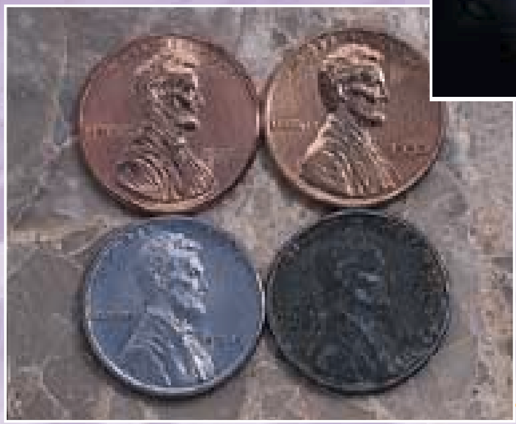
UNIT 2

HOW can the chemical and physical properties of matter be explained?

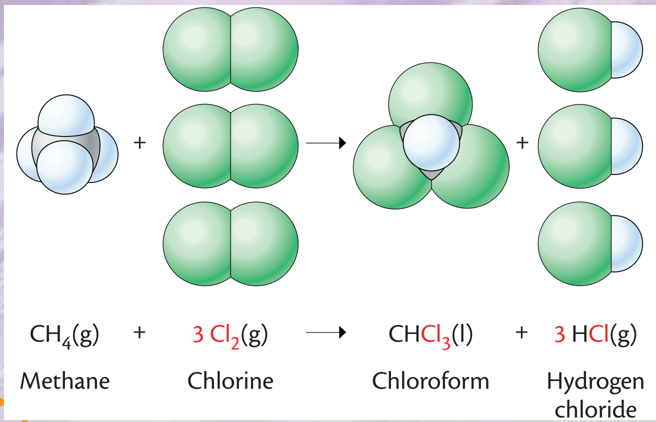


WHERE are mineral resources found and how are they processed?

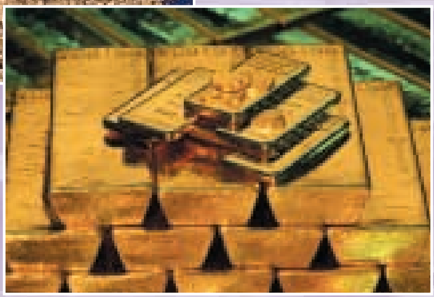
MATERIALS: STRUCTURE AND USES

WHAT information do chemical equations convey about matter and its changes?

SECTION **C** **Conservation** (page 128)



HOW can matter be modified to make it more useful?



SECTION **D** **Materials: Designing for Properties** (page 153)

Your local Congresswoman has invited you and your classmates to submit a design for a new U.S. half-dollar coin. What will the coin's composition be? Why? What makes a particular material best suited for each intended use? Turn the page to learn the answers to these questions—and perhaps be the lucky contest winner.

THE HONORABLE MARIA GONZALES
United States House of Representatives

MEMORANDUM

TO: District 12 High School Principals and Chemistry Teachers

FROM: The Hon. Maria Gonzales
U.S. House of Representatives

SUBJECT: Coin-Design Competition

As you may know, I plan to introduce a Bill in the House of Representatives authorizing the production of a new half-dollar coin by the United States Mint. The purpose of this memorandum is to let you know about a contest my office is sponsoring for high-school chemistry students in your Congressional District. The competition involves proposing a possible design for the new coin. The winning design will be used as an example in House Committee deliberations and on the floor of the House as I seek support from colleagues for authorization of the new 50-cent coin.

Each high school within your Congressional District may submit one complete design. The team of students (or student) who creates the winning design will be honored, along with the rest of their chemistry class, at an open house at my local office. In addition, the winning student or team will travel with my staff to Washington, D.C., for the introduction of my Bill and for a public presentation of the suggested coin design.

A complete coin-design proposal must include the following information:

- Full name(s) and address(es) of the designer(s)
- Chemistry teacher's name and course title
- School name and phone number
- Coin diameter, thickness, and mass
- Detailed drawing or actual model of the coin, enlarged 5x for clarity
- Specifications for the composition of the coin's material
- Plans for obtaining or creating the materials used in the coin
- Two-page rationale for key decisions made in the coin's design

All completed proposals will be due in my office within six weeks of receipt of this memorandum.

MG/hs

Buoyed by the U.S. Mint's release of a new dollar coin and the success of the recent quarter-coin series featuring each state, Congressional Representative Maria Gonzales is planning to introduce a Bill authorizing the U.S. Mint to produce a new half-dollar coin.

Realizing that Congressional colleagues will request information about the proposed replacement, Representative Gonzales is sponsoring a contest for local high school chemistry students to propose a prototype design of the new coin.

As her memo suggests, every aspect of the half-dollar coin—from its appearance to its size and composition—is to be included in the designs. Because only one design can be submitted from each school, your class will have to decide which team's coin proposal will be selected for further screening in this competition.

As you go on to consider important features in your coin's design, you will learn about Earth's mineral resources and how they are used by society. You will learn why certain materials are used for particular new products—coins and other useful things—and how those materials are developed from available resources. Throughout this unit, keep in mind how such chemical knowledge can help guide your design of a new coin.

SECTION A

WHY WE USE WHAT WE DO

Every human-produced object, old or new, is made of materials selected for their specific characteristics, or properties. What makes a particular material best for a particular use? You can begin to answer this question by exploring some properties of materials.

A.1 PROPERTIES MAKE THE DIFFERENCE

Overview CD-ROM WWW.

In this unit, you will be considering the design of something you use every day—money in the form of coins. Throughout history, people have used many different items as money: beads, stones, printed paper, even precious metals, to name a few. What characteristics make an object suitable (useful) for manufacturing money or minting coins? How important is appearance? Size? What other important characteristics can you suggest?

As you already know, every substance has characteristic properties that distinguish it from other substances, thus allowing it to be identified. These characteristic properties include **physical properties,** or properties that can be determined without altering the chemical makeup of the material. Color, density, and odor are examples of physical properties. The ability of a material to undergo **physical changes,** such as melting, boiling, and bending, is often important in its use. Remember that in a physical change, the identity of the substance remains the same.

The **chemical properties** of a material often play important roles in its usefulness. Chemical properties relate to the tendency of a substance to undergo **chemical changes**—that is, to transform into new substances. Consider the common chemical change of rust forming on iron surfaces. The tendency of a material to rust, or react to form an oxide, is the chemical property that accounts for this chemical change. A chemical change can often be detected by observing the formation of a gas or solid, a color change, a change on the surface of a solid, or a temperature change (indicating that thermal energy has been absorbed or given off). Figure 1 illustrates some physical and chemical changes involving copper.

In the following activity, you will classify some characteristics of common materials as either physical or chemical properties.

PHYSICAL AND CHEMICAL PROPERTIES

Building Skills 1

Consider this statement: *Copper compounds are often blue or green.* Does the statement describe a physical or chemical property? To answer the question, first think about whether a change in the identity of a substance is involved. Has the substance been chemically changed? If the answer is

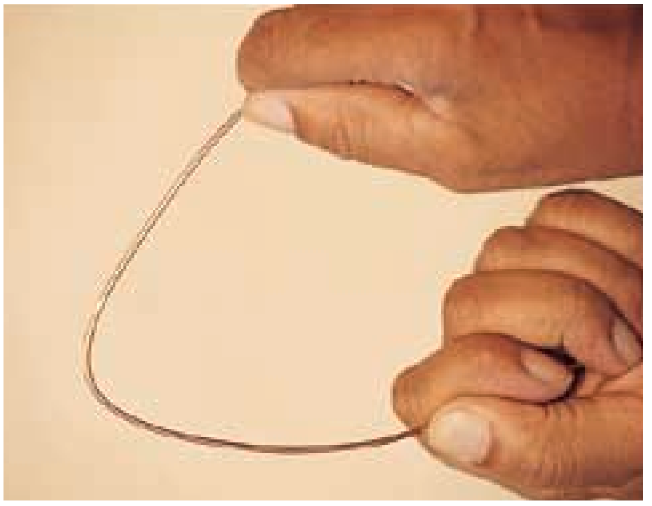


Figure 1 *Examples of physical and chemical changes involving copper.*

"no," then the statement describes a physical property; if the answer is "yes," then the description is of a chemical property.

Color is a characteristic physical property of many chemical compounds. A green copper compound in a jar on the shelf is not undergoing any change in its identity. Color, therefore, is a physical property. A change in color, however, often indicates a change in identity and thus a chemical change. For example, colored matter called litmus, derived from a plant-like organism called a lichen, turns from blue to pink when exposed to acid. This is a chemical change involving the chemical properties of litmus and acid.

Now consider this statement: *Oxygen gas supports the burning of wood.* Does the statement refer to a physical or chemical property of oxygen? If you apply the same key question—is there a change in the identity of the oxygen gas—you will arrive at the correct answer. The burning of wood—or combustion—involves chemical reactions between the wood and oxygen gas that change both reactants. The reaction products of ash, carbon dioxide, and water vapor are very different from wood and oxygen gas. Thus the statement refers to a chemical property of oxygen gas (as well as of wood).

Now it's your turn. Classify each statement as describing either a physical property or a chemical property. (*Hint:* Decide whether the chemical identity of the material does or does not change when the property is observed.)

1. Pure metals have a high luster (are shiny and reflect light).
2. The surfaces of some metals become dull when exposed to air.
3. Nitrogen gas, which is a relatively nonreactive element at room temperature, can form nitrogen oxides at the high temperatures of an operating automobile engine.
4. Milk turns sour if left too long at room temperature.
5. Diamonds are hard enough to be used on drill bits.
6. Metals are typically ductile (can be drawn into wires).
7. Bread dough increases in volume if it is allowed to "rise" before baking.

CD-ROM WWW. **Why We Use What We Do**

8. Argon gas, rather than air, is used in many lightbulbs to prevent oxidation of the metal filament.
9. Generally, metals are better conductors of heat and electricity than are nonmetals.

As you might imagine, many issues need to be considered when selecting materials for a specific use. A substance with properties well suited to a purpose may be either unavailable in sufficient quantity or too expensive. Or a substance may have undesirable physical or chemical properties that limit its use. In these and other situations, another material with most of the sought-after properties can often be found and used.

The cost of material is a particularly important issue when manufacturing coins and printed currency. Just imagine what would happen if the declared value of a coin were less than the cost of the metals contained in it. How would this affect the production and circulation of the coin? This situation actually occurred in the United States not too long ago. In the early 1980s, copper became too expensive to be used as the primary metal in pennies. In other words, the cost of the copper in a penny was greater than the value of the penny. A lower-cost replacement having similar properties was needed. Zinc, another metallic element, was chosen to replace most of the copper in all post-1982 pennies. Zinc is about as hard as copper and has a density (7.14 g/cm^3) close to that of copper (8.94 g/cm^3). Zinc is also readily available and less expensive than copper.

Unfortunately, zinc is more chemically reactive than copper. During World War II, copper metal was in short supply. To conserve that resource, zinc-plated steel pennies—known to coin collectors as "white cents" or "steel cents"—were created in 1943. The new pennies quickly corroded. As you can see in Figure 2, these pennies also looked considerably different from traditional copper pennies. Production of the zinc-plated pennies ended within a year.

Figure 2 *Zinc-copper and copper pennies (top); "new" and corroded zinc-steel pennies (bottom).*

The problems associated with the earlier zinc-plated pennies were solved in the early 1980s. In the new design, the properties of copper were used where they were most needed—on the coin's surface—and the properties of zinc where they were suitable—within the body of the coin. All post-1982 pennies are 97.5% zinc. They are composed of a zinc core surrounded by a thin layer of copper, added to increase the coin's durability and maintain its familiar appearance. Figure 3 shows a cross-section of a post-1982 penny.

Whether it is copper or zinc in a penny or tungsten in a lightbulb, the message is clear: Every substance has its own set of physical and chemical properties. But with millions of substances available, how can one identify the "best" substance(s) for a given need?

Fortunately, the list of possibilities can be greatly shortened. All substances are made of a relatively small number of building blocks—the atoms of the different chemical elements. Knowing the similarities and differences among atoms of elements and among combinations of those atoms can greatly simplify the challenge of matching a substance to its most appropriate uses.

Figure 3 Cross-section showing composition of a post-1982 penny.

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Representing Atoms and Ions

A.2 THE CHEMICAL ELEMENTS

You learned in Unit 1 that all matter is composed of atoms. One element differs from another because its atoms have properties that differ from those of all other elements. More than 100 chemical elements are known. The table in Figure 4 lists some common elements and their symbols. An alphabetical list of all the elements (names and symbols) can be found on page 108.

Elements can be grouped, or classified, in several ways according to similarities and differences in their properties. Two major classes are **metals** and **nonmetals**. Metals include such elements as iron, tin, zinc, and copper. Carbon and oxygen are examples of nonmetals. Everyday experience has given you some knowledge of metallic properties. The laboratory activity you will soon do will give you an opportunity to explore the properties of metals and nonmetals in more depth.

A relatively few elements called **metalloids** have properties that are intermediate to those of metals and nonmetals. That is, metalloids are like metals when it comes to some properties and like nonmetals when it comes to others. Examples of metalloids include silicon and germanium, both commonly used in the computer industry.

What properties of matter are used to distinguish metals, nonmetals, and metalloids? The next activity will help you find out.

A.3 METAL OR NONMETAL? Laboratory Activity

Introduction

In this activity you will investigate several properties of seven elements and then decide whether each element is a metal, nonmetal, or metalloid. You will examine the color, luster, and form of each element and attempt to crush each sample with a hammer. You or your teacher (as a demonstration) will also test the substance's ability to conduct electricity. Finally, you will determine the reactivity of each element with two solutions: hydrochloric acid, HCl(aq), and copper(II) chloride, $CuCl_2$(aq).

Common Elements

Name	Symbol
Aluminum	Al
Antimony	Sb
Argon	Ar
Barium	Ba
Beryllium	Be
Bismuth	Bi
Boron	B
Bromine	Br
Cadmium	Cd
Calcium	Ca
Carbon	C
Cesium	Cs
Chlorine	Cl
Chromium	Cr
Cobalt	Co
Copper	Cu
Fluorine	F
Gold	Au
Helium	He
Hydrogen	H
Iodine	I
Iron	Fe
Krypton	Kr
Lead	Pb
Lithium	Li
Magnesium	Mg
Manganese	Mn
Mercury	Hg
Neon	Ne
Nickel	Ni
Nitrogen	N
Oxygen	O
Phosphorus	P
Platinum	Pt
Potassium	K
Silicon	Si
Silver	Ag
Sodium	Na
Sulfur	S
Tin	Sn
Tungsten	W
Uranium	U
Zinc	Zn

Figure 4 *A table of common elements and their symbols.*

Procedure

1. In your laboratory notebook, prepare a data table that has enough space to record the properties of the seven element samples, which have been coded with letters *a* to *g*.

DATA TABLE

Element	Appearance	Conductivity (optional)	Result of Crushing	Reaction with Acid	Reaction with $CuCl_2(aq)$
a.					
b.					
c.					
d.					
e.					
f.					
g.					

2. *Appearance:* Observe and record the appearance of each element, including physical properties such as color, luster, and form. You can record the form as crystalline (like table salt), noncrystalline (like baking soda), or metallic (like iron).
3. *Conductivity:* If an electrical conductivity apparatus is available, use it to test each sample. **CAUTION:** *Avoid touching the bare electrode tips with your hands; some may deliver an uncomfortable electric shock.* Touch both electrodes to the element sample, but do not allow the electrodes to touch each other. See Figure 5. If the bulb lights, even dimly, electricity is flowing through the sample. Such a material is called a **conductor.** If the bulb fails to light, the material is a **nonconductor.**

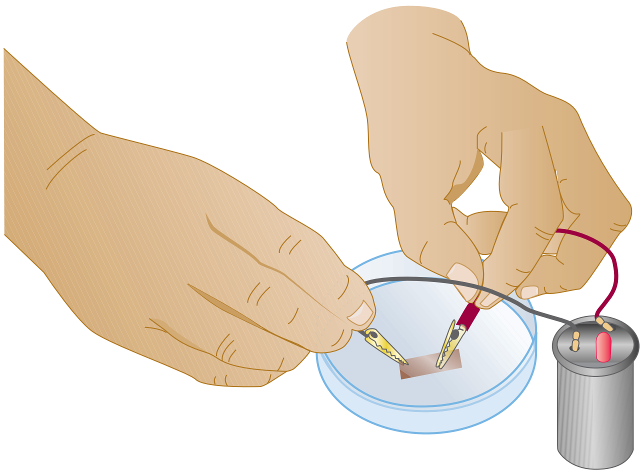

Figure 5 *Testing for conductivity.*

4. *Crushing:* Gently tap each element sample with a hammer. Based upon the results, decide whether the sample is **malleable,** which means it flattens without shattering when struck, or **brittle,** which means it shatters into pieces.
5. *Reactivity with acid.*
   a. Label seven wells of a clean wellplate *a* through *g*.
   b. Place a sample of each element in its appropriate well. The solid wire or ribbon samples provided by your teacher will be less than 1 cm in length. Other samples should be between 0.2 g and 0.4 g—you can estimate that as no larger than the size of a match head.
   c. Add 15 to 20 drops of 0.5 M HCl to each well that contains a sample. **CAUTION:** *0.5 M hydrochloric acid (HCl) can chemically attack skin if allowed to remain in contact for a long time. If any hydrochloric acid accidentally spills on you, ask a classmate to notify your teacher immediately. Wash the affected area immediately with tap water and continue for several minutes.*
   d. Observe and record each result. The formation of gas bubbles indicates that a chemical reaction has occurred. A change in the appearance of an element sample may also indicate a chemical reaction. Decide which elements reacted with the hydrochloric acid and which did not. Record these results.
   e. Discard the wellplate contents as instructed by your teacher.
6. *Reactivity with copper(II) chloride.*
   a. Repeat Steps 5a and 5b.
   b. Add 15 to 20 drops of 0.1 M copper(II) chloride ($CuCl_2$) to each sample.
   c. Observe each system for three to five minutes—changes may be slow. Decide which elements reacted with the copper(II) chloride and which did not. Recall the criteria you used in the acid test to determine if a reaction occurred. Record each result.
   d. Discard the wellplate contents as instructed by your teacher.
7. Wash your hands thoroughly before leaving the laboratory.

Questions

1. Classify each property tested in this activity as either a physical property or a chemical property.
2. Sort the seven coded elements into two groups based on similarities in their physical and chemical properties.
3. Which element(s) could fit into either group? Why?
4. Using the following information, classify each tested element as a metal, nonmetal, or metalloid.
   - Metals have a luster, are malleable, and conduct electricity.
   - Many metals react with acids; many metals also react with copper(II) chloride solution.
   - Nonmetals are usually dull in appearance, are brittle, and do not conduct electricity.
   - Metalloids have some properties of both metals and nonmetals.

You have learned one classification scheme for elements: metals, nonmetals, and metalloids. The quantity of detailed information about the elements is enormous, however. And when choosing or designing materials for specific uses, the more information available about the elements (including similarities and differences among them), the better the decisions. How then is all the knowledge about the elements conveniently organized? You have already been introduced to the answer—the periodic table. Now you will explore its origins and gain greater understanding of the chemical information it conveys.

A.4 THE PERIODIC TABLE

By the mid-1800s, about 60 elements had been identified. Five of these were nonmetals that were gases at room temperature: hydrogen (H), oxygen (O), nitrogen (N), fluorine (F), and chlorine (Cl). Two liquid elements were also known, the metal mercury (Hg) and the nonmetal bromine (Br). The rest of the known elements were solids with widely differing properties.

In an effort to impose some organization on the information related to the elements, several scientists tried to place elements with similar properties near one another on a chart. Such an arrangement is called a **periodic table**. Dimitri Mendeleev, a Russian chemist, published a periodic table in 1869. A similar table is still used today. In some respects, the periodic table has a pattern that resembles a monthly calendar, in which weeks repeat on a regular (periodic) seven-day cycle.

The periodic tables of the 1800s were organized according to two characteristics of elements. It was known that atoms of different elements have different masses. For example, hydrogen atoms have the lowest mass, oxygen atoms are about 16 times more massive than hydrogen atoms, and sulfur atoms are about twice as massive as oxygen atoms (making them about 32 times more massive than hydrogen atoms). Based on such comparisons, an **atomic weight** was assigned to each element in Mendeleev's periodic table. This atomic weight then became one of the two criteria for arranging elements in the periodic table.

The other criterion for organizing elements in early periodic tables was their respective "combining capacity" with other elements, such as chlorine and oxygen. It was known that atoms of various elements differ in the way that they combine with another element. For example, one atom of potassium (K) or cesium (Cs) combines with only one atom of chlorine (Cl) to produce the compound KCl or CsCl. Such one-to-one compounds can be represented as ECl, where E stands for the Element combining with chlorine. However, one atom of magnesium (Mg) or strontium (Sr) combines with two atoms of chlorine to produce the compound $MgCl_2$ or $SrCl_2$, which can be represented in general terms as ECl_2. Atoms of other elements may combine with three or four chlorine atoms to produce compounds with the general formula ECl_3 or ECl_4.

In the first periodic tables, elements with similar chemical properties were placed in vertical groups (columns). Horizontal arrangements were based on increasing atomic weights of the elements. In the activity that follows, you will develop a classification scheme for some elements in much the same way Mendeleev did.

A.5 GROUPING THE ELEMENTS | Making Decisions

You will be given a set of 20 element data cards. Each card lists some properties of a particular element.

1. Arrange the cards in order of increasing atomic weight.
2. Place the cards in a number of different groups. Each group should include elements with similar properties. You might need to try several methods of grouping before you find one that makes sense to you.
3. Examine the cards within each group for any patterns. Arrange the cards within each group in some logical sequence. Again, trial and error may be a useful method for accomplishing this task.
4. Observe how particular element properties vary from group to group.
5. Arrange all the card groups into some logical sequence.
6. Decide on the most reasonable and useful patterns within and among card groups. Then tape the cards onto a sheet of paper to preserve your pattern for classroom discussion.

A.6 THE PATTERN OF ATOMIC NUMBERS

Creators of early periodic tables were unable to offer explanations for similarities in properties found among neighboring elements. For example, all of the elements in the leftmost column of the periodic table are very reactive metals. All the elements in the rightmost column are unreactive gases. The reason for these similarities, which was discovered about 50 years after Mendeleev's work, serves as the basis for the modern periodic table.

As you will recall from Unit 1, all atoms are composed of smaller particles, including equal numbers of positively charged protons and negatively charged electrons. The number of protons, called the **atomic number,** distinguishes atoms of different elements. For example, every sodium atom (and only a sodium atom) contains 11 protons. The atomic number of sodium is 11. Each carbon atom contains 6 protons. If the number of protons in an atom is 9, it is a fluorine atom; if 12, it is a magnesium atom. Thus the atomic number (number of protons) identifies every atom as a particular element.

Early periodic tables, much like the one you just constructed, used atomic weights to organize the elements. Although this method produces reasonable results for elements with relatively small atomic weights, it does not work well for more massive atoms. The reason for this is the existence of another small particle that makes up the atom, the electrically uncharged neutron. The total mass of an atom is largely determined by the combined number of protons and neutrons in its **nucleus.** The nucleus is a concentrated region of positive charge (from the protons) in the center of an atom. See Figure 6.

You can learn more about these subatomic particles in Unit 6.

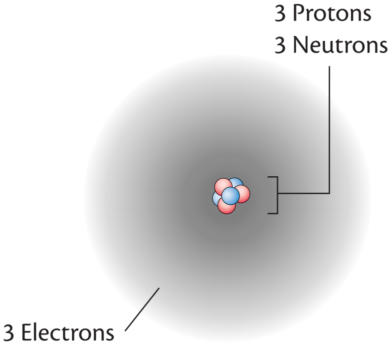

Figure 6 *Components of a particular atom of lithium (Li).*

The total number of protons and neutrons in the nucleus of an atom is called the **mass number.** Electrons make up the rest of an atom, but because each electron is about 1/2000th the mass of a proton or neutron, the total mass of the electrons does not contribute significantly to the mass of an atom.

While all atoms of a particular element have the same number of protons, the number of neutrons can differ from atom to atom of an element. For example, carbon atoms always contain 6 protons, but they may contain 6, 7, or 8 neutrons. Thus individual carbon atoms can have mass numbers of 12, 13, or 14. Atoms with the same number of protons but different numbers of neutrons are called **isotopes.** In other words, isotopes are atoms of the same element with different mass numbers.

In the modern Periodic Table of the Elements, elements are placed in sequence according to their increasing atomic number. But because electrically neutral (uncharged) atoms contain equal numbers of protons and electrons, the Periodic Table is also sequenced by the number of electrons that the neutral atoms of each element contain.

Is there a connection between the atomic numbers used to organize the modern Periodic Table and the element properties used by nineteenth-century chemists to create their periodic tables? If there is, what is that connection? Continue reading to explore the relationship between atomic numbers and the properties of elements.

PERIODIC VARIATION IN PROPERTIES

Building Skills 2

Your teacher will assist you in identifying the atomic numbers of the 20 elements you considered earlier in the unit. Use these atomic numbers and information about each element's properties to prepare the two graphs described below. Look for patterns between atomic numbers and element properties as you construct the graphs.

Follow the graphing guidelines you learned in Unit 1 (page 66).

Graph 1. Trends in a chemical property.

1. On a sheet of graph paper, draw a set of axes and title the graph *Trends in a Chemical Property*.

2. Label the *x* axis *Atomic Number of E*, and number it from 1 to 20.

3. Label the *y* axis *Number of Oxygen Atoms per Atom of E*. Number it from 0 to 3; in increments of 0.5.

4. Construct a bar graph, as demonstrated in Figure 7, by plotting the oxide data from the element cards. For example, if no oxide forms, the height of the bar will be 0 because oxygen atoms do not form a compound with atoms of E. If E_2O (1 oxygen atom for 2 E atoms) is formed, the height of the bar is 0.5, which is the number of oxygen atoms for each E atom in the compound. Similarly, the heights of the bars for other oxides are 1 for EO, 1.5 for E_2O_3, 2 for EO_2, and 2.5 for E_2O_5. Do you understand why?

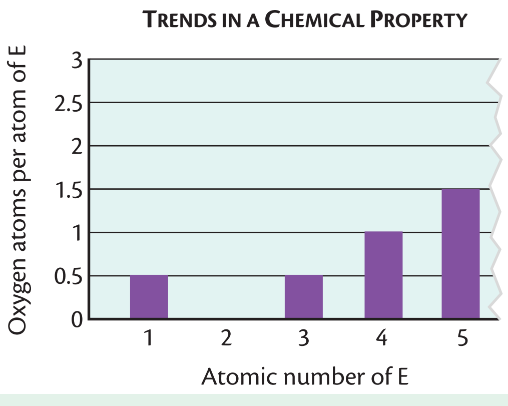

Figure 7 *Sample bar graph for oxide data.*

5. Label each bar with the actual symbol of the element E involved in that compound.

Graph 2. Trends in a physical property.

6. On a separate sheet of graph paper, draw a set of axes, and title the graph *Trends in a Physical Property*.
7. Label the *x* axis *Atomic Number* and number it from 1 to 20.
8. Label the *y* axis *Boiling Point (K)* and number it from 0 to 3000 K, as shown in Figure 8. Use as much of the space on the graph paper as possible to plot these kelvin temperatures.
9. Construct a graph as in Step 4, this time using the boiling point data from the element cards, as shown in Figure 8. Do not include data for the element with atomic number 6. The boiling point of this element (carbon) would be quite far off the graph.
10. Label each bar with the symbol of the element it represents.

Temperature in kelvins (K) is related to temperature in degrees Celsius (°C) by K = 273.15 + °C. You will learn more about the kelvin temperature scale in Unit 4.

QUESTIONS

1. Does either graph reveal a repeating, or cyclic, pattern? (*Hint:* Focus on elements represented by very large or very small bars.) Describe any patterns you observe.
2. Are these graphs consistent with patterns found in your earlier grouping of the elements? Explain.
3. Based on these two graphs, why is the chemist's organization of elements called a *periodic* table?
4. Where are elements with the highest oxide numbers located on the Periodic Table?
5. Where are elements with the highest boiling points located on the Periodic Table?
6. Explain any trends you noted in your answers to Questions 4 and 5.
7. Predict which element should have the lowest boiling point: selenium (Se), bromine (Br), or krypton (Kr). Explain how you decided.

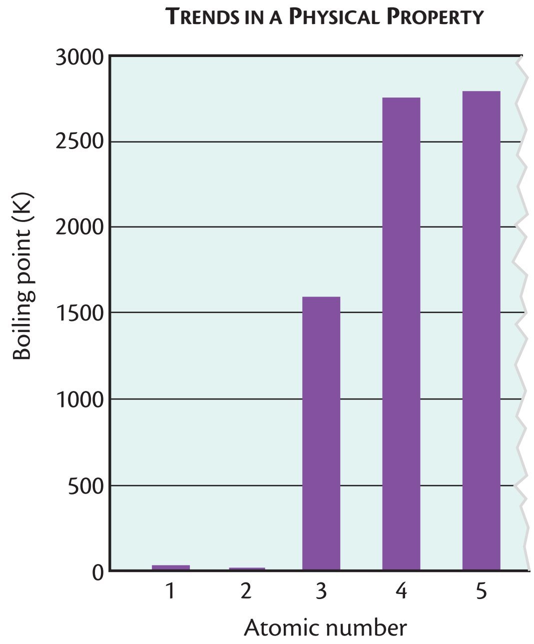

Figure 8 *Sample bar graph for boiling point data.*

When elements are listed in order of increasing atomic numbers and grouped according to similar properties, they form seven horizontal rows, called **periods.** This periodic relationship among elements is summarized in the modern Periodic Table, which you can see on page 104. To become more familiar with the Periodic Table, locate the 20 elements you grouped earlier. How do their relative positions compare with those shown on your chart?

PERIODIC TABLE OF THE ELEMENTS

Key

1 — Atomic number
Hydrogen — Name
H — Symbol
1.008 — Atomic weight

Metals
Metalloids
Nonmetals

Period	Group 1 (1A)	2 (2A)	3 (3B)	4 (4B)	5 (5B)	6 (6B)	7 (7B)	8 (8B)	9 (8B)	10 (8B)	11 (1B)	12 (2B)	13 (3A)	14 (4A)	15 (5A)	16 (6A)	17 (7A)	18 (8A)
1	1 Hydrogen **H** 1.008																	2 Helium **He** 4.003
2	3 Lithium **Li** 6.94	4 Beryllium **Be** 9.01											5 Boron **B** 10.81	6 Carbon **C** 12.01	7 Nitrogen **N** 14.01	8 Oxygen **O** 16.00	9 Fluorine **F** 19.00	10 Neon **Ne** 20.18
3	11 Sodium **Na** 22.99	12 Magnesium **Mg** 24.31											13 Aluminum **Al** 26.98	14 Silicon **Si** 28.09	15 Phosphorus **P** 30.97	16 Sulfur **S** 32.07	17 Chlorine **Cl** 35.45	18 Argon **Ar** 39.95
4	19 Potassium **K** 39.10	20 Calcium **Ca** 40.08	21 Scandium **Sc** 44.96	22 Titanium **Ti** 47.87	23 Vanadium **V** 50.94	24 Chromium **Cr** 52.00	25 Manganese **Mn** 54.94	26 Iron **Fe** 55.85	27 Cobalt **Co** 58.93	28 Nickel **Ni** 58.69	29 Copper **Cu** 63.55	30 Zinc **Zn** 65.39	31 Gallium **Ga** 69.72	32 Germanium **Ge** 72.61	33 Arsenic **As** 74.92	34 Selenium **Se** 78.96	35 Bromine **Br** 79.90	36 Krypton **Kr** 83.80
5	37 Rubidium **Rb** 85.47	38 Strontium **Sr** 87.62	39 Yttrium **Y** 88.91	40 Zirconium **Zr** 91.22	41 Niobium **Nb** 92.91	42 Molybdenum **Mo** 95.94	43 Technetium **Tc** (98)	44 Ruthenium **Ru** 101.07	45 Rhodium **Rh** 102.91	46 Palladium **Pd** 106.42	47 Silver **Ag** 107.87	48 Cadmium **Cd** 112.41	49 Indium **In** 114.82	50 Tin **Sn** 118.71	51 Antimony **Sb** 121.76	52 Tellurium **Te** 127.60	53 Iodine **I** 126.90	54 Xenon **Xe** 131.29
6	55 Cesium **Cs** 132.91	56 Barium **Ba** 137.33	71 Lutetium **Lu** 174.97	72 Hafnium **Hf** 178.49	73 Tantalum **Ta** 180.95	74 Tungsten **W** 183.84	75 Rhenium **Re** 186.21	76 Osmium **Os** 190.23	77 Iridium **Ir** 192.22	78 Platinum **Pt** 195.08	79 Gold **Au** 196.97	80 Mercury **Hg** 200.59	81 Thallium **Tl** 204.38	82 Lead **Pb** 207.2	83 Bismuth **Bi** 208.98	84 Polonium **Po** (209)	85 Astatine **At** (210)	86 Radon **Rn** (222)
7	87 Francium **Fr** (223)	88 Radium **Ra** (226)	103 Lawrencium **Lr** (262)	104 Rutherfordium **Rf** (261)	105 Dubnium **Db** (262)	106 Seaborgium **Sg** (263)	107 Bohrium **Bh** (264)	108 Hassium **Hs** (265)	109 Meitnerium **Mt** (268)	110 Ununnilium **Uun** (269)	111 Unununium **Uuu** (272)	112 Ununbium **Uub** (277)		114 Ununquadium **Uuq** (285)		116 Ununhexium **Uuh** (289)		118 Ununoctium **Uuo** (293)

Lanthanides	57 Lanthanum **La** 138.91	58 Cerium **Ce** 140.12	59 Praseodymium **Pr** 140.91	60 Neodymium **Nd** 144.24	61 Promethium **Pm** (145)	62 Samarium **Sm** 150.36	63 Europium **Eu** 151.96	64 Gadolinium **Gd** 157.25	65 Terbium **Tb** 158.93	66 Dysprosium **Dy** 162.50	67 Holmium **Ho** 164.93	68 Erbium **Er** 167.26	69 Thulium **Tm** 168.93	70 Ytterbium **Yb** 173.04
Actinides	89 Actinium **Ac** (227)	90 Thorium **Th** 232.04	91 Protactinium **Pa** 231.04	92 Uranium **U** 238.03	93 Neptunium **Np** (237)	94 Plutonium **Pu** (244)	95 Americium **Am** (243)	96 Curium **Cm** (247)	97 Berkelium **Bk** (247)	98 Californium **Cf** (251)	99 Einsteinium **Es** (252)	100 Fermium **Fm** (257)	101 Mendelevium **Md** (258)	102 Nobelium **No** (259)

Each vertical column in the Periodic Table contains elements with similar properties. Each column is called a **group** or **family** of elements. For example, the lithium (Li) family, also called the **alkali metal** family, consists of the six elements (starting with lithium) in the first column at the left of the table. Each element (E) in this family is a highly reactive metal that forms an ECl chloride and E_2O oxide. By contrast, the helium family, at the right of the table, consists of very unreactive, and even inert, elements. Of the helium family, also called the **noble gas** family, only xenon (Xe) and krypton (Kr) are known to form compounds under normal conditions.

The arrangement of elements in the Periodic Table provides an orderly summary of the key characteristics of each element. By knowing the major properties of a certain chemical family, some of the behavior of any element in that family can be predicted. This can be very helpful in evaluating elements for certain uses.

CD-ROM WWW. **Trends & Variation in the Periodic Table**

Like sodium chloride (NaCl), all chlorides and oxides of lithium-family elements are ionic compounds.

PREDICTING PROPERTIES

Building Skills 3

Some of an element's properties can be estimated by averaging the respective properties of the elements located just above and just below it. This is how Mendeleev predicted the properties of several elements unknown in his time. He was so convinced of the existence of these elements that he left gaps in the periodic table for them, along with some of their predicted properties. When those elements were eventually discovered, they fit exactly as expected. Mendeleev's fame rests largely on the accuracy of these predictions.

For example, germanium (Ge) was not known when Mendeleev proposed his periodic table. However, in 1871 he predicted the existence of germanium, calling it ekasilicon. Given that the boiling points of silicon (Si) and tin (Sn) are 3267 °C and 2603 °C, respectively, the boiling point of germanium can be estimated.

Eka- means "standing next in order."

The three elements are in the same group in the periodic table. Germanium is below silicon and above tin. (You can verify this by locating these elements in the Periodic Table.) Calculating the average of the boiling points of silicon and tin gives

$$\frac{(3267\ ^\circ\text{C}) + (2603\ ^\circ\text{C})}{2} = 2935\ ^\circ\text{C}$$

When germanium was discovered in 1886, its boiling point was found to be 2834 °C. The estimated boiling point of germanium, 2935 °C, is within 4% of its known boiling point. The periodic table helped guide Mendeleev (and now you) to a useful prediction.

Formulas for chemical compounds can also be predicted from relationships established in the Periodic Table. For example, carbon and oxygen form carbon dioxide (CO_2). What formula would be predicted for a compound of carbon and sulfur? The Periodic Table indicates that sulfur (S) and oxygen (O) are in the same family. Knowing that carbon and oxygen form CO_2, a logical—and correct—prediction would be CS_2 (carbon disulfide). Now it's your turn.

1. The element krypton (Kr) was not known in Mendeleev's time. Given that the boiling point of argon (Ar) is −186 °C and of xenon (Xe) −112 °C, estimate the boiling point of krypton.
2. a. Estimate the melting point of rubidium (Rb). The melting points of potassium (K) and cesium (Cs) are 337 K and 302 K, respectively.
   b. Would you expect the melting point of sodium (Na) to be higher or lower than that of rubidium (Rb)? Explain.
3. Mendeleev knew that silicon tetrachloride ($SiCl_4$) existed. Using his periodic table, he correctly predicted the existence of ekasilicon, an element just below silicon in the Periodic Table. Predict the formula for the compound formed by Mendeleev's ekasilicon and chlorine.
4. Here are formulas for several known compounds: NaI, $MgCl_2$, CaO, Al_2O_3, and CCl_4. Using that information, predict the formula for a compound formed from
   a. C and F.
   b. Al and S.
   c. K and Cl.
   d. Ca and Br.
   e. Sr and O.

A.7 WHAT DETERMINES PROPERTIES?

Properties of Metals CD-ROM WWW.

What is responsible for differences in the number of chlorine atoms that react with a given atom—or in other properties that vary from element to element? Recall that atoms of different elements have different numbers of protons (atomic numbers). Therefore, atoms of different elements also have different numbers of electrons. Many properties of elements are determined largely by the number of electrons in their atoms and how these electrons are arranged.

You will learn more about electron arrangements in Unit 3.

A major difference between atoms of metals and nonmetals is that metal atoms lose some of their electrons much more easily than nonmetal atoms do. Under suitable conditions, one or more outer electrons of metal atoms may transfer to other atoms or ions. This is why metallic elements tend to form positive ions (cations).

Some physical properties of metals depend on attractions among their atoms. For example, stronger attractions among atoms of a metal result in higher melting points. The melting point of magnesium is 651 °C, whereas that of sodium is 98 °C. Thus attractions among the atoms in magnesium metal must be stronger than those in sodium metal.

Chemical and physical properties of nonmetals and compounds are also explained by the makeup of their atoms, ions, or molecules and by attractions among these particles. As you learned in Unit 1, the abnormally high melting and boiling points of water are due to the strong attractions among water molecules.

Several thousand new compounds are synthesized each year.

Understanding properties of atoms is the key to predicting and even manipulating the behavior of materials. Combined with a bit of imagination, this information allows chemists to find new uses for materials and to create new chemical compounds to meet specific needs.

A.8 IT'S ONLY MONEY

Making Decisions

Based on what you have learned so far, you can start to make some decisions about your design for the new coin. A good first step is to specify some characteristics that are necessary or desirable in the material you will use. Apply your knowledge of existing coins, as well as what you have learned about properties of elements, to answer these questions.

1. What physical properties must material chosen for the new coin possess?
2. What other physical properties are desirable?
3. What chemical properties are required of the coin's material?
4. What other chemical properties are desirable?
5. Which would make the best primary material for the new coin: a metal, nonmetal, or metalloid? Explain.
6. What assumptions did you make in order to answer the preceding questions?

Save your answers to these questions—they will help guide your coin-design work later in this unit.

CD-ROM WWW. **Questions & Answers**

The Elements (Values in parentheses are the mass numbers of the longest-lived isotopes.)

Element	Symbol	Atomic Number	Atomic Weight	Element	Symbol	Atomic Number	Atomic Weight
Actinium	Ac	89	(227)	Neodymium	Nd	60	144.24
Aluminum	Al	13	26.98	Neon	Ne	10	20.18
Americium	Am	95	(243)	Neptunium	Np	93	(237)
Antimony	Sb	51	121.76	Nickel	Ni	28	58.69
Argon	Ar	18	39.95	Niobium	Nb	41	92.91
Arsenic	As	33	74.92	Nitrogen	N	7	14.01
Astatine	At	85	(210)	Nobelium	No	102	(259)
Barium	Ba	56	137.33	Osmium	Os	76	190.23
Berkelium	Bk	97	(247)	Oxygen	O	8	16.00
Beryllium	Be	4	9.01	Palladium	Pd	46	106.42
Bismuth	Bi	83	208.98	Phosphorus	P	15	30.97
Bohrium	Bh	107	(264)	Platinum	Pt	78	195.08
Boron	B	5	10.81	Plutonium	Pu	94	(244)
Bromine	Br	35	79.90	Polonium	Po	84	(209)
Cadmium	Cd	48	112.41	Potassium	K	19	39.10
Calcium	Ca	20	40.08	Praseodymium	Pr	59	140.91
Californium	Cf	98	(251)	Promethium	Pm	61	(145)
Carbon	C	6	12.01	Protactinium	Pa	91	231.04
Cerium	Ce	58	140.12	Radium	Ra	88	(226)
Cesium	Cs	55	132.91	Radon	Rn	86	(222)
Chlorine	Cl	17	35.45	Rhenium	Re	75	186.21
Chromium	Cr	24	52.00	Rhodium	Rh	45	102.91
Cobalt	Co	27	58.93	Rubidium	Rb	37	85.47
Copper	Cu	29	63.55	Ruthenium	Ru	44	101.07
Curium	Cm	96	(247)	Rutherfordium	Rf	104	(261)
Dubnium	Db	105	(262)	Samarium	Sm	62	150.36
Dysprosium	Dy	66	162.50	Scandium	Sc	21	44.96
Einsteinium	Es	99	(252)	Seaborgium	Sg	106	(263)
Erbium	Er	68	167.26	Selenium	Se	34	78.96
Europium	Eu	63	151.96	Silicon	Si	14	28.09
Fermium	Fm	100	(257)	Silver	Ag	47	107.87
Fluorine	F	9	19.00	Sodium	Na	11	22.99
Francium	Fr	87	(223)	Strontium	Sr	38	87.62
Gadolinium	Gd	64	157.25	Sulfur	S	16	32.07
Gallium	Ga	31	69.72	Tantalum	Ta	73	180.95
Germanium	Ge	32	72.61	Technetium	Tc	43	(98)
Gold	Au	79	196.97	Tellurium	Te	52	127.60
Hafnium	Hf	72	178.49	Terbium	Tb	65	158.93
Hassium	Hs	108	(265)	Thallium	Tl	81	204.38
Helium	He	2	4.003	Thorium	Th	90	232.04
Holmium	Ho	67	164.93	Thulium	Tm	69	168.93
Hydrogen	H	1	1.008	Tin	Sn	50	118.71
Indium	In	49	114.82	Titanium	Ti	22	47.87
Iodine	I	53	126.90	Tungsten	W	74	183.84
Iridium	Ir	77	192.22	Ununnilium	Uun	110	(269)
Iron	Fe	26	55.85	Unununium	Uuu	111	(272)
Krypton	Kr	36	83.80	Ununbium	Uub	112	(277)
Lanthanum	La	57	138.91	Ununquadium	Uuq	114	(285)
Lawrencium	Lr	103	(262)	Ununhexium	Uuh	116	(289)
Lead	Pb	82	207.2	Ununoctium	Uuo	118	(293)
Lithium	Li	3	6.94	Uranium	U	92	238.03
Lutetium	Lu	71	174.97	Vanadium	V	23	50.94
Magnesium	Mg	12	24.31	Xenon	Xe	54	131.29
Manganese	Mn	25	54.94	Ytterbium	Yb	70	173.04
Meitnerium	Mt	109	(268)	Yttrium	Y	39	88.91
Mendelevium	Md	101	(258)	Zinc	Zn	30	65.39
Mercury	Hg	80	200.59	Zirconium	Zr	40	91.22
Molybdenum	Mo	42	95.94				

SECTION SUMMARY

Reviewing the Concepts

- **The physical properties of a substance can be determined without altering the substance's chemical makeup; physical changes alter a substance's physical properties. Chemical properties describe a substance's tendency to react chemically; chemical changes transform the substance into one or more new substances.**

1. Classify each as a chemical or physical property:
   a. Copper has a reddish brown color.
   b. Iron may rust when left outdoors.
   c. Carbon dioxide gas can extinguish a flame.
   d. Molasses pours more slowly than water.
2. Classify each as a chemical or physical change:
   a. A candle burns.
   b. A carbonated beverage fizzes when the container is opened.
   c. Hair curls as a result of a "perm."
   d. As shoes wear out, holes appear in the soles.
3. a. List the steps you would complete in making chocolate-chip cookies.
   b. Classify each step as involving either a chemical or a physical change.

- **Elements can be classified as metals, nonmetals, or metalloids according to their physical and chemical properties.**

4. Classify each property as characteristic of metals, nonmetals, or metalloids.
   a. Shiny in appearance
   b. Does not react with acids
   c. Shatters easily
   d. Dull in appearance but electrically conductive
5. Classify each element as a metal, nonmetal, or metalloid.
   a. tungsten
   b. antimony
   c. krypton
   d. sodium
6. What would you expect to happen if you hit a sample of each of these elements with a hammer?
   a. iodine
   b. zirconium
   c. phosphorus
   d. nickel
7. What properties make nonmetals unsuitable for electric wiring?

- **Elements are arranged in rows (periods) on the Periodic Table. Elements with similar chemical properties are placed in the same vertical columns (groups or families).**

8. Given the formulas AlN and $BeCl_2$, predict the formula for a compound containing
   a. Mg and F.
   b. Ga and P.
9. The melting points of oxygen and selenium are −218 °C and 221 °C, respectively. Estimate the melting point of sulfur.
10. Would you expect the boiling point of chlorine to be higher or lower than that of iodine? Explain.
11. For medical reasons, people with high blood pressure are advised to limit the amount of sodium ions in their diet. Normal table salt (NaCl) is sometimes replaced by a substitute called Lite Salt (potassium chloride) for seasoning.
    a. Write the formula for Lite Salt.
    b. Why are the properties of Lite Salt similar to those of sodium chloride?

◆ **The number of protons in an atom (the atomic number) of a given element distinguishes it from atoms of all other elements.**

12. Complete the table to the right for each electrically neutral atom.

13. A student is asked to explain the formation of a lead(II) ion (Pb^{2+}) from an electrically neutral lead atom (Pb). The student says that a lead atom must have gained two protons to make the ion. How would you correct this student's explanation?

Element symbol	Number of protons	Number of neutrons	Number of electrons
a. ______	6	6	6
b. ______	6	7	6
Ca	c. ______	21	d. ______
e. ______	f. ______	117	78
U	g. ______	146	h. ______

◆ **The mass of an atom depends largely on the number of protons and neutrons contained within its nucleus. Atoms containing the same number of protons but different numbers of neutrons are considered isotopes of that element.**

14. Supply the numbers of protons and neutrons for each of the isotopes in the table on the right.

15. A scientist announces the discovery of a new element. The only characteristic given in the report is the element's mass number of 266. Is this information sufficient, by itself, to justify the claim of the discovery of a new element? Explain.

Element symbol	Mass number	Number of protons	Number of neutrons
Mg	24	a. ______	b. ______
Mg	25	c. ______	d. ______
Mg	26	e. ______	f. ______

◆ **The properties of an element are determined largely by the number and arrangement of electrons in its atoms.**

16. Predict whether each element would be more likely to form an anion or a cation.

a. sodium
b. calcium
c. fluorine
d. oxygen
e. lithium
f. iodine

17. Noble gas elements rarely lose or gain electrons. What does this indicate about their chemical reactivity?

Connecting the Concepts

18. Which pair is more similar chemically? Defend your choice.

a. copper metal and copper(II) ions
or
b. oxygen with mass number 16 and oxygen with mass number 18

19. Three kinds of observations that may indicate a chemical change are listed below. However, a physical change may also result in each observation. Describe a possible chemical cause *and* a possible physical cause for each observation.

a. change in color
b. change in temperature
c. formation of a gas

20. The diameter of a magnesium ion (Mg^{2+}) is 156 pm (picometers, where 1 pm $= 10^{-12}$ m); the diameter of a strontium ion (Sr^{2+}) is 254 pm. Estimate the diameter of a calcium ion (Ca^{2+}).

21. Identify the element in the Periodic Table described by each statement:

a. This element is a member of a group of nonmetals. It forms anions with a −1 charge. It is in the same period as the metals used to form a penny.
b. This element is a metalloid. It is in the same period as the elements found in table salt.

22. Mendeleev arranged elements in his periodic table in order of their atomic weights. In the modern Periodic Table, however, elements are arranged in order of their atomic numbers. Cite two examples from the Periodic Table for which these two schemes would produce a different ordering of adjacent elements.

Extending the Concepts

23. How is mercury different from other metallic elements? Using outside resources, describe some applications that take advantage of the unique properties of metallic mercury.

24. Depending on how it is heated and cooled, iron can either be hard and brittle or malleable. Explain how the same metal can have both characteristics.

25. Construct a graph of the price per gram of an element versus its atomic number for each of the first twenty elements. Can the current cost of those elements be regarded as a periodic property? Explain. (*Hint:* Use a chemical supply catalog or the Web to locate the current price of each element.)

26. Classify one or more pieces of jewelry you might possibly wear as being composed of metals, nonmetals, or metalloids.