5.1 Organizing the Elements

In a video store, the latest movies are usually placed on the shelves in alphabetical order. Older movies are grouped into categories such as Action or Comedy. The manager has to choose a set of categories and then place each movie in the most appropriate location.

Scientists faced a similar challenge when they looked for a logical way to organize the elements. They had to decide what categories to use and where to place each element. An organized table of the elements is one of the most useful tools in chemistry. The placement of elements on the table reveals the link between the atomic structure of elements and their properties.

The Search for Order

Until 1750, scientists had identified only 17 elements. These were mainly metals, such as copper and iron. The rate of discovery increased rapidly as chemists began to investigate materials in a systematic way. As the number of known elements grew, so did the need to organize them into groups based on their properties.

In 1789, French chemist Antoine Lavoisier (la vwaaz hree ay) grouped the known elements into categories he called metals, nonmetals, gases, and earths. For the next 80 years, scientists looked for different ways to classify the elements. But none of their systems provided an organizing principle that worked for all the known elements. A Russian chemist and teacher, Dmitri Mendeleev (Duht mee deev), would discover such a principle.
Mendeleev’s Periodic Table

In the 1860s, Mendeleev was working on a textbook to use with his chemistry students. Because he needed to describe 63 elements, Mendeleev was looking for the best way to organize the information. He found a way to approach the problem while playing his favorite card game, a version of solitaire. In this game, the player sorts a deck of cards by suit and value. To finish the game, the player must end up with four columns, as shown in Figure 2. Each column contains cards of a single suit arranged in order by value.

Mendeleev’s Proposal

Mendeleev's strategy for organizing the elements was modeled on the card game. Mendeleev made a “deck of cards” of the elements. On each card, he listed an element’s name, mass, and properties. He paid special attention to how each element behaved in reactions with oxygen and hydrogen. When Mendeleev lined up the cards in order of increasing mass, a pattern emerged. The key was to break the elements into rows, as shown in Figure 3. Mendeleev arranged the elements into rows in order of increasing mass so that elements with similar properties were in the same column. The final arrangement was similar to a winning arrangement in solitaire, except that the columns were organized by properties instead of suits. Within a column, the masses increased from top to bottom. Mendeleev’s chart was a periodic table. A periodic table is an arrangement of elements in columns, based on a set of properties that repeat from row to row.

Figure 2 A deck of cards can be divided into four suits—diamonds, spades, hearts, and clubs. In one version of solitaire, a player must produce an arrangement in which each suit is ordered from ace to king. This arrangement is a model for Mendeleev’s periodic table.

Figure 3 This is a copy of a table that Mendeleev published in 1872. He placed the elements in groups based on the compounds they formed with oxygen or hydrogen. Using Tables: How many elements did Mendeleev place in Group 8?

The Periodic Table

<table>
<thead>
<tr>
<th>Group I</th>
<th>Group II</th>
<th>Group III</th>
<th>Group IV</th>
<th>Group V</th>
<th>Group VI</th>
<th>Group VII</th>
<th>Group VIII</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>Li</td>
<td>Na</td>
<td>K</td>
<td>Ca</td>
<td>Mg</td>
<td>Al</td>
<td>Si</td>
</tr>
<tr>
<td>Li</td>
<td>Be</td>
<td>B</td>
<td>C</td>
<td>N</td>
<td>O</td>
<td>F</td>
<td>Cl</td>
</tr>
<tr>
<td>Na</td>
<td>Mg</td>
<td>Ca</td>
<td>Sr</td>
<td>Ba</td>
<td>H</td>
<td>He</td>
<td>Rb</td>
</tr>
<tr>
<td>K</td>
<td>Cs</td>
<td>Rb</td>
<td>Cs</td>
<td>Ba</td>
<td>H</td>
<td>He</td>
<td>Rb</td>
</tr>
<tr>
<td>Ca</td>
<td>Sr</td>
<td>Y</td>
<td>La</td>
<td>Ac</td>
<td>H</td>
<td>He</td>
<td>Rb</td>
</tr>
<tr>
<td>Sr</td>
<td>Y</td>
<td>Lu</td>
<td>Bi</td>
<td>Po</td>
<td>H</td>
<td>He</td>
<td>Rb</td>
</tr>
<tr>
<td>Y</td>
<td>Lu</td>
<td>Tl</td>
<td>Pb</td>
<td>Bi</td>
<td>H</td>
<td>He</td>
<td>Rb</td>
</tr>
<tr>
<td>Lu</td>
<td>Tl</td>
<td>Pb</td>
<td>Bi</td>
<td>H</td>
<td>He</td>
<td>Rb</td>
<td></td>
</tr>
</tbody>
</table>

The Periodic Table 127

Integrate Social Studies

Lavoisier based his classification of elements on a vast amount of observed data. He used Boyle’s definition of an element as a substance that cannot separate into simpler substances. Most of the elements Lavoisier identified were elements, but his list did include heat, light, and five oxides that scientists had not known how to decompose. Have students consider what it means to “discover” an element by having them research and compare discovery dates for elements with the dates those elements were first isolated. (For example, beryllium was discovered in 1797, but it was not isolated until 1828.)

Verbal, Interpersonal

Mendeleev’s Periodic Table

Use Visuals

Figure 3 Ask, How is the table organized? (Elements are arranged in order of increasing mass.) What do the long dashes represent? (They represent undiscovered elements.) Why are masses listed with some of the dashes, but not with all of them? (Mendeleev was able to predict properties for some unknown elements based on the properties of neighboring elements.)

Visual, Logical

FYI

In Section 5.1, the term mass is used as a shorthand for atomic mass because atomic mass is not defined until Section 5.2. Mendeleev was comparing the relative atomic masses of the elements. Mendeleev attended the first international chemistry congress in Karlsruhe in 1860. During that meeting, chemists agreed on a standard method for calculating atomic masses.

Customize for Inclusion Students

Learning Disabled

To reinforce the meaning of the word periodic, ask students to think of periodic activities in their own lives. Make a class list of these activities. Organize the list by time interval: daily, weekly, monthly, yearly, and so on. For example, students may have a weekly music lesson or a dance recital every six months. They celebrate a birthday once a year. You may also want to encourage students to think of periodic events that occur less frequently than once a year, for example, the Olympics or presidential elections.

Answer to . . .

Figure 3 Mendeleev placed eight elements in Group II.
Mendeleev’s Prediction  Mendeleev could not make a complete table of the elements because many elements had not yet been discovered. He had to leave spaces in his table for those elements. For example, Mendeleev placed bromine (Br) in Group VII because bromine and chlorine (Cl) have similar properties. This placement left four spaces in row 4 between zinc (Zn) and bromine. Mendeleev had only two elements, arsenic and selenium, to fill those spaces, based on their masses. He placed arsenic and selenium in the columns where they fit best and left gaps in the columns labeled Groups III and IV.

Mendeleev was not the first to arrange elements in a periodic table. He was not even the first to leave spaces in a periodic table for missing elements. But he was able to offer the best explanation for how the properties of an element were related to its location in his table.

An excellent test for the correctness of a scientific model, such as Mendeleev’s table, is whether the model can be used to make accurate predictions. Mendeleev was confident that the gaps in his table would be filled by new elements. He used the properties of elements located near the blank spaces in his table to predict properties for undiscovered elements. Some scientists didn’t accept these predictions. Others used the predictions to help in their search for undiscovered elements.

Reading Checkpoint Why did Mendeleev place bromine in Group VII of his periodic table?

Facts and Figures  Recognizing a Pattern  Actions Mendeleev took while developing his table show that he realized the table represented a fundamental pattern in nature. First, he left gaps in the table for undiscovered elements. Second, he sometimes ignored accepted knowledge. For example, Berzelius had reported a formula of Be₂O₃ for beryllium oxide, which (if true) would mean that beryllium belonged in the third column. But, Mendeleev used beryllium to fill a space in the second column. Third, Mendeleev did not place all elements in order by atomic mass. He placed tellurium before iodine even though tellurium has a larger atomic mass.
Evidence Supporting Mendeleev’s Table

Mendeleev named missing elements after elements in the same group. He gave the name eka-aluminum to the element that belonged one space below aluminum on the table. (Eka is a Sanskrit word meaning “one.”) Mendeleev predicted that eka-aluminum would be a soft metal with a low melting point and a density of 5.9 g/cm³.

In 1875, a French chemist discovered a new element. He named the element gallium (Ga) in honor of France. (The Latin name for France is Gallia.) Gallium is a soft metal with a melting point of 29.7°C and a density of 5.91 g/cm³. Figure 4 shows a sample of gallium and a traffic signal that uses gallium compounds.

The properties of gallium are remarkably similar to the predicted properties of eka-aluminum. Scientists concluded that gallium and eka-aluminum are the same element. The close match between Mendeleev’s predictions and the actual properties of new elements showed how useful his periodic table could be. The discovery of scandium (Sc) in 1879 and the discovery of germanium (Ge) in 1886 provided more evidence. With the periodic table, chemists could do more than predict the properties of new elements. They could explain the chemical behavior of different groups of elements.

Section 5.1 Assessment

Reviewing Concepts

1. Describe how Mendeleev organized the elements into rows and columns in his periodic table.
2. How did the discovery of new elements such as gallium demonstrate the usefulness of Mendeleev’s table?
3. Scientists before Mendeleev had proposed ways to organize the elements. Why was Mendeleev’s efforts more successful?
4. What characteristic of solitaire did Mendeleev use as a model for his periodic table?
5. Why did Mendeleev leave spaces in his table?
6. In general, how can a scientist test the correctness of a scientific model?

Critical Thinking

7. Inferring Explain why it would not have been possible for a scientist in 1750 to develop a table like Mendeleev’s.
8. Predicting How was Mendeleev able to predict the properties of elements that had not yet been discovered?

Writing to Persuade Write a paragraph about Mendeleev’s periodic table. Use the paragraph to convince a reader that the periodic table is extremely useful to scientists. (Hint: Use specific facts to support your argument.)

Figure 4 Gallium was discovered in 1875. Heat from a person’s hand can melt gallium. In some traffic signals, there are tiny light-emitting diodes (LEDs) that contain a compound of gallium. Comparing and Contrasting: How does the melting point of gallium (29.7°C) compare to room temperature (about 25°C)?

Section 5.1 Assessment

1. Mendeleev arranged the elements in rows in order of increasing mass so that elements with similar properties were in the same column. The close match between Mendeleev’s predictions and the actual properties of new elements showed how useful his periodic table could be.
2. Mendeleev provided an organizing principle that worked for all of the known elements.
3. In solitaire, cards are arranged into categories called suits and ordered by value.
4. In order to place elements with similar properties in the same column, Mendeleev needed to leave spaces for undiscovered elements.
5. The scientist tests whether the model can be used to make accurate predictions.
6. With only 17 known elements to work with, the scientist would not have had enough data.
7. Mendeleev based his predictions on the properties of nearby elements and other elements in the same column.

Answer to . . .

Mendeleev placed bromine in Group VII because bromine and chlorine have similar properties.
5.2 The Modern Periodic Table

Key Concepts
- How is the modern periodic table organized?
- What does the atomic mass of an element depend on?
- What categories are used to classify elements on the periodic table?
- How do properties vary across a period in the periodic table?

Vocabulary
- period
- group
- periodic law
- atomic mass unit (amu)
- metals
- transition metals
- nonmetals
- metalloids

Reading Strategy
Previewing  Copy the table below. Before you read, write two questions about the periodic table on pages 132 and 133. As you read, write answers to your questions.

Questions About the Periodic Table

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>b.</td>
</tr>
<tr>
<td>c.</td>
<td>d.</td>
</tr>
</tbody>
</table>

Figure 5 shows a synthesizer keyboard with labels for the notes that correspond to the white keys. If you strike the key labeled middle C and then play the white keys in order from left to right, you will hear the familiar do-re-mi-fa-sol-la-ti scale. The next white note is a C that is an octave above middle C. An octave is the interval between any two notes with the same name. (The prefix octa- means "eight.") Because the scale repeats at regular eight-note intervals, the scale is an example of a periodic pattern.

The sounds of musical notes that are separated by an octave are related, but they are not identical. In a similar way, elements in the same column of the periodic table are related because their properties repeat at regular intervals. But elements in different rows are not identical. You can use the modern periodic table of elements to classify elements and to compare their properties.
The Periodic Law
Mendeleev developed his periodic table before the discovery of protons. He did not know that all atoms of an element have the same number of protons. He did not know that atoms of two different elements could not have the same number of protons. In the modern periodic table, elements are arranged by increasing atomic number (number of protons). Figure 6 shows one way the known elements can be arranged in order by increasing atomic number.

**Periods** Each row in the table of elements in Figure 6 is a period. Period 1 has 2 elements. Periods 2 and 3 have 8 elements. Periods 4 and 5 have 18 elements. Period 6 has 32 elements. The number of elements per period varies because the number of available orbitals increases from energy level to energy level.

To understand the structure of the table, think about what happens as the atomic number increases. The first energy level has only one orbital. The one electron in a hydrogen atom and the two electrons in a helium atom can fit in this orbital. But one of the three electrons in a lithium atom must be in the second energy level. That is why lithium is the first element in Period 2. Sodium, the first element in Period 3, has one electron in its third energy level. Potassium, the first element in Period 4, has one electron in its fourth energy level. This pattern applies to all the elements in the first column on the table.

**Groups** Each column on the periodic table is called a group. The elements within a group have similar properties. Properties of elements repeat in a predictable way when atomic numbers are used to arrange elements into groups. The elements in a group have similar electron configurations. An element's electron configuration determines its chemical properties. Therefore, members of a group in the periodic table have similar chemical properties. This pattern of repeating properties is the periodic law.

Look at Figure 7 on pages 132 and 133. There are 18 groups in this periodic table. Some elements from Periods 6 and 7 have been placed below Period 7 so that the table is more compact.

---

**Customize for English Language Learners**

**Simplify the Presentation** Tailor your teaching presentation of the section content to the less proficient English skills of your students. Do this by speaking directly and simplifying the words and sentence structures used to explain the material. For example, split a cause-and-effect sentence into two sentences labeled Cause and Effect. Use visual aids. For example, use the keyboard in Figure 5 to explain the interval of an octave. Use body language when appropriate to emphasize important words. For example, use a horizontal gesture when discussing periods and rows. Use a vertical gesture when describing groups and columns.

---

**Answer to . . .**

**Figure 5** 3 octaves

**Figure 6** There are 2 elements in Period 1, 8 in Period 3, and 18 in Period 5.

---

**2 INSTRUCT**

**The Periodic Law Build Reading Literacy L1**

**Preview** Refer to page 36D in Chapter 2, which provides the guidelines for using a preview strategy.

Have students preview the section (pp. 130–138), focusing their attention on headings, visuals, and boldfaced material. Ask, Based on your preview, which figure in the section contains the most information? (Figure 7 on pp. 132–133) Based on your preview, name three classes of elements. (Metals, nonmetals, and metalloids)

**Visual, Verbal**

**Build Science Skills L2**

**Using Tables and Graphs** Use the data in Figure 7 to show the advantage of arranging elements by atomic number instead of atomic mass. Make a large graph with atomic number on the horizontal axis and atomic mass on the vertical axis for elements 1 through 20. Draw straight lines between the points. Ask, What does the graph show about the general relationship between atomic number and atomic mass? (As the atomic number increases, so does the atomic mass.) Are there any points on the graph that do not follow the pattern? (Yes, the atomic mass of element 18, argon, is greater than the atomic mass of element 19, potassium.) Point out that arranging the elements strictly by increasing atomic mass would result in some elements with unlike properties being grouped together.

**Visual, Logical**

Download a worksheet on the periodic law for students to complete, and find additional teacher support from NSTA SciLinks.
In a modern periodic table of the elements, elements are arranged in order of increasing atomic number.

Figure 7 Begin by having students compare the layouts in Figures 6 and 7. Ask, What is the major difference in the layouts? (Some elements from Periods 6 and 7 have been placed below the table.) How are the layouts alike? (Elements are arranged in order by atomic number. Elements with similar properties are in the same group and properties repeat in a predictable way from period to period.) Return to Figure 7 when atomic masses are discussed on p. 134, and when ways to classify elements on the periodic table are introduced on p. 135. (The table shows two classification systems: the 1–18 numbering system approved by the International Union of Pure and Applied Chemistry (IUPAC), and a system in which two sets of groups numbered 1–8 are distinguished by A and B labels. Unless students ask, you may want to let students wonder about the A and B classification system, which will be addressed in the introduction to Section 5.3.)

**FV**
Placement of the lanthanides and actinides below the main body of the table also serves to emphasize the similarities among these elements related to their electron configurations.
The Periodic Table 133

Integrate Language Arts

Elements 110, 111, 112, and 114 have not been named yet. Scientists can propose names for new elements, but the International Union of Pure and Applied Chemistry has final approval. Until new elements receive official names, chemists refer to them by their Latin-based atomic numbers. For example, element 114 is called ununquadium, Latin for one-one-four. Increase students’ familiarity with the periodic table by having them identify some of the strategies used to name elements (scientists, geographic locations, mythological characters).

Verbal, Portfolio

Build Science Skills

Comparing and Contrasting For this activity, use a periodic table displayed in the classroom, or make copies of a periodic table that is a few years old to distribute to students. To illustrate the dynamic nature of science, have students compare Figure 7 to the older periodic table. Ask, What differences do you notice between the two periodic tables? (Depending on when the older table was printed, the number of elements may vary and some elements in Period 7 may not have assigned names. Some values for atomic mass are likely to vary. A periodic table may include electron configurations for each element.) Make a list of responses on the board. Then ask, How will the periodic table change in the future? (Unnamed elements will be assigned official names and more elements may be discovered.) Visual, Verbal, Group

FYI

Although plutonium is classified as a synthetic element, traces of plutonium isotopes Pu-238 and Pu-239 appear at low concentrations (about one part per 1011) in pitchblende, a uranium ore. In 1971, Darlene Hoffman, a scientist at Los Alamos National Laboratory, discovered traces of Pu-244 in Precambrian rocks. Because this isotope has a half-life of about 82 million years, it probably existed when Earth formed.
Atomic Mass

This box provides four pieces of information about the element chlorine: its symbol, its name, its atomic number, and its atomic mass.

<table>
<thead>
<tr>
<th>Atomic number</th>
<th>17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Element symbol</td>
<td>Cl</td>
</tr>
<tr>
<td>Element name</td>
<td>Chlorine</td>
</tr>
<tr>
<td>Atomic mass</td>
<td>35.453</td>
</tr>
</tbody>
</table>

Figure 8

Atomic Mass

There are four pieces of information for each element in Figure 7: the name of the element, its symbol, its atomic number and its atomic mass. Atomic mass is a value that depends on the distribution of an element’s isotopes in nature and the masses of those isotopes. You will use atomic masses when you study chemical reactions in Chapter 7.

Atomic Mass Units

The mass of an atom in grams is extremely small and not very useful because the samples of matter that scientists work with contain trillions of atoms. In order to have a convenient way to compare the masses of atoms, scientists chose one isotope to serve as a standard. Recall that each isotope of an element has a different number of neutrons in the nuclei of its atoms. So the atoms of two isotopes have different masses.

Scientists assigned 12 atomic mass units to the carbon-12 atom, which has 6 protons and 6 neutrons. An atomic mass unit (amu) is defined as one-twelfth the mass of a carbon-12 atom.

Isotopes of Chlorine

In nature, most elements exist as a mixture of two or more isotopes. Figure 8 shows that the element chlorine has the symbol Cl, atomic number 17, and an atomic mass of 35.453 atomic mass units. (The unit for atomic mass is not listed in the periodic table, but it is understood to be the amu.) Where does the number 35.453 come from? There are two natural isotopes of chlorine, chlorine-35 and chlorine-37. An atom of chlorine-35 has 17 protons and 18 neutrons. An atom of chlorine-37 has 17 protons and 20 neutrons. So the mass of an atom of chlorine-37 is greater than the mass of an atom of chlorine-35.

Weighted Averages

Your teacher may use a weighted average to determine your grade. In a weighted average, some values are more important than other values. For example, test scores may count more heavily toward your final grade than grades on quizzes or grades on homework assignments.

Figure 9 lists the atomic masses for two naturally occurring chlorine isotopes. If you add the atomic masses of the isotopes and divide by 2, you get 35.967, not 35.453. The value of the atomic mass for chlorine in the periodic table is a weighted average. The isotope that occurs in nature about 75% of the time (chlorine-35) contributes three times as much to the average as the isotope that occurs in nature about 25% of the time (chlorine-37).

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Percentage</th>
<th>Atomic Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorine-35</td>
<td>75.78%</td>
<td>34.969</td>
</tr>
<tr>
<td>Chlorine-37</td>
<td>24.22%</td>
<td>36.966</td>
</tr>
</tbody>
</table>

Figure 9

Distribution of Chlorine Isotopes in Nature

This table shows the distribution and atomic masses for the two natural isotopes of chlorine. Using Tables Which Isotope occurs more often in nature?

Facts and Figures

Atomic Mass Units From the mid-1800s to 1960, oxygen was the standard for atomic masses. (Oxygen was likely chosen because it forms compounds with many elements.) After the discovery of isotopes, physicists and chemists began to use different standards. Physicists assigned the value 16.000 amu exclusively to oxygen-16. Other oxygen isotopes had different values. Chemists continued to use 16.000 amu as the average for all oxygen atoms. Although the differences between the standards were small, the situation was potentially confusing.

In 1961, chemists and physicists agreed on a unified standard based on the carbon-12 isotope, which is assigned a value of 12.000 amu. (Although the SI abbreviation for atomic mass unit was changed to u for unified when scientists adopted the unified atomic mass unit, the amu notation is still widely used.)
Classes of Elements

The periodic table in Figure 7 presents three different ways to classify elements. First, elements are classified as solids, liquids, or gases, based on their states at room temperature. The symbols for liquids are purple. The symbols for gases are red.

Second, elements are divided into those that occur naturally and those that do not. All but two elements with atomic numbers 1 through 92 occur on Earth. Elements with atomic numbers of 93 and higher do not occur naturally. The symbols for these elements are white. In Chapter 10, you will find out how elements that do not occur in nature are produced.

The third classification system puts elements into categories based on their general properties. Elements are classified as metals, nonmetals, and metalloids. In the periodic table, metals are located on the left, nonmetals are on the right, and metalloids are in between.

Metals

The majority of the elements on the periodic table are classified as metals. In Figure 7, they are represented by blue boxes. Metals are elements that are good conductors of electric current and heat. Except for mercury, metals are solids at room temperature. Most metals are malleable. Many metals are ductile; that is, they can be drawn into thin wires. Some metals are extremely reactive and some do not react easily. One way to demonstrate this difference is to compare the behavior of gold and the behavior of magnesium when these metals are exposed to the oxygen in air. Gold remains shiny because it does not react with the oxygen. Magnesium reacts with the oxygen and quickly dulls. Figure 10A shows one magnesium coil that is dull and one that is shiny. Figure 10B shows one use for a metal with a shiny surface.

Defining a Metal

Procedure

1. Use forceps to put a piece of magnesium into a test tube in a test tube rack. Using a graduated cylinder, add 5 mL of hydrochloric acid to the test tube.
CAUTION Wear plastic gloves because the acid can burn skin or clothing. Record your observations.

2. Repeat Step 1 with sulfur, aluminum, and silicon.

Analyze and Conclude

1. Classifying Based on their locations in the periodic table, classify the four elements as metals, metalloids, or nonmetals.

2. Comparing and Contrasting Compare the behavior of the metals with the acid to the behavior of the other elements with the acid.

3. Forming Operational Definitions Use your observations to write a definition of a metal.

Expected Outcome

<table>
<thead>
<tr>
<th>Element</th>
<th>Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnesium</td>
<td>Bubbles, test tube becomes hot, reaction complete in about 30 seconds, final solution clear.</td>
</tr>
<tr>
<td>Sulfur</td>
<td>No visible reaction</td>
</tr>
<tr>
<td>Aluminum</td>
<td>Slight bubbling in 5 minutes, test tube becomes warm after about 15 minutes, final mixture slightly cloudy with powdery gray precipitate.</td>
</tr>
<tr>
<td>Silicon</td>
<td>No visible reaction</td>
</tr>
</tbody>
</table>

Analyze and Conclude

1. Aluminum and magnesium are metals. Sulfur is a nonmetal and silicon is a metalloid.

2. Only the metals react with the acid.

3. A metal is a substance that reacts with HCl.

Logical

Class Time 20 minutes

Safety

Remind students to use care in adding the acid and to rinse any acid off skin or clothing with water. CAUTION The reaction of Mg in HCl will make the test tube hot. Keep spill-control materials (baking soda or citric acid) nearby to clean up spills. Repeat as necessary to remove all acid contamination. Elemental sulfur may emit H2S when dispersed in HCl. Test the sulfur beforehand in a fume hood or other well-ventilated area. Supply silicon as chips, not in powdered form, which is flammable. Neutralize the acid solutions with baking soda and wash them down the drain with excess water.

Teaching Tips

• Caution students not to get fingerprints on the Mg and Al samples.

• The complete reaction of Al and HCl will require more than 45 minutes. However, the results after 15 minutes will indicate how the materials react.

Answer to . . .

Figure 9 Chlorine-35

One-twelfth the mass of a carbon-12 atom
The metals in groups 3 through 12 are called transition metals. Transition metals are elements that form a bridge between the elements on the left and right sides of the table. Transition elements, such as copper and silver, were among the first elements discovered. One property of many transition metals is their ability to form compounds with distinctive colors. The How It Works box on page 137 describes the use of transition elements in the production of colored glass.

Some transition elements have more properties in common than elements in other groups. This is especially true of elements in the lanthanide and actinide series. These elements are so similar that chemists in the 1800s had difficulty separating them when they were found mixed together in nature. A compound of erbium and oxygen was used to tint the lenses shown in Figure 11.

**Nonmetals** In Figure 7, nonmetals are represented by yellow boxes. As their name implies, nonmetals generally have properties opposite to those of metals. Nonmetals are elements that are poor conductors of heat and electric current. Because nonmetals have low boiling points, many nonmetals are gases at room temperature. In fact, all the gases in the periodic table are nonmetals. The nonmetals that are solids at room temperature tend to be brittle. If they are hit with a hammer, they shatter or crumble. Nonmetals vary as much in their chemical properties as they do in their physical properties. Some nonmetals are extremely reactive, some hardly react at all, and some fall somewhere in between. Fluorine in Group 17 is the most reactive nonmetal. It even forms compounds with some gases in Group 18, which are the least reactive elements in the table. The toothpaste in Figure 12 contains a compound of the nonmetal fluorine and the metal sodium. This compound helps to protect your teeth against decay.

**Metalloids** In the periodic table in Figure 7, metalloids are represented by green boxes. Metalloids are elements with properties that fall between those of metals and nonmetals. For example, metals are good conductors of electric current and nonmetals are poor conductors of electric current. A metalloid’s ability to conduct electric current varies with temperature. Pure silicon (Si) and germanium (Ge) are good insulators at low temperatures and good conductors at high temperatures.

**Which type of metals tend to form compounds with distinctive colors?**

**Facts and Figures**

**Fluoride in Toothpaste** According to FDA regulations, toothpaste can contain sodium fluoride, sodium monofluorophosphate, or stannous fluoride at concentrations of 850 to 1150 ppm total fluorine. A package of toothpaste sold commercially cannot contain more than 276 mg of fluorine. Because too much fluoride can have adverse affects on health, people should rinse away excess toothpaste. There must be a warning on toothpaste packages to keep the product out of the reach of children under 6 years of age. Young children need to be supervised when they brush their teeth until they have learned how to minimize ingestion of the toothpaste.
Making Glass

For more than 4500 years, people have made glass from sand. The float-glass process shown below is used to make large sheets of glass for windows, while molds are used to make glass bottles. Interpreting Diagrams How is air used in making glass bottles?

Adding the raw ingredients Sand, lime, and soda ash are poured into the furnace and heated to 1550°C (2820°F). Recycled waste glass, called cullet, is also added, to reduce the cost of raw materials.

Heating in the furnace The furnace heats the ingredients, producing liquid glass at 1100°C (2010°F). Rollers move the hot and molten glass to the next stage.

Liquid glass The glass is floated over a bath of melted tin. The glass emerges at 600°C (1110°F) as a continuous sheet with the same thickness throughout.

Cooling the glass The glass is cooled slowly in a temperature-controlled oven to keep it from cracking.

Cutting the glass A diamond-tipped cutter is used to cut the cooled glass.

Making bottles Mass-produced glass bottles are made by adding hot glass to a mold and shaping the glass with air at high pressure.

Air pushes the glass to the bottom of the mold, where the neck of the bottle will form.

Making Glass

Float-glass plants are among the largest buildings in the world. Giant bins hold the raw materials for making glass. Huge roof ventilators and stacks release the intense heat needed to produce the liquid glass. The glassmaking operation is continuous, with the fires burning constantly. Often a glass plant will produce various tints of glass that are used in different applications.

Interpreting Diagrams Air at high pressure is used to force the liquid glass to take the shape of the mold.

Visual, Verbal

For Enrichment

Interested students can research and report on the work of glassblowers and compare their techniques for shaping glass with the molding process that is described on p. 137. Have students use the library to find books, magazine articles, and videos to help in their research.

Verbal, Portfolio

FYI

Tell students that showing the raw ingredients of glass as four equal segments of a pie is not meant to reflect their actual percentages in the mixture. Adding soda ash saves energy because sodium carbonate lowers the melting temperature of the mixture. Running the glass over rollers instead of the molten tin produces an uneven surface.
Variation Across a Period

**Period 3 Properties**

**Purpose**
Students observe differences in electrical conductivity among three Period 3 elements.

**Materials**
6-volt battery, flashlight bulb with holder, 3 pieces of insulated wire with the ends stripped, 2.5-cm aluminum strip, small silicon chip, 2.5-cm piece of sulfur

**Advance Prep**
Use the battery, flashlight bulb with holder, and the wires to make an open circuit.

**Procedure**
Touch the free ends of the two wires to each end of the aluminum strip. Have students observe the bulb. Repeat for silicon and sulfur.

**Expected Outcome**
The material used to complete the circuit determines the brightness of the light. For aluminum, the bulb is bright; for silicon, the bulb is dim; for sulfur, the bulb does not light. Students should conclude that the Period 3 elements become less metallic from left to right across the period.

**Visual, Logical**

**Variation Across a Period**
The properties within a period change in a similar way from left to right across the table, except for Period 1. Across a period from left to right, the elements become less metallic and more nonmetallic in their properties. The most reactive metals are on the left side of the table. The most reactive nonmetals are on the right in Group 17. The Period 3 elements shown in Figure 13 provide an example of this trend.

There are three metals, a metalloid, and four nonmetals in Period 3. If you were unwise enough to hold a piece of sodium in your hand, it would react quickly and violently with the water on your moist skin. But magnesium will not react with water unless the water is hot. Aluminum does not react with water, but it does react with oxygen.

Silicon is the least reactive element in Period 3 (except for argon). Under ordinary conditions, phosphorus and sulfur do not react with water, but they do react with oxygen. They also react with chlorine, which is a highly reactive nonmetal. Chlorine must be handled with as much care as sodium. Argon hardly reacts at all.

**Figure 13** From left to right across Period 3, there are three metals (Na, Mg, and Al), one metalloid (Si), and four nonmetals (P, S, Cl, and Ar). Many light bulbs are filled with argon gas.

**Explanatory Paragraph**
The word isotope comes from the Greek words iso, meaning “equal,” and topos, meaning “place.” Write a paragraph explaining how the isotopes chlorine-35 and chlorine-37 occupy the same place in the periodic table.

**Writing in Science**

7. **Applying Concepts**
   Explain how you know that no new element with an atomic number less than 100 will be discovered.

8. **Comparing and Contrasting**
   Compare the reactions with water of the elements sodium and magnesium.

**Critical Thinking**

6. **Formulating Hypotheses**
The atomic mass of iodine (I) is less than the atomic mass of tellurium (Te). But an iodine atom has one more proton than a tellurium atom. Explain how this situation is possible.

**Section 5.2 Assessment**

**Reviewing Concepts**

1. What determines the order of the elements in the modern periodic table?
2. Describe the periodic law.
3. What two factors determine the atomic mass of an element?
4. Name three categories that are used to classify the elements in the periodic table.
5. What major change occurs as you move from left to right across the periodic table?

**Answer to . . .**

Figure 13 Chlorine

6. Answers may include that the tellurium isotopes that are most abundant have many neutrons in their nuclei or that all tellurium atoms have more neutrons than iodine atoms.
7. The atomic number of an element corresponds to the number of protons in the element’s atoms. The atomic number must be a whole number. All the places between 1 and 100 are already filled with existing elements.
8. Sodium reacts quickly and violently with water at room temperature. Magnesium will not react unless the water is hot.
5.3 Representative Groups

Key Concepts
- Why do the elements in a group have similar properties?
- What are some properties of the A groups in the periodic table?

Vocabulary
- valence electron
- alkali metals
- alkaline earth metals
- halogens
- noble gases

Reading Strategy
Monitoring Your Understanding
Copy the table below. As you read, record an important fact about each element listed.

<table>
<thead>
<tr>
<th>Element</th>
<th>Important Fact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnesium</td>
<td></td>
</tr>
<tr>
<td>Aluminum</td>
<td></td>
</tr>
<tr>
<td>Chlorine</td>
<td></td>
</tr>
</tbody>
</table>

Reading Focus

Why is hydrogen located on the left side of the periodic table with the active metals? It is a nonmetal gas that seems to have more in common with the nonmetals in Group 17. Hydrogen’s location is related to its electron configuration, not its properties.

Valence Electrons

Did you wonder why there are two numbering schemes on the periodic table in Figure 7? When the A groups are numbered from 1 through 8, they provide a useful reminder about the electron configurations of the elements in those groups. The number of an A group matches the number of valence electrons in an electron configuration for an element in that group. A valence electron is an electron that is in the highest occupied energy level of an atom. These electrons play a key role in chemical reactions. Properties vary across a period because the number of valence electrons increases from left to right.

Elements in a group have similar properties because they have the same number of valence electrons. These properties will not be identical because the valence electrons are in different energy levels. Valence electrons explain the location of hydrogen. Because hydrogen has a single valence electron, it is grouped with other elements, such as lithium, that have only one valence electron.

Reading Focus

Build Vocabulary

Concept Map Have students construct a concept map with eight branches and title it Groups in the Periodic Table. As students read, they can add the names of groups to each branch, the group’s number of valence electrons, elements in the group, and some properties of these elements.

Reading Strategy

Possible answers: a. Magnesium plays a key role in the production of sugar in plants. Mixtures of magnesium and other metals can be as strong as steel, but much lighter. b. Aluminum is the most abundant metal in Earth’s crust. Much less energy is needed to purify recycled aluminum than to extract aluminum from bauxite. c. Chlorine is a highly reactive, nonmetal gas that is used to kill bacteria in water.

Section Resources

Print
- Laboratory Manual, Investigation 5B
- Reading and Study Workbook With Math Support, Section 5.3
- Transparencies, Section 5.3

Technology
- Interactive Textbook, Section 5.3
- Presentation Pro CD-ROM, Section 5.3
- Go Online, Science News, Elements

Valence Electrons

Integrate Space Science

Hydrogen exhibits metallic properties under extreme conditions. Scientists have theorized for decades that metallic hydrogen exists in the core of planets such as Jupiter. Interior pressure on Jupiter is millions of times greater than the pressure at the surface of Earth. At this pressure, electrons flow easily between hydrogen molecules. Have students do research and write a paragraph that compares and contrasts the cores of Jupiter and Earth, according to the current state of scientific knowledge.

Verbal, Portfolio

The Periodic Table 139
The Alkali Metals

Use Visuals

Figure 15 Ask students to study the two photos and the column of elements in Figure 15. Ask, What properties of sodium are shown in the photos? (Sodium is a soft solid at room temperature with a metallic luster when first exposed to air. Sodium is extremely reactive and it reacts violently with water to form hydrogen gas.) Point out to students that the reactivity of the alkali metals increases from the top of the group to the bottom. Ask, Which alkali metals are less reactive than cesium but more reactive than lithium? (Sodium, potassium, and rubidium)

Visual, Logical

Build Science Skills

Communicating Results Explain to students that Robert Bunsen and Gustav Kirchhoff discovered cesium in 1840 and rubidium in 1841 by burning the substances and observing the color of the flames. Have students research the origin of the terms cesium and rubidium. Have students explain why these names are appropriate. (Cesium comes from the Latin word caesium, which means “heavenly blue.” Rubidium comes from the Latin word rubidus, which means “dark red.” The names describe the colors of light emitted when the elements are burned.)

Logical

FYI

Francium has been described as the most unstable element among the first 103 elements. Its longest-lived isotope, francium-223, has a half-life of only 22 minutes. The estimate is that there is only about one ounce of francium on Earth at any moment.

The Alkali Metals

The elements in Group 1A are called alkali metals. These metals have a single valence electron and are extremely reactive. Because they are so reactive, alkali metals are found in nature only in compounds. The most familiar of these compounds is table salt—a compound of sodium and chlorine (sodium chloride). Sodium chloride can be obtained through the evaporation of seawater or from large salt deposits on the surface of Earth or underground.

Not all the elements in a group are equally reactive. Sodium is more reactive than lithium, potassium is more reactive than sodium, and rubidium is more reactive than potassium. The reactivity of alkali metals increases from the top of Group 1A to the bottom.

Sodium is about as hard as cold butter and can be cut with a sharp knife, as shown in Figure 15A. Sodium melts at about 98°C and has a lower density than water. A piece of sodium may be able to float on water, but Figure 15B shows that it won’t be there for long. The sodium reacts violently with water and releases enough energy to ignite the hydrogen gas that is produced. Sodium and potassium are stored under oil to keep them from reacting with the oxygen and water vapor in air. Cesium is so reactive that it reacts with water at temperatures as low as −115°C. Cesium is usually stored in a sealed glass tube containing argon gas.

How many valence electrons does an alkali metal have?

Customize for English Language Learners

Compare/Contrast Chart

After students have read about Groups 1A and 2A, create a chart on the board with the title Alkali Metals vs. Alkaline Earth Metals. Separate the chart into two columns labeled Similarities and Differences. Ask for student responses to help you fill in the chart. After all correct answers have been recorded, keep the chart displayed as a reference for students.
The Alkaline Earth Metals

The elements in Group 2A are called **alkaline earth metals**. All alkaline earth metals have two valence electrons. Metals in Group 2A are harder than metals in Group 1A. The melting point of magnesium is 650°C, which is much higher than the melting point of sodium—98°C.

**Differences in reactivity among the alkaline earth metals are shown by the ways they react with water.** Calcium, strontium, and barium react easily with cold water. Magnesium will react with hot water, but no change appears to occur when beryllium is added to water. Magnesium and calcium have essential biological functions and they provide materials used in construction and transportation.

**Magnesium**

Magnesium plays a key role in the process that uses sunlight to produce sugar in plants like the one in Figure 16. The compound at the center of this process is chlorophyll (klawr uh fil), and at the center of chlorophyll is magnesium. A mixture of magnesium and other metals can be as strong as steel, but much lighter. Reducing overall mass without sacrificing strength is an important consideration in transportation. The frames of bicycles and backpacks often contain magnesium.

**Calcium**

Your body needs calcium to keep your bones and teeth strong. Calcium carbonate—a compound of calcium, carbon, and oxygen—is the main ingredient in chalk, limestone, coral, and the pearl in Figure 16. Your toothpaste may contain the compound calcium carbonate because this hard substance can polish your teeth. The plaster cast in Figure 16 contains calcium sulfate, which is a compound of calcium, sulfur, and oxygen.

**Figure 16** Chlorophyll molecules in spinach contain magnesium. An oyster shell and a pearl are both made from calcium carbonate. A plaster cast contains the compound calcium sulfate.

**The Periodic Table**

<table>
<thead>
<tr>
<th>Group 2A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Be Beryllium</td>
</tr>
<tr>
<td>Mg Magnesium</td>
</tr>
<tr>
<td>Ca Calcium</td>
</tr>
<tr>
<td>Sr Strontium</td>
</tr>
<tr>
<td>Ba Barium</td>
</tr>
<tr>
<td>Ra Radium</td>
</tr>
</tbody>
</table>

**FVI**

The mineral gypsum is heated to produce a white powdery substance called plaster of Paris. When water is added to plaster of Paris, heat is released as the plaster quickly hardens. During the process, the plaster expands by about 0.3–0.6%. A plaster cast is often replaced by a sturdier, more lightweight fiberglass cast after the swelling around an injury subsides.

Egyptians used plaster to join blocks of stone in pyramids. Romans made plaster casts of Greek statues. In the 1700s, wooden houses in Paris were often covered in plaster to protect against fire. This measure was taken in response to the destruction of London by fire in 1666.
**The Boron Family**

Group 3A contains the metalloid boron, the well-known metal aluminum, and three less familiar metals (gallium, indium, and thallium). All these elements have three valence electrons.

- Aluminum is the most abundant metal in Earth’s crust. It is often found combined with oxygen in a mineral called bauxite (ROCKS eye). Aluminum is less reactive than sodium and magnesium. It is strong, lightweight, malleable, and a good conductor of electric current.

  More than 10 percent of the aluminum produced is used as packaging. Some aluminum is used in window screens, window frames, and gutters. Parts of cars and airplanes are also made from aluminum. People are encouraged to recycle aluminum because the energy needed to purify recycled aluminum is only about 5 percent of the energy needed to extract aluminum from bauxite.

  A compound of boron, silicon, and oxygen is used to make a type of glass that does not shatter easily when it undergoes a rapid change in temperature. Glass that contains boron is used to make laboratory glassware, such as the flasks in Figure 17. It is also used in cookware that can go directly from the oven to the refrigerator.

- The Carbon Family

Group 4A contains a nonmetal (carbon), two metalloids (silicon and germanium), and two metals (tin and lead). Each of these elements has four valence electrons. Notice that the metallic nature of the elements increases from top to bottom within the group. In keeping with this trend, germanium is a better conductor of electric current than silicon.

- Except for water, most of the compounds in your body contain carbon. Reactions that occur in the cells of your body are controlled by carbon compounds. Carbon and its compounds are discussed in Chapter 9, Carbon Chemistry.

  Silicon is the second most abundant element in Earth’s crust. It is found as silicon dioxide in quartz rocks, sand, and glass. The clay used to produce the pottery in Figure 18 contains silicon compounds called silicates. Silicon carbide, a compound of silicon and carbon, is extremely hard. Saw blades tipped with silicon carbide last many times longer than ordinary steel blades.

  Life on Earth would not exist without carbon.

- Which Group 3A element is a nonmetal?
The Nitrogen Family

Group 5A contains two nonmetals (nitrogen and phosphorus), two metalloids (arsenic and antimony), and one metal (bismuth). Like the groups on either side of it, Group 5A includes elements with a wide range of physical properties. Nitrogen is a nonmetal gas, phosphorus is a solid nonmetal, and bismuth is a dense metal. Despite their differences, all the elements in Group 5A have five valence electrons. Nitrogen and phosphorus are the most important elements in Group 5A.

When air is cooled, the oxygen condenses before the nitrogen because nitrogen has a lower boiling point than oxygen. Much of the nitrogen obtained from air is used to produce fertilizers, like the three shown in Figure 19. Besides nitrogen, fertilizers often contain phosphorus. Your body uses compounds containing nitrogen and phosphorus to control reactions and release energy from food.

Phosphorus exists as an element in several forms with different properties. White phosphorus is so reactive that it bursts into flame when it is in contact with oxygen. Red phosphorus is less reactive and is used to make matches ignite.

Figure 19 The composition of a fertilizer varies with its intended use. The numbers on the bags of fertilizer are, from left to right, the relative amounts of nitrogen, phosphorus, and potassium.

Analyzing Data Which type of fertilizer contains the most phosphorus?

The Nitrogen Family

Group 6A has three nonmetals (oxygen, sulfur, and selenium), and two metalloids (tellurium and polonium). All the elements in Group 6A have six valence electrons.

Oxygen is the most abundant element in Earth’s crust. Complex forms of life need oxygen to stay alive because oxygen is used to release the energy stored in food. Oxygen can be stored as a liquid under pressure in oxygen tanks. There must be no sparks or flames near an oxygen tank because materials that are flammable burn easily in pure oxygen.

Ozone is another form of the element oxygen. At ground level, ozone can irritate your eyes and lungs. At upper levels of the atmosphere, ozone absorbs harmful radiation emitted by the sun.

Sulfur was one of the first elements to be discovered because it is found in large natural deposits like the one in Figure 20. The main use of sulfur is in the production of sulfuric acid, a compound of sulfur, hydrogen, and oxygen. More sulfuric acid is produced in the United States than any other chemical. About 65 percent of the sulfuric acid produced is used to make fertilizers.

Figure 20 Sulfur is often found in nature in its elemental form—not combined with other elements.

Inferring What does this information tell you about the reactivity of sulfur?

The Oxygen Family

Phosphorus The element phosphorus has 10 forms, which are usually grouped as white, red, and black phosphorus for simplicity. The white phosphorus forms are the least stable. In 1680, Robert Boyle demonstrated that phosphorus ignited by friction could be used to light wooden splints that had been dipped in sulfur. There are two types of matches. In a strike-anywhere match, all of the required ingredients (often phosphorus sulfide and potassium chlorate) are in the match head. In a safety match, the ingredients are divided between the match head and a rough striking surface on the side of the matchbox. A safety match can be lit only when the tip is drawn across the striking surface, which contains phosphorus sulfide.

The Nitrogen Family Build Reading Literacy L1

Identify Main Idea/Details Refer to page 98D in Chapter 4, which provides the guidelines for identifying main ideas and details.

Guide students in applying this strategy to the text on page 143. Tell students to look for the main idea of each paragraph and then list one or two supporting details. If the paragraph has no topic sentence, have students list two important facts from the paragraph.

Verbal, Portfolio FYI

Of the 18 elements essential for plant growth, nitrogen, phosphorus, and potassium are most likely to be lacking. The numbers on the fertilizer packages shown in Figure 19 represent percent N, percent P2O5, and percent K2O. (In the past, oxides were often used as standards for chemical comparisons.) Nitrogen and phosphorus are often present as nitrates and phosphates.

The Nitrogen Family

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Figure 19 The composition of a fertilizer varies with its intended use. The numbers on the bags of fertilizer are, from left to right, the relative amounts of nitrogen, phosphorus, and potassium.

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The Halogens

**Section 5.3 (continued)**

**The Halogens**

**Build Reading Literacy**  
**KWL** Refer to page 124D in this chapter, which provides the guidelines for KWL (Know/Want to Know/Learned). Teach this independent study skill as a whole-class exercise.  1. Draw a three-column KWL chart on the board for students to copy.  2. Have students complete the Know column with facts, examples, and other information that they already know about the Group 7A elements (the halogens).  3. Tell students to complete the Want to Know column with questions about the halogens.  4. Have students read p. 144 to learn more about the halogens. As they read, have them note answers to their questions in the Learned column, along with other facts, examples, and details they learned.  5. Have students draw an Information I Expect to Use box below their KWL chart. Have them review the information in the Learned column and categorize the useful information in the box.  

**Verbal**

**Facts and Figures**

**Halogen** The name astatine comes from the Greek *astatos*, meaning “unstable.” Astatine is a radioactive element whose most stable isotope, At-210, has a half-life of only 8.1 h. Astatine is the most metallic of the halogens. It is usually classified as a metalloid, but is sometimes regarded as a nonmetal. Because of its rarity and instability, astatine has no practical uses. Both bromine and iodine are volatile. Iodine comes from the Greek *iōdēs*, meaning “violet colored.” It is named for the color of iodine vapor, not the color of its solid crystals, which are dark gray.

**The Halogens**

The elements in Group 7A are called **halogens**. Each halogen has seven valence electrons. Figure 21 shows the range of physical properties among the halogens. Fluorine and chlorine are gases, bromine is a liquid that evaporates quickly, and iodine is a solid that sublimes. Despite their physical differences, the halogens have similar chemical properties. They are highly reactive nonmetals, with fluorine being the most reactive and chlorine a close second. Halogens react easily with most metals. Figure 21 shows what happens when heated steel wool is plunged into chlorine.

Recall that a fluorine compound is used to prevent tooth decay. If you use pans with a nonstick coating to make omelets or muffins, you have seen another use of a fluorine compound. Have you ever noticed a sharp smell when adding bleach to a load of clothes? The smell comes from a small amount of chlorine gas that is released from a chlorine compound in the bleach. Chlorine is also used to kill bacteria in drinking water and swimming pools. The woman in Figure 21 is testing the level of chlorine in a swimming pool.

Your body needs iodine to keep your thyroid gland working properly. This gland controls the speed at which reactions occur in your body. Seafood is a good source of iodine. At a time when fresh fish was not available in all parts of the United States, people began to add iodine compounds to table salt. Salt that contains such compounds is called iodized salt.

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**Figure 21** At room temperature, chlorine is a gas, bromine is a liquid, and iodine is a solid. Halogens react easily with metals, such as the iron in steel wool. At a swimming pool, the chlorine content must be tested frequently. **Applying Concepts** What process causes iodine vapor to collect in a flask of solid iodine?
Comparing and Contrasting

In which e

The noble gases are called noble gases. Helium has two valence electrons. Each of the other noble gases has eight valence electrons. The noble gases are colorless and odorless and extremely unreactive. In Chapter 6, you will study the relationship between the electron configurations of the noble gases and their low reactivity.

It is not easy to discover a colorless, odorless gas. It is even harder if the gas rarely reacts. Scientists discovered argon when they noticed that the density of nitrogen collected from air did not match the density of nitrogen formed during chemical changes. In time, the scientists figured out that the “impurity” in atmospheric nitrogen was an unknown element.

An element that does not react easily with other elements can be very useful. For example, during one stage in the process of making computer chips, pure silicon is heated in a furnace at 1480°C. At this temperature, silicon reacts with both oxygen and nitrogen. So the heating must take place in an argon atmosphere.

Some light bulbs are filled with argon because the glowing filament in the bulb will not react with argon as it would react with oxygen. Using argon increases the number of hours the bulb can be lit before it burns out. All the noble gases except radon are used in “neon” lights like those shown in Figure 22.

The Noble Gases

The elements in Group 8A are called noble gases. Helium has two valence electrons. Each of the other noble gases has eight valence electrons. The noble gases are colorless and odorless and extremely unreactive. In Chapter 6, you will study the relationship between the electron configurations of the noble gases and their low reactivity.

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The Noble Gases

Build Science Skills

Inferring Hold up an incandescent light bulb and tell students that the filament in the light bulb is made of tungsten, which emits light when it is heated to a high temperature. Explain that a light bulb with a tungsten filament contains small amounts of gases, such as argon, that do not react easily. Ask, Why isn’t air used in the light bulb? (The heated filament would burn in air, which contains oxygen.)

Visual, Logical

3 ASSESS

Evaluate Understanding

Write the names of a group elements discussed in Section 3.3 on separate index cards. Distribute one card to each pair of students and have them add the following information to the card: chemical symbol, atomic number, group number and group name, number of valence electrons, physical state at room temperature, class of element (metal, nonmetal, or metalloid), and one or two properties of the element.

Reteach

Use the segments of the periodic table that appear throughout the section to review each A group. Emphasize how the metallic properties of elements increase from top to bottom within a group and how the number of valence electrons changes from left to right across the periodic table.

Examples of Identifying Materials: Distinguish halogens by their states and colors at room temperature.

Examples of Choosing Materials: Using hard calcium carbonate to polish teeth; using argon to increase the life of a light bulb.

Examples of Separating Materials: Sodium chloride from seawater by evaporation; nitrogen from oxygen based on their boiling points.

If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 5.3.

Answer to . . .

Figure 21 Sublimation

Section 5.3 Assessment

Reviewing Concepts
1. Explain why elements in a group have similar properties.
2. What is the relationship between an alkali metal’s location in Group 1A and its reactivity?
3. What element exists in almost every compound in your body?
4. Which Group 5A elements are found in fertilizer?
5. Which group of elements is the least reactive?
6. Why is hydrogen located in a group with reactive metals?
7. What biological function requires magnesium?
8. Why is aluminum recycled?
9. What is the main use of sulfur?
10. Why is chlorine added to drinking water?

Critical Thinking
11. Comparing and Contrasting In which class of elements is there a greater range of properties, the metals or the nonmetals? Give an example to support your answer.
12. Making Generalizations What happens to the reactivity of nonmetals within a group from the top of the group to the bottom?

Using Physical Properties In Section 2.2, three ways to use physical properties are discussed. Find one example in Section 5.3 that illustrates each use. If necessary, reread pages 48 and 50.
**Elemental Friends and Foes**

**Background**

All packaged and processed food sold in the United States displays a label with nutritional information. The label is designed to be easy to read and to enable consumers to quickly find the information they need to make appropriate food choices. The label contains a Daily Value percentage (%DV) for calorie-containing nutrients such as fats and carbohydrates, as well as for cholesterol, vitamins, and minerals. For vitamins and minerals, the %DV is based on the Reference Daily Intake (RDI) values established by the U.S. Food and Drug Administration. On current food labeling, the %DV for vitamins and minerals is the percentage of RDI available in a single serving. For example, the RDI for magnesium is 400 milligrams. If a single serving of a certain brand of cereal contains 40 milligrams of magnesium, the %DV for magnesium is listed as 10%. It is likely that the number of elements classified as essential will grow along with advancements in understanding of nutrition and the human body. For example, nickel is an essential element in some species, but has not yet been determined to be essential in humans.

**Elemental Friends and Foes**

Some elements are essential for your health, and some are extremely harmful. You need to obtain the right amounts of the twenty-five essential elements through a balanced diet, and to reduce your exposure to the harmful elements.

Eating a variety of foods helps to ensure that all the elements needed by your body are available. The required elements can be classified as major, lesser, or trace elements. An element is classified based on its percentage by mass in the body. The six major elements are hydrogen, oxygen, carbon, nitrogen, phosphorus, and calcium. These six major elements account for almost 99 percent of your body mass. Nearly every compound in your body contains carbon and hydrogen, and many contain oxygen too. The compounds that control all the chemical changes that take place in cells contain nitrogen. Calcium is essential for healthy bones and teeth. Phosphorus is found in your DNA and in the molecules that transfer energy within cells.

The lesser elements are iron, potassium, zinc, sodium, sulfur, chlorine, and magnesium. For each lesser element, there is a recommended amount that needs to be taken in daily. These amounts vary from 15 milligrams for zinc to 400 milligrams for magnesium. Lesser elements help your body build tissues and maintain other cell processes. For example, nerves and muscles require magnesium to function properly.

The trace elements are vanadium, chromium, molybdenum, manganese, cobalt, copper, boron, tin, silicon, selenium, fluorine, and iodine. The quantities required are tiny, but trace elements perform important functions. For example, red blood cells would not mature without cobalt.

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### Essential Elements of the Human Body

- **Major Elements**: Approximately 98.6% of total.
- **Lesser Elements**: Approximately 1.4% of total.
- **Trace Elements**: Less than 0.01% of total.
- **Nonessential Elements**
**Essential elements**

The 25 elements essential to the human body are generally ingested as part of compounds found in food. The roles and functions of a few of these elements are shown here.

- **Oxygen**
  - This is the most abundant element in your body. The most important function of oxygen is to help release the energy stored in foods. You absorb oxygen from the air you breathe.

- **Hydrogen**
  - Hydrogen is found in foods and in water, which accounts for more than 60 percent of body mass. Chemical reactions in cells take place in water.

- **Iodine**
  - Iodine is required in small amounts for the production of thyroxine by the thyroid gland. Thyroxine controls the rate of all chemical processes in the body. Fresh fish is a good source of iodine.

- **Vanadium**
  - Vanadium can help control blood sugar levels. It also plays an important role in the formation of bones and teeth. Vanadium can be found in black peppercorns.

- **Carbon**
  - Carbon is the second most common element in the human body. It is essential to life, because it is present in almost every compound in the body. If a food contains carbohydrates, proteins, or fats, it contains carbon compounds.

- **Iron**
  - Iron is a very important trace element because it is part of hemoglobin. This compound transports oxygen through the blood to every cell in the body. Meat, fish, and leafy green vegetables, such as spinach, are good sources of iron.

- **Potassium**
  - Potassium is essential to muscle and nerve function, and helps keep the body’s fluids in balance. It also stimulates the kidneys to remove body wastes. Potassium can be found in fruit and dairy products.
Harmful Elements

Some elements should be avoided completely. These foes include metals, such as lead and mercury, and the metalloid arsenic. Harmful elements may enter the body in water, air, or food. Inside the body, nonessential elements may compete with essential elements and disrupt cell functions. Large amounts of harmful elements can stress the body’s normal methods for eliminating toxins. Harmful elements can build up in body tissues.

For decades lead was used in paint and in gasoline to improve engine performance. These products are now lead free. The use of mercury in thermometers has been reduced and arsenic compounds are no longer used in pesticides.

Many trace elements are only helpful if ingested in the small recommended amounts. Larger quantities of most trace elements can be harmful, as can larger-than-required amounts of lesser elements, such as sodium.
Too much of a good thing

Many of the elements found in your body are needed in only very small amounts. Too much can often be harmful. The Food and Drug Administration provides guidelines on the safe daily quantities to take through food or supplements.

Zinc

This trace element can be found in almost every cell of your body. Among other things, it helps to support a healthy immune system. Beef is a good source of zinc, but no more than 40 milligrams of zinc should be taken daily. Too much zinc can cause anemia by reducing iron uptake.

Sodium

It is hard to avoid sodium in your diet because table salt contains a sodium compound (sodium chloride). Everybody needs some sodium each day to maintain water balance and nerve function. But too much sodium (more than 3 grams daily) can cause high blood pressure.

Selenium

This trace element helps to maintain a healthy immune system. Brazil nuts are a good source of selenium, as are fruits and vegetables. While selenium supplements may be useful for some people, no more than 400 micrograms should be taken daily. Too much selenium can cause nerve damage.

Integrate Health

A person’s diet must contain some sodium compounds so that important functions such as maintenance of appropriate water levels within cells and transmission of nerve impulses will occur. However, the level of sodium compounds in food (especially in processed foods) is so high that most people’s intake of sodium compounds exceeds required levels. Have students research the possible adverse health effects of an excess of sodium in the body.

Verbal

Going Further

Chromium: black pepper, broccoli, asparagus, mushrooms, liver, raisins, nuts, brewer’s yeast; molybdenum: legumes, leafy vegetables, grains; manganese: nuts, oatmeal, ginger, rice; cobalt: meat, dairy products, green leafy vegetables; silicon: whole grains, liver, red meat. (In exists in sufficient quantities in water, food, and air.)

Verbal, Portfolio

Going Further

• Choose a trace element other than vanadium, selenium, or iodine. Find out which foods are good sources of the element. Write a paragraph explaining how your diet meets or could be adjusted to meet your need for this element.

• Take a Discovery Channel Video Field Trip by watching “You Are What You Eat.”

Video Field Trip

You Are What You Eat

After students have viewed the Video Field Trip, ask them the following questions: How did some ancient civilizations preserve their dead? (By embalming, or using preservatives) What are two types of information that scientists discover by examining mummies? (Student answers may include age, gender, diet, and cause of death.) What evidence led forensic scientists to suspect Tutankhamen, also known as King Tut, might not have died from natural causes? (X-rays showed bone damage to his skull probably caused by a blow to his head.) List features that scientists found in the bones of mummies in Chile. (Student answers may include bone deformation around the ear, bones with significant nitrogen deposits, and strong and healthy teeth.) What do forensic scientists suspect to be the causes of the features found in these mummies? (Fishing in cold waters could have caused the growth around the ears. Nitrogen deposits in their bones could have been caused by a diet rich in seafood. A diet of fish could explain the strong, healthy teeth.)
Chapter 5
The Periodic Table

At a farm stand, each product is displayed in its own bin, just as each element has a specific location in the periodic table.

ASSESS PRIOR KNOWLEDGE

Use the Chapter Pretest below to assess students’ prior knowledge. As needed, review these Science Concepts with students.

Review Science Concepts

Section 5.1 Have students recall how symbols are used to represent elements. Have them list examples of physical and chemical properties. Review three clues for recognizing a chemical change (a color change, production of a gas, formation of a precipitate).

Section 5.2 Ask students to recall that the atomic number of an element is the number of protons in an atom of the element and that each element has a different atomic number. Review the concept of isotopes and remind students that isotopes of an element have different numbers of neutrons.

Section 5.3 Have students review energy levels in preparation for a discussion of valence electrons. Ask students what they recall about the reactivity of elements such as oxygen and nitrogen.

Chapter Pretest

1. Which of the following is a symbol for an element? (b)
   a. Aluminum
   b. Al
   c. al
   d. AL

2. Is flammability a physical property or a chemical property? (A chemical property)

3. What happens to the composition of matter during a physical change? (It remains the same.)

4. What does the atomic number of an element represent? (The number of protons in an atom of the element)

5. Isotopes of an element have different numbers of (a)
   a. neutrons
   b. electrons
   c. protons
   d. nuclei

6. True or False: Electrons in atoms occupy orbitals in energy levels. (True)

7. Which element is more reactive, oxygen or nitrogen? (Oxygen)
### Inquiry Activity

#### How Much Data Do You Need to Identify a Pattern?

**Procedure**
1. Your teacher will give you a stapled stack of paper. Look at the squares on the top sheet of paper. Try to figure out what familiar phrase you would see if all the squares were filled in. Record your prediction on the sheet.
2. Remove the top sheet and look at the second sheet. Again, try to figure out what letters belong in the squares. Record your prediction.
3. Continue this process until you have looked at all the sheets in the stack.

**Think About It**
1. **Observing** How did the information on the sheets change as you moved from the top to the bottom of the stack?
2. **Drawing Conclusions** How did the number of letters provided affect your ability to predict the phrase?
3. **Using Analogies** Describe another situation in which having more data makes it easier to recognize a pattern.

#### Video Field Trip

Encourage students to view the Video Field Trip “You Are What You Eat.”

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**ENGAGE/EXPLORE**

#### How Much Data Do You Need to Identify a Pattern?

**Purpose** In this activity, students identify a relationship between the amount of data available and the ability to recognize a pattern.

**Skills Focus** Predicting, Evaluating and Revising

**Prep Time** 15 minutes

**Materials** stapled stack of papers

**Advance Prep** Select a phrase that will be familiar to students. Draw a series of boxes on a sheet of paper to represent the letters of the phrase, leaving spaces between words. Make five copies of this sheet. Fill in two or three letters on the first copy. Add a few letters to each subsequent copy. Plan for two or three blanks on the fifth sheet. Give each student or group a stapled stack arranged in order of completeness with the least complete copy on top.

**Class Time** 10 minutes

**Teaching Tips**
- Before distributing the stacks, explain to students that they should not look ahead in the stack. For the activity to be successful, they must work with only one sheet at a time.

**Expected Outcome** Students’ predictions will become increasingly accurate as they progress through the stack.

**Think About It**
1. There was more information.
2. Increasing the number of letters made it easier to predict the phrase.
3. In the suggested situations, the data must be limited to start. (If students are having trouble thinking of an example, ask what they can tell about a movie from a trailer or about a novel after reading one page.) Logical

**For Enrichment**

Use a numerical example to reinforce the need for enough data to reveal a pattern. Ask students to predict the next number in the sequence 3, 5, and 7. (9) Then say that the next number is 11. Ask what property the numbers 3, 5, 7, and 11 have in common. (They are prime numbers.) Visual, Logical
Predicting the Density of an Element

Objective
After completing this activity, students will be able to
• state that density increases from the top to the bottom within a group in the periodic table.
• evaluate predictions of physical properties based on the periodic table.

Skills Focus Measuring, Predicting, Analyzing Data, Using Graphs and Tables

Prep Time 20 minutes

Advance Prep Place each of the elements into a separate small, labeled container. Select sample sizes that will fit in the available graduated cylinders.

Class Time 40 minutes

Safety Make sure that students wear safety goggles, disposable plastic gloves, and lab aprons and wash their hands before leaving the laboratory. Caution students about the proper handling of chemicals. If you cut pieces of tin for students to use, be sure to file the edges smooth. Do not discard lead.

Teaching Tips
• Review the proper techniques for accurate use of the balance. Also remind students to read volumes in a graduated cylinder at eye level and at the bottom of the meniscus.

Questioning Strategies
Ask, Why is it necessary to subtract the mass of the weighing paper from the total mass of the weighing paper and the sample? (To obtain the mass of the sample) Why is it necessary to subtract the volume of water from the total volume of water and sample when determining the volume of the silicon, tin, and lead? (To obtain the volume of each sample)

Expected Outcome The elements’ densities increase from the top to the bottom of Group 4A, but not in a simple linear manner.

Materials
• unlined white paper
• scissors
• metric ruler
• balance
• forceps
• silicon
• lead shot

Part A: Measuring Mass
1. On a sheet of paper, make a copy of the data table shown.
2. Cut out three 10-cm × 10-cm pieces of paper from a sheet of unlined white paper. Label one piece of paper Silicon, the second Tin, and the third Lead. Find the mass of each piece of paper and record it in your data table.

Part B: Measuring Volume
5. Place 25 mL of water in the graduated cylinder. Measure the volume of the water to the nearest 0.1 mL. Record the volume (in cm³) in your data table. (Hint: 1 mL = 1 cm³)
6. Tilt the graduated cylinder and carefully pour the silicon from the paper into the graduated cylinder, as shown on page 151. Make sure that the silicon is completely covered by the water. Measure and record the volume of the water and silicon in your data table. Then, subtract the volume of water from the volume of the water and silicon. Record the result in your data table.
7. Repeat Steps 5 and 6 to find the volumes of tin and lead.

Sample Data Table

<table>
<thead>
<tr>
<th>Element</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon</td>
<td>2.4</td>
</tr>
<tr>
<td>Tin</td>
<td>7.1</td>
</tr>
<tr>
<td>Lead</td>
<td>11.3</td>
</tr>
<tr>
<td>Germanium</td>
<td>4.6 (from student graph)</td>
</tr>
</tbody>
</table>
Part C: Calculating Density
8. To calculate the density of silicon, divide its mass by its volume.

\[
\text{Density} = \frac{\text{Mass}}{\text{Volume}}
\]

Record the density of silicon in your data table.
9. Repeat Step 8 to find the densities of tin and lead.
10. Make a line graph that shows the relationship between the densities of silicon, tin, and lead and the periods in which they are located in the periodic table. Place the number of the period (from 1 to 7) on the horizontal axis and the density (in g/cm³) on the vertical axis. Draw a straight line that comes as close as possible to all three points.
11. Germanium is in Period 4. To estimate the density of germanium, draw a dotted vertical line from the 4 on the horizontal axis to the solid line. Then, draw a dotted horizontal line from the solid line to the vertical axis. Read and record the density of germanium.
12. Wash your hands with warm water and soap before you leave the laboratory.

**Analyze and Conclude**

1. **Classifying** List lead, silicon, and tin in order of increasing density.
2. **Comparing and Contrasting** How does your estimate of the density of germanium compare with the actual density of germanium, which is 5.3 g/cm³?
3. **Calculating** Use the formula for percent error (PE) to calculate a percent error for your estimate of the density of germanium.

\[
\text{PE} = \frac{\text{Estimated value} - \text{Accepted value}}{\text{Accepted value}} \times 100
\]

4. **Drawing Conclusions** How does the density of the elements change from silicon to lead in Group 4A?

**Go Further**

Use reference books or sites on the Internet to research properties of Group 4A elements. Construct a graph that shows how another property, such as melting point or boiling point, varies among the Group 4A elements you explored. Determine whether knowing the values for three of the elements would allow you to accurately predict a value for the fourth element.
<table>
<thead>
<tr>
<th>SECTION OBJECTIVES</th>
<th>STANDARDS NATIONAL</th>
<th>STANDARDS STATE</th>
<th>ACTIVITIES and LABS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>5.1 Organizing the Elements, pp. 126–129</strong></td>
<td>A-1, A-2, B-1, B-2, G-1, G-2, G-3</td>
<td></td>
<td><strong>SE</strong> Inquiry Activity: How Much Data Do You Need to Identify a Pattern? p. 125 <strong>SE</strong> Quick Lab: Making a Model of a Periodic Table, p. 128</td>
</tr>
<tr>
<td>1 block or 2 periods</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.1.1 Describe how Mendeleev arranged the elements in his table.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.1.2 Explain how the predictions Mendeleev made and the discovery of new elements demonstrated the usefulness of his periodic table.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>5.2 Modern Periodic Table, pp. 130–138</strong></td>
<td>A-1, A-2, B-1, B-2</td>
<td></td>
<td><strong>SE</strong> Quick Lab: Defining a Metal, p. 135 <strong>SE</strong> Exploration Lab: Predicting the Density of an Element, pp. 150–151 <strong>TE</strong> Teacher Demo: Period 3 Properties, p. 138 <strong>LM</strong> Investigation 5A: Analyzing Patterns in the Periodic Table</td>
</tr>
<tr>
<td>1 block or 2 periods</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.2.1 Describe the arrangement of elements in the modern periodic table.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.2.2 Explain how the atomic mass of an element is determined and how atomic mass units are defined.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.2.3 Identify general properties of metals, nonmetals, and metalloids.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.2.4 Describe how properties of elements change across a period in the periodic table.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>5.3 Representative Groups, pp. 139–145</strong></td>
<td>B-1, B-2, B-3, C-1, C-5, F-1, F-3, F-5</td>
<td></td>
<td><strong>LM</strong> Investigation 5B: Comparing Chemical Properties</td>
</tr>
<tr>
<td>1 block or 2 periods</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.3.1 Relate the number of valence electrons to groups in the periodic table and to properties of elements in those groups.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.3.2 Predict the reactivity of some elements based on their locations within a group.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.3.3 Identify some properties of common A group elements.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Organizing the Elements 5.1

After Lavoisier classified elements into metals, nonmetals, gases and earths in 1789, there were many attempts to find a rational system for organizing the elements. In 1829, Johann Döbereiner proposed a law of triads. A triad is a group of similar elements in which the properties of the middle element fall midway between the properties of the lighter and heavier elements as shown here for the atomic masses of alkali metals. Notice that the atomic mass of sodium (22.990) is close to the arithmetic mean of the atomic masses of lithium and potassium: \((6.941 + 39.098)/2 = 23.02\).

In 1865, John Newlands arranged elements into seven columns in order of increasing atomic mass. The arrangement was inspired by the notes in a Western musical scale. Many modern chemists credit Newlands with the concept of periodicity, which he described in his law of octaves. However, he was not able to develop a useful system from his concept. In 1865, William Odling revised Newlands’s system and produced a table that was similar to the one developed by Mendeleev. However, Odling did not explain the relationships shown in his table. In 1870, the German chemist Lothar Meyer published a plot of atomic volume vs. atomic mass, which showed a series of waves with sharp peaks at the beginning of each new period. Meyer is sometimes credited with an independent discovery of the periodic table. When Mendeleev prepared his table, he was not aware of the work of Newlands, Odling, or Meyer.

<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>Atomic Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithium</td>
<td>Li</td>
<td>6.941</td>
</tr>
<tr>
<td>Sodium</td>
<td>Na</td>
<td>22.990</td>
</tr>
<tr>
<td>Potassium</td>
<td>K</td>
<td>39.098</td>
</tr>
</tbody>
</table>

In 1865, John Newlands arranged elements into seven columns in order of increasing atomic mass. The arrangement was inspired by the notes in a Western musical scale. Many modern chemists credit Newlands with the concept of periodicity, which he described in his law of octaves. However, he was not able to develop a useful system from his concept. In 1865, William Odling revised Newlands’ system and produced a table that was similar to the one developed by Mendeleev. However, Odling did not explain the relationships shown in his table. In 1870, the German chemist Lothar Meyer published a plot of atomic volume vs. atomic mass, which showed a series of waves with sharp peaks at the beginning of each new period. Meyer is sometimes credited with an independent discovery of the periodic table. When Mendeleev prepared his table, he was not aware of the work of Newlands, Odling, or Meyer.

Students may think that advances in science are always achieved by scientists working alone. They may not realize that most advances are the result of contributions by many scientists. For a strategy to overcome this misconception, see Address Misconceptions on page 129.
**Metalloids 5.2**

Many periodic tables use a diagonal line to divide the metallic and nonmetallic regions of the periodic table. Elements that lie close to the line are described as having properties intermediate to those of metals and nonmetals. Because these borderline elements look like metals, they are often referred to as metalloids even though they do not exhibit all the general properties of metals. There is not universal agreement on which elements to classify as metalloids. Polonium is often classified as a metal and astatine is sometimes classified as a nonmetal. (The classification of metalloids presents similar issues as the classification of colloids—the intermediate category between solutions and suspensions.)

**Diagonal Relationships 5.3**

Using the first element in a group to refer to the group as a whole, as in The Boron Family, can be misleading because there can be significant differences between the properties of the first element and the properties of the rest of the group. Sometimes the first element has more in common with the second element of the neighboring group than with the second element in its own group. These cross-group relationships are called diagonal relationships. They exist between lithium and magnesium, beryllium and aluminum, and boron and silicon.

Lithium and magnesium can serve as an example. Lithium is the only alkali metal to react with nitrogen in air to form a nitride. Magnesium reacts with nitrogen in air, too. Lithium carbonate and magnesium hydroxide decompose when heated. So do magnesium carbonate and magnesium hydroxide. Carbonates and hydroxides of the other alkali metals are stable when heated. Many lithium compounds are less soluble in water than comparable compounds of other alkali metals. The lithium compounds are similar in solubility to magnesium compounds. Similarities between the chemistry of lithium and magnesium are mainly attributed to the similar sizes of their atoms and ions. (See the table of atomic and ionic radii in the Data Analysis on page 160.)

**Build Reading Literacy**

**KWL (Know-Want-Learned)**

**What I Know/Want to Know/Learned**

**Strategy** To help students access prior knowledge, set a purpose for reading, recall what has been read, and link new information to prior knowledge. The KWL strategy has students create and complete a three-column chart similar to the one below. As students read, they complete the Learned column.

<table>
<thead>
<tr>
<th>Know</th>
<th>Want to Know</th>
<th>Learned</th>
</tr>
</thead>
</table>

Finally, students categorize information they learned in a box titled Information I Expect to Use.

**Information I Expect to Use**

Assign a section in Chapter 5, such as Classes of Elements, pp. 135–136, for students to read. Before they begin, have them create and complete the first two columns of the KWL chart.

**Example**

1. Draw a three-column KWL chart on the board for students to copy.
2. Have students complete the Know column with facts, examples, and other information they already know about the topic.
3. Tell students to complete the Want to Know column with questions about the topic that they want answers to. Students may scan the section to help them generate questions.
4. Have students read the section to learn more about the topic and determine answers to their questions. As they read, have them note answers in the Learned column, along with other facts, examples, and details they learned.
5. Below their KWL chart, have students draw an Information I Expect to Use box. Have them review the information in the Learned column and use it to complete the box with the useful categories of information.

See p. 144 for a script on how to use the KWL strategy with students. For additional Build Reading Literacy strategies, see pp. 126, 131, 136, and 143.
5.1 Organizing the Elements

Key Concepts
- Mendeleev arranged the elements into rows in order of increasing mass so that elements with similar properties were in the same column.
- The close match between Mendeleev's predictions and the actual properties of new elements showed how useful his periodic table could be.

Vocabulary
periodic table, p. 127

5.2 The Modern Periodic Table

Key Concepts
- In the modern periodic table, elements are arranged by increasing atomic number (number of protons). Each row on the table is a period. Each column is a group.
- Properties of elements repeat in a predictable way when atomic numbers are used to arrange elements into groups.
- Atomic mass is a value that depends on the distribution of an element's isotopes in nature and the masses of those isotopes.
- Elements are classified as metals, nonmetals, and metalloids. Metals are elements that are good conductors of electric current and heat. Nonmetals are poor conductors of electric current and heat. Metalloids are elements with properties that fall between those of metals and nonmetals.
- Across a period from left to right, the elements become less metallic and more nonmetallic in their properties.

Vocabulary
period, p. 131
group, p. 131
periodic law, p. 131
atomic mass unit (amu), p. 134
metals, p. 135
transition metals, p. 136
nonmetals, p. 136
metalloids, p. 136

5.3 Representative Groups

Key Concepts
- Elements in a group have similar properties because they have the same number of valence electrons.
- The alkali earth metals in Group 1A are extremely reactive. The reactivity of these metals increases from the top of the group to the bottom.
- Differences in reactivity among the alkaline earth metals in Group 2A are shown by the ways they react with water.
- Group 3A contains the most abundant metal in Earth's crust—aluminum. The energy needed to recycle aluminum is 5 percent of the energy needed to extract aluminum from bauxite.
- Group 4A contains the nonmetal carbon. Most compounds in your body contain carbon. Carbon compounds control reactions that occur in cells.
- Fertilizers usually contain the Group 5A elements nitrogen and phosphorus.
- Oxygen, in Group 6A, is the most abundant element in Earth's crust.
- Despite their physical differences, the halogens in Group 7A are all highly reactive nonmetals.
- The noble gases, in Group 8A, are colorless and odorless and extremely unreactive.

Vocabulary
valence electron, p. 139
alkali metals, p. 140
alkaline earth metals, p. 141
halogens, p. 144
noble gases, p. 145

Thinking Visually
Web Diagram Use information from the chapter to complete the web diagram below. The web relates states of matter at room temperature to categories of elements.

- a. ?
- b. ?
- Gases
- Metals

Chapter Resources

Print
- Chapter and Unit Tests, Chapter 5
  Test A and Test B
- Test Prep Resources, Chapter 5

Technology
- Computer Test Bank, Chapter Test 5
- Interactive Textbook, Chapter 5
- Go Online, PhSchool.com, Chapter 5
The most reactive metals are the

Elements that have the same number of valence 
electrons are

An element that is shiny and conducts electric 
current is likely to be a

An atomic mass unit is

Mendeleev arranged the elements in his periodic 
table in order of

Mendeleev’s decision to leave gaps in his periodic 
table was supported by the discovery of

In a modern periodic table, elements are arranged 
in order of

An atomic mass unit is

An element that is shiny and conducts electric 
current is likely to be a

Copper is an example of

Elements that have the same number of valence 
electrons are

The most reactive metals are the

Which elements are all gases at room temperature?

11. What information did Mendeleev have about the 
elements he organized into a periodic table?

12. How did Mendeleev know where to leave the 
spaces in his table?

13. Why is the table of the elements shown in 
Figure 7 called a periodic table?

14. Why does the number of elements vary from 
period to period?

15. Explain how the atomic mass of an element is 
affected by the distribution of its isotopes in nature.

16. List three ways that the elements in the periodic 
table can be classified.

17. In general, what happens to the reactivity of 
elements in groups labeled A as atomic numbers 
increase across a period?

18. Why don’t the elements within an A group in the 
periodic table have identical properties?

19. Why was it difficult to discover the noble gases?

Use this portion of the periodic table to answer 
Questions 20–23.

20. How many of the elements shown are metals? How 
many are nonmetals? How many are metalloids?

21. Which element is a liquid at room temperature 
and which is a gas at room temperature?

22. Which of the two halogens shown is more 
reactive? Give a reason for your answer.

23. Does selenium have more in common with sulfur 
or bromine? Explain your answer.

Assessment

If your class subscribes to the Interactive Textbook, your students 
can go online to access an interactive version of the Student Edition and a 
self-test.

Understanding Concepts

11. Mendeleev knew where to leave the 

12. Mendeleev placed elements in the 
groups where they logically belonged 
based on their properties.

13. The table is called a periodic table 
because the properties of the elements 
repeat at regular intervals from row 
to row.

14. The number of elements per period 
varies because the number of available 
orbitals increases as the energy level 
increases.

15. An atomic mass is a weighted 
average of the atomic masses of an 
element’s isotopes. The distribution 
of the isotopes determines how much each 
isotope affects the weighted average.

16. Elements can be classified by their 
state at room temperature; by whether 
they exist in nature; and by whether 
they are metals, nonmetals, or 
metalloids.

17. Across a period from left to right, 
metals become less reactive and 
nonmetals become more reactive, 
excluding the elements in Group 8A.

18. Elements in the same A group do 
not have identical properties because 
their valence electrons are in different 
energy levels.

19. The noble gases were difficult to 
discover because they are colorless, 
orid, and very rarely react.

20. 0 metals, 5 nonmetals, and 3 
metalloids

21. Bromine is a liquid and chlorine 
is a gas.

22. Chlorine is more reactive than 
bromine because the reactivity of 
nonmetals increases from the bottom 
to the top of a group.

23. Selenium has more in common with 
sulfur because they are in the same 
group and have the same number of 
valence electrons.

The Periodic Table 153
Chapter 5

Assessment (continued)

Critical Thinking

24. There is not enough data for the solid because solids at room temperature can be metals, nonmetals, or metalloids. There is enough data for the gas because there are no gaseous metals or metalloids at room temperature.
25. Boron, with an atomic mass of 10.81
26. Three
27. Cesium is an extremely reactive metal; argon is an extremely unreactive nonmetal.
28. Halogens are always found in nature in compounds because halogens are highly reactive nonmetals.
29. Silicon
30. You would choose fluorine because it is much more likely to react than nitrogen is.
31. Elements X and Y are in Group 1 (1A) and Element Z is in Group 17 (7A).
32. Elements Y and Z are gases; element X is a solid.
33. Element Y is hydrogen, because hydrogen is the only gas in Group 1.

Concepts in Action

34. The beaker might shatter.
35. Students are likely to say nitrogen and phosphorus.
36. An element that is helpful in small quantities may be harmful when present in larger quantities. For example, trace amounts of selenium help maintain the immune system, but larger amounts can cause nerve damage.
37. The books would not fall apart if stored in a noble-gas atmosphere.
38. There is a repeating pattern of days and months on a calendar. However, Tuesdays do not necessarily have a different set of properties from Thursdays and there are no trends among Tuesdays equivalent to the trends in atomic mass or reactivity within a group in the periodic table.
39. Magnesium is required to produce chlorophyll, the green pigment in plants.
40. The essays should contain accurate information and make a reasonable argument for the value of the element.

Critical Thinking

24. Classifying If you know that an element is a solid at room temperature, do you have enough data to classify the element as a metal, metalloid, or nonmetal? If you know that the element is a gas at room temperature, do you have enough data? Explain your answers.
25. Applying Concepts An element on the periodic table has two naturally occurring isotopes. One isotope has an atomic mass of about 10 amu. The other isotope has an atomic mass of about 11 amu. What is the name of this element?
26. Predicting How many valence electrons would an element with atomic number 113 have?
27. Applying Concepts Why are samples of the alkali metal cesium usually stored in argon gas?
28. Applying Concepts Why are halogens found in nature only in compounds?
29. Applying Concepts Which element on the periodic table has chemical properties that are most similar to those of carbon?
30. Designing Experiments If you were trying to make a compound of the noble gas xenon, would you use nitrogen or fluorine? Explain your choice.

Use the table to answer Questions 31-33.

Properties of Elements X, Y, and Z:

<table>
<thead>
<tr>
<th>Element</th>
<th>Melting Point</th>
<th>Boiling Point</th>
<th>Valence Electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>97.80°C</td>
<td>88.3°C</td>
<td>1</td>
</tr>
<tr>
<td>Y</td>
<td>−259.34°C</td>
<td>−252.87°C</td>
<td>1</td>
</tr>
<tr>
<td>Z</td>
<td>−101.5°C</td>
<td>−34.04°C</td>
<td>7</td>
</tr>
</tbody>
</table>

31. Analyzing Data In general, where would you find Elements X, Y, and Z on the periodic table?
32. Classifying Describe the state of each element at room temperature based on its melting and boiling points.
33. Drawing Conclusions Use your answers to Questions 31 and 32 to identify element Y. Explain your reasoning.

34. Predicting What might happen to a heated beaker made from glass that does not contain boron if the beaker were placed in a pan of ice water?
35. Inferring Based on the content of most fertilizers, name two elements other than carbon that are found in compounds in plants.
36. Making Generalizations Explain how the amount of a trace element an organism is exposed to affects the element’s ability to help or harm an organism. Use the example of selenium.
(Hint: Refer to the discussion on page 149.)
37. Problem Solving Sometimes old books fall apart when they are stored in air. Use what you know about the reactivity of elements to propose a way that old books could be kept from falling apart.
38. Using Analogies Explain how a calendar is similar to a periodic table and how it is different.
39. Relating Cause and Effect When corn plants have yellow leaves, it is a sign that the plants lack an essential element. Which element must be added to the soil to produce leaves with a healthy green color?
40. Writing in Science You write for a newsletter that has a feature called Element of the Month. It is your turn to write the feature. Pick an element that you think is worthy of attention. Write a brief essay and suggest a photo to be used with your feature.

Performance-Based Assessment

Design Your Own Periodic Table Make a version of the periodic table that presents the information provided in Figure 7 in a different, but useful, way.

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Test-Taking Tip

Narrowing the Choices

If after reading all the answer choices you are not sure which one is correct, eliminate those answers that you know are wrong. In the question below, first eliminate the answers that require a whole number. Then focus on the remaining choices.

The number 12.011 is the
(A) atomic number for carbon.
(B) mass number for carbon.
(C) atomic mass of carbon-12.
(D) average atomic mass of carbon.
(E) percentage of carbon-12 in nature.

(Answer: D)

Choose the letter that best answers the question or completes the statement.

1. Which elements are as reactive as alkali metals?
   (A) alkaline earth metals
   (B) halogens
   (C) noble gases
   (D) transition metals
   (E) metalloids

2. How many valence electrons do atoms of oxygen and sulfur have?
   (A) 2
   (B) 4
   (C) 6
   (D) 8
   (E) 10

3. Moving across a period from left to right,
   (A) elements become less metallic.
   (B) elements become more metallic.
   (C) elements become more reactive.
   (D) elements become less reactive.
   (E) elements have fewer valence electrons.

4. Which statement best describes nonmetals?
   (A) Nonmetals are good conductors of heat and electric current.
   (B) Nonmetals are brittle solids.
   (C) Many general properties of nonmetals are opposite to those of metals.
   (D) Nonmetals are located on the left side of the periodic table.
   (E) All nonmetals are extremely reactive.

Use this portion of the periodic table to answer Questions 5–7.

5. Which list of elements contains only metalloids?
   (A) aluminum and gallium
   (B) silicon and germanium
   (C) phosphorus and arsenic
   (D) aluminum, silicon, and phosphorus
   (E) gallium, germanium, and arsenic

6. Which elements did Mendeleev leave spaces for in his first periodic table?
   (A) aluminum and phosphorus
   (B) aluminum and germanium
   (C) silicon and arsenic
   (D) gallium and germanium
   (E) gallium and aluminum

7. Which of the elements are among the most abundant in Earth's crust?
   (A) silicon and phosphorus
   (B) aluminum and phosphorus
   (C) phosphorus and arsenic
   (D) gallium and arsenic
   (E) aluminum and silicon