CHAPTER

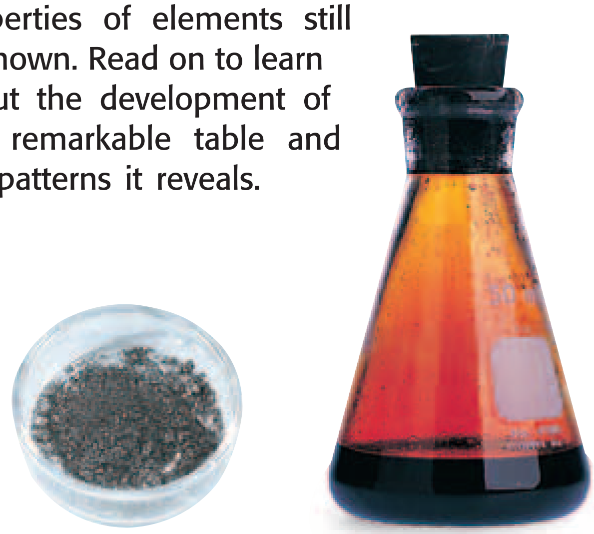
13 The Periodic Table

Would You Believe . . . ?

Suppose someone told you that the small animal shown above—a yellow-spotted rock hyrax—is genetically related to an elephant. Impossible, you say? But it's true! Even though this animal looks more like a rabbit or a rodent, scientists have determined through DNA studies that the closest relatives of the hyrax are aardvarks, sea cows, and elephants. Biologists have uncovered similar genetic links between other seemingly different species.

Scientists have also discovered that many different-looking elements, like those shown at right, actually have common properties. For almost 150 years, scientists have organized elements by observing the similarities (both obvious and not so obvious) between them. One scientist in particular—a Russian named Dmitri Mendeleev (MEN duh LAY uhf)—organized the known elements in such a way that a repeating pattern emerged. Mendeleev actually used this pattern to predict the properties of elements that had not even been discovered! His method of organization became known as the periodic table.

The modern periodic table is arranged somewhat differently than Mendeleev's, but it is still a useful tool for organizing the known elements and predicting the properties of elements still unknown. Read on to learn about the development of this remarkable table and the patterns it reveals.



Although solid iodine and liquid bromine have very different appearances, they have similar chemical properties.

Investigate!

Placement Pattern

Just as with animals, scientists have found patterns among the elements. You too can find patterns—right in your classroom! By gathering and analyzing information about your classmates, you can determine the pattern behind a new seating chart your teacher has created.

Procedure

1. In your ScienceLog, draw a seating chart for the classroom arrangement designated by your teacher. Write the name of each of your classmates in the correct place on the chart.
2. Write information about yourself, such as your name, date of birth, hair color, and height, in the space that represents you on the chart.
3. Starting with the people around you, ask questions to gather the same type of information about them. Write information about each person in the corresponding spaces on the seating chart.

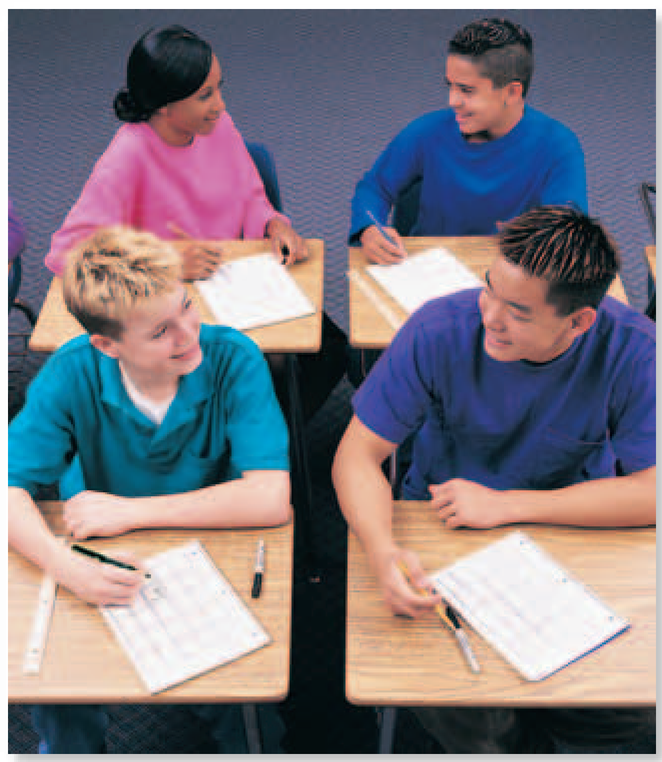
Analysis

4. In your ScienceLog, identify a pattern within the information you gathered that could be used to explain the order of people in the seating chart. If you cannot find a pattern, collect more information, and look again.
5. Test your pattern by gathering information from a person you did not talk to before.
6. If the new information does not support your pattern, reanalyze your data, and collect more information as needed to determine another pattern.

What Do You Think?

In your ScienceLog, try to answer the following questions based on what you already know:

1. How are elements organized in the periodic table?
2. Why is the table of the elements called "periodic"?
3. What one property is shared by elements in a group?



Going Further

The science of classifying organisms is called *taxonomy.* Find out more about the way the Swedish scientist Carolus Linnaeus classified organisms.

Section 1

Arranging the Elements

NEW TERMS

periodic
periodic law
period
group

OBJECTIVES

- Describe how elements are arranged in the periodic table.
- Compare metals, nonmetals, and metalloids based on their properties and on their location in the periodic table.
- Describe the difference between a period and a group.

Imagine you go to a new grocery store in your neighborhood to buy a box of cereal. You are surprised by what you find when you walk into the store. None of the aisles are labeled, and there is no pattern to the products on the shelves! In frustration, you think it might take you days to find your cereal.

Some scientists probably felt a similar frustration before 1869. By that time, more than 60 different elements had been discovered and described. However, the elements were not organized in any special way. But in 1869, the elements were organized into a table in much the same way products are arranged (usually!) by shelf and aisle in a grocery store.

Discovering a Pattern

In the 1860s, a Russian chemist named Dmitri Mendeleev began looking for patterns among the properties of the known elements. He wrote the names and properties of these elements on small pieces of paper. He included information such as density, appearance, atomic mass, melting point, and any information he had about the compounds formed from the element. He then arranged and rearranged the pieces of paper, as shown in **Figure 1.** After much thought and work, he determined that there was a repeating pattern to the properties of the elements when the elements were arranged in order of increasing atomic mass.

Figure 1 *By playing "chemical solitaire" on long train rides, Mendeleev organized the elements according to their properties.*

The Properties of Elements Are Periodic Mendeleev saw that the properties of the elements were **periodic,** meaning they had a regular, repeating pattern. Many things that are familiar to you are periodic. For example, the days of the week are periodic because they repeat in the same order every 7 days.

When the elements were arranged in order of increasing atomic mass, similar chemical and physical properties were observed in every eighth element. Mendeleev's arrangement of the elements came to be known as a periodic table because the properties of the elements change in a periodic way.

Explore

In your ScienceLog, make a list of five things that are periodic. Explain which repeating property causes each one to be periodic.

Figure 2 *Mendeleev used question marks to indicate some elements that he believed would later be identified.*

Predicting Properties of Missing Elements Look at Mendeleev's periodic table in **Figure 2.** Notice the question marks. Mendeleev recognized that there were elements missing. Instead of questioning his arrangement, he boldly predicted that elements yet to be discovered would fill the gaps. He also predicted the properties of the missing elements by using the pattern of properties in the periodic table. When one of the missing elements, gallium, was discovered a few years later, its properties matched Mendeleev's predictions very well, and other scientists became interested in his work. Since that time, all of the missing elements on Mendeleev's periodic table have been discovered. In the chart below, you can see Mendeleev's predictions for another missing element—germanium—and the actual properties of that element.

Properties of Germanium

	Mendeleev's predictions	Actual properties
Atomic mass	72	72.6
Density	5.5 g/cm^3	5.3 g/cm^3
Appearance	dark gray metal	gray metal
Melting point	high melting point	937°C

Changing the Arrangement

Mendeleev noticed that a few elements in the table were not in the correct place according to their properties. He thought that the calculated atomic masses were incorrect and that more accurate atomic masses would eventually be determined. However, new measurements of the atomic masses showed that the masses were in fact correct.

The mystery was solved in 1914 by a British scientist named Henry Moseley (MOHZ lee). From the results of his experiments, Moseley was able to determine the number of protons—the atomic number—in an atom. When he rearranged the elements by atomic number, every element fell into its proper place in an improved periodic table.

Since Moseley's rearrangement of the elements, more elements have been discovered. The discovery of each new element has supported the periodic law, considered to be the basis of the periodic table. The **periodic law** states that the chemical and physical properties of elements are periodic functions of their atomic numbers. The modern version of the periodic table is shown on the following pages.

Moseley was 26 when he made his discovery. His work allowed him to predict that only three elements were yet to be found between aluminum and gold. The following year, as he fought for the British in World War I, he was killed in action at Gallipoli, Turkey. The British government no longer assigns scientists to combat duty.

Periodic Table of the Elements

Each square on the table includes an element's name, chemical symbol, atomic number, and atomic mass.

Atomic number	6
Chemical symbol	C
Element name	Carbon
Atomic mass	12.0

The background color indicates the type of element. Carbon is a nonmetal.

The color of the chemical symbol indicates the physical state at room temperature. Carbon is a solid.

Background	Chemical symbol
Metals	Solid
Metalloids	Liquid
Nonmetals	Gas

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9
Period 1	1 H Hydrogen 1.0								
Period 2	3 Li Lithium 6.9	4 Be Beryllium 9.0							
Period 3	11 Na Sodium 23.0	12 Mg Magnesium 24.3							
Period 4	19 K Potassium 39.1	20 Ca Calcium 40.1	21 Sc Scandium 45.0	22 Ti Titanium 47.9	23 V Vanadium 50.9	24 Cr Chromium 52.0	25 Mn Manganese 54.9	26 Fe Iron 55.8	27 Co Cobalt 58.9
Period 5	37 Rb Rubidium 85.5	38 Sr Strontium 87.6	39 Y Yttrium 88.9	40 Zr Zirconium 91.2	41 Nb Niobium 92.9	42 Mo Molybdenum 95.9	43 Tc Technetium (97.9)	44 Ru Ruthenium 101.1	45 Rh Rhodium 102.9
Period 6	55 Cs Cesium 132.9	56 Ba Barium 137.3	57 La Lanthanum 138.9	72 Hf Hafnium 178.5	73 Ta Tantalum 180.9	74 W Tungsten 183.8	75 Re Rhenium 186.2	76 Os Osmium 190.2	77 Ir Iridium 192.2
Period 7	87 Fr Francium (223.0)	88 Ra Radium (226.0)	89 Ac Actinium (227.0)	104 Rf Rutherfordium (261.1)	105 Db Dubnium (262.1)	106 Sg Seaborgium (263.1)	107 Bh Bohrium (262.1)	108 Hs Hassium (265)	109 Mt Meitnerium (266)

A row of elements is called a period.

A column of elements is called a group or family.

Lanthanides	58 Ce Cerium 140.1	59 Pr Praseodymium 140.9	60 Nd Neodymium 144.2	61 Pm Promethium (144.9)	62 Sm Samarium 150.4
Actinides	90 Th Thorium 232.0	91 Pa Protactinium 231.0	92 U Uranium 238.0	93 Np Neptunium (237.0)	94 Pu Plutonium 244.1

These elements are placed below the table to allow the table to be narrower.

This zigzag line reminds you where the metals, nonmetals, and metalloids are.

Group 10	Group 11	Group 12	Group 13	Group 14	Group 15	Group 16	Group 17	Group 18
								2 **He** Helium 4.0
			5 **B** Boron 10.8	6 **C** Carbon 12.0	7 **N** Nitrogen 14.0	8 **O** Oxygen 16.0	9 **F** Fluorine 19.0	10 **Ne** Neon 20.2
			13 **Al** Aluminum 27.0	14 **Si** Silicon 28.1	15 **P** Phosphorus 31.0	16 **S** Sulfur 32.1	17 **Cl** Chlorine 35.5	18 **Ar** Argon 39.9
28 **Ni** Nickel 58.7	29 **Cu** Copper 63.5	30 **Zn** Zinc 65.4	31 **Ga** Gallium 69.7	32 **Ge** Germanium 72.6	33 **As** Arsenic 74.9	34 **Se** Selenium 79.0	35 **Br** Bromine 79.9	36 **Kr** Krypton 83.8
46 **Pd** Palladium 106.4	47 **Ag** Silver 107.9	48 **Cd** Cadmium 112.4	49 **In** Indium 114.8	50 **Sn** Tin 118.7	51 **Sb** Antimony 121.8	52 **Te** Tellurium 127.6	53 **I** Iodine 126.9	54 **Xe** Xenon 131.3
78 **Pt** Platinum 195.1	79 **Au** Gold 197.0	80 **Hg** Mercury 200.6	81 **Tl** Thallium 204.4	82 **Pb** Lead 207.2	83 **Bi** Bismuth 209.0	84 **Po** Polonium (209.0)	85 **At** Astatine (210.0)	86 **Rn** Radon (222.0)
110 **Uun** Ununnilium (271)	111 **Uuu** Unununium (272)	112 **Uub** Ununbium (277)						

The names and symbols of elements 110–112 are temporary. They are based on the atomic number of the element. The official name and symbol will be approved by an international committee of scientists.

63 **Eu** Europium 152.0	64 **Gd** Gadolinium 157.3	65 **Tb** Terbium 158.9	66 **Dy** Dysprosium 162.5	67 **Ho** Holmium 164.9	68 **Er** Erbium 167.3	69 **Tm** Thulium 168.9	70 **Yb** Ytterbium 173.0	71 **Lu** Lutetium 175.0
95 **Am** Americium (243.1)	96 **Cm** Curium (247.1)	97 **Bk** Berkelium (247.1)	98 **Cf** Californium (251.1)	99 **Es** Einsteinium (252.1)	100 **Fm** Fermium (257.1)	101 **Md** Mendelevium (258.1)	102 **No** Nobelium (259.1)	103 **Lr** Lawrencium (262.1)

A number in parentheses is the mass number of the most stable isotope of that element.

Finding Your Way Around the Periodic Table

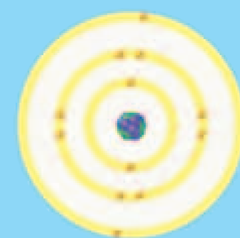
At first glance, you might think studying the periodic table is like trying to explore a thick jungle without a guide—it would be easy to get lost! However, the table itself contains a lot of information that will help you along the way.

Classes of Elements Elements are classified as metals, nonmetals, and metalloids, according to their properties. The number of electrons in the outer energy level of an atom also helps determine which category an element belongs in. The zigzag line on the periodic table can help you recognize which elements are metals, which are nonmetals, and which are metalloids.

Metals

Most of the elements in the periodic table are metals. Metals are found to the left of the zigzag line on the periodic table. Atoms of most metals have few electrons in their outer energy level, as shown at right.

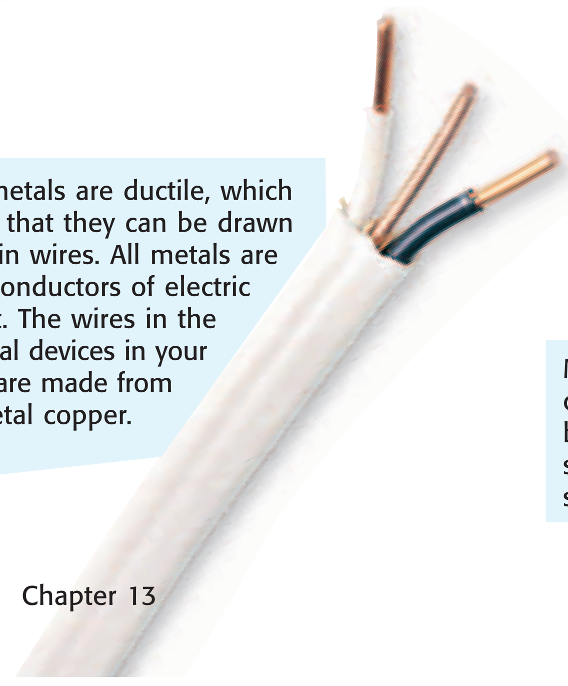
Most metals are solid at room temperature. Mercury, however, is a liquid. Some additional information on properties shared by most metals is shown below.



A model of a magnesium atom

Most metals are good conductors of thermal energy. This iron griddle conducts thermal energy from a stovetop to cook your favorite foods.

Most metals are malleable, meaning that they can be flattened with a hammer without shattering. Aluminum is flattened into sheets to make cans and foil.



Most metals are ductile, which means that they can be drawn into thin wires. All metals are good conductors of electric current. The wires in the electrical devices in your home are made from the metal copper.

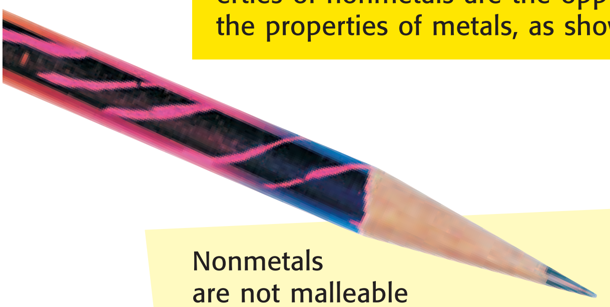
Metals tend to be shiny. You can see a reflection in a mirror because light reflects off the shiny surface of a thin layer of silver behind the glass.

Nonmetals

Nonmetals are found to the right of the zigzag line on the periodic table. Atoms of most nonmetals have an almost complete set of electrons in their outer level, as shown at right. (Atoms of one group of nonmetals, the noble gases, have a complete set of electrons, with most having eight electrons in their outer energy level.)

More than half of the nonmetals are gases at room temperature. The properties of nonmetals are the opposite of the properties of metals, as shown below.

A model of a chlorine atom



Nonmetals are not malleable or ductile. In fact, solid nonmetals, like carbon (shown here in the graphite of the pencil lead), are brittle and will break or shatter when hit with a hammer.

Sulfur, like most nonmetals, is not shiny.

Nonmetals are poor conductors of thermal energy and electric current. If the gap in a spark plug is too wide, the nonmetals nitrogen and oxygen in the air will stop the spark, and a car's engine will not run.

QuickLab

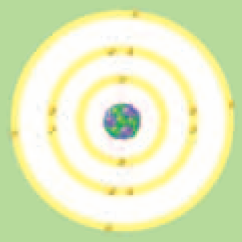
Conduction Connection

1. Fill a **clear plastic cup** with **hot water.**
2. Stand a piece of **copper wire** and a **graphite lead** from a mechanical pencil in the water.
3. After 1 minute, touch the top of each object. Record your observations.
4. Which material conducted thermal energy the best? Why?

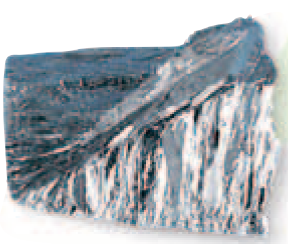
Metalloids

Metalloids, also called semiconductors, are the elements that border the zigzag line on the periodic table. Atoms of metalloids have about a half-complete set of electrons in their outer energy level, as shown at right.

Metalloids have some properties of metals and some properties of nonmetals, as shown below.



A model of a silicon atom



Tellurium is shiny, but it is also brittle and is easily smashed into a powder.

Boron is almost as hard as diamond, but it is also very brittle. At high temperatures, boron is a good conductor of electric current.

Explore

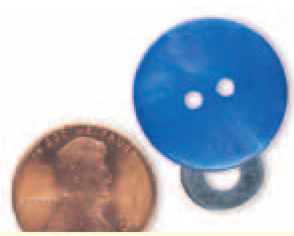
Draw a line down a sheet of paper to divide it into two columns. Look at the elements with atomic numbers 1 through 10 on the periodic table. Write all the chemical symbols and names that follow one pattern in one column on your paper and all chemical symbols and names that follow a second pattern in the second column. Write a sentence describing each pattern you found.

Each Element Is Identified by a Chemical Symbol Each square on the periodic table contains information about an element, including its atomic number, atomic mass, name, and chemical symbol. An international committee of scientists is responsible for approving the names and chemical symbols of the elements. The names of the elements come from many sources. For example, some elements are named after important scientists (mendelevium, einsteinium), and others are named for geographical regions (germanium, californium).

The chemical symbol for each element usually consists of one or two letters. The first letter in the symbol is always capitalized, and the second letter, if there is one, is always written in lowercase. The chart below lists the patterns that the chemical symbols follow, and the Explore activity will help you investigate two of those patterns further.

Writing the Chemical Symbols

Pattern of chemical symbols	Examples
first letter of the name	S—sulfur
first two letters of the name	Ca—calcium
first letter and third or later letter of the name	Mg—magnesium
letter(s) of a word other than the English name	Pb—lead (from the Latin *plumbum,* meaning "lead")
first letter of root words that stand for the atomic number (used for elements whose official names have not yet been chosen)	Uun—ununnilium (uhn uhn NIL ee uhm) (for atomic number 110)

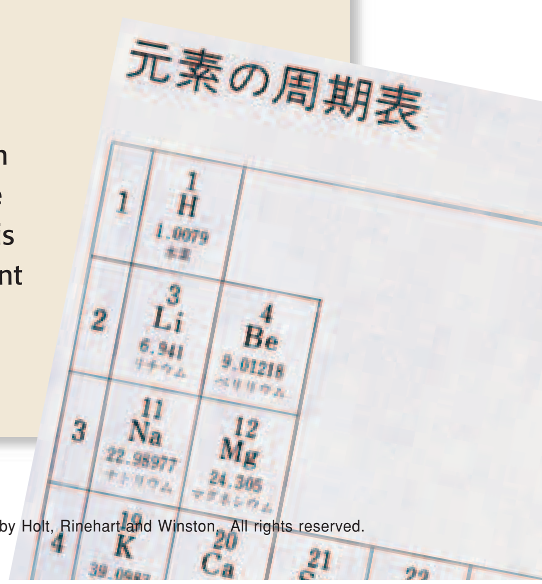


LabBook

You can create your own well-rounded periodic table using coins, washers, and buttons on page 572 of the LabBook.

APPLY

Look at the periodic table shown here. How is it the same as the periodic table you saw earlier? How is it different? Explain why it is important for scientific communication that the chemical symbols used are the same around the world.



Rows Are Called Periods Each horizontal row of elements (from left to right) on the periodic table is called a **period.** For example, the row from lithium (Li) to neon (Ne) is Period 2. A row is called a period because the properties of elements in a row follow a repeating, or periodic, pattern as you move across each period. The physical and chemical properties of elements, such as conductivity and the number of electrons in the outer level of atoms, change gradually from those of a metal to those of a nonmetal in each period. Therefore, elements at opposite ends of a period have very different properties from one another, as shown in **Figure 3.**

To remember that a period goes from left to right across the periodic table, just think of reading a sentence. You read from left to right across the page until you come to a period.

Figure 3 *The elements in a row become less metallic from left to right.*

19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr

Elements at the left end of a period, such as titanium, are very metallic in their properties.

Elements farther to the right, like germanium, are less metallic in their properties.

Elements at the far right end of a period, such as bromine, are nonmetallic in their properties.

Columns Are Called Groups Each column of elements (from top to bottom) on the periodic table is called a **group.** Elements in the same group often have similar chemical and physical properties. For this reason, sometimes a group is also called a family. You will learn more about each group in the next section.

REVIEW

1. Compare a period and a group on the periodic table.
2. How are the elements arranged in the modern periodic table?
3. **Comparing Concepts** Compare metals, nonmetals, and metalloids in terms of their electrical conductivity.

Section 2

Grouping the Elements

NEW TERMS

alkali metals
alkaline-earth metals
halogens
noble gases

OBJECTIVES

- Explain why elements in a group often have similar properties.
- Describe the properties of the elements in the groups of the periodic table.

You probably know a family with several members that look a lot alike. Or you may have a friend whose little brother or sister acts just like your friend. Members of a family often—but not always—have a similar appearance or behavior. Likewise, the elements in a family or group in the periodic table often—but not always—share similar properties. The properties are similar because the atoms of the elements have the same number of electrons in their outer energy level.

Groups 1 and 2: Very Reactive Metals

The most reactive metals are the elements in Groups 1 and 2. What makes an element reactive? The answer has to do with electrons in the outer energy level of atoms. Atoms will often take, give, or share electrons with other atoms in order to have a complete set of electrons in their outer energy level. Elements whose atoms undergo such processes are *reactive* and combine to form compounds. Elements whose atoms need to take, give, or share only one or two electrons to have a filled outer level tend to be very reactive.

The elements in Groups 1 and 2 are so reactive that they are only found combined with other elements in nature. To study the elements separately, the naturally occurring compounds must first be broken apart through chemical changes.

Group 1: Alkali Metals

3	**Li**	Lithium
11	**Na**	Sodium
19	**K**	Potassium
37	**Rb**	Rubidium
55	**Cs**	Cesium
87	**Fr**	Francium

Group contains: Metals
Electrons in the outer level: 1
Reactivity: Very reactive
Other shared properties: Soft; silver-colored; shiny; low density

Alkali (AL kuh LIE) **metals** are soft enough to be cut with a knife, as shown in **Figure 4.** The densities of the alkali metals are so low that lithium, sodium, and potassium are actually less dense than water.

Figure 4 *Metals so soft that they can be cut with a knife? Welcome to the alkali metals.*

Although the element hydrogen appears above the alkali metals on the periodic table, it is not considered a member of Group 1. It will be described separately at the end of this section.

Alkali metals are the most reactive of the metals. This is because their atoms can easily give away the single electron in their outer level. For example, alkali metals react violently with water, as shown in **Figure 5.** Alkali metals are usually stored in oil to prevent them from reacting with water and oxygen in the atmosphere.

The compounds formed from alkali metals have many uses. Sodium chloride (table salt) can be used to add flavor to your food. Sodium hydroxide can be used to unclog your drains. Potassium bromide is one of several potassium compounds used in photography.

Figure 5 *As alkali metals react with water, they form hydrogen gas.*

Group 2: Alkaline-earth Metals

4	**Be**	Beryllium
12	**Mg**	Magnesium
20	**Ca**	Calcium
38	**Sr**	Strontium
56	**Ba**	Barium
88	**Ra**	Radium

Group contains: Metals
Electrons in the outer level: 2
Reactivity: Very reactive, but less reactive than alkali metals
Other shared properties: Silver-colored; more dense than alkali metals

Alkaline-earth metals are not as reactive as alkali metals because it is more difficult for atoms to give away two electrons than to give away only one when joining with other atoms.

The alkaline-earth metal magnesium is often mixed with other metals to make low-density materials used in airplanes. Compounds of alkaline-earth metals also have many uses. For example, compounds of calcium are found in cement, plaster, chalk, and even you, as shown in **Figure 6.**

Figure 6 *Smile! Calcium, an alkaline-earth metal, is an important component of a compound that makes your bones and teeth healthy.*

Groups 3–12: Transition Metals

Groups 3–12 do not have individual names. Instead, these groups are described together under the name *transition metals*.

Group contains: Metals
Electrons in the outer level: 1 or 2
Reactivity: Less reactive than alkaline-earth metals
Other shared properties: Shiny; good conductors of thermal energy and electric current; higher densities and melting points (except for mercury) than elements in Groups 1 and 2

21 **Sc** Scandium	22 **Ti** Titanium	23 **V** Vanadium	24 **Cr** Chromium	25 **Mn** Manganese	26 **Fe** Iron	27 **Co** Cobalt	28 **Ni** Nickel	29 **Cu** Copper	30 **Zn** Zinc
39 **Y** Yttrium	40 **Zr** Zirconium	41 **Nb** Niobium	42 **Mo** Molybdenum	43 **Tc** Technetium	44 **Ru** Ruthenium	45 **Rh** Rhodium	46 **Pd** Palladium	47 **Ag** Silver	48 **Cd** Cadmium
57 **La** Lanthanum	72 **Hf** Hafnium	73 **Ta** Tantalum	74 **W** Tungsten	75 **Re** Rhenium	76 **Os** Osmium	77 **Ir** Iridium	78 **Pt** Platinum	79 **Au** Gold	80 **Hg** Mercury
89 **Ac** Actinium	104 **Rf** Rutherfordium	105 **Db** Dubnium	106 **Sg** Seaborgium	107 **Bh** Bohrium	108 **Hs** Hassium	109 **Mt** Meitnerium	110 **Uun** Ununnilium	111 **Uuu** Unununium	112 **Uub** Ununbium

The atoms of transition metals do not give away their electrons as easily as atoms of the Group 1 and Group 2 metals do, making transition metals less reactive than the alkali metals and the alkaline-earth metals. The properties of the transition metals vary widely, as shown in **Figure 7.**

Figure 7 *Transition metals have a wide range of physical and chemical properties.*

Mercury is used in thermometers because, unlike the other transition metals, it is in the liquid state at room temperature.

Some transition metals, including the titanium in the artificial hip at right, are not very reactive. But others, such as iron, are reactive. The iron in the steel trowel above has reacted with oxygen to form rust.

Many transition metals are silver-colored—but not all! This gold ring proves it!

Self-Check

Why are alkali metals more reactive than alkaline-earth metals? *(See page 596 to check your answer.)*

57 La Lanthanum 138.9
89 Ac Actinium (227.0)

Lanthanides and Actinides Some transition metals from Periods 6 and 7 are placed at the bottom of the periodic table to keep the table from being too wide. The properties of the elements in each row tend to be very similar.

Lanthanides	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinides	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Elements in the first row are called *lanthanides* because they follow the transition metal lanthanum. The lanthanides are shiny, reactive metals. Some of these elements are used to make different types of steel. An important use of a compound of one lanthanide element is shown in **Figure 8.**

Elements in the second row are called *actinides* because they follow the transition metal actinium. All atoms of actinides are radioactive, which means they are unstable. The atoms of a radioactive element can change into atoms of a different element. Elements listed after plutonium, element 94, do not occur in nature but are instead produced in laboratories. You might have one of these elements in your home. Very small amounts of americium (AM uhr ISH ee uhm), element 95, are used in some smoke detectors.

Figure 8 *Seeing red? The color red appears on a computer monitor because of a compound formed from europium that coats the back of the screen.*

REVIEW

1. What are two properties of the alkali metals?
2. What causes the properties of elements in a group to be similar?
3. **Applying Concepts** Why are neither the alkali metals nor the alkaline-earth metals found uncombined in nature?

Groups 13–16: Groups That Include Metalloids

Moving from Group 13 across to Group 16, the elements shift from metals to nonmetals. Along the way, you find the metalloids. These elements have some properties of metals and some properties of nonmetals.

Group 13: Boron Group

5 **B** Boron
13 **Al** Aluminum
31 **Ga** Gallium
49 **In** Indium
81 **Tl** Thallium

Group contains: One metalloid and four metals
Electrons in the outer level: 3
Reactivity: Reactive
Other shared properties: Solid at room temperature

The most common element from Group 13 is aluminum. In fact, aluminum is the most abundant metal in Earth's crust. Until the 1880s, it was considered a precious metal because the process used to produce pure aluminum was very expensive. In fact, aluminum was even more valuable than gold, as shown in **Figure 9.**

Today, the process is not as difficult or expensive. Aluminum is now an important metal used in making lightweight automobile parts and aircraft, as well as foil, cans, and wires.

Figure 9 *During the 1850s and 1860s, Emperor Napoleon III of France, nephew of Napoleon Bonaparte, used aluminum dinnerware because aluminum was more valuable than gold!*

Group 14: Carbon Group

6 **C** Carbon
14 **Si** Silicon
32 **Ge** Germanium
50 **Sn** Tin
82 **Pb** Lead

Group contains: One nonmetal, two metalloids, and two metals
Electrons in the outer level: 4
Reactivity: Varies among the elements
Other shared properties: Solid at room temperature

The metalloids silicon and germanium are used to make computer chips. The metal tin is useful because it is not very reactive. A tin can is really made of steel coated with tin. The tin is less reactive than the steel, and it keeps the steel from rusting.

environmental science CONNECTION

Recycling aluminum uses less energy than obtaining aluminum in the first place. Aluminum must be separated from bauxite, a mixture containing naturally occurring compounds of aluminum. Twenty times more electrical energy is required to separate aluminum from bauxite than to recycle used aluminum.

The nonmetal carbon can be found uncombined in nature, as shown in **Figure 10.** Carbon forms a wide variety of compounds. Some of these compounds, including proteins, fats, and carbohydrates, are essential to life on Earth.

A particle of carbon shaped like a soccer ball? You'll get a kick out of reading about buckyballs on page 347.

Figure 10 *Diamonds and soot have very different properties, yet both are natural forms of carbon.*

Diamond is the hardest material known. It is used as a jewel and on cutting tools such as saws, drills, and files.

Soot—formed from burning oil, coal, and wood—is used as a pigment in paints and crayons.

Group 15: Nitrogen Group

7	**N**	Nitrogen
15	**P**	Phosphorus
33	**As**	Arsenic
51	**Sb**	Antimony
83	**Bi**	Bismuth

Group contains: Two nonmetals, two metalloids, and one metal
Electrons in the outer level: 5
Reactivity: Varies among the elements
Other shared properties: All but nitrogen are solid at room temperature.

Nitrogen, which is a gas at room temperature, makes up about 80 percent of the air you breathe. Nitrogen removed from air is reacted with hydrogen to make ammonia for fertilizers.

Although nitrogen is unreactive, phosphorus is extremely reactive, as shown in **Figure 11.** In fact, phosphorus is only found combined with other elements in nature.

Figure 11 *Simply striking a match on the side of this box causes chemicals on the match to react with phosphorus on the box and begin to burn.*

Group 16: Oxygen Group

8	**O**	Oxygen
16	**S**	Sulfur
34	**Se**	Selenium
52	**Te**	Tellurium
84	**Po**	Polonium

Group contains: Three nonmetals, one metalloid, and one metal
Electrons in the outer level: 6
Reactivity: Reactive
Other shared properties: All but oxygen are solid at room temperature.

Oxygen makes up about 20 percent of air. Oxygen is necessary for substances to burn, such as the chemicals on the match in Figure 11. Sulfur, another common member of Group 16, can be found as a yellow solid in nature. The principal use of sulfur is to make sulfuric acid, the most widely used compound in the chemical industry.

Groups 17 and 18: Nonmetals Only

The elements in Groups 17 and 18 are nonmetals. The elements in Group 17 are the most reactive nonmetals, but the elements in Group 18 are the least reactive nonmetals. In fact, the elements in Group 18 normally won't react at all with other elements.

Figure 12 *Physical properties of some halogens at room temperature are shown here.*

Group 17: Halogens

9	F	Fluorine
17	Cl	Chlorine
35	Br	Bromine
53	I	Iodine
85	At	Astatine

Group contains: Nonmetals
Electrons in the outer level: 7
Reactivity: Very reactive
Other shared properties: Poor conductors of electric current; react violently with alkali metals to form salts; never found uncombined in nature

Halogens are very reactive nonmetals because their atoms need to gain only one electron to have a complete outer level. The atoms of halogens combine readily with other atoms, especially metals, to gain that missing electron.

Although the chemical properties of the halogens are similar, the physical properties are quite different, as shown in **Figure 12.**

Both chlorine and iodine are used as disinfectants. Chlorine is used to treat water, while iodine mixed with alcohol is used in hospitals.

Group 18: Noble Gases

2	He	Helium
10	Ne	Neon
18	Ar	Argon
36	Kr	Krypton
54	Xe	Xenon
86	Rn	Radon

Group contains: Nonmetals
Electrons in the outer level: 8 (2 for helium)
Reactivity: Unreactive
Other shared properties: Colorless, odorless gases at room temperature

Noble gases are unreactive nonmetals. Because the atoms of the elements in this group have a complete set of electrons in their outer level, they do not need to lose or gain any electrons. Therefore, they do not react with other elements under normal conditions.

All of the noble gases are found in Earth's atmosphere in small amounts. Argon, the most abundant noble gas in the atmosphere, makes up almost 1 percent of the atmosphere.

The term *noble gases* describes the nonreactivity of these elements. Just as nobles, such as kings and queens, did not often mix with common people, the noble gases do not normally react with other elements.

The nonreactivity of the noble gases makes them useful. Ordinary light bulbs last longer when filled with argon than they would if filled with a reactive gas. Because argon is unreactive, it does not react with the metal filament in the light bulb even when the filament gets hot. The low density of helium causes blimps and weather balloons to float, and its nonreactivity makes helium safer to use than hydrogen. One popular use of noble gases that does *not* rely on their nonreactivity is shown in **Figure 13.**

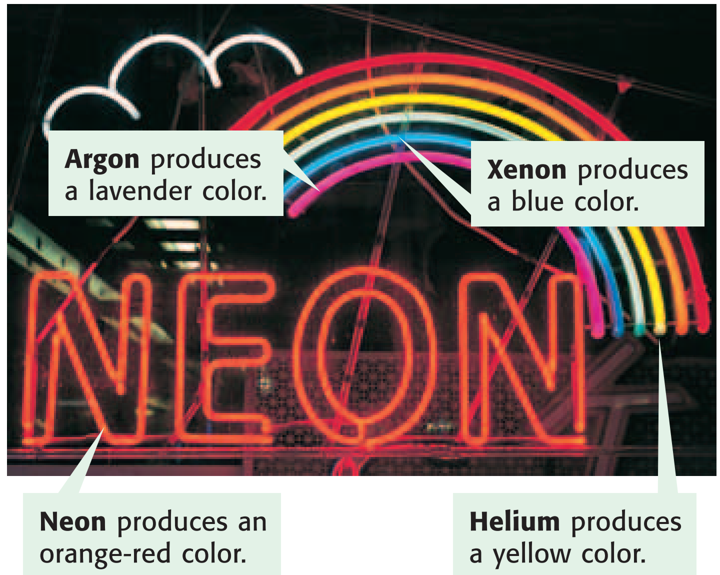


Figure 13 *Besides neon, other noble gases are often used in "neon" lights.*

Hydrogen Stands Apart

1 H Hydrogen	**Electrons in the outer level:** 1 **Reactivity:** Reactive **Other properties:** Colorless, odorless gas at room temperature; low density; reacts explosively with oxygen

The properties of hydrogen do not match the properties of any single group, so hydrogen is set apart from the other elements in the table.

Hydrogen is placed above Group 1 in the periodic table because atoms of the alkali metals also have only one electron in their outer level. Atoms of hydrogen, like atoms of alkali metals, can give away one electron when joining with other atoms. However, hydrogen's physical properties are more like the properties of nonmetals than of metals. As you can see, hydrogen really is in a group of its own.

Hydrogen is the most abundant element in the universe. Hydrogen's reactive nature makes it useful as a fuel in rockets, as shown in **Figure 14.**

Figure 14 *Hydrogen is a reactive nonmetal. As hydrogen burns, it joins with oxygen, and the hot water vapor that forms pushes the rocket up.*

REVIEW

1. In which group are the unreactive nonmetals found?
2. What are two properties of the halogens?
3. **Making Predictions** In the future, a new noble gas may be synthesized. Predict its atomic number and properties.
4. **Comparing Concepts** Compare the element hydrogen with the alkali metal sodium.

Chapter Highlights

SECTION 1

Vocabulary

periodic *(p. 326)*
periodic law *(p. 327)*
period *(p. 333)*
group *(p. 333)*

Section Notes

- Mendeleev developed the first periodic table. He arranged elements in order of increasing atomic mass. The properties of elements repeated in an orderly pattern, allowing Mendeleev to predict properties for elements that had not yet been discovered.
- Moseley rearranged the elements in order of increasing atomic number.
- The periodic law states that the chemical and physical properties of elements are periodic functions of their atomic numbers.
- Elements in the periodic table are divided into metals, metalloids, and nonmetals.
- Each element has a chemical symbol that is recognized around the world.
- A horizontal row of elements is called a period. The elements gradually change from metallic to nonmetallic from left to right across each period.
- A vertical column of elements is called a group or family. Elements in a group usually have similar properties.

Labs

Create a Periodic Table *(p. 572)*

Skills Check

Visual Understanding

PERIODIC TABLE OF THE ELEMENTS Scientists rely on the periodic table as a resource for a large amount of information. Review the periodic table on pages 328–329. Pay close attention to the labels and the key; they will help you understand the information presented in the table.

CLASSES OF ELEMENTS Identifying an element as a metal, nonmetal, or metalloid gives you a better idea of the properties of that element. Review the figures on pages 330–331 to understand how to use the zigzag line on the periodic table to identify the classes of elements and to review the properties of elements in each category.

SECTION 2

Vocabulary

alkali metals *(p. 334)*
alkaline-earth metals *(p. 335)*
halogens *(p. 340)*
noble gases *(p. 340)*

Section Notes

- The alkali metals (Group 1) are the most reactive metals. Atoms of the alkali metals have one electron in their outer level.
- The alkaline-earth metals (Group 2) are less reactive than the alkali metals. Atoms of the alkaline-earth metals have two electrons in their outer level.
- The transition metals (Groups 3–12) include most of the well-known metals as well as the lanthanides and actinides located below the periodic table.
- Groups 13–16 contain the metalloids along with some metals and nonmetals. The atoms of the elements in each of these groups have the same number of electrons in their outer level.
- The halogens (Group 17) are very reactive nonmetals. Atoms of the halogens have seven electrons in their outer level.
- The noble gases (Group 18) are unreactive nonmetals. Atoms of the noble gases have a complete set of electrons in their outer level.
- Hydrogen is set off by itself because its properties do not match the properties of any one group.

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TOPIC: Buckminster Fuller and the Buckyball	***sci*LINKS NUMBER:** HSTP300

Chapter Review

USING VOCABULARY

Complete the following sentences by choosing the appropriate term from each pair of terms listed below.

1. Elements in the same vertical column in the periodic table belong to the same __?__. (*group* or *period*)

2. Elements in the same horizontal row in the periodic table belong to the same __?__. (*group* or *period*)

3. The most reactive metals are __?__. (*alkali metals* or *alkaline-earth metals*)

4. Elements that are unreactive are called __?__. (*noble gases* or *halogens*)

UNDERSTANDING CONCEPTS

Multiple Choice

5. An element that is a very reactive gas is most likely a member of the
   a. noble gases.
   b. alkali metals.
   c. halogens.
   d. actinides.

6. Which statement is true?
   a. Alkali metals are generally found in their uncombined form.
   b. Alkali metals are Group 1 elements.
   c. Alkali metals should be stored under water.
   d. Alkali metals are unreactive.

7. Which statement about the periodic table is false?
   a. There are more metals than nonmetals.
   b. The metalloids are located in Groups 13 through 16.
   c. The elements at the far left of the table are nonmetals.
   d. Elements are arranged by increasing atomic number.

8. One property of most nonmetals is that they are
   a. shiny.
   b. poor conductors of electric current.
   c. flattened when hit with a hammer.
   d. solids at room temperature.

9. Which is a true statement about elements?
   a. Every element occurs naturally.
   b. All elements are found in their uncombined form in nature.
   c. Each element has a unique atomic number.
   d. All of the elements exist in approximately equal quantities.

10. Which is NOT found on the periodic table?
    a. The atomic number of each element
    b. The symbol of each element
    c. The density of each element
    d. The atomic mass of each element

Short Answer

11. Why was Mendeleev's periodic table useful?

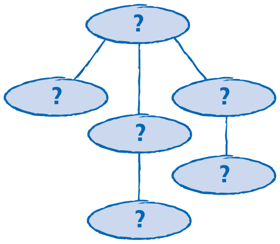
12. How is Moseley's basis for arranging the elements different from Mendeleev's?

13. How is the periodic table like a calendar?

14. Describe the location of metals, metalloids, and nonmetals on the periodic table.

Concept Mapping

15. Use the following terms to create a concept map: periodic table, elements, groups, periods, metals, nonmetals, metalloids.



CRITICAL THINKING AND PROBLEM SOLVING

16. When an element with 115 protons in its nucleus is synthesized, will it be a metal, a nonmetal, or a metalloid? Explain.

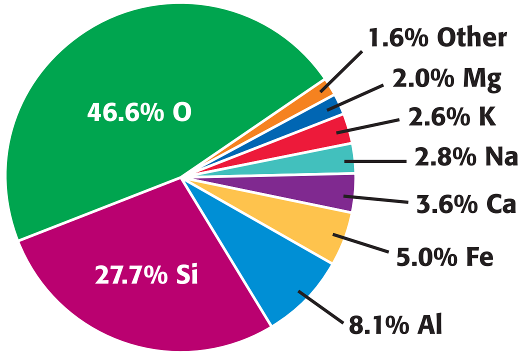
17. Look at Mendeleev's periodic table in Figure 2. Why was Mendeleev not able to make any predictions about the noble gas elements?

18. Your classmate offers to give you a piece of sodium he found while hiking. What is your response? Explain.

19. Determine the identity of each element described below:
    a. This metal is very reactive, has properties similar to magnesium, and is in the same period as bromine.
    b. This nonmetal is in the same group as lead.
    c. This metal is the most reactive metal in its period and cannot be found uncombined in nature. Each atom of the element contains 19 protons.

MATH IN SCIENCE

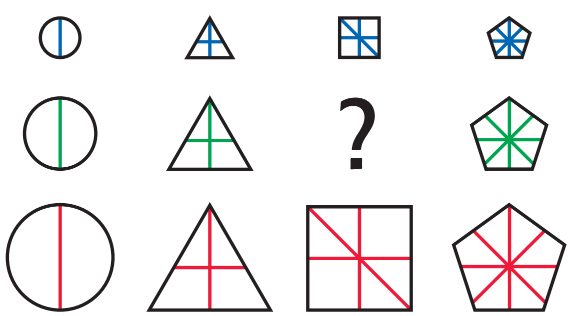
20. The chart below shows the percentages of elements in the Earth's crust.



Excluding the "Other" category, what percentage of the Earth's crust is
a. alkali metals?
b. alkaline-earth metals?

INTERPRETING GRAPHICS

21. Study the diagram below to determine the pattern of the images. Predict the missing image, and draw it. Identify which properties are periodic and which properties are shared within a group.



NOW What Do You Think?

Take a minute to review your answers to the ScienceLog questions on page 325. Have your answers changed? If necessary, revise your answers based on what you have learned since you began this chapter.

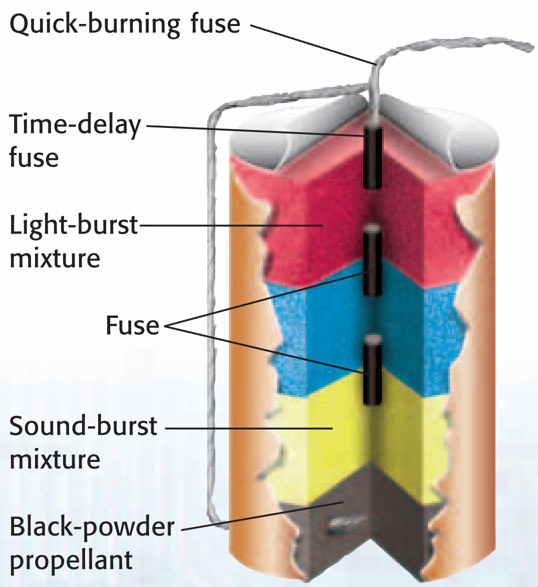
Science, Technology, and Society

The Science of Fireworks

What do the space shuttle and the Fourth of July have in common? The same scientific principles that help scientists launch a space shuttle also help pyrotechnicians create spectacular fireworks shows. The word *pyrotechnics* comes from the Greek words for "fire art." Explosive and dazzling, a fireworks display is both a science and an art.

An Ancient History

More than 1,000 years ago, Chinese civilizations made black powder, the original gunpowder used in pyrotechnics. They used the powder to set off firecrackers and primitive missiles. Black powder is still used today to launch fireworks into the air and to give fireworks an explosive charge. Even the ingredients—saltpeter (potassium nitrate), charcoal, and sulfur—haven't changed since ancient times.



▲ *Cutaway view of a typical firework. Each shell creates a different type of display.*

Snap, Crackle, Pop!

The shells of fireworks contain the ingredients that create the explosions. Inside the shells, black powder and other chemicals are packed in layers. When ignited, one layer may cause a bright burst of light while a second layer produces a loud booming sound. The shell's shape affects the shape of the explosion. Cylindrical shells produce a trail of lights that looks like an umbrella. Round shells produce a star-burst pattern of lights.

The color and sound of fireworks depend on the chemicals used. To create colors, chemicals like strontium (for red), magnesium (for white), and copper (for blue) can be mixed with the gunpowder.

Explosion in the Sky

Fireworks are launched from metal, plastic, or cardboard tubes. Black powder at the bottom of the shell explodes and shoots the shell into the sky. A fuse begins to burn when the shell is launched. Seconds later, when the explosive chemicals are high in the air, the burning fuse lights another charge of black powder. This ignites the rest of the ingredients in the shell, causing an explosion that lights up the sky!

Bang for Your Buck

▶ The fireworks used during New Year's Eve and Fourth of July celebrations can cost anywhere from $200 to $2,000 apiece. Count the number of explosions at the next fireworks show you see. If each of the fireworks cost just $200 to produce, how much would the fireworks for the entire show cost?