6.1 Organizing the Elements

Connecting to Your World In 1916, a self-service grocery store opened in Memphis, Tennessee. Shoppers could select items from shelves instead of waiting for a clerk to gather the items for them. In a self-service store, the customers must know how to find the products. From your experience, you know that products are grouped according to similar characteristics. You don't expect to find fresh fruit with canned fruit, or bottled juice with frozen juice. With a logical classification system, finding and comparing products is easy. In this section, you will learn how elements are arranged in the periodic table and what that arrangement reveals about the elements.

Guide for Reading

Key Concepts

- How did chemists begin to organize the known elements?
- How did Mendeleev organize his periodic table?
- How is the modern periodic table organized?
- What are three broad classes of elements?

Vocabulary

periodic law
metals
nonmetals
metalloid

Reading Strategy

Comparing and Contrasting As you read, compare and contrast Figures 6.4 and 6.5. How are these two versions of the periodic table similar? How are they different?

Searching For an Organizing Principle

A few elements have been known for thousands of years, including copper, silver, and gold. Yet only 13 elements had been identified by the year 1700. Chemists suspected that other elements existed. They had even assigned names to some of these elements, but they were unable to isolate the elements from their compounds. As chemists began to use scientific methods to search for elements, the rate of discovery increased. In one decade (1765–1775), chemists identified five new elements, including three colorless gases—hydrogen, nitrogen, and oxygen. Was there a limit to the number of elements? How would chemists know when they had discovered all the elements? To begin to answer these questions, chemists needed to find a logical way to organize the elements.

Chemists used the properties of elements to sort them into groups. In 1829, a German chemist, J. W. Dobereiner (1780–1849), published a classification system. In his system, elements were grouped into triads. A triad is a set of three elements with similar properties. The elements in Figure 6.1 formed one triad. Chlorine, bromine, and iodine may look different. But they have very similar chemical properties. For example, they react easily with metals. Dobereiner noted a pattern in his triads. One element in each triad tended to have properties with values that fell midway between those of the other two elements. For example, the average of the atomic masses of chlorine and iodine is [(35.453 + 126.90)/2] or 81.177 amu. This value is close to the atomic mass of bromine, which is 79.904 amu. Unfortunately, all the known elements could not be grouped into triads.

Figure 6.1 Chlorine, bromine, and iodine have very similar chemical properties. The numbers shown are the average atomic masses for these elements.

Section Resources

Print

- **Guided Reading and Study Workbook,** Section 6.1
- **Core Teaching Resources,** Section 6.1, Review, Interpreting Graphics
- **Transparencies,** T65–T66

Technology

- **Interactive Textbook with ChemASAP,** Assessment 6.1
- **Go Online,** Section 6.1

6.1

1 FOCUS

Objectives

6.1.1 **Explain** how elements are organized in a periodic table.

6.1.2 **Compare** early and modern periodic tables.

6.1.3 **Identify** three broad classes of elements.

Guide for Reading

Build Vocabulary L2

Word Parts Point out that *metal, nonmetal,* and *metalloid* all have the same root. Discuss the meanings of the suffix *-oid* (resembling) and prefix *non-* (not).

Reading Strategy L2

Use Prior Knowledge Ask students to write down three things they know about the development of the periodic table. After they read the section, have them revise their statements and record three new things that they learned.

2 INSTRUCT

Connecting to Your World

Have students look at the opening photograph and describe the types of characteristics that might be used to group produce in a store. Explain that an initial classification may be broad, as in produce dairy, and canned goods. Then these categories can be subdivided.

Searching For an Organizing Principle

TEACHER Demo

Organizing Elements L2

Display as many samples of elements as possible. If elements are not available, use photographs. Ask students to use properties of the elements to organize them into groups, and to provide an explanation for their groupings.

Section 6.1 (continued)

Mendeleev's Periodic Table

Use Visuals L1

Figure 6.3 Have students study Mendeleev's version of the periodic table. Show students how the elements with similar chemical properties were arranged in horizontal rows. Point out the gaps in the table where Mendeleev left room for elements that had not yet been discovered. Emphasize that Mendeleev did not make the first periodic table, but he did make the first table that gained wide acceptance.

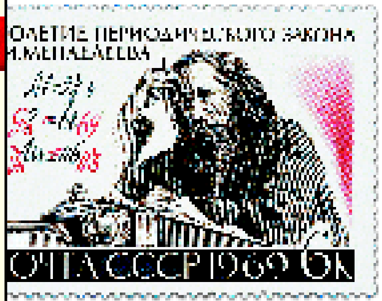


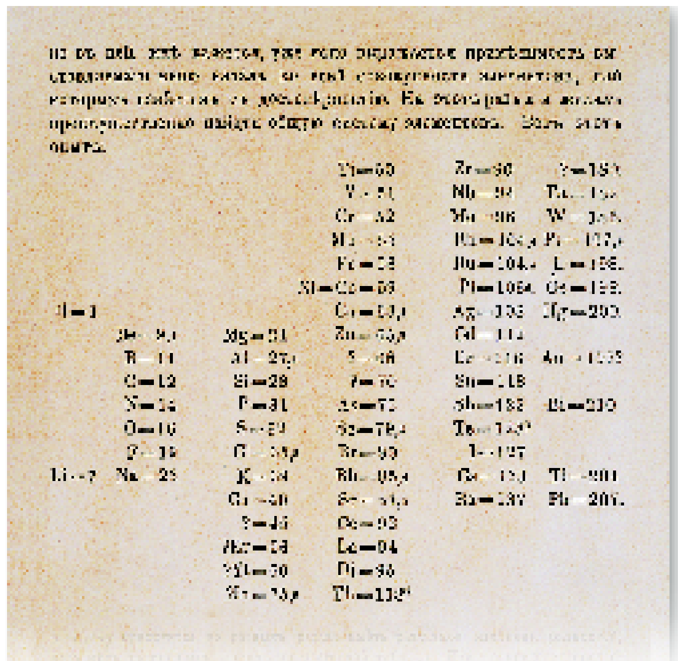
Figure 6.2 Dimitri Mendeleev proposed a periodic table that could be used to predict the properties of undiscovered elements.

Mendeleev's Periodic Table

From 1829 to 1869, different systems were proposed, but none of them gained wide acceptance. In 1869, a Russian chemist and teacher, Dmitri Mendeleev, published a table of the elements. Later that year, a German chemist, Lothar Meyer, published a nearly identical table. Mendeleev was given more credit than Meyer because he published his table first and because he was better able to explain its usefulness. The stamp in Figure 6.2 is one of many ways that Mendeleev's work has been honored.

Mendeleev developed his table while working on a textbook for his students. He needed a way to show the relationships among more than 60 elements. He wrote the properties of each element on a separate note card. This approach allowed him to move the cards around until he found an organization that worked. The organization he chose was a periodic table. Elements in a periodic table are arranged into groups based on a set of repeating properties. **Mendeleev arranged the elements in his periodic table in order of increasing atomic mass.**

Figure 6.3 is an early version of Mendeleev's periodic table. Look at the column that starts with Ti = 50. Notice the two question marks between the entries for zinc (Zn) and arsenic (As). Mendeleev left these spaces in his table because he knew that bromine belonged with chlorine and iodine. He predicted that elements would be discovered to fill those spaces, and he predicted what their properties would be based on their locations in the table. The elements between zinc and arsenic were gallium and germanium, which were discovered in 1875 and 1886, respectively. There was a close match between the predicted properties and the actual properties of these elements. This match helped convince scientists that Mendeleev's periodic table was a powerful tool.



			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 6.3 In this early version of Mendeleev's periodic table, the rows contain elements with similar properties. **Observing** ***A fourth element is grouped with chlorine (Cl), bromine (Br), and (I) iodine. What is this element's symbol?***

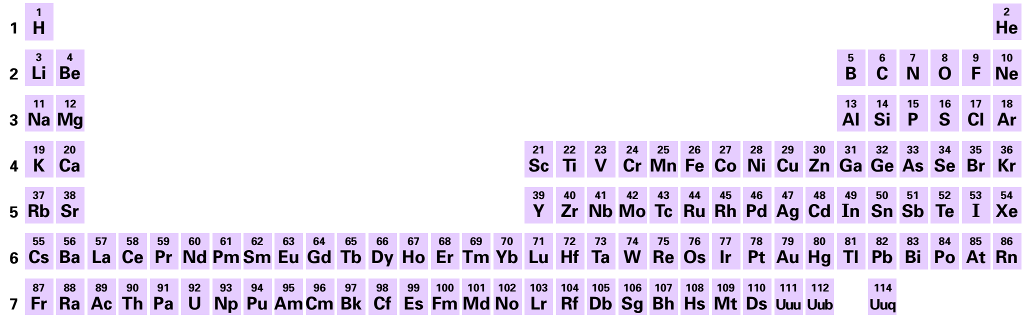


Figure 6.4 In the modern periodic table, the elements are arranged in order of increasing atomic number.
Interpreting Diagrams ***How many elements are there in the second period?***

The Periodic Law

The atomic mass of iodine (I) is 126.90. The atomic mass of tellurium (Te) is 127.60. Based on its chemical properties, iodine belongs in a group with bromine and chlorine. So Mendeleev broke his rule and placed tellurium before iodine in his periodic table. He assumed that the atomic masses for iodine and tellurium were incorrect, but they were not. Iodine has a smaller atomic mass than tellurium does. A similar problem occurred with other pairs of elements. The problem wasn't with the atomic masses but with using atomic mass to organize the periodic table.

Mendeleev developed his table before scientists knew about the structure of atoms. He didn't know that the atoms of each element contain a unique number of protons. Remember that the number of protons is the atomic number. In 1913, a British physicist, Henry Moseley, determined an atomic number for each known element. Tellurium's atomic number is 52 and iodine's is 53. So it makes sense for iodine to come after tellurium in the periodic table. **In the modern periodic table, elements are arranged in order of increasing atomic number.**

The elements in Figure 6.4 are arranged in order of atomic number, starting with hydrogen, which has atomic number 1. There are seven rows, or periods, in the table. Period 1 has 2 elements, Period 2 has 8 elements, Period 4 has 18 elements, and Period 6 has 32 elements. Each period corresponds to a principal energy level. There are more elements in higher numbered periods because there are more orbitals in higher energy levels. (Recall the rules you studied in Chapter 5 for how electrons fill orbitals.)

The elements within a column, or group, in the periodic table have similar properties. The properties of the elements within a period change as you move across a period from left to right. However, the pattern of properties within a period repeats as you move from one period to the next. This pattern gives rise to the **periodic law:** When elements are arranged in order of increasing atomic number, there is a periodic repetition of their physical and chemical properties.

Checkpoint ***How many periods are there in a periodic table?***

Word *Origins*

Periodic comes from the Greek roots *peri* meaning "around" and *hodos,* meaning "path." In a periodic table, properties repeat from left to right across each period. The Greek word *metron* means "measure." **What does *perimeter* mean?**

The Periodic Law

Use Visuals L1

Figure 6.4 This is the first of three periodic tables in the chapter. The information in this first table is limited so that students can see how all the elements fit in the table, and can focus on atomic number as an organizing principle. Have students compare Figures 6.3 and 6.4. Ask, **How is the modern periodic table shown here similar to the early periodic table?** *(In both tables, elements are arranged in rows and columns. Early periodic tables ordered the elements according to atomic mass. Modern periodic tables order elements according to atomic number.)* **What does an element's position in the table indicate about its properties?** *(The properties of an element are similar to those of other elements in the same group.)*

Discuss L2

To emphasize the concept that elements in the same group of the periodic table have similar properties, point out one group and describe some properties of the elements in that group. You can point to the group on the far right, and explain that all of these elements are gases that do not normally form compounds. Using a large poster-size display of the periodic table, trace one period across the table. Describe some physical and chemical properties of each element in the period. Then have students compare these elements to those below them in the next period.

Word *Origins* L2

One meaning of *perimeter* is "a line or boundary around an area." It comes from *peri*, "around," and *meter*, "measure."

Answers to...

Figure 6.3 F
Figure 6.4 8

Checkpoint 7

Metals, Nonmetals, and Metalloids

Use Visuals L1

Figure 6.5 The focus in Figure 6.5 is on the classification of elements as metals, nonmetals, and metalloids. Point out the sections of the table that correspond to metals, nonmetals, and metalloids. Emphasize the periodic trend across each period from metals to nonmetals. Ask, **Which class of elements do most of the elements belong to?** *(metals)* **What do the three numbers at the top of each column represent?** *(different systems for numbering the groups)*

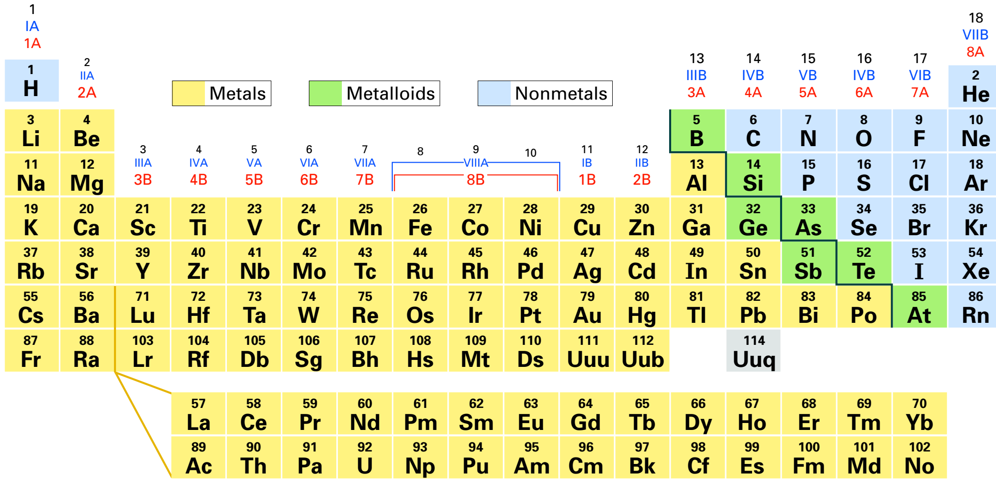


Figure 6.5 One way to classify elements in the periodic table is as metals, nonmetals, and metalloids. **Inferring** ***What is the purpose for the black stair-step line?***

Metals, Nonmetals, and Metalloids

Most periodic tables are laid out like the one in Figure 6.5. Some elements from Periods 6 and 7 are placed beneath the table. This arrangement makes the periodic table more compact. It also reflects an underlying structure of the periodic table, which you will study in Section 6.2. Each group in the table in Figure 6.5 has three labels. Scientists in the United States used the labels shown in red. Scientists in Europe used the labels shown in blue. There is some overlap between the systems, but in many cases two different groups have the same letter and number combination.

For scientists to communicate clearly, they need to agree on the standards they will use. The International Union of Pure and Applied Chemistry (IUPAC) is an organization that sets standards for chemistry. In 1985, IUPAC proposed a new system for labeling groups in the periodic table. They numbered the groups from left to right 1 through 18 (the black labels in Figure 6.5). The large periodic table in Figure 6.9 includes the IUPAC system and the system used in the United States. The latter system will be most useful when you study how compounds form in Chapters 7 and 8.

Dividing the elements into groups is not the only way to classify them based on their properties. The elements can be grouped into three broad classes based on their general properties. **Three classes of elements are metals, nonmetals, and metalloids.** Across a period, the properties of elements become less metallic and more nonmetallic.

Metals The number of yellow squares in Figure 6.5 shows that most elements are metals—about 80 percent. **Metals** are good conductors of heat and electric current. A freshly cleaned or cut surface of a metal will have a high luster, or sheen. The sheen is caused by the metal's ability to reflect light. All metals are solids at room temperature, except for mercury (Hg). Many metals are ductile, meaning that they can be drawn into wires. Most metals are malleable, meaning that they can be hammered into thin sheets without breaking. Figure 6.6 shows how the properties of metals can determine how metals are used.

Differentiated Instruction

Less Proficient Readers L1

Make a chart on the board of the three types of elements. Ask students to fill in details about the general characteristics of the three classes as they read about them.

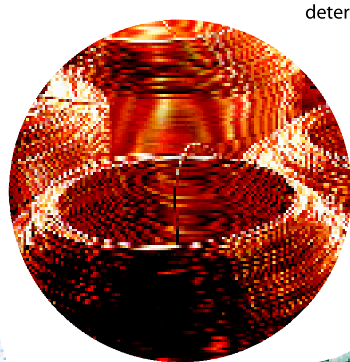
Nonmetals In Figure 6.5, blue is used to identify the nonmetals. These elements are in the upper-right corner of the periodic table. There is a greater variation in physical properties among nonmetals than among metals. Most nonmetals are gases at room temperature, including the main components of air—nitrogen and oxygen. A few are solids, such as sulfur and phosphorus. One nonmetal, bromine, is a dark-red liquid.

The variation among nonmetals makes it difficult to describe one set of general properties that will apply to all nonmetals. However, nonmetals are not metals, as their name implies. So they tend to have properties that are opposite to those of metals. In general, **nonmetals** are poor conductors of heat and electric current. Carbon is an exception to this rule. Solid nonmetals tend to be brittle, meaning that they will shatter if hit with a hammer.

Checkpoint ***Which type of elements tend to be good conductors of heat and electric current?***

Figure 6.6 The metals iron, copper, and aluminum have many important uses. How each metal is used is determined by its properties.

Iron (Fe)
The Gateway Arch in St. Louis, Missouri, is covered in stainless steel containing iron and two other metals, chromium (Cr) and nickel (Ni). The steel is shiny, malleable, and strong. It also resists rusting.



Copper (Cu)
Copper is ductile and second to only silver as a conductor of electric current. The copper used in electrical cables must be 99.99% pure.

Aluminum (Al)
Aluminum is one of the metals that can be shaped into a thin sheet, or foil. To qualify as a foil, a metal must be no thicker than about 0.15 mm.

CLASS Activity

Name The Element L1

Have each student choose an element without revealing the choice to other students. Each student should write a short description of the chosen element to read to the class. Ask the other students to identify the element from its description. Encourage students to be as specific as possible in their descriptions. Example: bromine is a reddish-brown liquid.

FYI

At a height of 630 feet, The Gateway Arch is the tallest monument in the United States. It commemorates the westward expansion of the U.S. in the nineteenth century.

Answers to...

Figure 6.5 Students are likely to say the line separates the metals from the nonmetals.

Checkpoint metals

Section 6.1 (continued)

Discuss **L2**

Point out silicon's position in the periodic table and explain that silicon is a metalloid, an element having both metallic and nonmetallic properties. Ask students about the properties that distinguish metals from nonmetals. Have them name other elements that are classified as metalloids. (Chemists do not always agree on which elements to classify as metalloids. Some include polonium (Po) and astatine (At) as metalloids. Some classify polonium as a metal and astatine as a nonmetal.)

3 ASSESS

Evaluate Understanding **L2**

Have students draw a concept map relating the following terms: *groups, periods, periodic law, periodic table, repeating properties, metals, nonmetals,* and *metalloids.*

Reteach **L1**

Compare and contrast the periodic table and a monthly calendar. Similarity: The same progression of days occurs each week. Difference: Although the length of a day is based on a natural event (Earth's rotation), what happens on a Monday or Saturday depends on human decisions, not on an underlying natural principle.

Connecting Concepts

The atomic number of an element tells you how many protons are in its nucleus. It is a good way to organize elements because atomic number is unique for each element, while other properties, such as atomic mass, can vary for atoms of an element.

Interactive Textbook

If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 6.1.

with ChemASAP

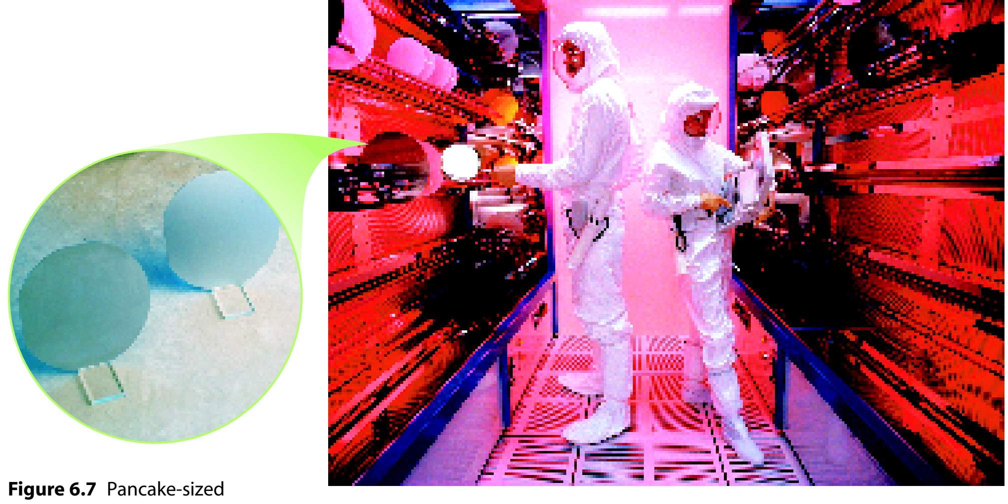


Figure 6.7 Pancake-sized circular slices of silicon, called wafers, are used to make computer chips. Because a tiny speck of dust can ruin a wafer, the people who handle the wafers must wear "bunny" suits. The suits prevent skin, hair, or lint from clothing from entering the room's atmosphere.

Metalloids There is a heavy stair-step line in Figure 6.5 that separates the metals from the nonmetals. Most of the elements that border this line are shaded green. These elements are metalloids. A **metalloid** generally has properties that are similar to those of metals and nonmetals. Under some conditions, a metalloid may behave like a metal. Under other conditions, it may behave like a nonmetal. The behavior often can be controlled by changing the conditions. For example, pure silicon is a poor conductor of electric current, like most nonmetals. But if a small amount of boron is mixed with silicon, the mixture is a good conductor of electric current, like most metals. Silicon can be cut into wafers, like those being inspected in Figure 6.7, and used to make computer chips.

6.1 Section Assessment

1. **Key Concept** How did chemists begin the process of organizing elements?
2. **Key Concept** What property did Mendeleev use to organize his periodic table?
3. **Key Concept** How are elements arranged in the modern periodic table?
4. **Key Concept** Name the three broad classes of elements.
5. Which of these sets of elements have similar physical and chemical properties?
   - **a.** oxygen, nitrogen, carbon, boron
   - **b.** strontium, magnesium, calcium, beryllium
   - **c.** nitrogen, neon, nickel, niobium
6. Identify each element as a metal, metalloid, or nonmetal.
   - **a.** gold
   - **b.** silicon
   - **c.** sulfur
   - **d.** barium
7. Name two elements that have properties similar to those of the element sodium.

Connecting Concepts

Atomic Number What does an atomic number tell you about the atoms of an element? Why is atomic number better than atomic mass for organizing the elements in a periodic table? Use what you learned in Section 4.2 to answer this question.

Interactive Textbook

Assessment 6.1 Test yourself on the concepts in Section 6.1.

with ChemASAP

Section 6.1 Assessment

1. Chemists used the properties of elements to sort them into groups.
2. in order of increasing atomic mass
3. in order of increasing atomic number
4. metal, metalloid, nonmetal
5. b
6. **a.** metal
   b. metalloid
   c. nonmetal
   d. metal
7. lithium, potassium, rubidium, cesium, or francium

160 Chapter 6