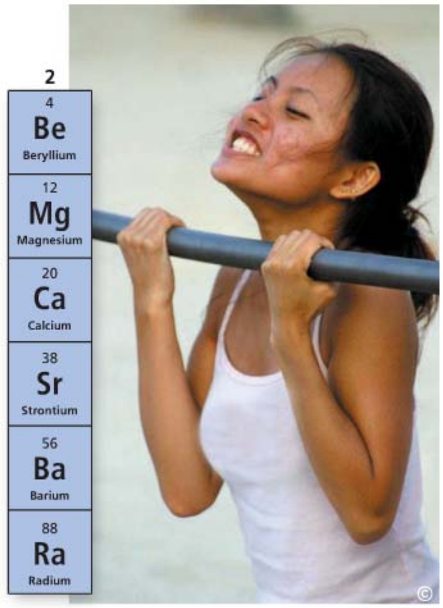
The two most important alkali metals are sodium and potassium. Sodium compounds are found in large amounts in seawater and salt beds. Your diet includes foods that contain compounds of sodium and potassium. Another alkali metal, lithium, is used in batteries and some medicines.

Reading Checkpoint **What are the alkali metals located in the periodic table?**

**Alkaline Earth Metals** Group 2 of the periodic table contains the **alkaline earth metals.** Each is fairly hard, gray-white, and a good conductor of electricity. Alkaline earth metals react by losing two electrons. These elements are not as reactive as the metals in Group 1, but they are more reactive than most other metals. Like the Group 1 metals, the Group 2 metals are never found uncombined in nature.

Magnesium and calcium are the most common alkaline earth metals. Mixing magnesium and a small amount of aluminum makes a strong but lightweight material used in ladders, wheel rims, and airplanes. Calcium compounds are an essential part of teeth and bones. Calcium also helps muscles work properly.

Comparing magnesium (atomic number 12) and sodium (atomic number 11) shows how just a slight change in atomic structure can result in different properties. Magnesium is a hard metal that melts at 648.8°C. Sodium is a soft metal that melts at 97.8°C.



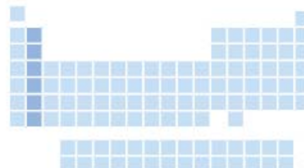



**FIGURE 19**
### Alkaline Earth Metals
Calcium is one of the Group 2 elements. Without Calcium, muscles and bones cannot grow and function.

**Reviewing Math:** Algebra and Functions 7.1.5

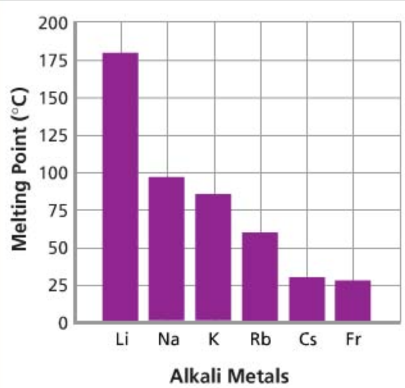
## Math Analyzing Data

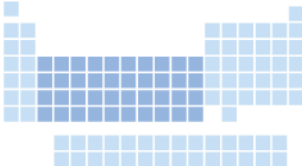
### Melting Points in a Group of Elements

The properties of elements within a single group in the periodic table often vary in a certain pattern. The following graph shows the melting points of Group 1 elements (alkali metals) from lithium to francium.

1. **Reading Graphs** As you look at Group 1 from lithium to francium, describe how the melting points of the alkali metals change.
2. **Predicting** If element number 119 were synthesized, it would fall below francium in Group 1 of the periodic table. Predict the approximate melting point of new element 119.
3. **Interpreting Data** Which of the alkali metals are liquids at 35°C?

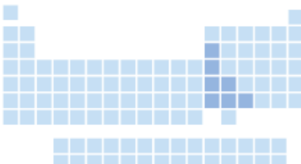
**Melting Points of Alkali Metals**



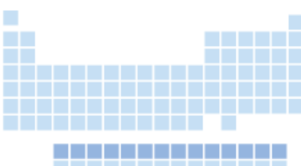


**Transition Metals** The elements in Groups 3 through 12 are called the **transition metals.** The transition metals include most of the familiar metals, such as iron, copper, nickel, silver, and gold. Most of the transition metals are hard and shiny. All of the transition metals are good conductors of electric current. Many of these metals form colorful compounds.

The transition metals are less reactive than the metals in Groups 1 and 2. When iron reacts with oxygen, forming rust, it sometimes takes many years to react completely. The lack of reactivity of gold is the reason ancient gold coins and jewelry are as beautiful today as they were thousands of years ago. Still, most transition metals are never found uncombined in nature. Some transition metals are important to your health. For example, iron forms the core of a large molecule called hemoglobin, which carries oxygen in your bloodstream.



**Metals in Mixed Groups** Only some of the elements in Groups 13 through 15 of the periodic table are metals. These metals are never found uncombined in nature. The most familiar of these metals are aluminum, tin, and lead. Aluminum is the lightweight metal used in beverage cans and airplane bodies. A thin coating of tin protects steel from corrosion in some cans of food. Lead was once used in paints and water pipes. But lead is poisonous, so it is no longer used for these purposes. Now, its most common uses are in automobile batteries and weights for balancing tires.



**Lanthanides** Two rows of elements are placed below the main part of the periodic table. This makes the table more compact. In the top row are the lanthanides (LAN thuh nydz). Lanthanides are sometimes mixed with more common metals to make alloys. An alloy is a mixture of a metal with at least one other element, usually another metal. Different lanthanides are usually found together in nature, always combined with other elements.

Two Group 3 elements—scandium (Sc) and yttrium (Y)—also show properties similar to the lanthanides. So, scientists group scandium, yttrium, and the lanthanides together as the rare earth elements. Some rare earth elements can be used to produce very strong magnets.

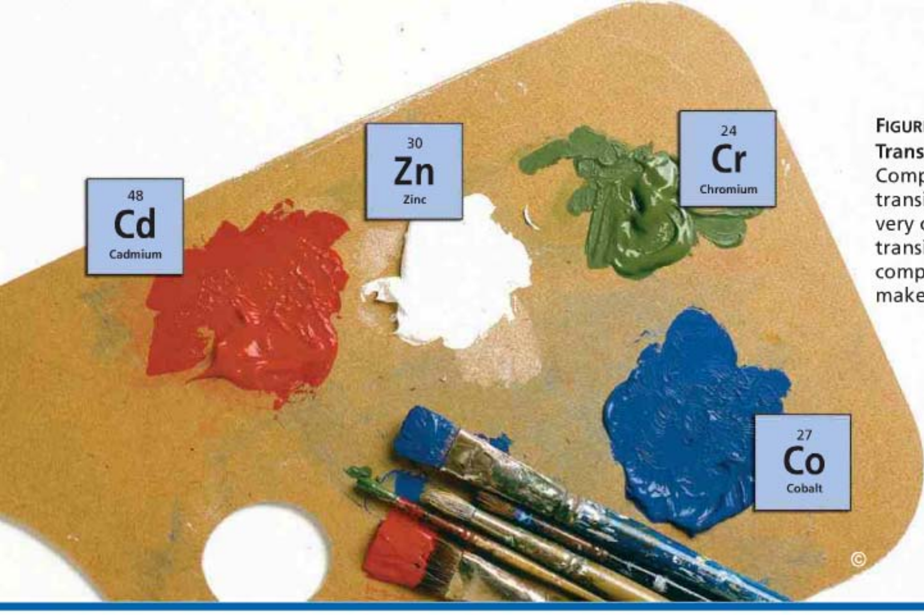



**FIGURE 20**
**Transition Metals**
Compounds made with transition metals can be very colorful. Several transition-metal compounds are used to make paints.

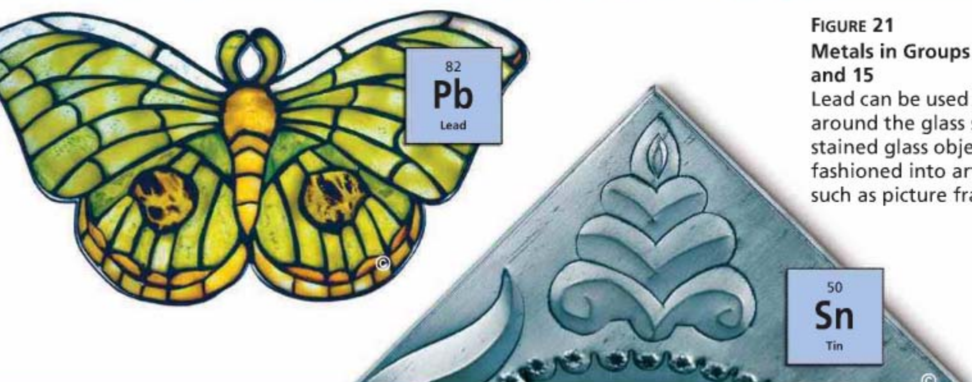



**FIGURE 21**
**Metals in Groups 13, 14, and 15**
Lead can be used in the borders around the glass sections in stained glass objects. Tin can be fashioned into artistic objects, such as picture frames.

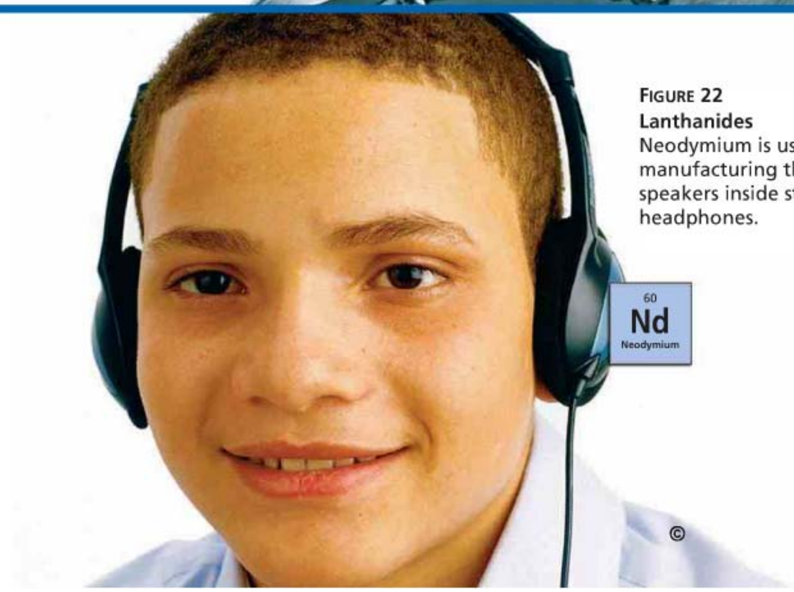
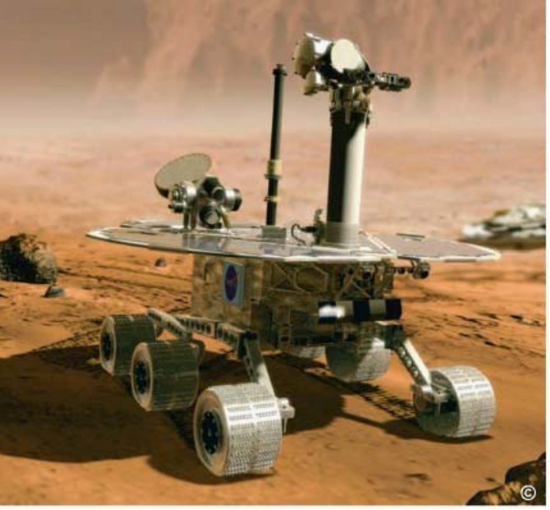



**FIGURE 22**
**Lanthanides**
Neodymium is used in manufacturing the tiny speakers inside stereo headphones.



**Actinides** The elements below the lanthanides are called actinides (AK tuh nydz). Of the actinides, only actinium (Ac), thorium (Th), protactinium (Pa), and uranium (U) occur naturally on Earth. Uranium is used to produce energy in nuclear power plants.

All of the elements after uranium were created artificially in laboratories. The nuclei of these elements are very unstable, meaning that they break apart very quickly into smaller nuclei. In fact, many of these elements are so unstable that they last only a fraction of a second after they are made.

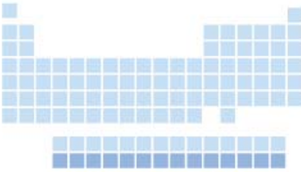


FIGURE 23
**Actinides**
Curium, one of the actinide elements, is used as a source of high-energy particles that heat and provide power for certain scientific equipment aboard the Mars Exploration Rover.
**Posing Questions** *Based on this information, write a question about curium.*

## Synthetic Elements

Elements with atomic numbers higher than 92 are sometimes called synthetic elements. These elements are not found naturally on Earth. Instead, scientists make, or synthesize, them. **Scientists make synthetic elements by forcing nuclear particles to crash into one another.** For example, plutonium is made by bombarding nuclei of uranium-238 with neutrons in a nuclear reactor. Americium-241 is made by bombarding plutonium nuclei with neutrons.

To make even heavier elements (with atomic numbers above 95), scientists use powerful machines called particle accelerators. **Particle accelerators** move atomic nuclei faster and faster until they have reached very high speeds. If these fast-moving nuclei crash into the nuclei of other elements with enough energy, the particles can sometimes combine into a single nucleus. Curium (Cm) was the first synthetic element to be made by colliding nuclei. In 1940, scientists in Chicago synthesized curium by colliding helium nuclei with plutonium nuclei.

In general, the difficulty of synthesizing new elements increases with atomic number. So, new elements have been synthesized only as more powerful particle accelerators have been built. For example, German scientists synthesized element 112 in 1996 by accelerating zinc nuclei and crashing them into lead. Element 112, like other elements with three-letter symbols, has been given a temporary name and symbol. In the future, scientists around the world will agree on permanent names and symbols for these elements.

Reading Checkpoint **Which elements are described as synthetic elements and why?**

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**FIGURE 24**
**Synthetic Elements**
Synthetic elements are not found naturally on Earth.

## Section 3 Assessment

S 8.7.a, 8.7.c,
E-LA: Reading 8.2.0

**Target Reading Skill** **Preview Visuals** Review your graphic organizer for Figure 17. How did you answer your questions?

**Reviewing Key Concepts**

HINT **1. a. Explaining** Explain what the terms *ductility* and *thermal conductivity* mean.

HINT **b. Classifying** Give an example of how the ductility of metal can be useful.

HINT **c. Inferring** What property of metals led to the use of plastic or wood handles on many metal cooking utensils? Explain.

HINT **2. a. Identifying** What family of elements in the periodic table contains the most reactive metals?

HINT **b. Applying Concepts** What area of the periodic table is the best place to look for a metal that could be used to coat another metal to protect it from corrosion?

**c. Inferring** Period 4 of the periodic table contains the elements potassium, calcium, and copper. Which is the least reactive? HINT

**3. a. Describing** Describe the general process by which new elements are synthesized. HINT

**b. Applying Concepts** How is plutonium made? HINT

### Lab zone At-Home Activity

**Everyday Metals** Make a survey of compounds in your home that contain metals. Look at labels on foods, cooking ingredients, dietary supplements, medicines, and cosmetics. Also look for examples of how metals are used in your home, such as in cookware and wiring. Identify for your family the ways that the properties of metals make them useful in daily life.

**Lab zone** **Consumer Lab**

# Copper or Carbon? That Is the Question

S 8.7.c, 8.9.c

©

## Problem

Materials scientists work to find the best materials for different products. In this lab, you will look for an answer to the following problem: How do the properties of copper and graphite determine their uses? You will compare the properties of a copper wire and a pencil lead. Pencil lead is made mostly of graphite, a form of the nonmetal element carbon.

## Skills Focus

observing, classifying, controlling variables, drawing conclusions

## Materials

- 1.5-V dry cell battery
- 250-mL beaker • stopwatch
- flashlight bulb and socket
- 3 lengths of insulated wire
- thin copper wire with no insulation, about 5–6 cm long
- 2 graphite samples (lead from a mechanical pencil), each about 5–6 cm long
- hot plate
- water

## Procedure

1. Fill a 250-mL beaker about three-fourths full with water. Heat it slowly on a hot plate. Let the water continue to heat as you complete Part 1 and Part 2 of the investigation.

### PART 1 Physical Properties

2. Compare the shininess and color of your copper and graphite samples. Record your observations.
3. Bend the copper wire as far as possible. Next, bend one of the graphite samples as far as possible. Record the results of each test.

### PART 2 Electrical Conductivity

4. Place a bulb into a lamp socket. Use a piece of insulated wire to connect one pole of a dry cell battery to the socket, as shown in the photo below.
5. Attach the end of a second piece of insulated wire to the other pole of the dry cell battery. Leave the other end of this wire free.
6. Attach the end of a third piece of insulated wire to the other pole of the lamp socket. Leave the other end of this wire free.

©

7. Touch the free ends of the insulated wire to the ends of the copper wire. Record your observations of the bulb.
8. Repeat Step 7 using a graphite sample instead of the copper wire.

## PART 3 Thermal Conductivity

9. Turn off the hot plate.
10. Hold one end of a graphite sample between the fingertips of one hand. Hold one end of the copper wire between the fingertips of the other hand. **CAUTION:** *Be careful not to touch the beaker.*
11. Dip both the graphite and copper wire into the hot water at the same time. Allow only about 1 cm of each piece to reach under the water's surface. From your fingertips to the water, the lengths of both the graphite sample and the copper wire should be approximately equal.
12. Time how long it takes to feel the heat in the fingertips of each hand. Record your observations.

## Analyze and Conclude

1. **Observing** Compare the physical properties of copper and graphite that you observed.
2. **Classifying** Based on the observations you made in this lab, explain why copper is classified as a metal.
3. **Controlling Variables** What parameter was controlled in Step 11 of the procedure? Explain why it was important to control this parameter.
4. **Drawing Conclusions** Which of the two materials, graphite or copper, would work better to cover the handle of a frying pan? Explain your choice.
5. **Communicating** Write a paragraph explaining why copper is better than graphite for electrical wiring. Include supporting evidence from your observations in this lab.

## More to Explore

Research other uses of copper in the home and in industry. For each use, list the physical properties that make the material a good choice.

Section 4

# Nonmetals, Inert Gases, and Semimetals

CALIFORNIA **Standards Focus**

**S 8.7.a** Students know how to identify regions corresponding to metals, nonmetals, and inert gases.

**S 8.7.c** Students know substances can be classified by their properties, including their melting temperature, density, hardness, and thermal and electrical conductivity.

- What are the properties of nonmetals and inert gases?
- How are semimetals useful?

**Key Terms**

- nonmetal
- diatomic molecule
- halogen
- inert gas
- semimetal
- semiconductor

Lab zone **Standards Warm-Up**

### What Are the Properties of Charcoal?

1. Break off a piece of charcoal and roll it between your fingers. Record your observations.
2. Rub the charcoal on a piece of paper. Describe what happens.
3. Strike the charcoal sharply with the blunt end of a fork. Describe what happens.
4. When you are finished with your investigation, return the charcoal to your teacher and wash your hands.

**Think It Over**

**Classifying** Charcoal is a form of the element carbon. Would you classify carbon as a metal or a nonmetal? Use your observations from this activity to explain your answer.

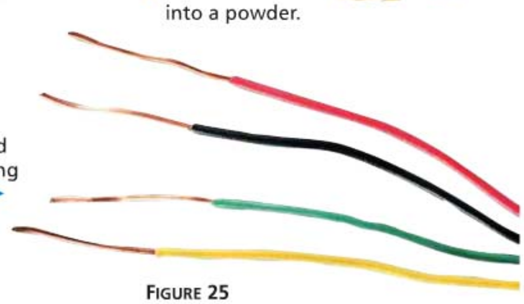
Life on Earth depends on certain nonmetals. For example, the air you breathe contains several nonmetals, including oxygen and nitrogen. And carbon, another nonmetal, is essential to the compounds that make up all living organisms.

Metals make up the majority of the elements in the periodic table. In this section you will learn about the other classes of elements—nonmetals, inert gases, and semimetals.

**These bears, the grass behind them, and all life on Earth are based on carbon, a nonmetal.** ▶

▲ A scuba diver's air tank contains mostly nitrogen and oxygen, which are gases at room temperature.

▲ Sulfur crumbles into a powder.



Nonmetals are good insulators. Carbon compounds are found in the plastic insulating these copper wires. ►

FIGURE 25
**Physical Properties of Nonmetals**
Nonmetals have properties that are the opposite of metals.
**Comparing and Contrasting** *Contrast the properties of these nonmetals with those of metals.*

## Properties of Nonmetals

A **nonmetal** is an element that lacks most of the properties of a metal. **Most nonmetals are poor conductors of electric current and heat. Solid nonmetals are dull and brittle.** Look at the periodic table again. All of the elements in light green-tinted boxes are nonmetals. Many of the nonmetals are common elements on Earth.

**Physical Properties** Four nonmetals are gases at room temperature. The air you breathe is mostly a mixture of two nonmetals, nitrogen (N) and oxygen (O). Other nonmetals, such as carbon (C), iodine (I), and sulfur (S), are solids at room temperature. Bromine (Br) is the only nonmetal that is liquid at room temperature.

Look at examples of nonmetals in Figure 25. In general, the physical properties of nonmetals are the opposite of those of the metals. Solid nonmetals are dull, meaning not shiny, and brittle, meaning not malleable or ductile. If you hit most solid nonmetals with a hammer, they break or crumble into a powder. Nonmetals are also poor conductors of heat and electric current.

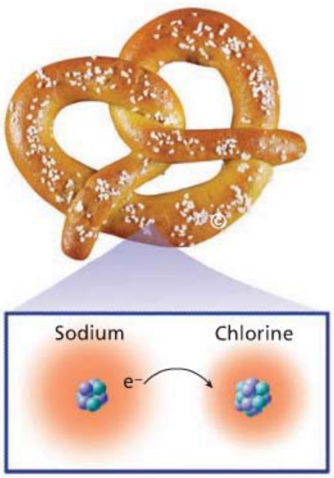



**FIGURE 26**
**Reactions of Nonmetals**
The table salt on a pretzel is mined from deposits found on Earth. The same compound can also be formed from a reaction between the metal sodium and the nonmetal chlorine.

**Chemical Properties** Atoms of nonmetals usually gain or share electrons when they react with other atoms. When nonmetals and metals react, electrons move from the metal atoms to the nonmetal atoms, as shown by the formation of salt, shown in Figure 26. Another example is rust—a compound made of iron and oxygen ($Fe_2O_3$). It's the reddish, flaky coating you might see on an old piece of steel or an iron nail.

Many nonmetals can also form compounds with other nonmetals. The atoms share electrons and become bonded together into molecules.

**Reading Checkpoint** **In which portion of the periodic table do you find nonmetals?**

## Families With Nonmetals

Look again at the periodic table. Notice that in Groups 14 through 17, there is a mix of nonmetals and other kinds of elements.

**The Carbon Family** Each element in the carbon family has atoms that can gain, lose, or share four electrons when reacting with other elements. In Group 14, only carbon is a nonmetal. What makes carbon especially important is its role in the chemistry of life. Molecules containing long chains of carbon atoms are found in all living things.

Most of the fuels that are burned to yield energy contain carbon. Coal, for example, is mostly the element carbon. Gasoline is made from crude oil, a mixture of carbon compounds with chains of 5 to 50 or more carbon atoms in their molecules.

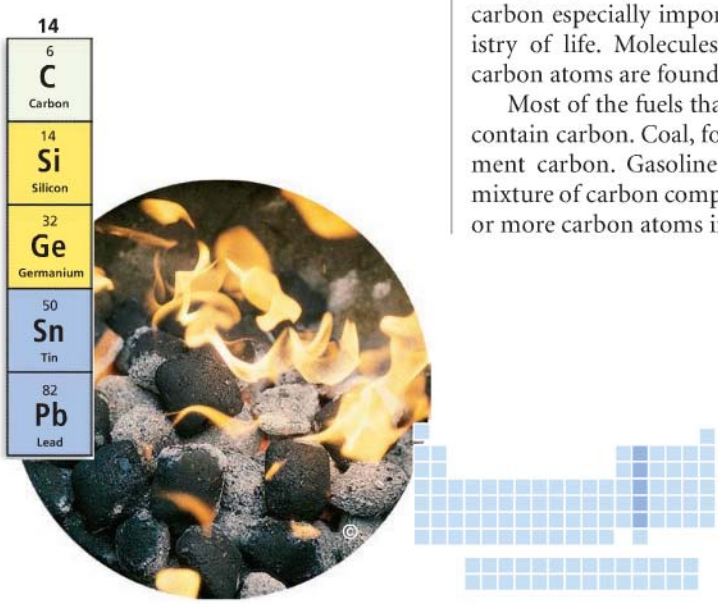



**FIGURE 27**
**Carbon**
Charcoal is one form of carbon, the only nonmetal in Group 14.

**The Nitrogen Family** Group 15, the nitrogen family, contains two nonmetals, nitrogen and phosphorus. These nonmetals usually gain or share three electrons when reacting with other elements.

Earth's atmosphere is almost 80 percent nitrogen gas. Nitrogen occurs in nature as $N_2$, which is a diatomic molecule. A **diatomic molecule** is a molecule that consists of two atoms. In this form, nitrogen is not very reactive. Although living things need nitrogen, most of them are unable to use nitrogen from the air. However, certain kinds of bacteria can use this nitrogen to form compounds. This process is called nitrogen fixation. Plants can then take up these nitrogen compounds formed in the soil by the bacteria. Farmers also add nitrogen compounds to the soil in the form of fertilizers. Like all animals, you get the nitrogen you need from the food you eat—from plants, or from animals that ate plants.

Even though nitrogen and carbon appear next to each other on the periodic table, they have very different properties. Carbon is a solid up to very high temperatures (3,600°C). Nitrogen is a gas until it is cooled below −196°C. This illustrates how just a slight change in atomic structure can result in dramatically different properties.

Phosphorus is the other nonmetal in the nitrogen family. Phosphorus is much more reactive than nitrogen, so phosphorus in nature is always found in compounds.

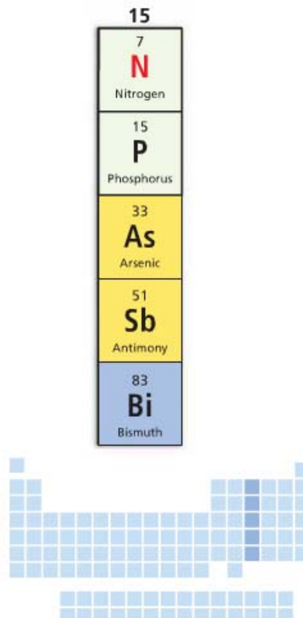



FIGURE 28
## The Nitrogen Family
Nitrogen and phosphorus are grouped in the same family of the periodic table, Group 15. **Making Generalizations** *How do atoms of both these elements change when they react?*

▼ Nitrogen is a key ingredient of fertilizers.


▲ Match heads contain a highly reactive phosphorus compound that ignites easily.

## Lab zone Try This Activity

### Show Me the Oxygen

How can you test for the presence of oxygen?

1. Pour about a 3-cm depth of hydrogen peroxide ($H_2O_2$) into a test tube.
2. Add a pea-sized amount of manganese dioxide ($MnO_2$) to the test tube.
3. Observe the test tube for about 1 minute.
4. When instructed by your teacher, set a wooden splint on fire.
5. Blow the splint out after 5 seconds and immediately plunge the glowing splint into the mouth of the test tube. Avoid getting the splint wet.

**Observing** Describe the change in matter that occurred in the test tube. What evidence indicates that oxygen was produced?

**The Oxygen Family** Group 16, the oxygen family, contains three nonmetals—oxygen, sulfur, and selenium. These elements usually gain or share two electrons when reacting with other elements.

You are using oxygen right now. With every breath, oxygen travels into your lungs. There, it is absorbed into your bloodstream, which distributes it all over your body. You could not live without a steady supply of oxygen. Like nitrogen, the oxygen you breathe is a diatomic molecule ($O_2$). In addition, oxygen sometimes forms a triatomic (three-atom) molecule, which is called ozone ($O_3$). Ozone collects in a layer in the upper atmosphere, where it screens out harmful radiation from the sun. However, ozone is a dangerous pollutant at ground level because it is highly reactive.

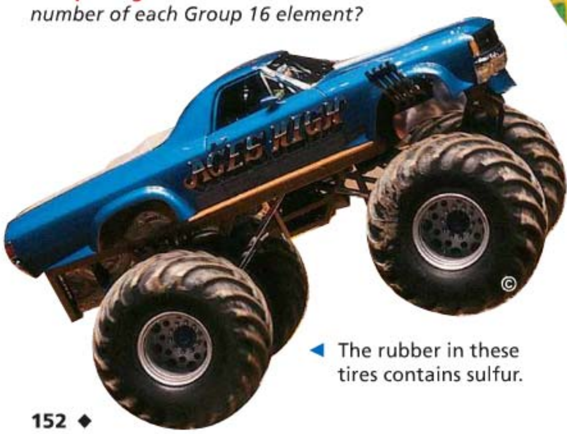
Because oxygen is highly reactive, it can combine with almost every other element. It also is the most abundant element in Earth's crust and the second-most abundant element in the atmosphere. (The first is nitrogen.)

Sulfur is the other common nonmetal in the oxygen family. If you have ever smelled the odor of a rotten egg, then you are already familiar with the smell of some sulfur compounds. Sulfur is used in the manufacture of rubber for rubber bands and automobile tires. Most sulfur is used to make sulfuric acid ($H_2SO_4$), one of the most important chemicals used in industry.

**FIGURE 29**

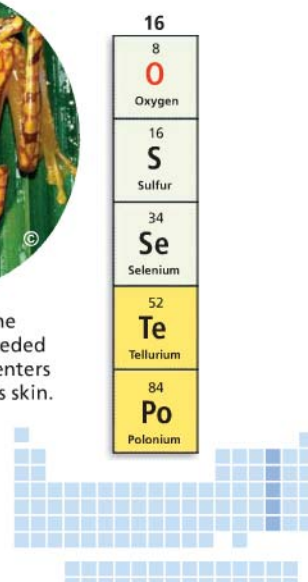
### The Oxygen Family

The nonmetals oxygen and sulfur are the most common elements in Group 16.
**Interpreting Tables** *What is the atomic number of each Group 16 element?*



◀ The rubber in these tires contains sulfur.

▲ Some of the oxygen needed by a frog enters through its skin.



**The Halogen Family** Group 17 contains fluorine, chlorine, bromine, iodine, and astatine. These elements are also known as the **halogens,** which means "salt forming." All but astatine are nonmetals. A halogen atom typically gains or shares one electron when it reacts with other elements.

All of the halogens are very reactive, and the uncombined elements are dangerous to humans. Fluorine is so reactive that it reacts with almost every other known substance. Even water and powdered glass will burn in fluorine. Chlorine gas is extremely dangerous, but it is used in small amounts to kill bacteria in water supplies.

Though the halogen elements are dangerous, many of the compounds that halogens form are quite useful. Compounds of carbon and fluorine make up the nonstick coating on cookware. Small amounts of fluorine compounds that are added to water supplies help prevent tooth decay. Chlorine is one of the elements in ordinary table salt (the other is sodium). Another salt of chlorine, calcium chloride, is used to help melt ice on roads and walkways. Bromine reacts with silver to form silver bromide, which is used in photographic film.

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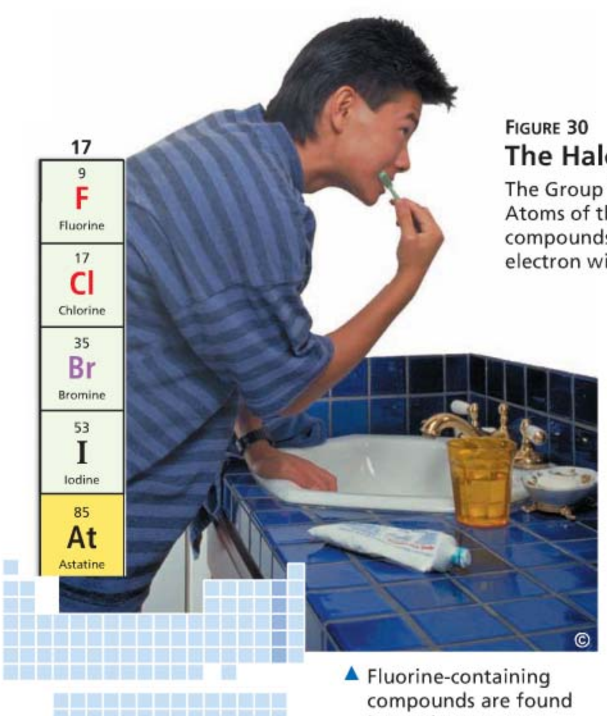
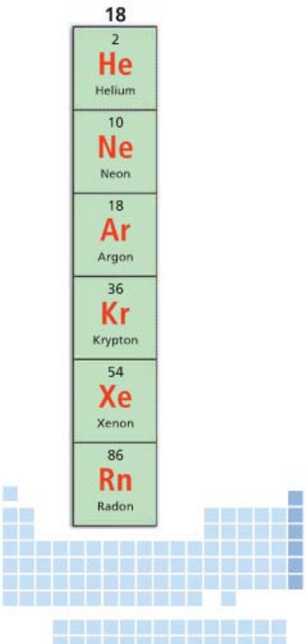
FIGURE 30
**The Halogens**
The Group 17 elements are very reactive. Atoms of these elements easily form compounds by sharing or gaining one electron with atoms of other elements.




▲ Fluorine-containing compounds are found in toothpaste.

◀ Bromine is highly reactive, and will burn skin on contact.


**FIGURE 31**
**The Inert Gases**
Electric current makes the Group 18 elements glow brightly inside glass tubes. **Applying Concepts** *Why are neon and the other noble gases so unreactive?*




## Inert Gases

The elements in Group 18 are the **inert gases.** The inert gases do not ordinarily form compounds because atoms of inert gases do not usually gain, lose, or share electrons. **The inert gases tend to be unreactive.** Despite the name, the inert gases are not truly inert. Scientists have been able to synthesize some inert gas compounds in the laboratory. The inert gases are also known as noble gases.

All the inert gases exist in Earth's atmosphere, but only in small amounts. Because they are so unreactive, the inert gases were not discovered until the late 1800s. You have probably seen a floating balloon filled with helium, an inert gas. Inert gases are also used in glowing electric lights. These lights are commonly called neon lights, even though they are often filled with argon, xenon, or other inert gases.

**Reading Checkpoint** **What is another name for the inert gases?**

## Hydrogen

Alone in the upper left corner of the periodic table is hydrogen—the element with the simplest atoms. Most hydrogen atoms have one proton and one electron. Some hydrogen atoms also have neutrons. Because the chemical properties of hydrogen differ very much from those of the other elements, it really cannot be grouped into a family. Although hydrogen makes up more than 90 percent of the atoms in the universe, it makes up only 1 percent of the mass of Earth's crust, oceans, and atmosphere. Hydrogen is rarely found on Earth as a pure element. Most hydrogen is combined with oxygen in water ($H_2O$).


**FIGURE 32**
**Importance of Hydrogen**
Water is a compound of hydrogen and oxygen.
Without liquid water, life on Earth would be impossible.

## Semimetals

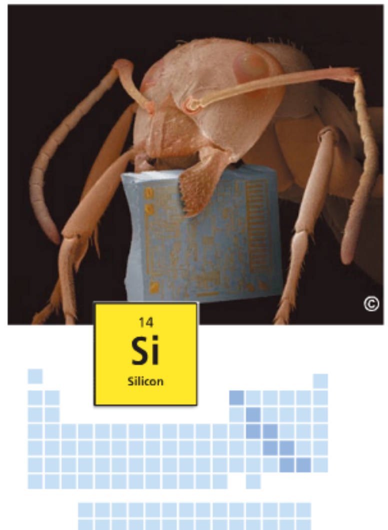
Between the metals and the nonmetals in the periodic table lie the semimetals. These elements are listed in the yellow squares in the periodic table. **Semimetals** have some properties of metals but also have properties that are typical of nonmetals. All semimetals are solids at room temperature. They are brittle, hard, and somewhat reactive.

The most common semimetal is silicon (Si). Silicon combines with oxygen to form silicon dioxide ($SiO_2$). Ordinary sand, which is mostly $SiO_2$, is the main component of glass. A compound of boron (B) and oxygen is added during the process of glassmaking to make heat-resistant glass. Compounds of boron are also used in some cleaning materials.

**The most useful property of the semimetals is their varying ability to conduct electric current.** The electrical conductivity of a semimetal can depend on temperature, exposure to light, or the presence of impurities. Semimetals are examples of **semiconductors**, or substances that can conduct electric current under some conditions but not under other conditions. Silicon, germanium (Ge), and arsenic (As) are common semiconductor materials. Semiconductors are used to make computer chips, transistors, and lasers.

Reading Checkpoint What is the most common semimetal?

FIGURE 33
**Silicon**
A silicon computer chip is dwarfed by an ant, but the chip's properties as a semiconductor make it a powerful part of modern computers.




## Section 4 Assessment

S 8.7.a, 8.7.c,
E-LA: Reading 8.1.2

**Vocabulary Skill** Greek Word Origins How does knowing the meaning of the Greek word *hals* help you remember the word *halogen?*

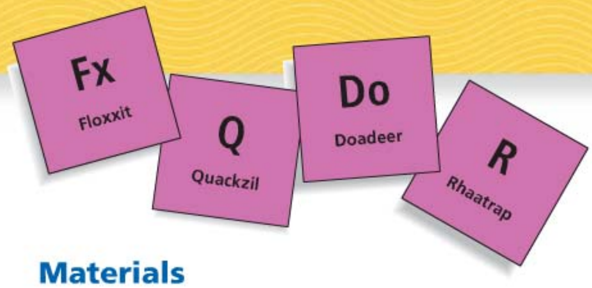
### Reviewing Key Concepts

1. a. Listing What are some properties of nonmetals?
   b. Making Generalizations What happens to the atoms of most nonmetals when they react with other elements?
   c. Comparing and Contrasting How do the physical and chemical properties of the halogens compare with those of the inert gases?
2. a. Identifying Where in the periodic table are the semimetals found?
   b. Describing What are three uses of semimetals?
   c. Applying Concepts What property makes semimetals useful as "switches" to turn a small electric current on and off?

### Lab zone At-Home Activity

**Halogen Hunt** Identify compounds in your home that contain halogens. Look at labels on foods, cooking ingredients, cleaning materials, medicines, and cosmetics. The presence of a halogen is often indicated by the words *fluoride, chloride, bromide,* and *iodide* or the prefixes *fluoro-, chloro-, bromo-,* and *iodo-*. Show your family these examples and describe properties of the halogens.

Lab zone **Skills Lab**




# Alien Periodic Table

S 8.7.a, 8.9

## Problem

Imagine that inhabitants of another planet send a message to Earth that contains information about 30 elements. However, the message contains different names and symbols for these elements than those used on Earth. Which elements on the periodic table do these "alien" names represent?

## Skills Focus

drawing conclusions, classifying, interpreting data, inferring

## Materials

- ruler
- periodic table from text for reference

## Procedure

1. Copy the blank periodic table on the next page into your notebook.
2. Listed below are data on the chemical and physical properties of the 30 elements. Place the elements in their proper position in the blank periodic table.

### Alien Elements

The inert gases are **bombal** (Bo), **wobble** (Wo), **jeptum** (J), and **logon** (L). Among these gases, wobble has the greatest atomic mass and bombal the least. Logon is lighter than jeptum.

The most reactive group of metals are **xtalt** (X), **byyou** (By), **chow** (Ch), and **quackzil** (Q). Of these metals, chow has the lowest atomic mass. Quackzil is in the same period as wobble.

**Apstrom** (A), **vulcania** (V), and **kratt** (Kt) are nonmetals whose atoms typically gain or share one electron. Vulcania is in the same period as quackzil and wobble.

The semimetals are **ernst** (E), **highho** (Hi), **terriblum** (T), and **sississ** (Ss). Sississ is the semimetal with the greatest atomic mass. Ernst is the semimetal with the lowest atomic mass. Highho and terriblum are in Group 14. Terriblum has more protons than highho. **Yazzer** (Yz) touches the zigzag line, but it's a metal, not a semimetal.

The lightest element of all is called **pfsst** (Pf). The heaviest element in the group of 30 elements is **eldorado** (El). The most chemically active nonmetal is apstrom. Kratt reacts with byyou to form table salt.

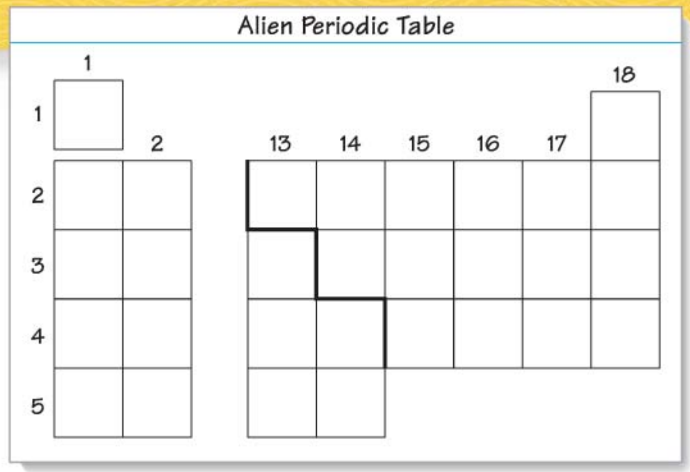
The element **doggone** (D) has only 4 protons in its atoms.

**Floxxit** (Fx) is important in the chemistry of life. It forms compounds made of long chains of atoms. **Rhaatrap** (R) and **doadeer** (Do) are metals in the fourth period, but rhaatrap is less reactive than doadeer.

**Magnificon** (M), **goldy** (G), and sississ are all members of Group 15. Goldy has fewer electrons than magnificon.

**Urrp** (Up), **oz** (Oz), and **nuutye** (Nu) all gain 2 electrons when they react. Nuutye is found as a diatomic molecule and has the same properties as a gas found in Earth's atmosphere. Oz has a lower atomic number than urrp.

The element **anatom** (An) has atoms with a total of 49 electrons. **Zapper** (Z) and **pie** (Pi) lose two electrons when they react. Zapper is used to make lightweight alloys.




## Analyze and Conclude

1. **Drawing Conclusions** List the Earth names for the 30 alien elements in order of atomic number.
2. **Classifying** Were you able to place some elements within the periodic table with just a single clue? Explain using examples.
3. **Interpreting Data** Why did you need two or more clues to place other elements? Explain using examples.
4. **Inferring** Why could you use clues about atomic mass to place elements, even though the table is now based on atomic numbers?
5. **Communicating** Write a paragraph describing which groups of elements are not included in the alien periodic table. Explain whether or not you think it is likely that an alien planet would lack these elements.

## More to Explore

Notice that Period 5 is incomplete on the alien periodic table. Create names and symbols for each of the missing elements. Then, compose a series of clues that would allow another student to identify these elements. Make your clues as precise as possible.

▼ Radio telescopes in New Mexico

Section 5

Integrating Technology

# Radioactive Elements

CALIFORNIA Standards Focus

**S 8.7.b** Students know each element has a specific number of protons in the nucleus (the atomic number) and each isotope of the element has a different but specific number of neutrons in the nucleus.

- How was radioactivity discovered?
- What types of particles and energy can radioactive decay produce?
- In what ways are radioactive isotopes useful?

## Key Terms

- radioactive decay
- radioactivity
- alpha particle
- beta particle
- gamma radiation
- tracer

Lab zone **Standards Warm-Up**

### What Happens When an Atom Decays?

1. Using green beads to represent protons and purple beads to represent neutrons, make a model of a beryllium-8 nucleus. Your model should contain 4 protons and 4 neutrons.
2. Beryllium-8 is an unstable isotope of the element beryllium. Its atoms can undergo decay by losing a particle made of two protons and two neutrons. Remove the appropriate number of beads from your model to represent this process.
3. Count the number of protons and neutrons left in your model.

**Think It Over**

**Drawing Conclusions** What element does your nuclear model now represent? How do you know? What is the mass number of the new model nucleus?

What if you could find a way to turn dull, cheap lead metal into valuable gold? More than a thousand years ago, many people thought it was a great idea, too. They tried everything they could think of. However, nothing worked. There is no chemical reaction that converts one element into another. Even so, elements do sometimes change into other elements. For example, atoms of carbon can become atoms of nitrogen. (But lead never changes into gold, unfortunately!) How is it possible for these changes to happen?

**FIGURE 34**
**Trying to Make Gold From Lead**
This painting from 1570 shows people trying to change lead into gold. No such chemical reaction was ever accomplished.

## Radioactivity

Remember that atoms with the same number of protons and different numbers of neutrons are called isotopes. Some isotopes are unstable; that is, their nuclei do not hold together well. In a process called **radioactive decay**, the atomic nuclei of unstable isotopes release fast-moving particles and energy.

### Discovery of Radioactivity

**In 1896, the French scientist Henri Becquerel discovered the effects of radioactive decay by accident while studying a mineral containing uranium.** He observed that with exposure to sunlight, the mineral gave off a penetrating energy that could expose film. Becquerel assumed that sunlight was necessary for the energy release. So, when the weather turned cloudy, he put away his materials in a dark desk drawer, including a sample of the mineral placed next to a photographic plate wrapped in paper.

Later, when Becquerel opened his desk to retrieve these items, he was surprised to find an image of the mineral on the photographic plate. Sunlight wasn't necessary at all. Becquerel hypothesized that uranium spontaneously gives off energy, called radiation, all the time.

Becquerel presented his findings to a young researcher, Marie Curie, and her husband, Pierre. After further study, the Curies concluded that a reaction was taking place within the uranium nuclei. The uranium showed a property of being able to spontaneously emit radiation. Marie Curie called this property **radioactivity.**

### Polonium and Radium

Marie Curie was surprised to find that some minerals containing uranium were even more radioactive than pure uranium. Suspecting that the minerals contained small amounts of other, highly radioactive elements, the Curies set to work. They eventually isolated two new elements, which Marie named polonium and radium.

**Reading Checkpoint** **What is radioactivity?**

**FIGURE 35**
**Radiation From Uranium**
As with Becquerel's discovery, radiation from the uranium-containing mineral has exposed the photographic film.

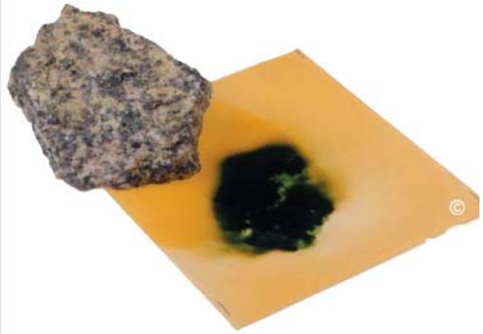


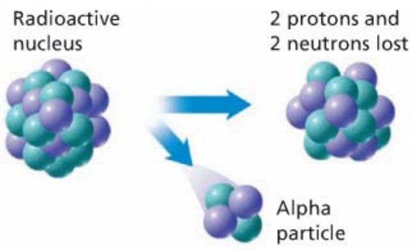
**FIGURE 36**
**Marie Curie**
Marie Curie, her husband Pierre, and Henri Becquerel pioneered the study of radioactive elements.

FIGURE 37

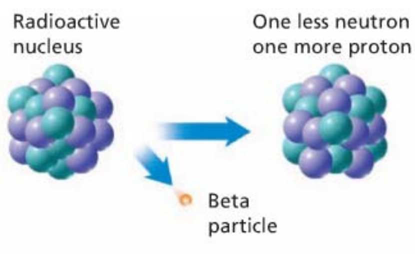
### Radioactive Decay

Radioactive elements give off particles and energy during radioactive decay. **Interpreting Diagrams** *Which type of radioactive decay produces a negatively charged particle?*

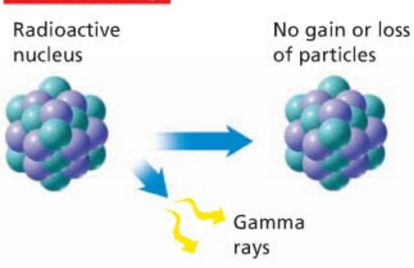
**Alpha Decay**




**Beta Decay**




**Gamma Decay**




## Types of Radioactive Decay

There are three major forms of radiation produced during the radioactive decay of an unstable nucleus. **Radioactive decay can produce alpha particles, beta particles, and gamma rays.** The particles and energy produced during radioactive decay are forms of nuclear radiation.

**Alpha Decay** An **alpha particle** consists of two protons and two neutrons and is positively charged. It is the same as a helium nucleus. The release of an alpha particle by an atom decreases the atomic number by 2 and the mass number by 4. For example, a thorium-232 nucleus (atomic number 90) decays to produce an alpha particle and a radium-228 nucleus (atomic number 88).

**Beta Decay** Some atoms are unstable because they have too many neutrons. During beta decay, a neutron inside the nucleus of an unstable atom changes into a negatively charged beta particle and a proton. A **beta particle** is a fast-moving electron given off by a nucleus during radioactive decay. The new proton remains inside the nucleus. That means that the nucleus now has one less neutron and one more proton. Its mass number remains the same but its atomic number increases by 1. For example, a carbon-14 nucleus decays to produce a beta particle and a nitrogen-14 nucleus.

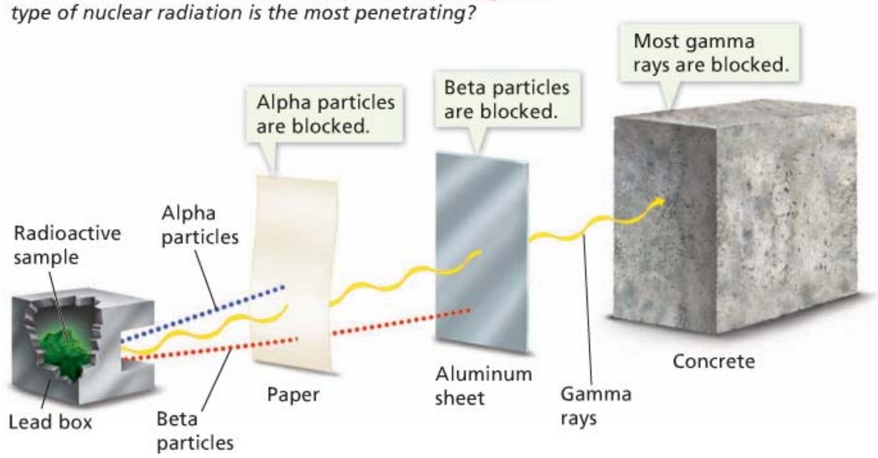
**Gamma Decay** Alpha and beta decay are almost always accompanied by gamma radiation. **Gamma radiation** consists of high-energy waves, similar to X-rays. Gamma radiation (also called gamma rays) has no charge and does not cause a change in either the atomic mass or the atomic number.

**Effects of Nuclear Radiation** Although alpha particles move very fast, they are stopped by collisions with atoms. In Figure 38, you can see that alpha particles are blocked by a sheet of paper. Alpha radiation can cause an injury to human skin that is much like a bad burn.

FIGURE 38

**The Penetrating Power of Nuclear Radiation**

The three types of nuclear radiation were named based on how easily each one could be blocked. Alpha, beta, and gamma are the first three letters of the Greek alphabet. **Inferring** *Which type of nuclear radiation is the most penetrating?*




Beta particles are much faster and more penetrating than alpha particles. They can pass through paper, but they are blocked by an aluminum sheet 5 millimeters thick. Beta particles can also travel into the human body and damage its cells.

Gamma rays are the most penetrating type of radiation. You would need a piece of lead several centimeters thick or a concrete wall about a meter thick to stop gamma rays. They can pass right through a human body, delivering intense energy to cells and causing severe damage.

**Reading Checkpoint** **How can alpha radiation affect the body?**

## Using Radioactive Isotopes

Radioactive isotopes have many uses in science and industry. In some cases, the energy released by radioactive isotopes is itself useful. Nuclear power plants, for example, harness this energy to generate electricity. In other cases, radiation is useful because it can be easily detected. **Uses of radioactive isotopes include tracing the steps of chemical reactions and industrial processes, and diagnosing and treating disease.**

**Lab zone Skills Activity**

### Predicting

Look at the table of radioactive isotopes below.

| Isotope | Type of Decay |
|---|---|
| Uranium-238 | Alpha |
| Nickel-63 | Beta |
| Iodine-131 | Beta |
| Radium-226 | Alpha |

With the help of a periodic table, predict the element that forms in each case. Explain your reasoning.

Go Online active art

For: Radioactive Tracers activity
Visit: PHSchool.com
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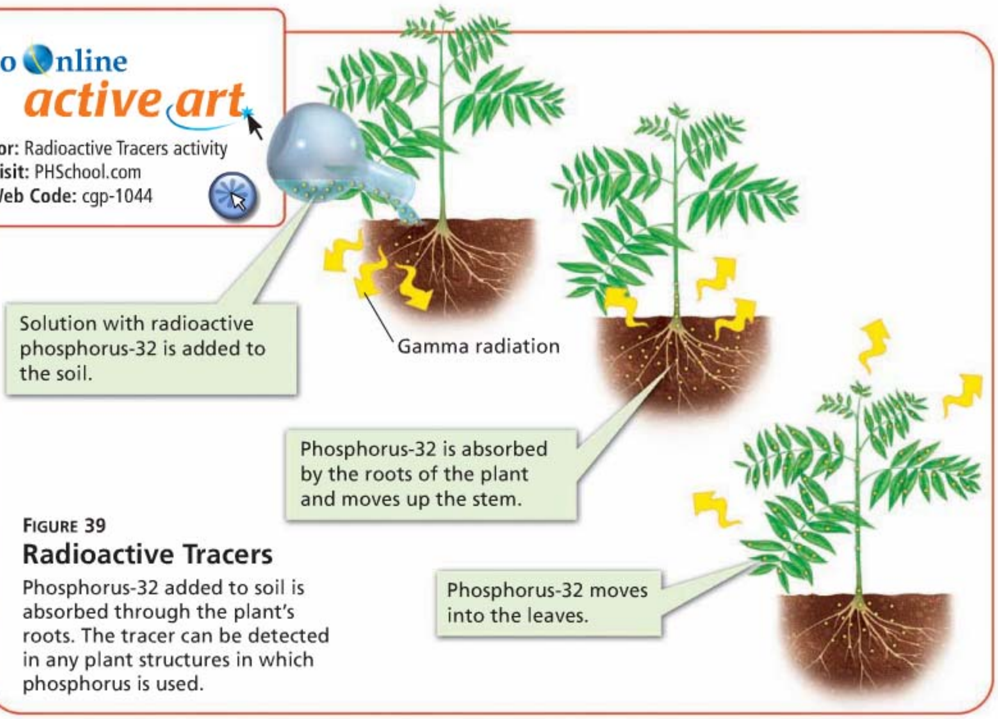



FIGURE 39
**Radioactive Tracers**
Phosphorus-32 added to soil is absorbed through the plant's roots. The tracer can be detected in any plant structures in which phosphorus is used.

**Uses in Science and Industry** Like a lighthouse flashing in the night, a radioactive isotope "signals" where it is by emitting radiation that can be detected. **Tracers** are radioactive isotopes that can be followed through the steps of a chemical reaction or an industrial process. Tracers behave chemically the same way as nonradioactive forms of an element. For example, phosphorus is used by plants in small amounts for healthy growth. As shown in Figure 39, a plant will absorb radioactive phosphorus-32 added to the soil just as it does the nonradioactive form. Radiation will be present in any part of the plant that contains the isotope. In this way, biologists can learn where and how plants use phosphorus.

In industry, tracers are used to find weak spots in metal pipes, especially oil pipelines. When added to a liquid, tracers can easily be detected if they leak out of the pipes. Gamma rays can pass through metal and be detected on a photographic film. By looking at the gamma-ray images, structural engineers can detect small cracks in the metal of bridges and building frames. Without these images, a problem might not be discovered until a disaster occurs.

Reading Checkpoint **What is a tracer?**

**Uses in Medicine** Doctors use radioactive isotopes to detect medical problems and to treat some diseases. Tracers injected into the body travel to organs and other structures where that chemical is normally used. Using equipment that detects radiation, technicians make images of the bone, blood vessel, or organ affected. For example, tracers made with technetium-99 are used to diagnose problems in the bones, liver, kidneys, and digestive system.

In a process called radiation therapy, radioactive elements are used to destroy unhealthy cells. For example, iodine-131 is given to patients with tumors of the thyroid gland—a gland in the neck that controls the rate at which nutrients are used. Because the thyroid gland uses iodine, the radioactive iodine-131 collects in the gland. Radiation from this isotope destroys unwanted cells in the gland without serious effects on other parts of the body.

Cancer tumors of different kinds often are treated from outside the body with high-energy gamma rays. Many hospitals use cobalt-60 for this purpose. When gamma radiation is directed toward a cancer tumor, it causes changes that kill the cancer cells.


FIGURE 40
**Radioactive Isotopes in Medicine**
Front and back body scans of a healthy patient were made using a radioactive isotope.

## Section 5 Assessment

S 8.7.b, E-LA: Reading 8.1.2, Writing 8.2.1

**Vocabulary Skill** **Greek Word Origins** Use what you know about the Greek words *alpha* and *beta* to explain the meanings of *alpha particle* and *beta particle.*

### Reviewing Key Concepts

HINT **1. a. Identifying** Under what circumstances did Becquerel first notice the effects of radioactivity?

HINT **b. Interpreting Photographs** Look at the photo in Figure 35. Explain in your own words what happened.

HINT **c. Applying Concepts** How did Becquerel's work lead to the discovery of two new elements?

HINT **2. a. Listing** What are three products of radioactive decay?

HINT **b. Comparing and Contrasting** Contrast the penetrating power of the three major types of nuclear radiation.

**c. Predicting** Predict the identity and mass number of the nucleus formed during the beta decay of magnesium-28. HINT

**3. a. Explaining** How can radioactive isotopes be used as tracers? HINT

**b. Relating Cause and Effect** How is the use of radioactive isotopes in treating some forms of cancer related to certain properties of gamma radiation? HINT

### Writing in Science

**Firsthand Account** Suppose you could go back in time to interview Henri Becquerel on the day of his discovery of radioactivity. From his perspective, write an account of the discovery.

# Chapter 4 Study Guide

**The BIG Idea** The organization of the periodic table is based on the properties of the elements and reflects the structure of atoms.

## 1 Introduction to Atoms

**Key Concepts** S 8.3.a, 8.7.b

- Atomic theory grew as a series of models based on evidence. As more evidence was collected, the theory and models were revised.
- At the center of the atom is a tiny, massive nucleus containing protons and neutrons. It is surrounded by a cloudlike region of electrons.

**Key Terms**

| | | |
|---|---|---|
| atom | proton | atomic number |
| electron | energy level | isotope |
| nucleus | neutron | mass number |

## 2 Organizing the Elements

**Key Concepts** S 8.7.a

- Mendeleev noticed a pattern of properties in elements arranged by increasing atomic mass.
- The properties of an element can be predicted from its location in the periodic table.
- The periodic table lists each element's atomic number, symbol, name, and atomic mass.

**Key Terms**

| | |
|---|---|
| atomic mass | group |
| periodic table | chemical symbol |
| period | |

## 3 Metals

**Key Concepts** S 8.7.a, 8.7.c

- Physical properties of metals include luster, malleability, ductility, and conductivity.
- The reactivity of metals tends to decrease from left to right across the periodic table.
- Scientists make synthetic elements by forcing nuclear particles to crash into one another.

**Key Terms**

| | |
|---|---|
| metal | corrosion |
| malleable | alkali metal |
| ductile | alkaline earth metal |
| thermal conductivity | transition metal |
| electrical conductivity | particle accelerator |
| reactivity | |

## 4 Nonmetals Inert Gases, and Semimetals

**Key Concepts** S 8.7.a, 8.7.c

- Most nonmetals are poor conductors of heat and electric current. Solid nonmetals are dull and brittle.
- The inert gases tend to be unreactive.
- The most useful property of the semimetals is their varying ability to conduct electric current.

**Key Terms**

| | |
|---|---|
| nonmetal | inert gas |
| diatomic molecule | semimetal |
| halogen | semiconductor |

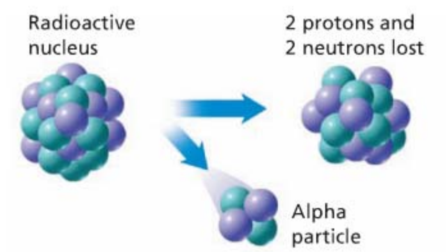
## 5 Radioactive Elements

**Key Concepts** S 8.7.b

- In 1896, the French scientist Henri Becquerel discovered radioactive decay quite by accident while studying a mineral containing uranium.
- Natural radioactive decay can produce alpha particles, beta particles, and gamma rays.
- Uses of radioactive isotopes include tracing the steps of chemical reactions and industrial processes, and diagnosing and treating disease.

**Key Terms**

| | |
|---|---|
| radioactive decay | beta particle |
| radioactivity | gamma radiation |
| alpha particle | tracer |



# Review and Assessment

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## Target Reading Skill

**Preview Visuals** Complete the following graphic organizer to show that you understand Figure 37 on page 160. Add more questions and answers as needed.

**Radioactive Decay**

**Q.** What process does the art show?

**A.**

**Q.** Why are there three similar diagrams?

**A.**

**Q.** What do the arrows show?

**A.**

## Reviewing Key Terms

**Choose the letter of the best answer.**

HINT
**1.** The atomic number of an atom is determined by the number of
**a.** protons.
**b.** electrons.
**c.** neutrons.
**d.** isotopes.

HINT
**2.** The horizontal rows in the periodic table are called
**a.** groups.
**b.** periods.
**c.** nonmetals.
**d.** metals.

HINT
**3.** Of the following, the group that contains elements that are the most reactive is the
**a.** alkali metals.
**b.** alkaline earth metals.
**c.** carbon family.
**d.** inert gases.

HINT
**4.** Unlike metals, solid nonmetals are
**a.** good conductors of heat and electric current.
**b.** malleable.
**c.** dull and britttle.
**d.** ductile.

HINT
**5.** Unstable atomic nuclei that release fast-moving particles and energy are
**a.** radioactive.
**b.** alloys.
**c.** isotopes.
**d.** alpha particles.

**Complete the following sentences so that your answers clearly explain the key terms.**

HINT
**6.** Carbon-12 and carbon-13 are examples of **isotopes,** or __________ .

HINT
**7.** Dmitri Mendeleev constructed the first **periodic table,** which is ______________ .

HINT
**8.** A property of metals is high **thermal conductivity,** which means ______________ .

HINT
**9.** Germanium is an example of a **semimetal,** an element whose properties are __________ .

HINT
**10.** Uranium and radon share the property of **radioactivity,** which means ___________ .

## Writing in Science

**News Report** Imagine you are writing an article for a space magazine about the life cycle of a star. Which elements are produced in a star at different stages? How are these elements distributed into space?

**Video Assessment**
**Discovery Channel School**
*Elements and the Periodic Table*

# Review and Assessment

## Checking Concepts

**11.** What discoveries about the atom did Rutherford make from his team's experiments?

**12.** How do two isotopes of an element differ from one another? How are they similar?

**13.** Use the periodic table to find the atomic number and atomic mass of neon (Ne).

**14.** Use the periodic table to name two elements that have properties similar to those of chlorine (Cl).

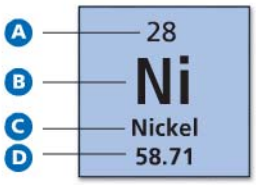
**15.** Of the elements oxygen (O), zinc (Zn), and iodine (I), which one is likely to be a poor conductor of electricity and a brittle solid at room temperature?

**16.** What properties of radioactive isotopes make them useful?

## Thinking Critically

**17. Comparing and Contrasting** List the three kinds of particles that make up atoms, and compare their masses and their locations in an atom.

**18. Applying Concepts** Below is a square taken from the periodic table. Identify the type of information given by each labeled item.




**19. Relating Cause and Effect** The atomic mass of iron is 55.847 amu. Why isn't this value a whole number?

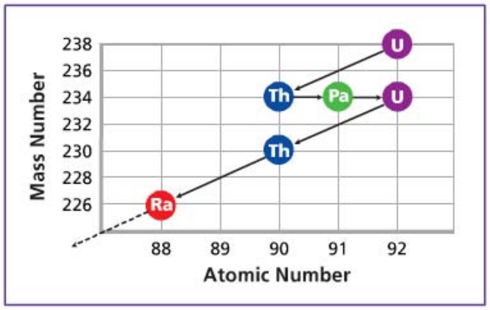
**20. Predicting** Using the periodic table, predict which element—potassium, iron, or aluminum—is most reactive. Explain.

**21. Inferring** What property of the materials used in computer chips makes them useful as switches that turn electricity on and off?

## Applying Skills

**Use the diagram to answer Questions 22–27.**

*The diagram below shows the first few steps of the radioactive decay of uranium-238.*




**22. Reading Graphs** What do the numbers on the *x*-axis and *y*-axis tell you about atomic particles in the nuclei of the isotopes?

**23. Interpreting Data** How many elements are in the diagram? How many different isotopes of each element are there?

**24. Classifying** What type of radioactive decay resulted in uranium-238 becoming thorium-234? How do you know?

**25. Interpreting Diagrams** Describe how thorium-234 is changed into uranium-234.

**26. Inferring** How do you know from the diagram that thorium-230 is radioactive?

**27. Posing Questions** What information would you need to have in order to extend the graph to show how radon-226 changes?

## Lab zone Standards Investigation

**Performance Assessment** Display the chart showing the metals you studied. Be ready to discuss which properties are common to all metals. Describe other properties of metals you could not test. List all the properties that could be used to find out whether an unknown element is a metal.

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# Standards Practice

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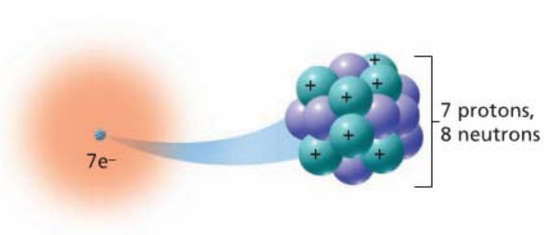
**Choose the letter of the best answer.**

**1.** Why is the mass of a carbon atom greater than the total mass of its protons and electrons?
**A** The mass of a proton is greater than the mass of an electron.
**B** A proton is positively charged and an electron is negatively charged.
**C** Most of the atom's volume is the sphere-shaped cloud of electrons.
**D** One or more neutrons in the nucleus add mass to the atom. **S 8.3.a**

**2.** Elements that are shiny conductive solids at room temperature are likely to be classified as which of the following?
**A** metals
**B** nonmetals
**C** inert gases
**D** semimetals **S 8.7.c**

**Use the diagram below to answer Question 3.**




**3.** What isotope does the diagram represent?
**A** carbon-12
**B** nitrogen-14
**C** nitrogen-15
**D** oxygen-15 **S 8.7.b**

**4.** Which property of aluminum makes it a suitable metal for soft drink cans?
**A** It has good electrical conductivity.
**B** It can be hammered into a thin sheet (malleability).
**C** It can be drawn into long wires (ductility).
**D** It can reflect light (shininess). **S 8.7.c**

**Use the table below to answer Questions 5–7.**

| | | |
|---|---|---|
| 8 **O** Oxygen 15.999 | 9 **F** Fluorine 18.998 | 10 **Ne** Neon 20.179 |
| 16 **S** Sulfur 32.06 | 17 **Cl** Chlorine 35.453 | 18 **Ar** Argon 39.948 |

**5.** What element has an atomic number of 18?
**A** hydrogen
**B** oxygen
**C** fluorine
**D** argon **S 8.7.b**

**6.** An atom of fluorine has 10 neutrons. What is the total number of other subatomic particles in this atom?
**A** 9 protons and 9 electrons
**B** 9 protons and 19 electrons
**C** 10 protons and 10 electrons
**D** 19 protons and 19 electrons **S 8.3.a**

**7.** Which elements are inert gases?
**A** oxygen, fluorine, and neon
**B** sulfur, chlorine, and argon
**C** oxygen, fluorine, and chlorine
**D** neon and argon **S 8.7.a**

## Apply the BIG Idea

**8.** Suppose scientists synthesized a new element with the atomic number 120. Use what you know about the organization of the periodic table to predict the properties of this new element. **S 8.7**

# Chemical Building Blocks
## Unit 1 Review

Chapter 1
### Introduction to Physical Science
The BIG Idea

**Scientists investigate the natural world by posing questions, developing hypotheses, designing experiments, analyzing data, drawing conclusions, and communicating results.**

- What do physical scientists study?
- What role do models, theories, and laws play in science?
- Why do scientists use a standard system of measurement?
- What should you do if a lab accident occurs?

Chapter 2
### The Nature of Matter
The BIG Idea

**Chemistry is the study of the properties of matter and how matter changes.**

- What kinds of properties are used to describe matter?
- What is a physical change?
- How is chemical energy related to chemical change?

Chapter 3
### Solids, Liquids, and Gases
The BIG Idea

**In solids, the particles vibrate in closely packed, fixed positions. In liquids, the particles are loosely connected and collide with one another. In gases, the particles are free to move independently.**

- How can you describe the behavior of particles in a solid?
- What happens to a substance during changes between liquid and gas?
- How are the volume, temperature, and pressure of a gas related?

Chapter 4
### Elements and the Periodic Table
The BIG Idea

**The organization of the periodic table is based on the properties of the elements and reflects the structure of atoms.**

- How are the elements organized in the modern periodic table?
- How does the reactivity of metals change across the periodic table?
- What are the properties of nonmetals and inert gases?

# Unit 1 Assessment

## Connecting the BIG Ideas

Sue and Juanita are throwing a big party for their friends. They purchase 100 2-liter bottles of seltzer (water with carbon dioxide gas in it), fill their car's trunk with all the bottles, and drive home. Since the party won't be until tomorrow, they decide to leave the seltzer in the car overnight.

The next morning, they open the car's trunk and discover that all the seltzer has frozen! They bring the bottles inside the house and let them warm up until the seltzer is liquid again.

At the party, one of the guests, Ben, asks if he can make an old-fashioned chocolate soda to drink. He fills a glass three-quarters of the way with seltzer, adds some dark brown chocolate syrup and white milk, and stirs it thoroughly. When he's done, the chocolate soda has a light brown color.


**1.** If the mass of all the seltzer that Sue and Juanita bought was 200 kilograms, what was the density of the seltzer? *(Chapter 1)*
**a.** 1 kg/L **b.** 2 kg/L
**c.** 100 kg/L **d.** 200 kg/L

**2.** Ben's chocolate soda is an example of a(n) *(Chapter 2)*
**a.** heterogeneous mixture
**b.** homogeneous mixture
**c.** element
**d.** compound

**3.** As the frozen seltzer melted into a liquid, what happened to the freedom of motion of the water molecules? *(Chapter 3)*
**a.** It increased. **b.** It decreased.
**c.** It stayed the same. **d.** It became zero.

**4.** The main component of seltzer is water. Water is a compound made up of the elements hydrogen and oxygen. Which class of elements does oxygen belong to? *(Chapter 4)*
**a.** metals **b.** nonmetals
**c.** semimetals **d.** inert gases

**5.** **Summary** Write a paragraph that summarizes the changes that the seltzer in the description above went through. Did the seltzer undergo a chemical change? Explain.