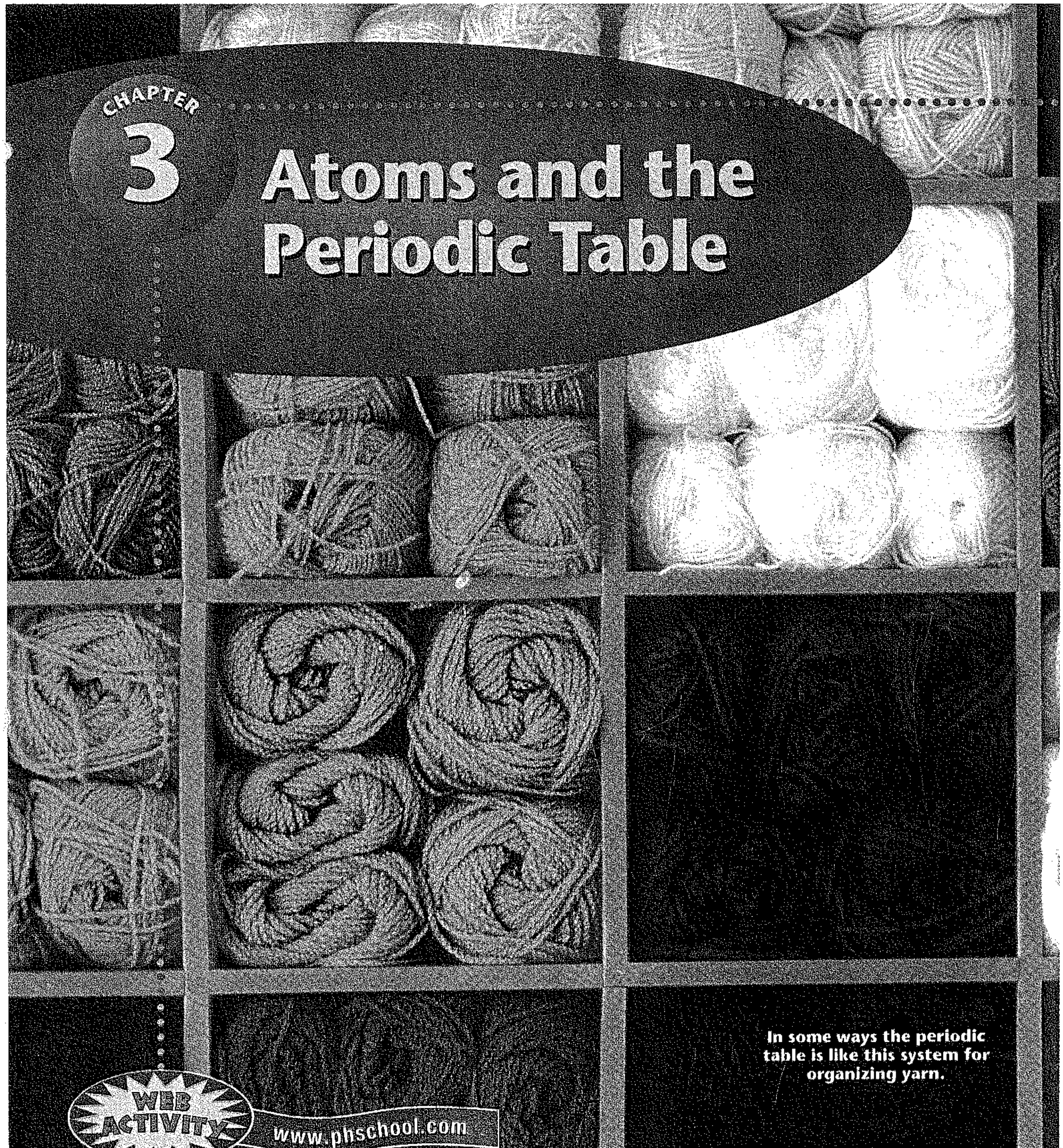
CHAPTER 3

Atoms and the Periodic Table



In some ways the periodic table is like this system for organizing yarn.

WEB ACTIVITY www.phschool.com

SECTION 1 Inside an Atom

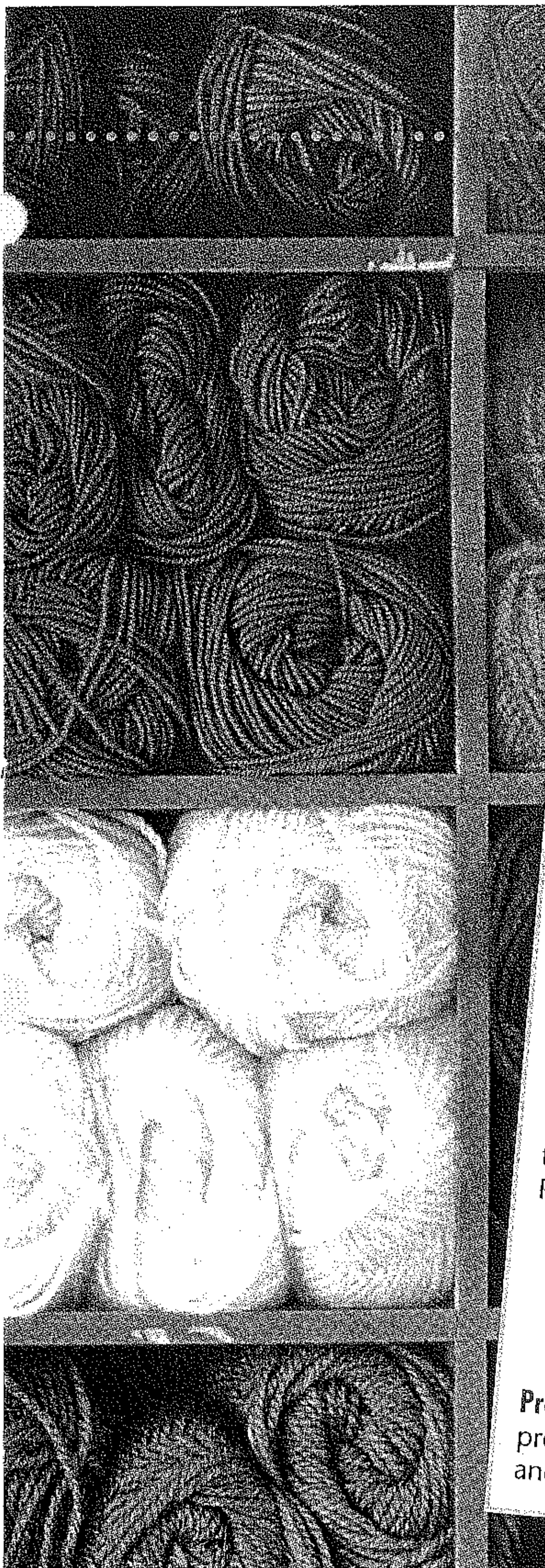
Discover How Far Away Is the Electron?
Science at Home Atoms on Display

SECTION 2 Organizing the Elements

Discover Which is Easier?
Sharpen Your Skills Classifying

SECTION 3 Metals

Discover Why Use Aluminum?
Sharpen Your Skills Observing
Real-World Lab Testing 1, 2, 3



CHAPTER 3 PROJECT

Getting Organized

Imagine searching for matching skeins of yarn if all the yarn had been tossed randomly into a large bin. Luckily, the owner of the store has grouped the yarn by color and by the thickness of the yarn strands. You may have seen similar systems of organization in other stores or in your own home.

Chemists also have a system of organization—a system for organizing the elements. There are more than 100 elements. As you will learn in this chapter, about 80 elements are classified as metals. In this project, you will examine the properties of different metals more closely.

Your Goal To survey the properties of several metal samples.

To complete the project you must

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

Get Started Begin by brainstorming with your classmates about metals. How do you think metals differ from nonmetals? Your teacher will assign samples of metals to your group. You will be observing their properties in this project.

Check Your Progress You'll be working on this project as you study this chapter. To keep your project on track, look for Check Your Progress boxes at the following points.

Section 2 Review, page 88: Extract information from the periodic table.

Section 3 Review, page 94: Design experiments to test for properties.

Section 5 Review, page 108: Conduct tests on all samples.

Present Your Project At the end of the chapter (page 111), you will prepare a presentation comparing and contrasting the expected and observed properties of the metals you investigated.

Chapter 3 – Physical Science

Section 1 Inside an Atom

Discover — Activity

How Far Away Is the Electron?

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

Think It Over

Making Models The diameter of an actual atom can be 100,000 times the diameter of its nucleus. Calculate the diameter of your model atom. How close was your prediction in Step 3 to your calculation? (*Hint:* To compare your result to the real world, change the units of your prediction from centimeters to meters.)

GUIDE FOR READING

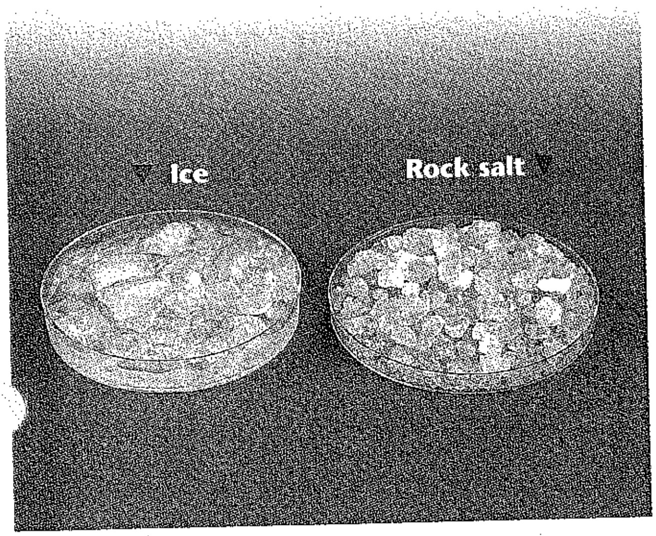
- What is the structure of an atom?
- What role do valence electrons play in forming chemical bonds?

Reading Tip As you read, make a table listing the particles found in an atom. Include the name of each particle, its charge, and where in an atom the particle is located.

Picture this: It's –5°C. Two white solids—ice and salt—are side by side. You slowly heat the materials. At 0°C, the ice melts, making liquid water. It then boils into a gas at 100°C. The salt doesn't change until it's at 801°C, when it begins to melt. It boils away at 1,413°C. These differences are caused by the kinds of chemical bonds holding the atoms together. To understand chemical bonds, you need to know more about atoms.

Structure of an Atom

If you could look into an atom, what might you see? Theories about the shape and structure of atoms have changed over the last 200 years and continue to change even now. But some ideas about atoms are well understood.



Three Kinds of Particles Although atoms are extremely small, they are made of even smaller parts. **An atom consists of a nucleus surrounded by one or more electrons.** The **nucleus** (NOO clee us) (plural *nuclei*) is the tiny, central core of an atom. Nuclei contain particles called protons and neutrons. **Protons** have a positive electric charge (indicated by a plus symbol, +). **Neutrons** have no charge. They are neutral. (Could you guess that from their name?) A third type of particle moves in the space around the nucleus. These are very energetic particles, called **electrons,** which move rapidly in all directions. Electrons carry a negative charge (indicated by a negative symbol, –).

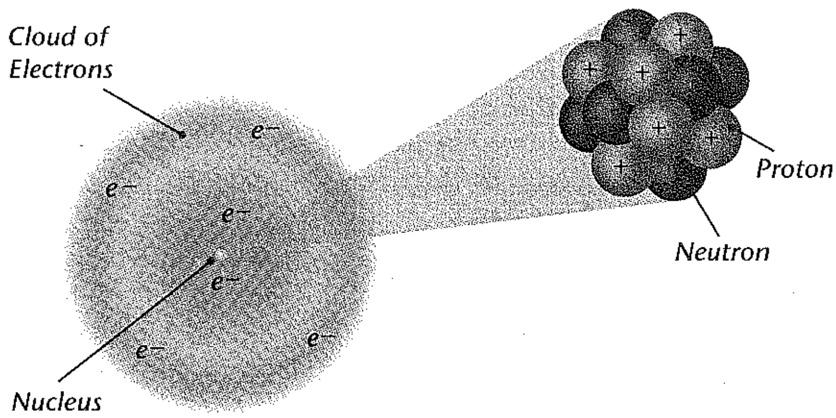


Figure 1 An atom's tiny nucleus contains protons and neutrons. The electrons move in the space around the nucleus.
Applying Concepts *Is this carbon atom negatively charged, positively charged, or neutral overall?*

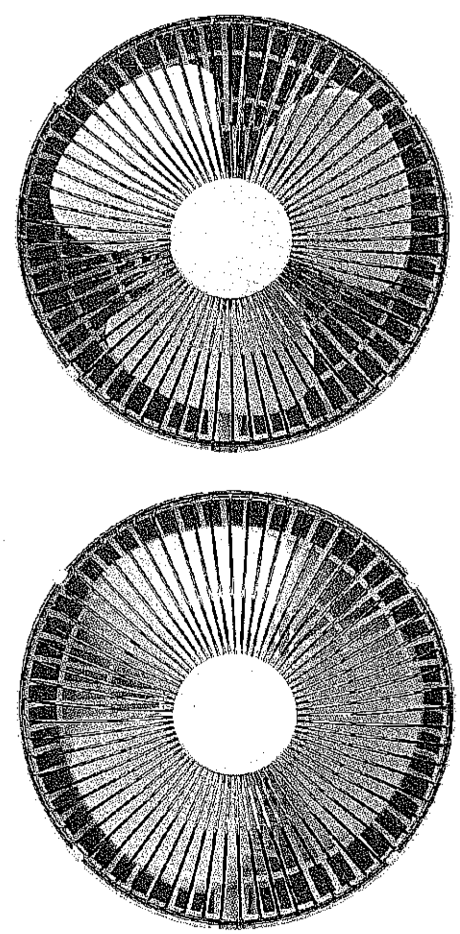
Atomic Number Every atom of a particular element contains the same number of protons. For example, every carbon atom contains six protons. Thus, an element's **atomic number**—the number of protons in its nucleus—is a unique property that identifies that element. And in an atom, the number of protons and the number of electrons are equal, making the atom neutral.

Atomic Mass Atoms cannot be measured with everyday units of mass because they are so small. For this reason, scientists have created the **atomic mass unit (amu)** to measure the particles in atoms. The mass of a proton or a neutron is about one atomic mass unit. Electrons have a much smaller mass. It takes almost 2,000 electrons to equal one atomic mass unit. That means that most of an atom's mass is in its nucleus. An atom that contains 6 protons, 6 neutrons, and 6 electrons has a mass of about 12 atomic mass units.

Although atoms of any particular element always have the same number of protons, the number of neutrons they contain may vary. Carbon atoms, for instance, always have six protons. But they may have five, six, seven, or eight neutrons. That means that the mass of atoms of an element can vary. However, the neutrons do not play a role in chemical reactions. The atoms of a particular element all have the same chemical properties despite their different masses.

☑ *Checkpoint* *Which particles in an atom are in the nucleus?*

Figure 2 When a fan is turned on, you see a blur instead of separate blades. A fan is a model for the way electrons fill the space around the nucleus of an atom.



The Role of Electrons

Electrons move around the nucleus so fast that it is impossible to know exactly where any electron is at a particular time. Think about the blades of a moving fan. They go too fast to be seen. As electrons move around the nucleus, the effect is like the fan blades, but in three dimensions. The space around the nucleus is like a spherical cloud of negatively charged electrons.

Little Particles, Big Spaces Most of an atom's mass comes from its protons and neutrons. But most of an atom's volume is the space in which the electrons move. That space is huge compared to the space occupied by the nucleus. To picture the difference, imagine standing at the pitcher's mound in a baseball stadium. If the nucleus were the size of a pencil eraser, the electrons could be in the outfield or as far away as the top row of seats!

☑ *Checkpoint* *Where are the electrons in an atom?*

SCIENCE & History

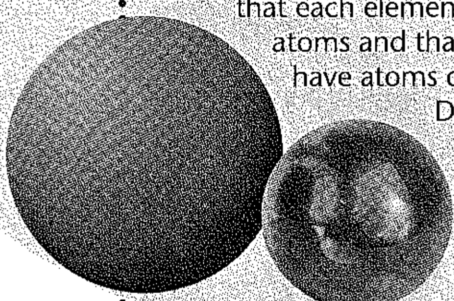
Models of Atoms

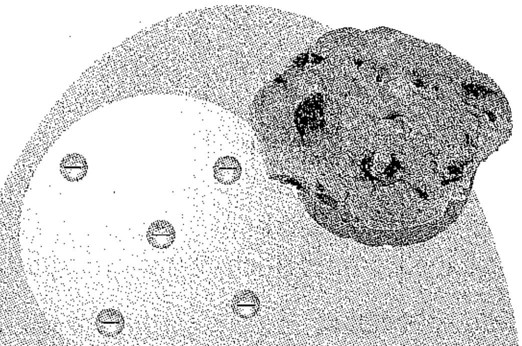
For over two centuries, models of atoms have helped scientists understand why matter behaves as it does. As scientists have learned more, the model of the atom has changed.

1808

Dalton Model

British chemist John Dalton published his *New System of Chemical Philosophy,* explaining that each element is made of small atoms and that different elements have atoms of different mass. Dalton imagined atoms as tiny, solid balls.





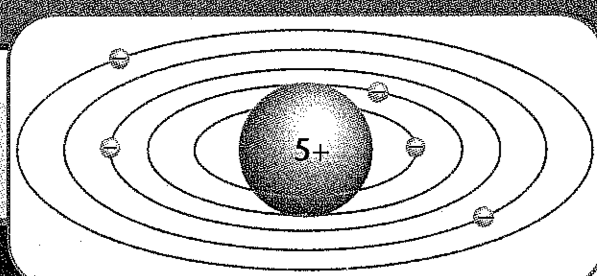
1897

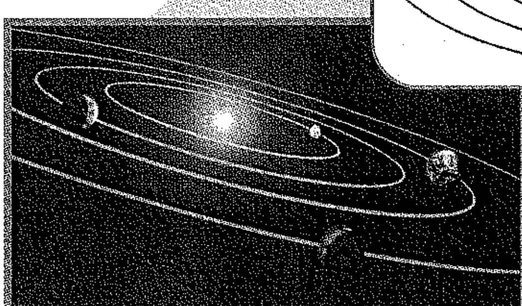
Thomson Model

British scientist J. J. Thomson proposed a new model. He suggested that an atom is a positively charged sphere with electrons embedded in it. His model could be described as looking like a muffin with berries scattered through it.

1800 **1900**

For almost 100 years, not much new information was learned about atoms. ▲





1904 Nagaoka Model

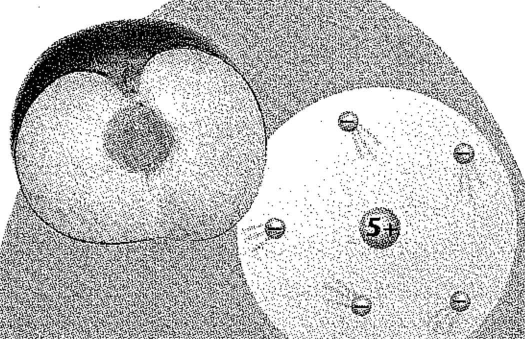
Japanese physicist Hantaro Nagaoka proposed a model of the atom that had a large sphere in the center with a positive charge. His model showed the electrons revolving around this sphere like the planets around the sun.

Valence Electrons The electrons in an atom are not all the same distance away from the nucleus. Those farthest away from the nucleus, called **valence electrons** (VAY luns), are involved in the formation of chemical bonds.

A chemical bond forms between two atoms when valence electrons move between them. The valence electrons may be transferred from one atom to another, or they may be shared between atoms. In either case, the change causes the atoms to become connected, or bonded.

In Your Journal

Find out more about one of the scientists who worked on models of the atom. Write an imaginary interview with this person in which you discuss his work with him.



1911

Rutherford Model

British physicist Ernest Rutherford concluded that the atom is mostly empty space. Electrons orbit randomly around a small, positively charged nucleus.

1932

Chadwick Model

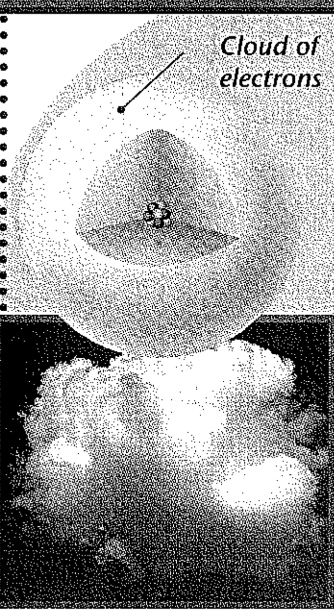
British physicist James Chadwick discovered the neutron, a particle having about the same mass as the proton but with no electrical charge. The existence of the neutron explained why atoms were heavier than the total mass of their protons and electrons.

1910 | 1920 | 1930 | 1940 | 1950

1913

Bohr Model

Danish physicist Niels Bohr determined that electrons aren't randomly located around the nucleus. His model showed electrons moving in specific layers, or shells. He said that atoms absorb or give off energy when the electrons move from one shell to another.

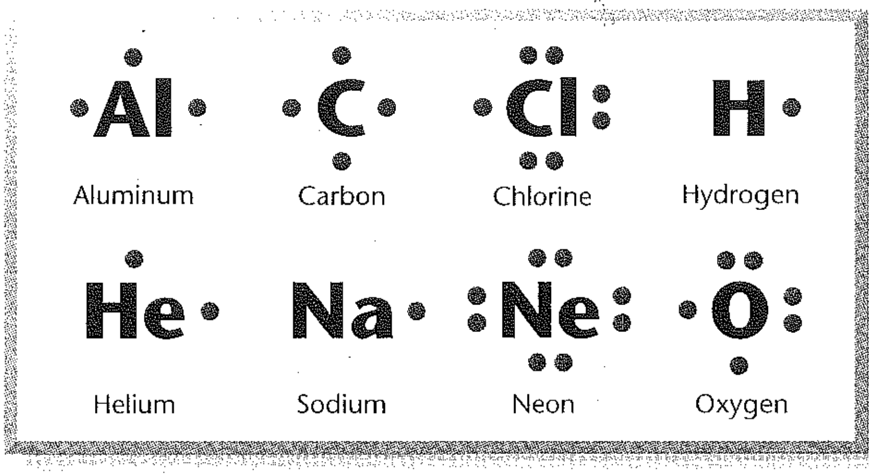


1920s to Present

Modern Model

The current model of the atom came from the work of many scientists from the 1920s to the present. It shows the electrons as forming a negatively charged cloud around the nucleus. It is impossible to determine exactly where an electron is at any given time.

Figure 3 In these electron dot diagrams, each dot represents a valence electron. The total number of dots around the symbol shows the number of valence electrons the element has.
Interpreting Diagrams *Which two elements in this diagram have the same number of valence electrons? Which element has the largest number of valence electrons?*



The number of valence electrons in an atom can range from one to eight. Each element has a typical number of valence electrons. Oxygen has six valence electrons, for example. Carbon has four. Hydrogen's single electron is considered a valence electron.

Chemists often represent valence electrons with simple diagrams like those in Figure 3. An **electron dot diagram** is made up of the symbol for an element surrounded by dots. Each dot stands for one valence electron.

When an atom forms a chemical bond, one of two things usually happens. Either the number of valence electrons increases to a total of eight, or all the valence electrons are given up. When atoms end up with eight or zero valence electrons, the atoms become more stable—or less reactive—than they were before. Later in this chapter, you will learn which elements are likely to give up electrons and which are likely to gain electrons. In Chapter 4, you will find out how valence electrons determine the kind of compound that particular elements form.

Section 1 Review

1. Describe the parts of an atom and tell where each is found.
2. Explain why the electrical charge on an atom is zero, or neutral.
3. What happens to valence electrons during the formation of chemical bonds?
4. Explain why electrons make up much of an atom's volume but not much of its mass.
5. **Thinking Critically Applying Concepts** What information can you get from an electron dot diagram?

Science at Home

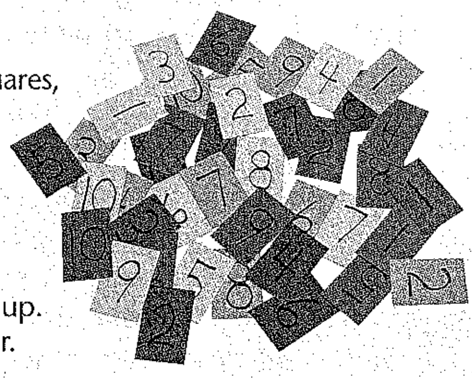
Atoms on Display Draw sketches or construct models of atoms to show to your family. The models can be made of clay, beads, string, and other simple materials. Explain what makes the atoms of different elements different from each other. Emphasize that there are only about 100 elements. Everything in your home is made of atoms of some combination of these elements.

SECTION 2 Organizing the Elements

DISCOVER ACTIVITY

Which Is Easier?

1. Make 4 sets of 10 paper squares, using a different color for each set. Number the squares in each set from 1 through 10.
2. Place all of the squares on a flat surface, numbered side up. Don't arrange them in order.
3. Ask your partner to name a square by color and number. Have your partner time how long it takes you to find this square.
4. Repeat Step 3 twice, choosing different squares each time. Calculate the average value of the three times.



5. Rearrange the squares into four rows, one for each color. Order the squares in each row from 1 to 10.
6. Repeat Step 3 three times. Calculate an average time.
7. Trade places with your partner and repeat Steps 2 through 6.

Think It Over

Inferring Which average time was shorter, the one produced in Step 4 or Step 6? Why do you think the times were different?

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

The calendar arranges the days of the month into horizontal periods called weeks and vertical groups called days of the week. Just as Monday always starts the school week, Saturday always starts the weekend. The calendar is useful because it organizes the days of the year. In the same way that days can be organized into a calendar, the elements can be organized into something like a calendar. As you'll discover in this section, the name of the "chemists' calendar" is the periodic table.

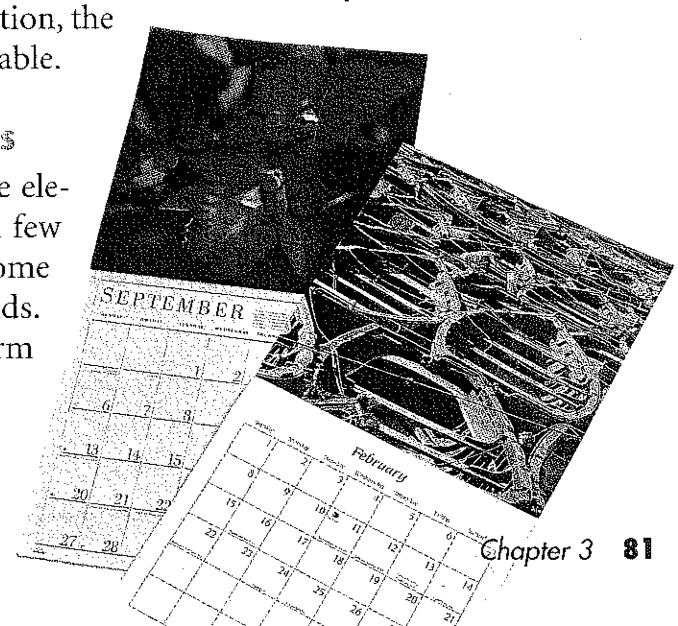
GUIDE FOR READING

- **How was the periodic table developed?**
- **What information does the periodic table present?**
- **How are valence electrons related to the periodic table?**

Reading Tip **As you read this section, refer to *Exploring the Periodic Table* on pages 84–85. Look for patterns.**

Looking for Patterns in the Elements

By 1830, 55 elements had been discovered. These elements displayed a wide variety of properties. A few were gases. Two were liquids. Most were metals. Some reacted explosively as they formed compounds. Others reacted more slowly. Still others did not form compounds at all.



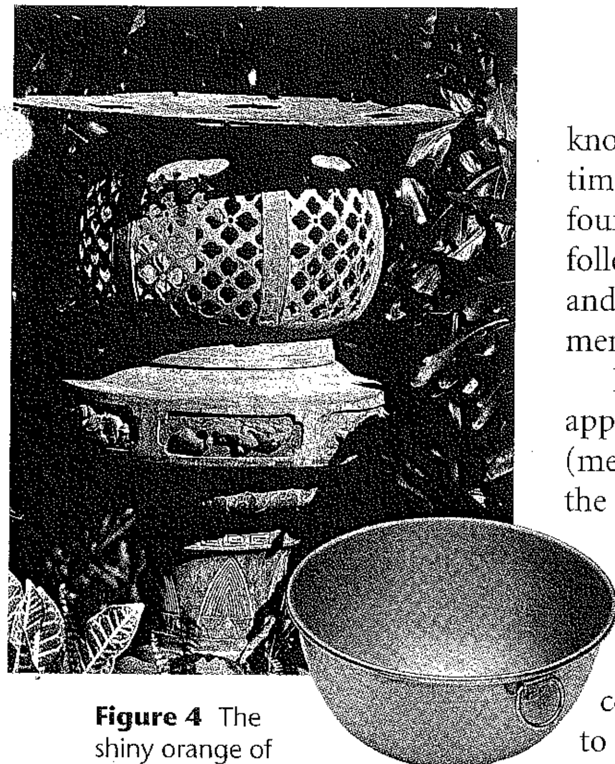


Figure 4 The shiny orange of this copper bowl will gradually turn to dull blue-green, like the tarnished copper sculpture. Mendeleev realized that several metals share with copper the property of tarnishing when exposed to air.
Classifying *Is tarnishing a physical or chemical property?*

Scientists of the 1800s suspected that the growing number of known elements could be organized in a useful way. (During this time, no one knew about atomic numbers.) One investigator found that some groups of elements, such as those in Figure 5, followed a pattern: The average of the atomic masses of the first and third elements roughly equaled the mass of the middle element. However, this system did not work for most elements.

By the 1860s, a Russian scientist had discovered a system that applied to all the elements. His name was Dimitri Mendeleev (men duh LAY ef). Like any good detective, Mendeleev studied the evidence, considered each clue, and looked for patterns.

Along with other scientists of his time, he observed that some elements have similar chemical and physical properties. Fluorine and chlorine, for example, are both gases that irritate your lungs if you breathe them. Silver and copper are both shiny metals that gradually tarnish if exposed to air. Mendeleev was convinced that these similarities were important clues to a hidden pattern.

To help him find that pattern, he wrote facts about the elements on individual cards. He noted all the properties he knew about an element, including its melting point, density, and color. He included two especially important properties: atomic mass and the number of chemical bonds an element could form. The **atomic mass** of an element is the average mass of one atom of the element. In Mendeleev's day, scientists figured out atomic masses in comparison to hydrogen, the lightest element. They found the number of bonds an element can form by studying the compound each element formed with oxygen.

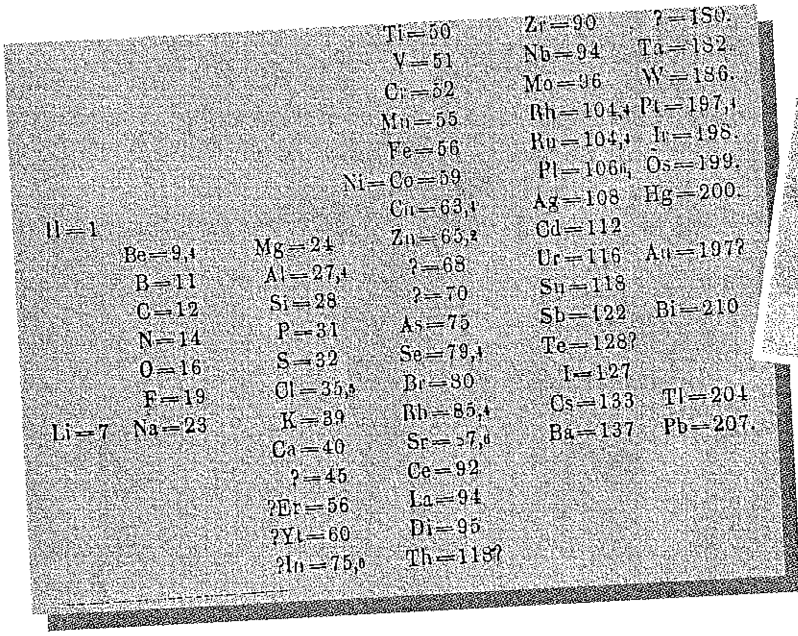
The Periodic Table

Mendeleev liked to play Patience, a solitaire card game, so he had practice in seeing patterns. He tried arranging his cards on the elements in various ways. **Mendeleev noticed that patterns appeared when the elements were arranged in order of increasing atomic mass.**

Figure 5 In the 1800s, scientists tried different ways to organize the elements. They found that some groups of three elements displayed curious patterns.
Calculating *When you average the atomic masses of calcium and barium, how closely does the result come to the atomic mass of strontium? Do the densities follow the same pattern?*

Three Similar Elements

Element	Description	Chemical Properties	Atomic Mass	Density (gm/cm^3)
Calcium	silvery metal	Reacts readily with oxygen and water	40.1	1.55
Strontium	silvery metal	Reacts readily with oxygen and water	87.6	2.6
Barium	silvery metal	Reacts readily with oxygen and water	137	3.5



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

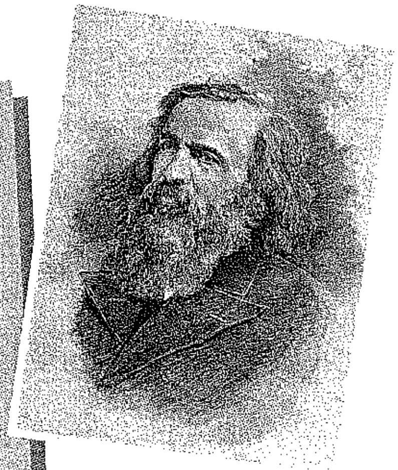


Figure 6 Mendeleev (above) published this first periodic table in 1869. He left question marks in some places. Based on the properties of surrounding elements, he predicted that new elements with specific characteristics would be discovered.

Mendeleev's Periodic Table Mendeleev discovered a repetition of properties. After fluorine, for instance, the next heaviest element he knew was sodium. (Neon had not yet been discovered.) Sodium (Na) bonded in the same way that lithium (Li) and potassium (K) did. So he placed the cards for these elements into a group. He did the same with other similar elements.

However, Mendeleev discovered that arranging the known elements strictly by increasing atomic mass did not always produce similar groups. So he moved his element cards into groups where they fit best. Doing this left three blank spaces. Mendeleev was confident enough of his discovery to predict that the blank spaces would be filled by elements that had not yet been discovered. He even predicted the properties of those new elements!

Mendeleev published the first periodic table, shown in Figure 6, in 1869. Within 16 years, chemists discovered the three missing elements, named scandium, gallium, and germanium. Their properties are close to what Mendeleev had predicted.

The Modern Periodic Table The word *periodic* means "a regular, repeated pattern." In the modern **periodic table,** the properties of the elements repeat in each period—or row—of the table. Since Mendeleev's time, new discoveries have required a few changes in the periodic table. The most important came in the early 1900s, when scientists learned about atomic number. Also, new elements were added as they were discovered. An up-to-date version of the table appears on the next two pages.

☑ *Checkpoint* *What does "periodic" mean?*

Sharpen your Skills

Classifying ACTIVITY

Choose any 10 elements and assign them letters *A* through *J*. On an index card for each element, write the letter for the element and list some of its properties. You may list properties that you learned in this chapter, or list properties presented in an encyclopedia or other reference source.

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

EXPLORING *the Periodic Table*

The periodic table has grown to include over 100 elements. Once you understand how the periodic table is organized, you can predict an element's properties from its position in the table.

C	Solid
Br	Liquid
H	Gas

Period
A row of the periodic table is called a period. Notice that the table becomes wider at periods 2, 4, and 6.

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

Group
Each column of the periodic table is called a group or family. The elements in a group have similar properties, although the similarities are stronger in some groups than in others.

Period	1	2	3	4	5	6	7	8	9
1	1 **H** Hydrogen 1.008								
2	3 **Li** Lithium 6.941	4 **Be** Beryllium 9.012							
3	11 **Na** Sodium 22.990	12 **Mg** Magnesium 24.305							
4	19 **K** Potassium 39.098	20 **Ca** Calcium 40.078	21 **Sc** Scandium 44.956	22 **Ti** Titanium 47.88	23 **V** Vanadium 50.942	24 **Cr** Chromium 51.996	25 **Mn** Manganese 54.938	26 **Fe** Iron 55.847	27 **Co** Cobalt 58.933
5	37 **Rb** Rubidium 85.468	38 **Sr** Strontium 87.62	39 **Y** Yttrium 88.906	40 **Zr** Zirconium 91.224	41 **Nb** Niobium 92.906	42 **Mo** Molybdenum 95.94	43 **Tc** Technetium (98)	44 **Ru** Ruthenium 101.07	45 **Rh** Rhodium 102.906
6	55 **Cs** Cesium 132.905	56 **Ba** Barium 137.327	57 **La** Lanthanum 138.906	72 **Hf** Hafnium 178.49	73 **Ta** Tantalum 180.948	74 **W** Tungsten 183.85	75 **Re** Rhenium 186.207	76 **Os** Osmium 190.23	77 **Ir** Iridium 192.22
7	87 **Fr** Francium (223)	88 **Ra** Radium (226)	89 **Ac** Actinium (227)	104 **Rf** Rutherfordium (261)	105 **Db** Dubnium (262)	106 **Sg** Seaborgium (263)	107 **Bh** Bohrium (264)	108 **Hs** Hassium (265)	109 **Mt** Meitnerium (268)

58 **Ce** Cerium 140.115	59 **Pr** Praseodymium 140.908	60 **Nd** Neodymium 144.24	61 **Pm** Promethium (145)	62 **Sm** Samarium 150.36
90 **Th** Thorium 232.038	91 **Pa** Protactinium 231.036	92 **U** Uranium 238.029	93 **Np** Neptunium (237)	94 **Pu** Plutonium (244)

To make the table easier to read, elements 58–71 (the lanthanides) and elements 90–103 (the actinides) are printed below the rest of the table. Follow the blue line to see how they fit in the table.

- Metal
- Metalloid
- Nonmetal
- Discovered recently

Atomic Number
The atomic number is the number of protons in an atom's nucleus (for example, five for boron). In the modern periodic table, the elements are arranged according to their atomic numbers.

Atomic Mass
Atomic mass is the average mass of an element's atoms. Usually, atomic mass increases with atomic number.

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

10	11	12	13	14	15	16	17	18
								2 He Helium 4.003
			5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
			13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948
28 Ni Nickel 58.69	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.723	32 Ge Germanium 72.61	33 As Arsenic 74.922	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80
46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.75	52 Te Tellurium 127.60	53 I Iodine 126.904	54 Xe Xenon 131.29
78 Pt Platinum 195.08	79 Au Gold 196.967	80 Hg Mercury 200.59	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
110 Uun Ununnilium (269)	111 Uuu Unununium (272)	112 Uub Ununbium (277)		114 Uuq Ununquadium		116 Uuh Ununhexium		118 Uuo Ununoctium

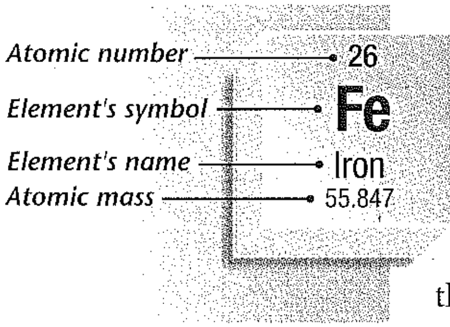
63 Eu Europium 151.965	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.50	67 Ho Holmium 164.930	68 Er Erbium 167.26	69 Tm Thulium 168.934	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

Elements 93 and higher have been created artificially. Elements with atomic numbers 114, 116, and 118 are the newest. Until chemists agree on permanent names, a few elements have Latin names that relate to their atomic numbers.

Reading the Periodic Table

The periodic table contains over 100 squares, one separate square for each element. **Each square of the periodic table usually includes the element's atomic number, chemical symbol, name, and atomic mass.**

Figure 7 Four important facts about an element are supplied in each square of the periodic table.



Inside the Squares On the periodic table on the previous two pages, find the square for iron, located in the top position in column 8 in the center of the table. That square is reproduced in Figure 7. The first entry in the square is the number 26, the atomic number of iron. That tells you that every iron atom has 26 protons and 26 electrons.

Just below the atomic number are the letters Fe, which is the chemical symbol for iron. Most chemical symbols for elements contain either one or two letters. The last entry in the square is the atomic mass, which is 55.847 for iron. Remember that atomic mass is the average mass of an element's atoms. Some iron atoms have 29 neutrons in the nucleus, others have 30, and still others have 31. All of these atoms have different atomic masses. Despite the different masses, all iron atoms react the same way chemically.

Organization of the Periodic Table Remember that the periodic table is arranged by atomic number. Look over the entire table, starting at the top left with hydrogen (H), which has atomic number 1. Follow the atomic numbers from left to right, and read across each row.

An element's properties can be predicted from its location in the periodic table. As you look at elements across a row or down a column, the elements' properties change in a predictable way. This predictability is the reason why the periodic table is so useful to chemists.

Groups The main body of the periodic table is arranged into eighteen vertical columns and seven horizontal rows. The elements in a column are called a **group.** Groups are also known as **families.** Notice that each group is numbered, from Group 1 on the left of the table to Group 18 on the right. Typically, the group is given a family name based on the first element in the column. Group 14, for example, is the carbon family. Group 15 is the nitrogen family.

The elements in each group, or family, have similar characteristics. The elements in Group 1 are all metals that react violently with water. The metals in Group 11 all react with water slowly or not at all. Group 17 elements react violently with elements from Group 1, while Group 18 elements rarely react at all.

Language Arts CONNECTION

You are learning science in the English language. But in other centuries, the language of science was Greek or Latin or even Arabic. This is why the names and chemical symbols of many elements don't match modern names. For example, the symbol for iron (Fe) comes from the Latin *ferrum*.

In Your Journal

List some of the elements that have puzzling chemical symbols, such as sodium (Na), potassium (K), tin (Sn), gold (Au), silver (Ag), lead (Pb), and mercury (Hg). Look up these names and symbols in the dictionary to learn the original names of these elements.

Periods Each horizontal row across the table is called a **period.** A period contains a series of different types of elements from different families, just as a week on a calendar has a series of different days. Unlike the elements in a family, the elements in a period have very different properties. In fact, as you move across a period from left to right, those properties not only change, they change according to a pattern.

In the fourth period, for example, the elements change from very reactive metals, such as potassium (K) and calcium (Ca), to relatively unreactive metals, such as nickel (Ni) and copper (Cu), to metalloids and nonmetals, such as arsenic (As) and bromine (Br). The last element in a period is always a particularly inactive gas. In this period, that element is krypton (Kr). Krypton bears no relationship to the fictional substance Kryptonite, which is the only thing feared by Superman!

As you can see, there are seven periods of elements. Periods have different numbers of elements. Period 1 has only two elements, hydrogen (H) and helium (He). You can count that Periods 2 and 3 each have 8 elements. Periods 4 and 5 each have 18 elements.

You will also notice that some elements of Period 6 and some elements of Period 7 have been separated out of the table. These elements are part of the periodic table, even though they appear as rows below its main section. The elements are shown separately to keep the table from becoming too wide. Imagine what it would look like if Periods 6 and 7 were stretched out to show all 32 elements in a row.

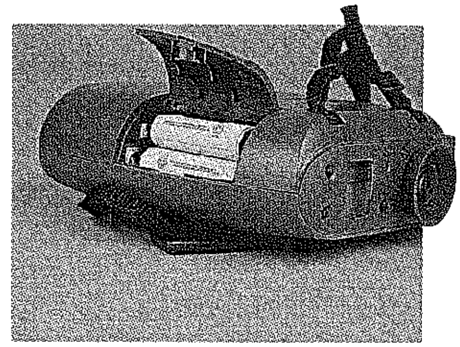


Figure 8 You can find the names of elements in the names of some common products, such as the ni-cad batteries in this camera. ***Inferring*** *What is one of the metals you would expect to find in a ni-cad battery?*

☑ *Checkpoint* *What is the name for a column of elements in the periodic table?*

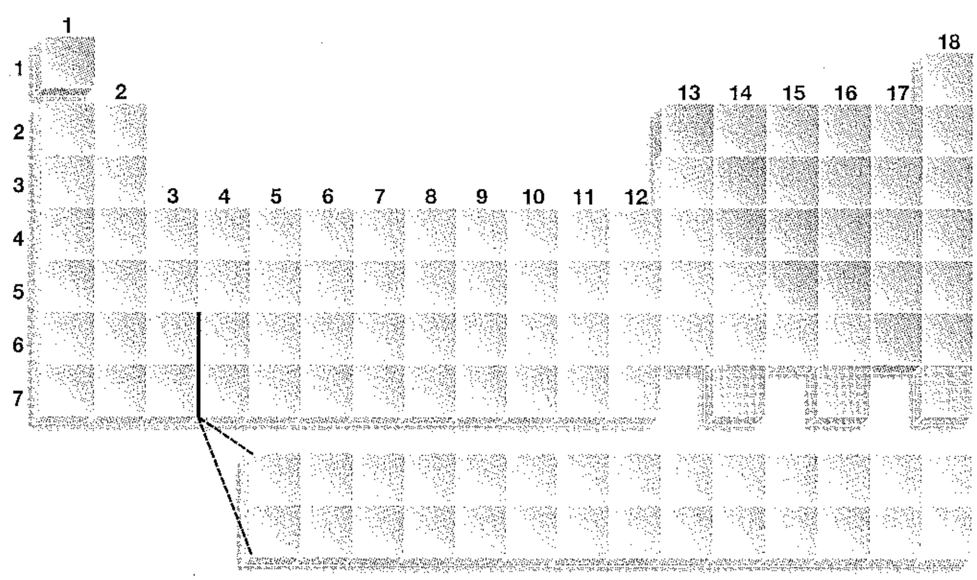


Figure 9 The columns in the periodic table are called groups or families. The rows are called periods.

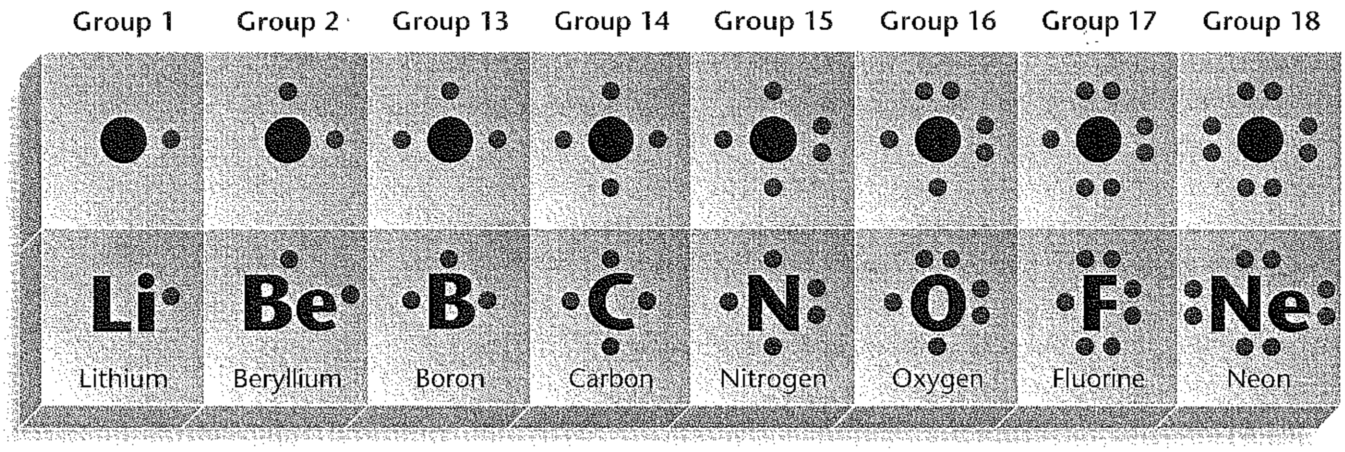


Figure 10 In a row of eight elements, the number of valence electrons follows the pattern shown in the first row of this diagram. The circle represents the inner part of the atom. ***Predicting*** *The atomic number of neon is 10. The atomic number of sodium (Na) is 11. What will the electron dot diagram of sodium look like?*

Why the Periodic Table Works

Although Mendeleev successfully used the periodic table to predict new discoveries, he could not explain why the table works. **The periodic table works because it's based on the structure of atoms, especially the valence electrons.** Look at the electron dot diagrams in Figure 10 to see why.

Think of how atoms change from left to right across a period. You know that from one element to the next, the atomic number increases by one. That means that an element has one more valence electron than the element to its left. And since the first element in a period has one valence electron, the number of valence electrons in a row of eight increases from one to eight. As a result, the properties across a period change in a regular way.

By contrast, the elements in a family all have the same number of valence electrons. The elements in Group 1 have one valence electron. The elements in Group 2 have two. The elements in Group 17 have seven valence electrons, and Group 18 elements have eight. Because the valence electrons within a family are the same, the elements in that group have similar properties.

Section 2 Review

1. How did Mendeleev organize the elements into the periodic table?
2. What information is listed in each square of the periodic table?
3. Why do elements in a group have similar properties?
4. **Thinking Critically Comparing and Contrasting** Element A is in the same group as element B and the same period as element C. Which two of the three elements are likely to have similar properties? Explain your answer.

CHAPTER PROJECT

Check Your Progress

Find the squares in the periodic table for each metal that you have been assigned. Prepare a chart in which to record the chemical symbol, group number, atomic number, and atomic mass of the metals, as well as their characteristic properties. Record data from the periodic table in your chart.

SECTION 3 Metals

DISCOVER ACTIVITY

Why Use Aluminum?

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

Think It Over

Inferring Use your observations to list as many properties of aluminum as you can. Based on your list of properties, infer why aluminum was used to make each object. Which objects do you think could be made from other metals? Explain your answer.

GUIDE FOR READING

- What are the properties of metals?
- How can you characterize each family of metals?

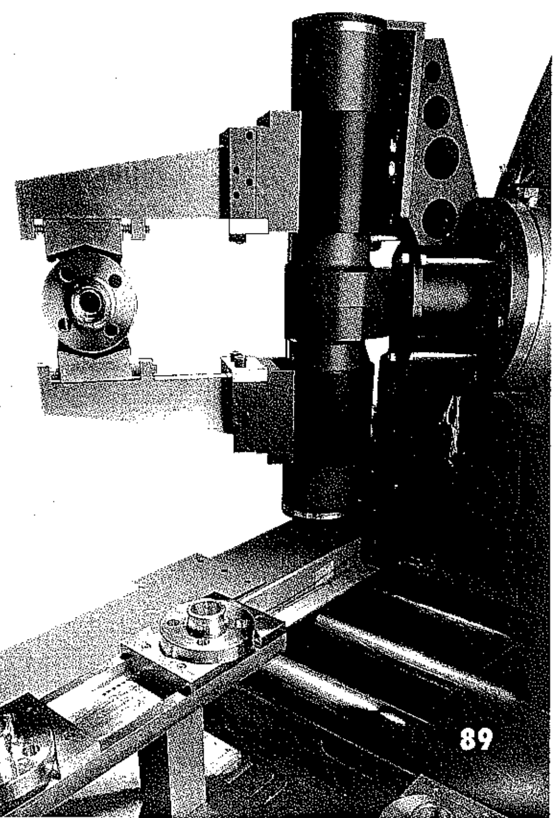
Reading Tip As you read, list the name of a new metal or group of metals and record its location on the periodic table.

Metals are all around you. The cars and buses you ride in are made of steel, which is mostly iron. Airplanes are made of aluminum. Many coins are combinations of zinc with copper, nickel, or silver. Copper wires carry electricity into table lamps, stereos, and computers. It's hard to imagine life without metals.

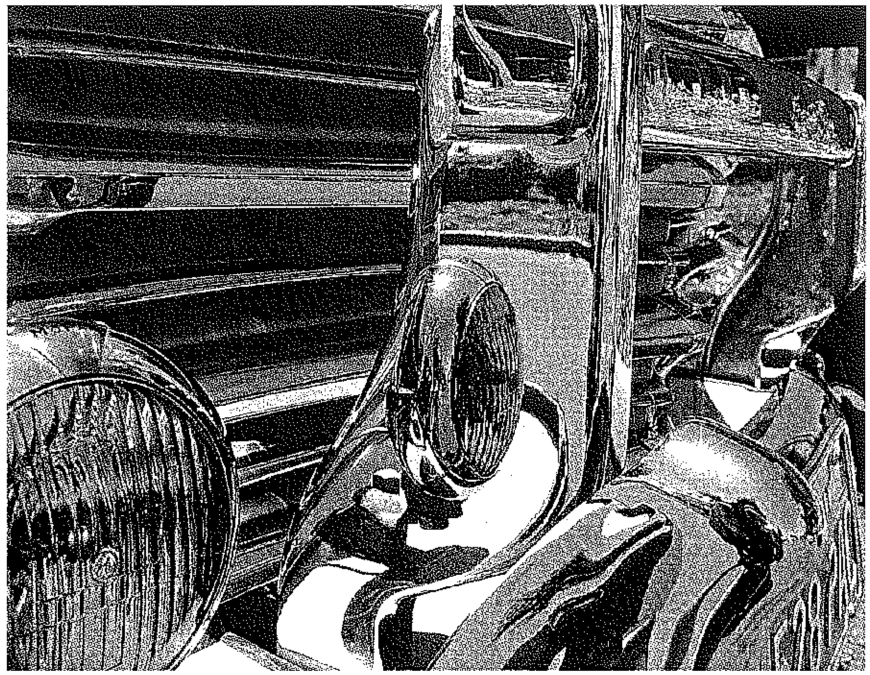
What Is a Metal?

Look at the periodic table, either in Section 2 or in Appendix D. Most of the elements are metals, found to the left of the zigzag line in the periodic table. The other elements are classified as nonmetals and metalloids. You'll learn more about nonmetals and metalloids in the next section.

Physical Properties What is a metal? Take a moment to describe a familiar metal, such as iron, tin, gold, or silver. What words did you use—hard, shiny, smooth? **Chemists classify an element as a metal based on physical properties such as hardness, shininess, malleability, and ductility.** Polished silver (Ag) is a good example of shininess. A **malleable** material is one that can be pounded into shapes. A **ductile** material is one that can be pulled out, or drawn, into a long wire. Copper sheeting and copper wires can be made because of copper's malleability and ductility.



Robot handling metal heart valves ▶



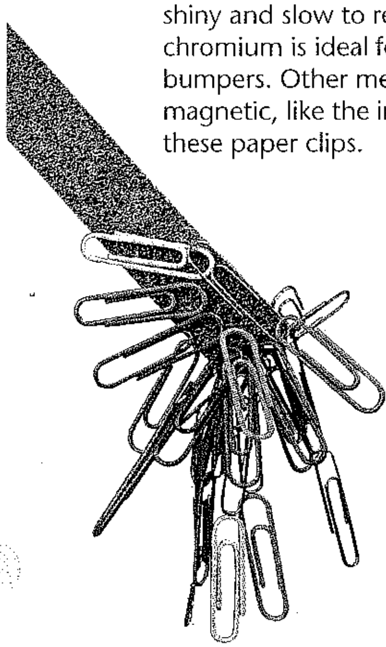


Figure 11 Because it is shiny and slow to react, chromium is ideal for car bumpers. Other metals are magnetic, like the iron in these paper clips.

Most metals are called good **conductors** because they transmit heat and electricity easily. Several metals are attracted to magnets and can be made into magnets. Thus, iron (Fe), cobalt (Co), and nickel (Ni) are described as **magnetic.**

Most metals are solids at room temperatures. This is because most metals have the property of very high melting points. In fact, you would need to raise the temperature of some metals as high as 3,400°C to melt them. An exception is mercury (Hg), which is a liquid at room temperature.

Chemical Properties **Metals show a wide range of chemical properties.** Some metals are very reactive. They combine with other elements and compounds quickly, giving off energy. For example, sodium (Na) and potassium (K) will react vigorously if exposed to air or water. To prevent reactions, they must be stored under oil in sealed containers.

By comparison, gold (Au) and chromium (Cr) are unreactive. Gold is valued because it is rare and also because it stays shiny instead of reacting with air. Chromium is plated on objects left outdoors, such as automobile trim, because it is extremely slow to react with air and water.

Other metals fall somewhere between sodium and gold in the ease and speed of their reactions. They react slowly with oxygen in the air, forming metal oxides. For example, if iron is left unprotected, its surface will slowly turn to reddish-brown rust. This rust, or iron oxide, can flake off. The destruction of a metal through this process is called **corrosion.**

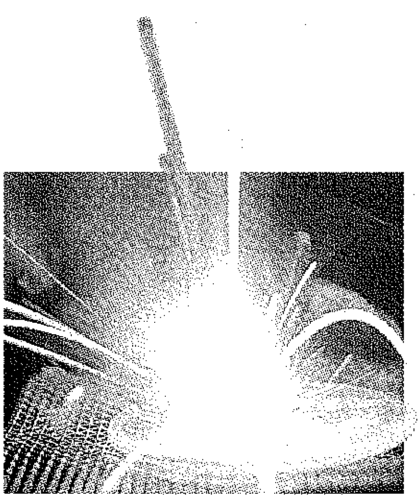


Figure 12 When water is dripped onto sodium metal, a rapid, vigorous reaction occurs.

☑ *Checkpoint* *How do reactive metals behave?*

Alloys

As you learned in Chapter 1, a mixture consists of two or more substances that are in the same place but are not chemically changed. Do metals form useful mixtures? Think about the steel in an automobile, the brass in a trumpet, and the bronze in a statue. Each of these materials is made of different metals mixed together.

A mixture of metals is called an alloy. Useful alloys combine the best properties of two or more metals into a single substance. For example, copper is a fairly soft and malleable metal. But mixed with tin, it forms bronze, which can be cast into statues that last hundreds of years. Brass is an alloy of copper and zinc. Pure iron rusts very easily, but when mixed with carbon, chromium, and vanadium, iron forms stainless steel. Knives and forks made of stainless steel can be washed over and over again without rusting.

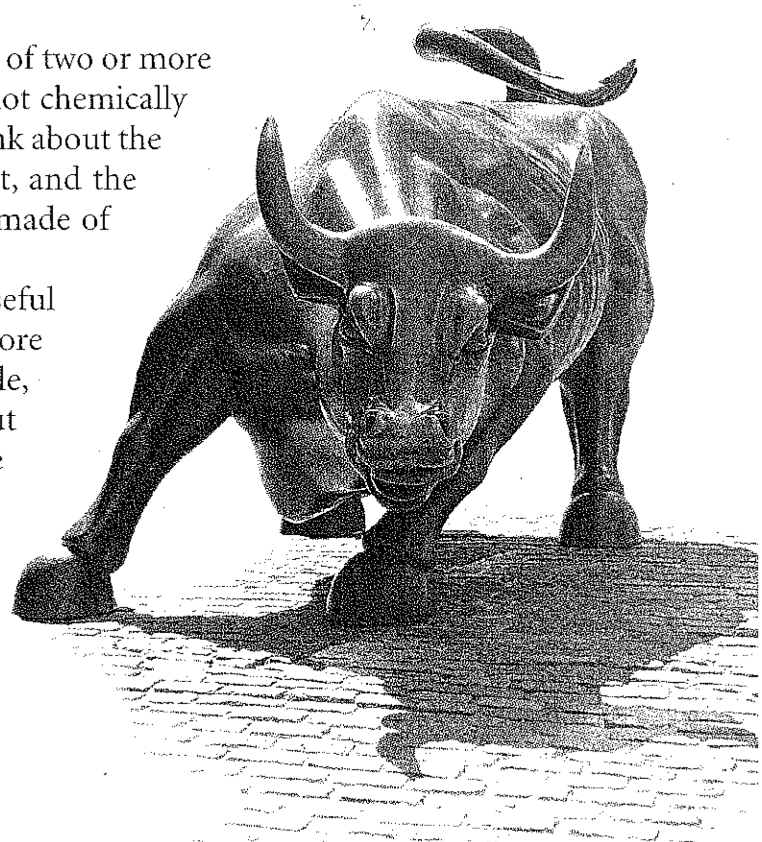


Figure 13 The bronze of this statue is an alloy of copper and tin. ***Classifying*** *Is an alloy an element, compound, or mixture?*

Metals in the Periodic Table

The metals in a group, or family, have similar properties, and these family properties change gradually as you move across the table. Metals tend to become less reactive as you move from left to right across the periodic table.

Alkali Metals The metals in Group 1, from lithium to francium, are called the **alkali metals.** They are the most reactive metals of all. They are never found uncombined in nature. In other words, they are never found as elements but only in compounds. In the laboratory, however, scientists have been able to isolate the uncombined forms. As elements, the alkali metals are very soft and shiny. They are so soft, in fact, that you could cut them with a plastic knife!

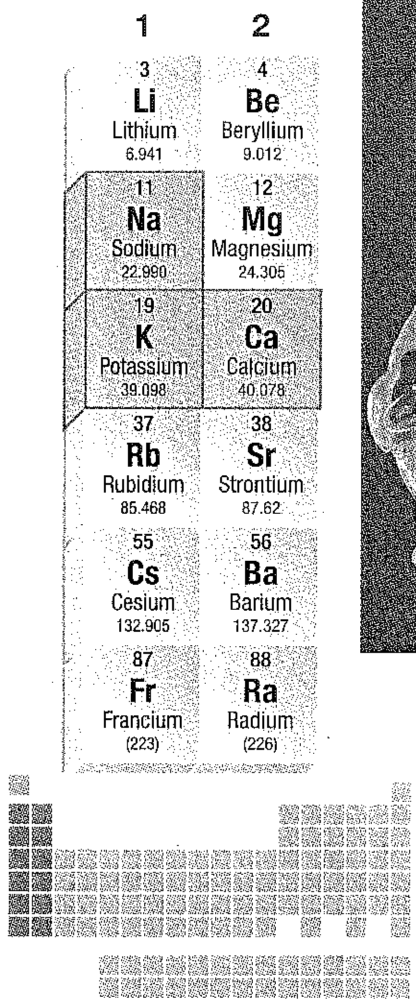
Why are the alkali metals so reactive? Think of their location on the far left of the periodic table. Elements of Group 1 have atoms with one valence electron that is easily transferred to other atoms during a chemical change. When that valence electron is gone, the part of the atom that remains is much more stable.

The two most important alkali metals are sodium and potassium. Sodium compounds are found in large amounts in sea water and salt beds. Your diet includes many compounds that contain sodium and potassium, which are essential for life. Lithium compounds are used in batteries and some medicines.

Sharpen your Skills

Observing ACTIVITY

1. Find a penny from 1983 or later. Rub one edge on sandpaper to scrape away the copper. Place the penny in a foam cup. Add vinegar to a depth of 1–2 cm.
2. Wait 24 hours. Then describe any changes. What property of metals have you demonstrated?



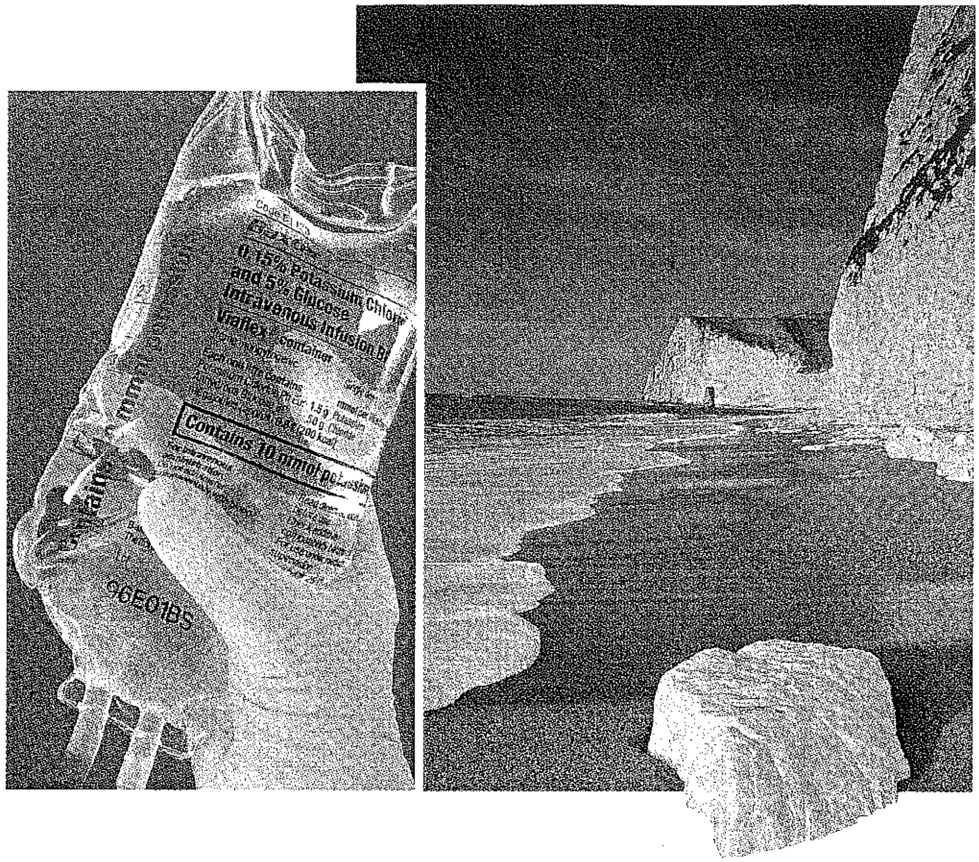


Figure 14 Intravenous fluids (above center) must provide elements, such as potassium and sodium, that are important to living cells. Calcium is part of the compound that makes up the limestone of these cliffs (above right). ***Interpreting Diagrams*** *To which families do the metals potassium, sodium, and calcium belong?*

Alkaline Earth Metals Group 2 of the periodic table contains the **alkaline earth metals.** While not as reactive as the metals in Group 1, these elements are more reactive than most metals. They are never found uncombined in nature. Each is fairly hard, gray-white, and a good conductor of electricity.

The two most common alkaline earth metals are magnesium and calcium. Magnesium was once used in flash bulbs because it gives off a very bright light when it burns. Magnesium also combines with aluminum, making a strong but lightweight alloy. This alloy is used to make ladders, airplane parts, and other products. Calcium is an essential part of teeth and bones, and it also helps muscles work properly. You get calcium from milk and other dairy products, as well as from green, leafy vegetables.

Each atom of an alkaline earth metal has two valence electrons. Like the alkali metals, the alkaline earth metals easily lose their valence electrons in chemical reactions. Each alkaline earth metal is almost as reactive as its neighbor to the left in the periodic table.

Transition Metals The elements in Groups 3 through 12 are called the **transition metals.** The transition metals form a bridge between the very reactive metals on the left side of the periodic table and the less reactive metals and other elements on the right side. The transition metals are so similar to one another that differences between nearby columns are often difficult to detect.

The transition metals include most of the familiar metals, such as iron, copper, nickel, silver, and gold. Most of the transition metals are hard and shiny. Gold, copper, and some other transition metals have unusual colors. All of the transition metals are good conductors of electricity.

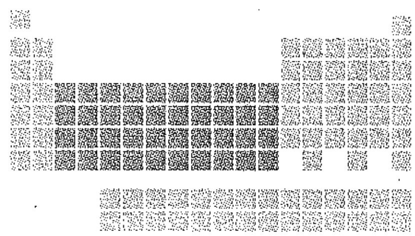
The transition metals are fairly stable, reacting slowly or not at all with air and water. Ancient gold coins and jewelry are as beautiful and detailed today as they were thousands of years ago. Even when iron reacts with air and water, forming rust, it sometimes takes many years to react completely, not at all like the violent reactions of the alkali metals.

INTEGRATING LIFE SCIENCE Would you believe that you use transition metals inside your body? In fact, you would not survive very long without one of the transition metals—iron. Iron is an important part of a large molecule called hemoglobin, which carries oxygen in your bloodstream. Hemoglobin also gives blood its bright red color.

Metals in Mixed Groups Groups 13 through 16 of the periodic table include metals, nonmetals, and metalloids. The metals in these groups to the right of the transition metals are not nearly as reactive as those on the left side of the table. The most familiar of these metals are aluminum, tin, and lead. Aluminum is the lightweight metal used in beverage cans and airplane bodies. A thin layer of tin is used to coat steel to protect it from corrosion in cans of food. Lead is a shiny, blue-white metal that was once used in paints and water pipes. But lead is poisonous, so it is no longer used for these purposes. Now its most common use is in automobile batteries.

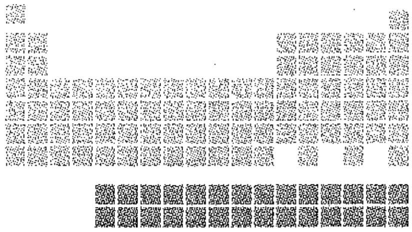
Figure 15 Transition metals are used to make colorful paints, including cobalt blue, zinc white, cadmium red, and chromium oxide green.

Checkpoint *Which groups are considered transition metals?*



3	4	5	6	7	8	9	10	11	12
21 **Sc** Scandium 44.956	22 **Ti** Titanium 47.88	23 **V** Vanadium 50.942	24 **Cr** Chromium 51.996	25 **Mn** Manganese 54.938	26 **Fe** Iron 55.847	27 **Co** Cobalt 58.933	28 **Ni** Nickel 58.69	29 **Cu** Copper 63.546	30 **Zn** Zinc 65.39
39 **Y** Yttrium 88.906	40 **Zr** Zirconium 91.224	41 **Nb** Niobium 92.906	42 **Mo** Molybdenum 95.94	43 **Tc** Technetium (98)	44 **Ru** Ruthenium 101.07	45 **Rh** Rhodium 102.906	46 **Pd** Palladium 106.42	47 **Ag** Silver 107.868	48 **Cd** Cadmium 112.411
57 **La** Lanthanum 138.906	72 **Hf** Hafnium 178.49	73 **Ta** Tantalum 180.948	74 **W** Tungsten 183.85	75 **Re** Rhenium 186.207	76 **Os** Osmium 190.23	77 **Ir** Iridium 192.22	78 **Pt** Platinum 195.08	79 **Au** Gold 196.967	80 **Hg** Mercury 200.59
89 **Ac** Actinium (227)	104 **Rf** Rutherfordium (261)	105 **Db** Dubnium (262)	106 **Sg** Seaborgium (263)	107 **Bh** Bohrium (264)	108 **Hs** Hassium (265)	109 **Mt** Meitnerium (268)	110 **Uun** Ununnilium (269)	111 **Uuu** Unununium (272)	112 **Uub** Ununbium (277)

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
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



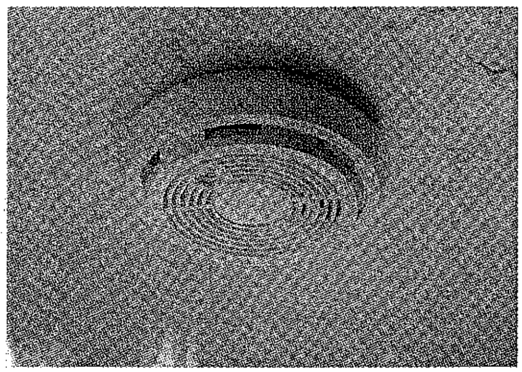


Figure 16 The actinide metal named americium is used in smoke detectors like this one.
Interpreting Diagrams What is the atomic number of americium?

Lanthanides and Actinides At the bottom of the periodic table are the **lanthanides** (LAN thuh nydz), in the top row, and **actinides** (AK tuh nydz), on the bottom. These elements, called the rare earth elements, fit in Periods 6 and 7 between the alkaline earth metals and the transition metals. They are placed below the periodic table for convenience.

Lanthanides are soft, malleable, shiny metals with high conductivity. They are used in industry to make various alloys. Different lanthanides are usually found together in nature. They are difficult to separate from one another because all of them have very similar properties.

Of the actinides, only thorium (Th) and uranium (U) exist on Earth in any significant amounts. You may already have heard of uranium, which is used to produce energy in nuclear power plants. All of the elements after uranium in the periodic table were created artifically in laboratories. The nuclei of these elements are very unstable, meaning that they break apart very quickly into smaller nuclei. In fact, many of these synthetic elements are so unstable that they last for only a fraction of a second after they are made.

Section 3 Review

1. List four properties of most metals.
2. Compare the way the metals on the left side of the periodic table react to the way metals on the right side of the periodic table react.
3. If you point to an element in the periodic table at random, is it more likely to be a metal, a nonmetal, or a metalloid? Explain your answer.
4. **Thinking Critically Predicting** Element 119 has not yet been made or discovered. If this element existed, however, where would it be placed in the periodic table? (*Hint:* Start at the square for element 112.) Would you expect it to be a metal, a nonmetal, or a metalloid? What properties would you predict for this element? Explain your answer.

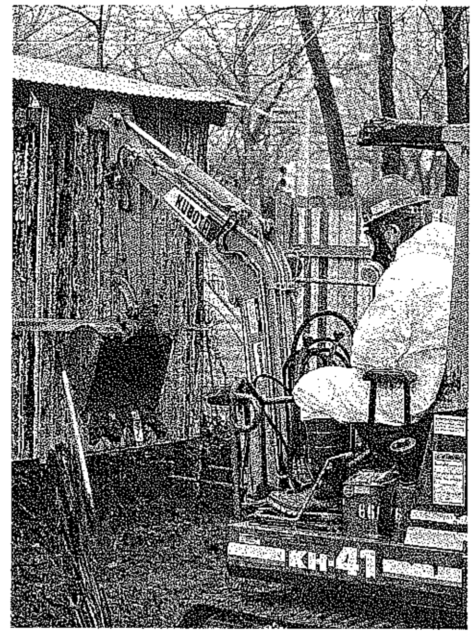
CHAPTER PROJECT

Check Your Progress

Observe your samples for properties such as shininess, hardness, and color. Record these observations in your chart. Plan how to test other properties of metals such as electrical and heat conductivity, density, and reactions with acids and oxygen. Remember that you need to compare the properties of your metal samples. Have your teacher approve your experimental plan.

SCIENCE AND SOCIETY

Cleaning Up Metal Contamination



Metals are an important resource. For example, mercury is used in thermometers, medicines, and electrical equipment. Cadmium and lead are used to make batteries, and lead was used to make paints. However, these metals are poisonous, or toxic, to humans who are exposed to them over a long period of time.

Years of manufacturing have left factory buildings and the surrounding soil contaminated with toxic metals. Until 1980, no one was required to clean up property contaminated with toxic metals. Then the federal government passed the Superfund law, which made landowners or previous users of properties responsible for toxic cleanups.

The Issues

Should People Clean Up and Build on Contaminated Land? About 450,000 factories, mines, and dumps in the United States have been closed because of contamination with toxic metals. One cleanup method is to scrape off the contaminated layer of soil and take it to a landfill specially constructed for hazardous wastes. Another common method is to cover the contaminated land with a thick layer of clean soil or a substance that water can't penetrate. The idea is to stop the spread of contamination.

Health experts say the worst sites should be cleaned up to keep people from being exposed to toxic metals. Or at least, sites need to be fenced off. They do not want the sites used again.

Builders, on the other hand, want to clean up the land and build new factories, offices, and houses on it. Some public officials also favor building on the land because construction provides jobs.

How Much Cleanup Is Necessary? Some people only want to clean up sites where people live. They say that contact with toxic metals in homes is more dangerous than contact in workplaces since people spend more time at home than at work. These people favor complete cleanup of building sites for homes but less complete cleanup of factory and office sites. Limiting the amount of cleanup also reduces the cost.

Other people favor a complete cleanup of all contaminated sites. Toxic metals in the soil of industrial sites could spread to nearby homes or seep into groundwater. People also might build their homes near contaminated sites in the future.

Who Is Responsible for Cleanups? Taking down contaminated buildings, removing soil, and covering sites is expensive. And, determining who is responsible for long-abandoned sites is complicated. The Superfund law, other federal laws, and laws of the individual states differ as to whether current owners or past users are responsible. For some sites, federal or state money may be required to pay for cleanups.

You Decide

1. Identify the Problem
In your own words, explain the problem of sites contaminated with toxic metals.

2. Analyze the Options
How could people benefit by building on contaminated lands? How might people be hurt?

3. Find a Solution
Suppose you are a builder, a factory worker, a landowner, or someone living next to a contaminated site. State and defend your opinion on building on that site.

Testing 1, 2, 3

What materials make the best plumbing pipes? Or the best electrical wiring? Or the best lead for a pencil? A materials scientist answers questions such as these. Materials scientists work to find the best materials for different products. To understand materials, you need to know their basic properties. In this lab, you will be comparing the properties of a copper wire and a sample of graphite. Graphite is a form of the element carbon.

Problem

How does copper compare to graphite?

Skills Focus

observing, interpreting data, classifying

Materials

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

Procedure

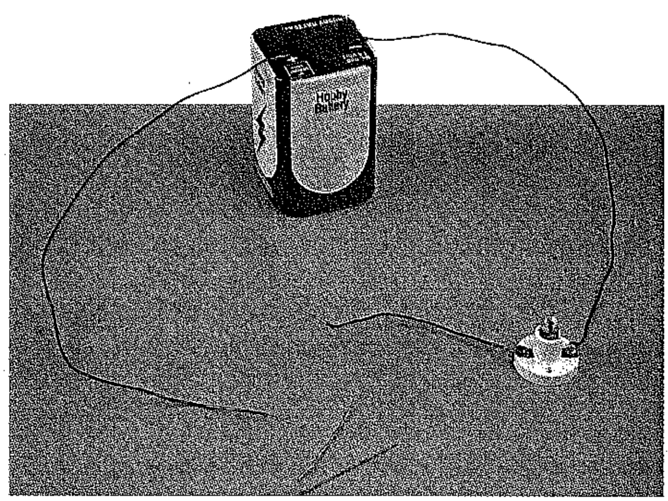
1. Fill a 200-mL beaker about three-fourths full with water. Heat it slowly on a hot plate. Let the water continue to heat as you complete Part 1 and Part 2 of the investigation.

Part 1 Physical Properties

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

Part 2 Electrical Conductivity

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



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

Part 3 Heat Conductivity

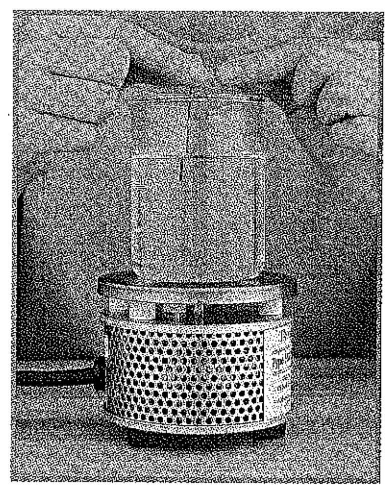
9. Turn off the hot plate.
10. Hold one end of a graphite sample between the fingertips of one hand. Hold one end of the copper wire between the fingertips of the other hand.
11. Dip both the graphite and copper wire into the hot water at the same time. Allow only about 1 cm of each piece to reach under the water's surface. From your fingertips to the water, the lengths of both the graphite sample and the copper wire should be approximately equal.
12. Time how long it takes to feel the heat in the fingertips of each hand. Record your observations.

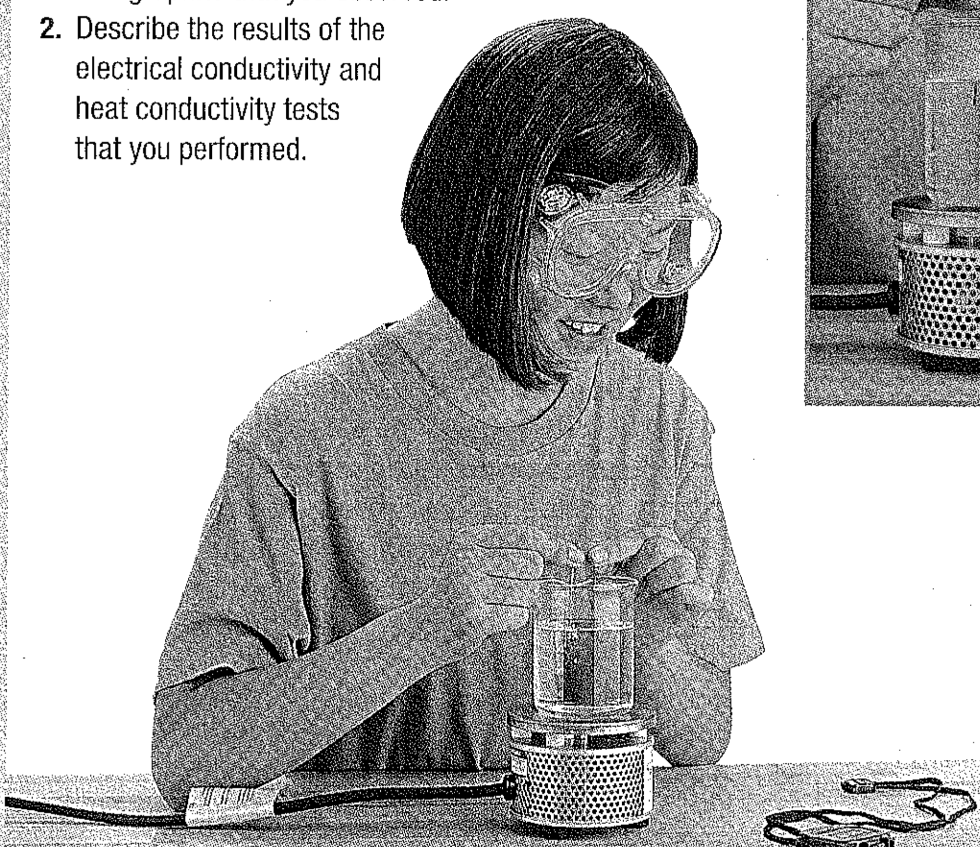
Analyze and Conclude

1. Compare the physical properties of copper and graphite that you observed.
2. Describe the results of the electrical conductivity and heat conductivity tests that you performed.
3. Based on the observations you made in this lab, explain why copper is classified as a metal and carbon is not classified as a metal.
4. In Step 11, why was it important to use equal lengths of copper wire and graphite?
5. **Apply** Based on your observations and conclusions from this lab, for what products might copper and graphite be best suited?

Design an Experiment

The density of metals is generally greater than the density of nonmetals. Design a procedure that would compare the density of copper and graphite. With your teacher's approval, conduct your investigation.





SECTION 4

Nonmetals and Metalloids

DISCOVER — ACTIVITY

What Are the Properties of Charcoal?

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

Think It Over

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

GUIDE FOR READING

- **Where are nonmetals and metalloids located on the periodic table?**
- **What are the properties of nonmetals and metalloids?**

Reading Tip **As you read about each family of nonmetals, make a list of their properties.**

Think of ten objects that do not contain metal. Some of the objects might be soft and smooth, such as an animal's fur, a blade of grass, or a silk shirt. But you may have thought of objects that are much harder, such as the bark or wood of a tree or the plastic case of a computer. You might also have thought of liquids, such as water and gasoline, or gases, such as the nitrogen and oxygen gases that make up the atmosphere.

Your world is full of materials that contain little or no metal. What's more, these materials have a wide variety of properties, ranging from soft to hard, from flexible to breakable, and from solid to gaseous. To understand these properties, you need to study another important category of the elements: the nonmetals.

What Is a Nonmetal?

Nonmetals are the elements that lack most of the properties of metals. **The nonmetals are located to the right of the zigzag line in the periodic table.** As you will discover, many of the nonmetals are very common elements, as well as extremely important to all living things on Earth.

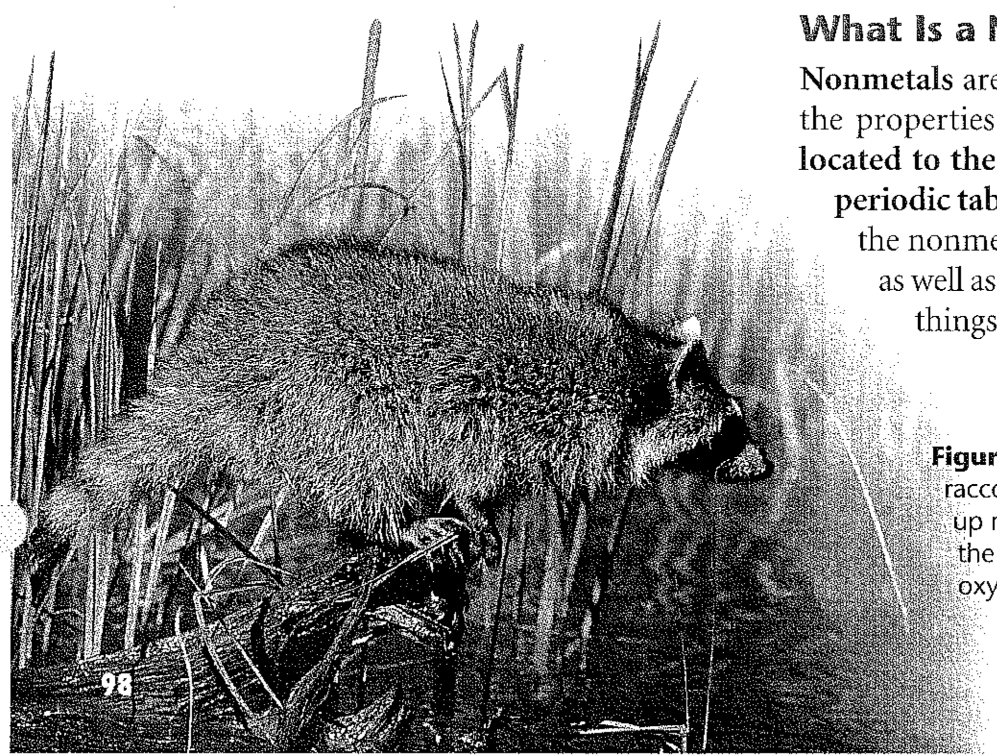


Figure 17 Living organisms, like this raccoon and these reeds, are made up mostly of nonmetals, such as the elements carbon, hydrogen, oxygen, and nitrogen.

Physical Properties Many of the nonmetal elements are gases at room temperature, which means they have low boiling points. The air you breathe is made mostly of two nonmetals, nitrogen (N) and oxygen (O). Other nonmetal elements, such as carbon (C) and iodine (I), are solids at room temperature. Bromine (Br) is the only nonmetal that is liquid at room temperature.

In general, the physical properties of nonmetals are opposite to those that characterize the metals. Most nonmetals are dull, unlike shiny metals. Solid nonmetals are brittle, meaning they are not malleable and not ductile. If you pound on most solid nonmetals with a hammer, they break easily or crumble into a powder. Nonmetals usually have lower densities than metals. Nonmetals are also poor conductors of heat and electricity.

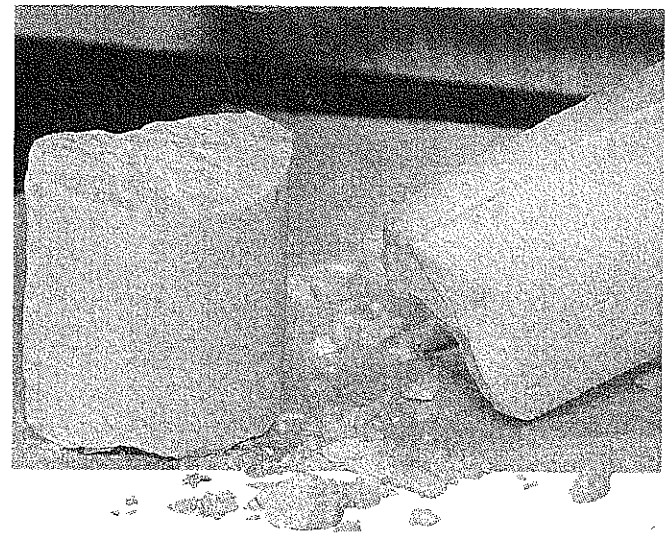


Figure 18 Nonmetal solids, such as this sulfur, tend to be crumbly when hit with a hammer. ***Comparing and Contrasting*** *What would you expect to happen if you hammered a metal such as copper or gold?*

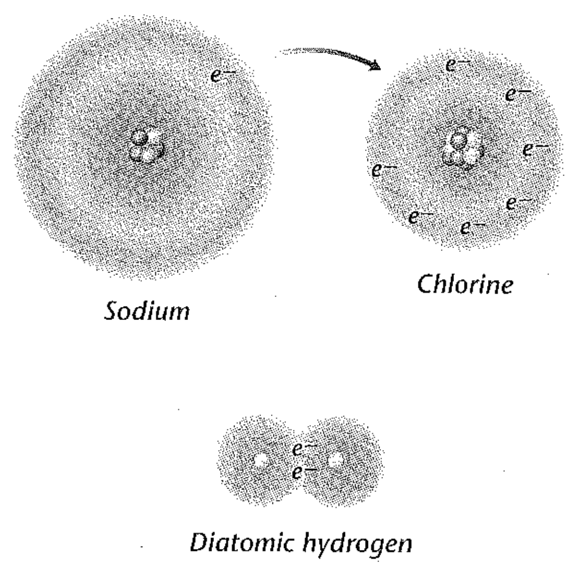
Chemical Properties Most nonmetals readily form compounds. But the Group 18 elements hardly ever do. The difference has to do with valence electrons. Atoms of the Group 18 elements do not gain, lose, or share electrons. For this reason, the Group 18 elements do not react with other elements.

The rest of the nonmetals have atoms that can gain or share electrons. In either case, the atoms of these nonmetals can react with other atoms, leading to the formation of compounds.

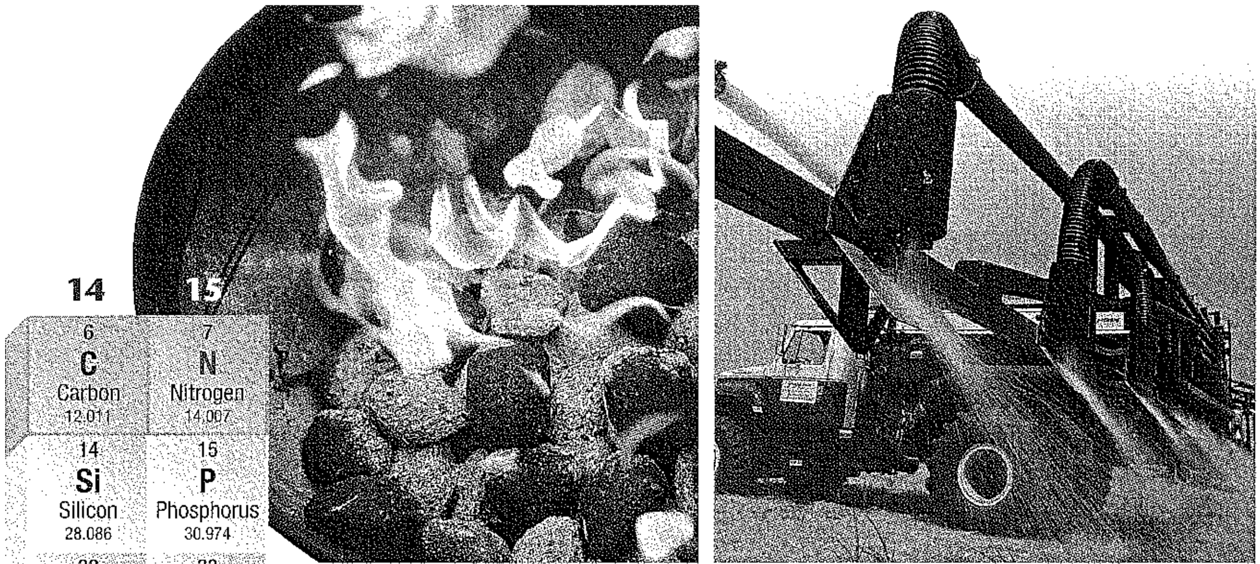
Compounds of Nonmetals When nonmetals and metals react, valence electrons move from the metal atoms to the nonmetal atoms. Group 17 elements react easily this way. For example, common table salt (NaCl) is formed from sodium (Na) and chlorine (Cl). Other groups of nonmetals form compounds with metals, too. Rust is a compound made of iron and oxygen (Fe_2O_3). It's the reddish, flaky coating you might see on an old piece of steel or an iron nail.

Nonmetals can also form compounds with other nonmetals. The atoms share electrons and become bonded together into molecules, such as carbon monoxide (CO) and carbon dioxide (CO_2). Many nonmetals even form molecules of two identical atoms, which are called **diatomic molecules.** Examples of diatomic molecules are oxygen (O_2), nitrogen (N_2), and hydrogen (H_2).

Figure 19 When a metal, such as sodium, reacts with a nonmetal, such as chlorine, a valence electron is transferred from each sodium atom to a chlorine atom. When two identical atoms of a nonmetal react, they share electrons.



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



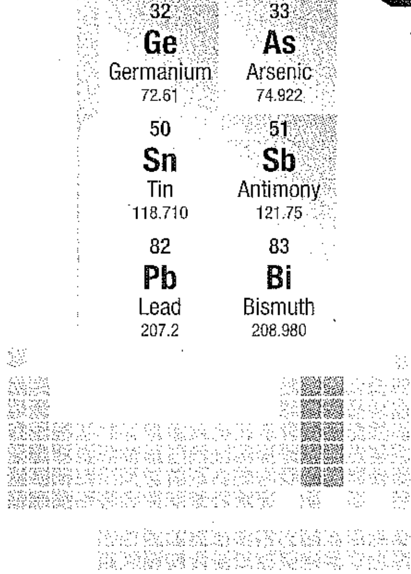


Figure 20 Charcoal (above center) is composed mostly of the element carbon. Farmers provide their growing plants with fertilizers (above right) that include the element nitrogen. ***Applying Concepts*** *Which has the greater mass, an atom of carbon or an atom of nitrogen? How can you tell?*

Families of Nonmetals

Look at the periodic table in Section 2 or in Appendix D, and notice the groups that contain nonmetals. Only Group 18 contains nonmetals exclusively. Other groups, such as Groups 14 and 15, contain three classes of elements: nonmetals, metals, and a third class of elements called metalloids. For this reason, the elements in Groups 14 and 15 are not as similar to one another as are elements in other groups.

The Carbon Family Group 14 is also known as the carbon family. Each element in the carbon family has atoms with 4 valence electrons. Only one of the elements is a nonmetal, and that element is carbon itself. (The next two elements, silicon and germanium, are metalloids. Tin and lead are metals.)

What makes carbon especially important is its role in the chemistry of life. All living things contain compounds that are made of long chains of carbon atoms. Scientists have identified millions of these compounds, some of which have carbon chains more than a billion atoms long. You will learn much more about carbon and its compounds in the next chapter.

The Nitrogen Family Group 15, the nitrogen family, contains elements that have 5 valence electrons in their atoms. The two nonmetals in the family are nitrogen and phosphorus. To introduce yourself to nitrogen, take a deep breath. The atmosphere is almost 80 percent nitrogen gas. Nitrogen (N_2) gas does not readily react with other elements, however, so you breathe out as much nitrogen as you breathe in.

INTEGRATING LIFE SCIENCE

Living things do use nitrogen, but most living things are unable to use the nitrogen gas in the air. Only certain kinds of bacteria—tiny, microscopic creatures—are able to combine the nitrogen in the air with other elements, a process called nitrogen fixation. Plants can then take up the nitrogen compounds formed in the soil by the bacteria. Farmers also add nitrogen compounds to the soil in the form of fertilizers. Like all animals, you get the nitrogen you need from the food you eat—from plants, or from animals that ate plants.

Phosphorus is the other nonmetal in the nitrogen family. Unlike nitrogen, phosphorus is not stable as an element. So, phosphorus in nature is always found in compounds. Phosphorus is used to make matches and flares partly because it is so reactive.

☑ *Checkpoint* *Which elements are in Group 15?*

The Oxygen Family Group 16, the oxygen family, contains elements that have 6 valence electrons in their atoms. An atom in Group 16 typically gains or shares 2 electrons when it reacts. The three nonmetals in the oxygen family are oxygen, sulfur, and a rarer element named selenium.

You are using oxygen right now. With every breath, oxygen travels through your lungs and into your bloodstream, which distributes it all over your body. You could not live long without a steady supply of oxygen. The oxygen you breathe is a diatomic molecule (O_2). In addition, oxygen sometimes forms a triatomic (three-atom) molecule, which is called ozone (O_3). Ozone collects in a layer in the upper atmosphere, where it screens out harmful radiation from the sun.

Oxygen is very reactive, and can combine with almost every other element. It also is the most abundant element in Earth's crust and the second most abundant element in the atmosphere.

Sulfur is the other common nonmetal in the oxygen family. If you have ever smelled the odor of a rotten egg, then you are already familiar with the smell of many sulfur compounds. These compounds have a strong, unpleasant odor. You can also find sulfur in rubber bands, automobile tires, and many medicines.

TRY THIS

Show Me the Oxygen

ACTIVITY

How can you test for the presence of oxygen?

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

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

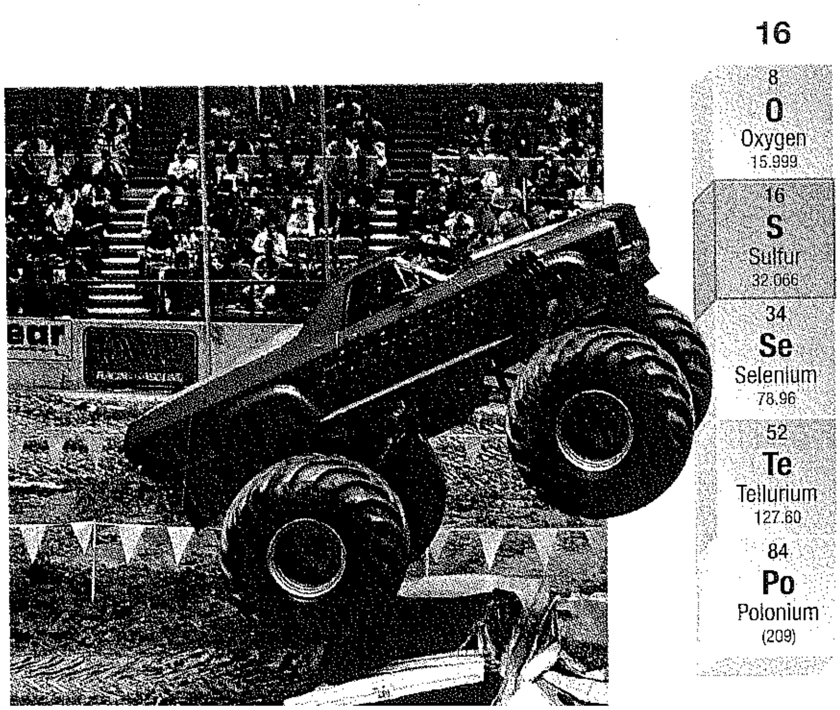
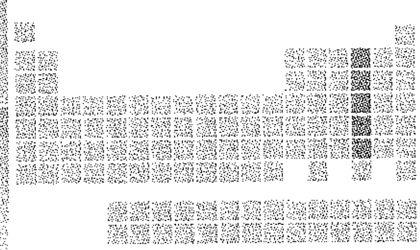


Figure 21 The making of modern rubber depends on the element sulfur. ***Interpreting Diagrams*** *Which element is above sulfur in the periodic table?*



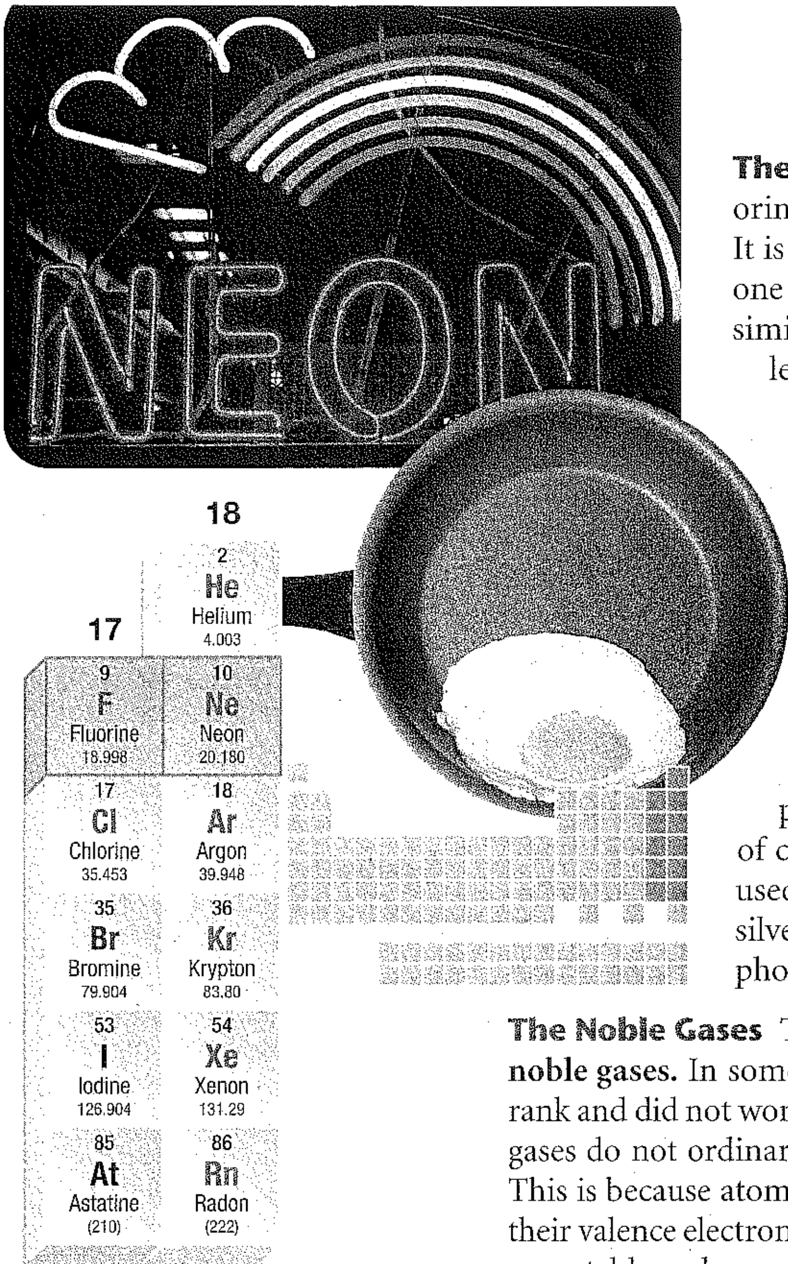


Figure 22 The halogen fluorine is found in the nonstick surface of this cookware. Fluorine is a very reactive element, unlike the noble gas neon in these brightly lit signs. *Relating Cause and Effect What makes the element neon so stable?*

The Halogen Family Group 17 contains fluorine, chlorine, bromine, iodine, and astatine. It is also known as the **halogen family.** All but one of the halogens are nonmetals, and all share similar properties. A halogen atom has 7 valence electrons and typically gains or shares one electron when it reacts.

All of the halogens are very reactive, and most of them are dangerous to humans. But many of the compounds that halogens form are also quite useful. Fluorine, the most reactive of all the nonmetals, is found in nonstick cookware and compounds that help prevent tooth decay. Chlorine is already familiar to you in one form—ordinary table salt is a compound of sodium and chlorine. Other salts of chlorine include calcium chloride, which is used to help melt snow. Bromine reacts with silver to form silver bromide, which is used in photographic film.

The Noble Gases The elements in Group 18 are known as the **noble gases.** In some cultures, "noble" individuals held a high rank and did not work or mix with "ordinary" people. The noble gases do not ordinarily form compounds with other elements. This is because atoms of noble gases do not gain, lose, or share their valence electrons. As a result, the noble gases are chemically very stable and unreactive.

All the noble gases exist in Earth's atmosphere, but only in small amounts. Because of the stability and relative scarcity of the noble gases, most were not discovered until the late 1800s. Helium was discovered by a scientist who was studying not the atmosphere but the sun.

Have you ever come in contact with a noble gas? You have if you have purchased a balloon filled with helium. Noble gases are also used in glowing electric lights. These lights are commonly called neon lights, even though they are often filled with argon, xenon, or other noble gases.

Hydrogen Alone in the upper left corner of the periodic table is hydrogen. Hydrogen is the simplest element—usually each of its atoms contains only one proton and one electron. Because the chemical properties of hydrogen differ very much from those of the other elements, it really cannot be grouped into a family.

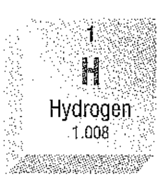


Figure 23 The tiny atoms of the element hydrogen are very reactive.

Although hydrogen makes up more than 90 percent of the atoms in the universe, it makes up only 1.0 percent of the mass of Earth's crust, oceans, and atmosphere. Hydrogen is rarely found on Earth as an element. Most of it is combined with oxygen in water. When an electric current is passed through water, bonds are broken and diatomic hydrogen (H_2) gas molecules are formed.

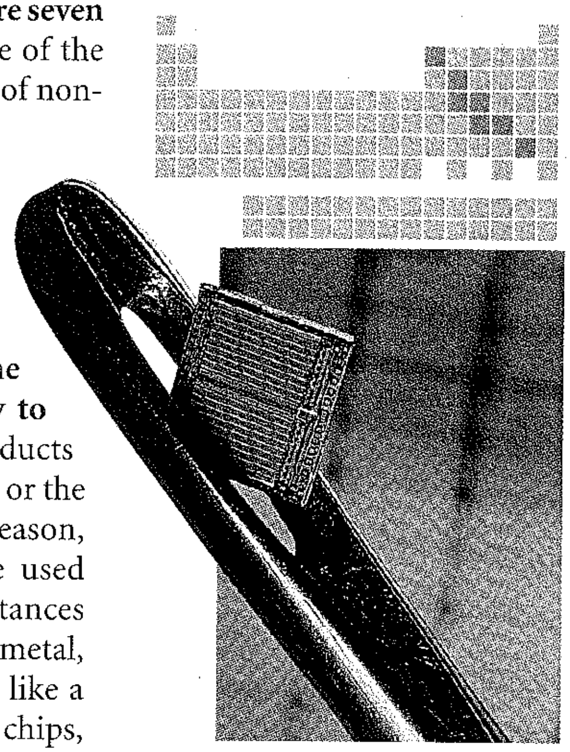
Checkpoint *Which elements are called halogens?*

The Metalloids

On the border between the metals and the nonmetals are seven elements called metalloids. The **metalloids** have some of the characteristics of metals and some of the characteristics of nonmetals. The most common metalloid is silicon (Si). Silicon combines with oxygen to form a number of familiar substances, including sand, glass, and cement. You also may have encountered boron, which is used in some cleaning solutions. You would not want to encounter arsenic, which is a poison.

INTEGRATING PHYSICS **The most useful property of the metalloids is their varying ability to conduct electricity.** Whether or not a metalloid conducts electricity can depend on temperature, exposure to light, or the presence of small amounts of impurities. For this reason, metalloids such as silicon and germanium (Ge) are used to make semiconductors. **Semiconductors** are substances that under some conditions can carry electricity, like a metal, while under other conditions cannot carry electricity, like a nonmetal. Semiconductors are used to make computer chips, transistors, and lasers.

Figure 24 As this close-up view shows, a silicon computer chip is so small it can fit through the eye of a needle.



Section 4 Review

1. Which elements in the periodic table are nonmetals and which are metalloids?
2. What properties identify nonmetals?
3. How do the noble gases differ from the other elements?
4. Describe an important use of metalloids.
5. **Thinking Critically Interpreting Diagrams** Find the following elements in the periodic table: iodine, xenon, selenium. What properties of these elements are indicated by their positions in the periodic table?

Science at Home

Halogens in the Home Make a survey of compounds in your home that contain halogens. Look at labels on foods, cooking ingredients, cleaning materials, medicines, cosmetics, and pesticides. The presence of a halogen is often indicated by the prefixes *fluoro-*, *chloro-*, *bromo-*, and *iodo-*. Show your family examples of substances in your home that contain halogens and describe the properties of the halogen family.

Skills Lab

Classifying

Alien Periodic Table

Imagine that scientists have made radio contact with life on a distant planet. The planet is composed of many of the same elements as are found on Earth. But the inhabitants of the planet have different names and symbols for the elements. The radio transmission gave data on the known chemical and physical properties of 30 elements that belong to Groups 1, 2, 13, 14, 15, 16, 17, and 18. You need to place the elements into a blank periodic table based on these properties.

Problem

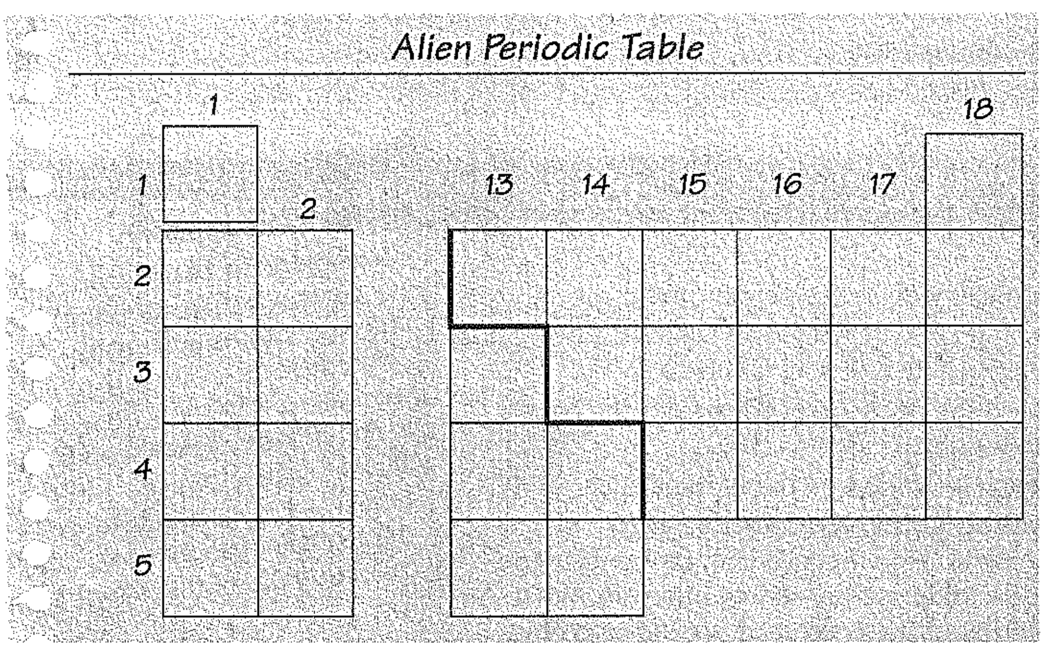
Where do the alien elements fit in the periodic table?

Materials

ruler
periodic table from text for reference

Procedure

1. Copy the blank periodic table below into your notebook.
2. Listed below are data on the chemical and physical properties of the 30 elements. Place the elements in their proper position in the blank periodic table.
   - The noble gases are bombal (Bo), wobble (Wo), jeptum (J), and logon (L). Among these gases, wobble has the greatest atomic mass and bombal the least. Logon is lighter than jeptum.
   - The most reactive group of metals are xtalt (X), byyou (By), chow (Ch), and quackzil (Q). Of these metals, chow has the lowest atomic mass. Quackzil is in the same period as wobble.
   - Apstrom (A), vulcania (V), and kratt (Kt) are nonmetals whose atoms typically gain or share one electron. Vulcania is in the same period as quackzil and wobble.



- The metalloids are ernst (E), highho (Hi), terriblum (T), and sississ (Ss). Sissis is the metalloid with the greatest atomic mass. Ernst is the metalloid with the lowest atomic mass. Highho and terriblum are in Group 14. Terriblum has more protons than highho. Yazzer (Yz) touches the zigzag line, but it's a metal, not a metalloid.
- The lightest element of all is called pfsst (Pf). The heaviest element in the group of 30 elements is eldorado (El). The most chemically active nonmetal is apstrom. Kratt reacts with byyou to form table salt.
- The element doggone (D) has only 4 protons in its atom.
- Floxxit (Fx) is important in the chemistry of life. It forms compounds made of long chains of atoms. Rhaatrap (R) and doadeer (Do) are metals in the fourth period, but rhaatrap is less reactive than doadeer.
- Magnificon (M), goldy (G), and sississ are all members of Group 15. Goldy has fewer total electrons than magnificon.
- Urrp (Up), oz (Oz), and nuutye (Nu) all gain 2 electrons when they react. Nuutye is found as a diatomic molecule and has the same properties as a gas found in Earth's atmosphere. Oz has a lower atomic number than urrp.
- The element anatom (An) has atoms with a total of 49 electrons. Zapper (Z) and pie (Pi) lose two electrons when they react. Zapper is used in flashbulbs.

Analyze and Conclude

1. List the Earth names for the 30 alien elements in order of atomic number.
2. Were you able to place some elements within the periodic table with just a single clue? Explain using examples.
3. Why did you need two or more clues to place other elements? Explain using examples.
4. Why could you use clues about atomic mass to place elements, even though the table is now based on atomic number?
5. **Think About It** Which groups of elements are not included in the alien periodic table? Do you think it is likely that an alien planet would lack these elements? Explain.

More to Explore

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

SECTION 5 Elements From Stardust

DISCOVER — ACTIVITY

Can Helium Be Made From Hydrogen?

1. Every hydrogen atom consists of a nucleus of 1 proton surrounded by an electron. Most hydrogen nuclei do not contain neutrons, but some contain 1 or 2 neutrons. Draw models of each of the three kinds of hydrogen atoms.
2. All helium atoms have 2 protons and 2 electrons, and almost all have 2 neutrons. Draw a model of a typical helium atom.

Think It Over

Developing Hypotheses How might hydrogen atoms combine to form a helium atom? Draw a diagram to illustrate your hypothesis. Why would hydrogen nuclei with neutrons be important for this process?

GUIDE FOR READING

- How do new elements form inside stars?

Reading Tip **Before you read, think of questions to pose about what happens inside stars like the sun. Then read to find answers to your questions.**

Have you wondered where the elements come from? Would you like to know why some elements are common here on Earth, while others are much rarer?

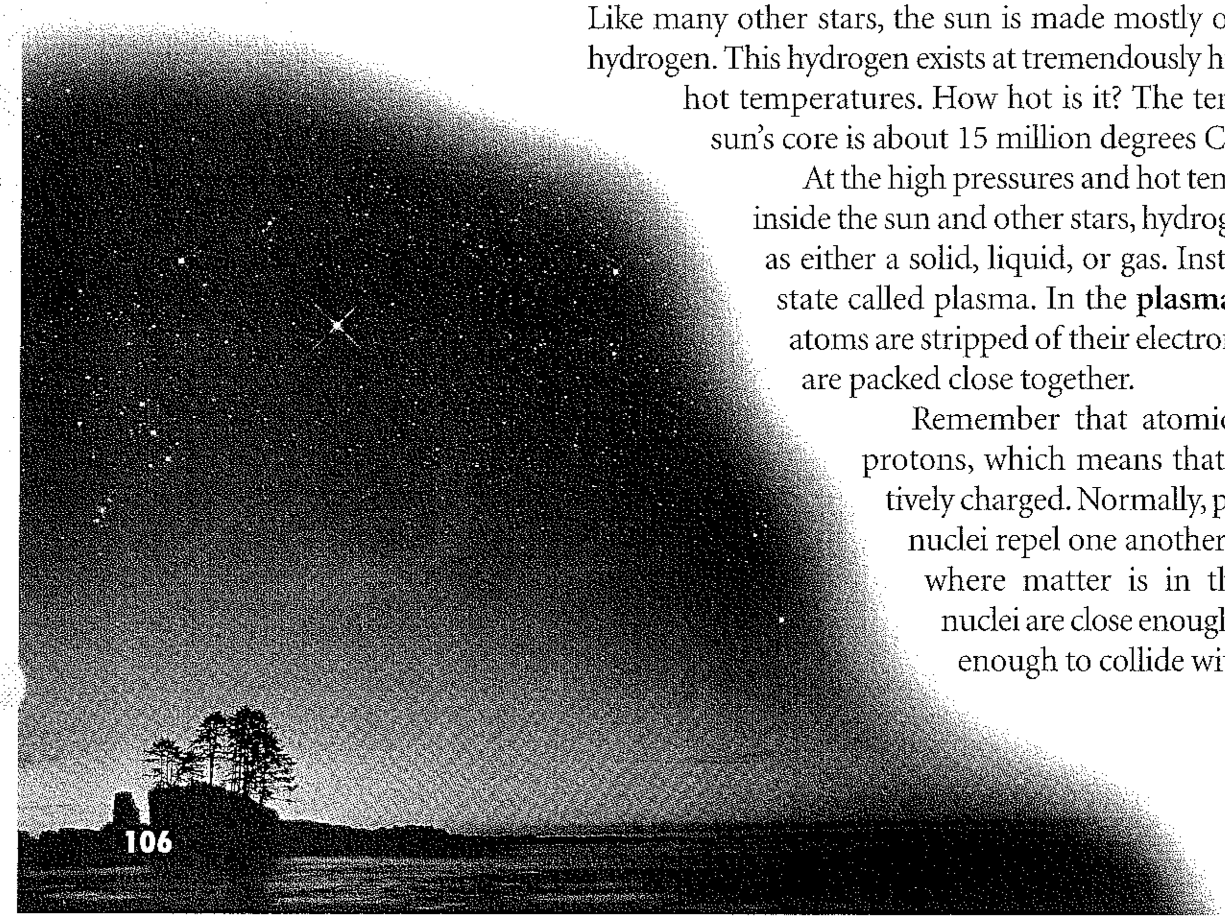
To answer questions such as these, scientists have looked in a place that might surprise you: the inside of stars. By studying the sun and other stars, scientists have formed some interesting hypotheses about the origins of matter here on Earth.

Atomic Nuclei Collide

Like many other stars, the sun is made mostly of one element—hydrogen. This hydrogen exists at tremendously high pressures and hot temperatures. How hot is it? The temperature in the sun's core is about 15 million degrees Celsius.

At the high pressures and hot temperatures found inside the sun and other stars, hydrogen does not exist as either a solid, liquid, or gas. Instead, it exists in a state called plasma. In the **plasma** state of matter, atoms are stripped of their electrons, and the nuclei are packed close together.

Remember that atomic nuclei contain protons, which means that nuclei are positively charged. Normally, positively charged nuclei repel one another. But inside stars, where matter is in the plasma state, nuclei are close enough and moving fast enough to collide with one another.



When colliding nuclei have enough energy, they can join together in a process called nuclear fusion. In **nuclear fusion,** atomic nuclei combine to form a larger nucleus, releasing huge amounts of energy in the process. **Inside stars, nuclear fusion combines smaller nuclei into larger nuclei, thus creating heavier elements.** For this reason, you can think of stars as "element factories."

☑ *Checkpoint* *What does "nuclear fusion" mean?*

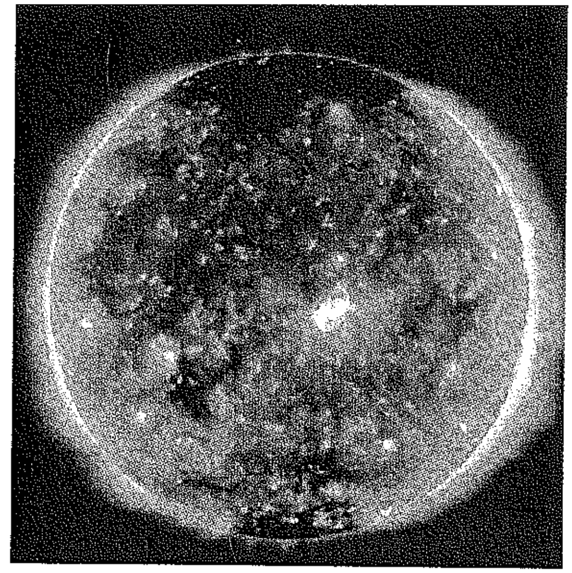


Figure 25 Without the nuclear fusion inside the sun, no sunlight would reach Earth. ***Predicting*** *What might happen in 5 billion years when all the hydrogen in the sun's core is used up?*

Elements From the Sun

What are the steps of nuclear fusion in the sun and other stars? To answer this question, you need to take a close look at the nuclei of hydrogen atoms. A hydrogen nucleus always contains one proton. However, different types of hydrogen nuclei can contain 2 neutrons, 1 neutron, or no neutrons at all.

Inside the sun, hydrogen nuclei undergo a nuclear fusion reaction that produces helium nuclei, as illustrated in Figure 26. Notice that the reaction requires a type of hydrogen nucleus that contains neutrons. This form of hydrogen is rare on Earth, but it is much more common inside the sun.

As two hydrogen nuclei fuse together, they release a great deal of energy. In fact, this reaction is the major source of the energy that the sun now produces. In other words, hydrogen is the fuel that powers the sun. Although the sun will eventually run out of hydrogen, scientists estimate that the sun has enough hydrogen to last another 5 billion years.

As more and more helium builds up in the core, the sun's temperature and volume also change. These changes allow different nuclear fusion reactions to occur. Over time, two or more helium nuclei combine to form the nuclei of slightly heavier elements. First, two helium nuclei combine, forming a beryllium nucleus. Then, another helium nucleus can join with the beryllium nucleus, forming a carbon nucleus. And yet another helium

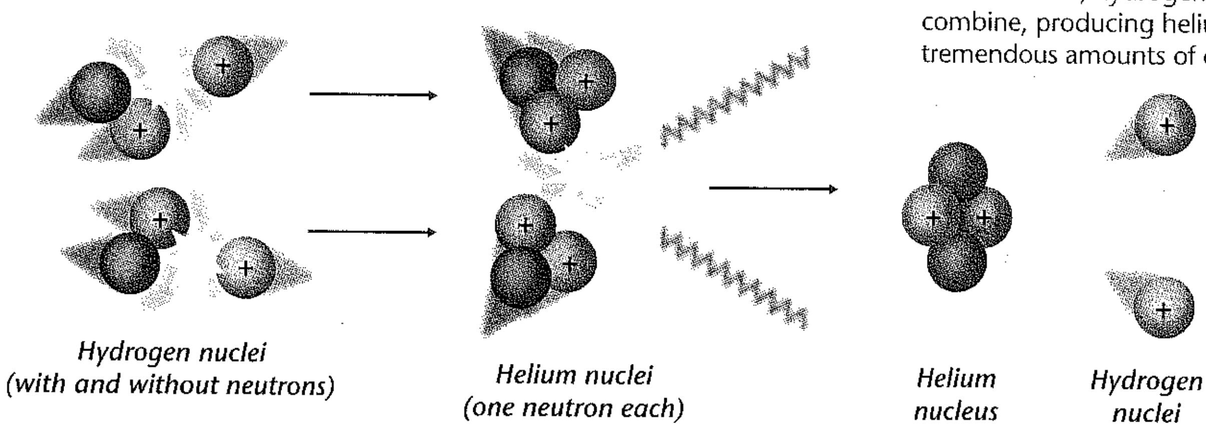


Figure 26 In the process of nuclear fusion, hydrogen nuclei combine, producing helium and tremendous amounts of energy.

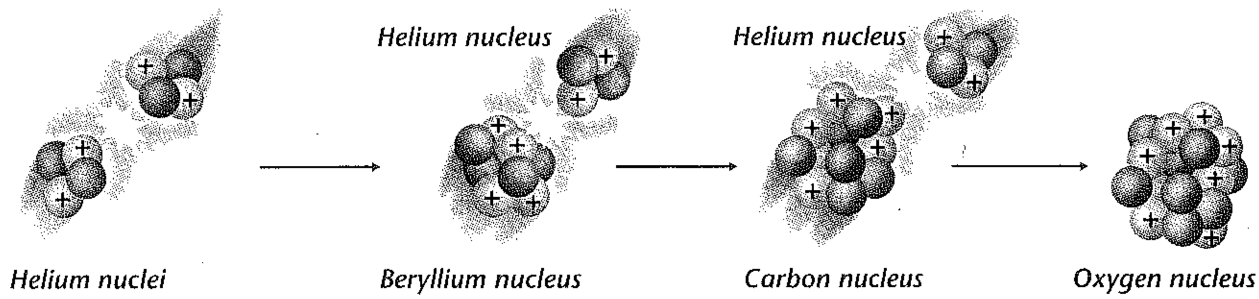


Figure 27 A series of nuclear fusion reactions forms nuclei larger than helium. *Interpreting Diagrams Which elements are being formed?*

nucleus can join with the carbon nucleus, forming oxygen. But stars the size of the sun do not contain enough energy to produce elements heavier than oxygen.

Elements From Large Stars

As they age, larger stars become even hotter than the sun. These stars have enough energy to produce heavier elements, such as magnesium and silicon. In more massive stars, fusion continues until the core is almost all iron.

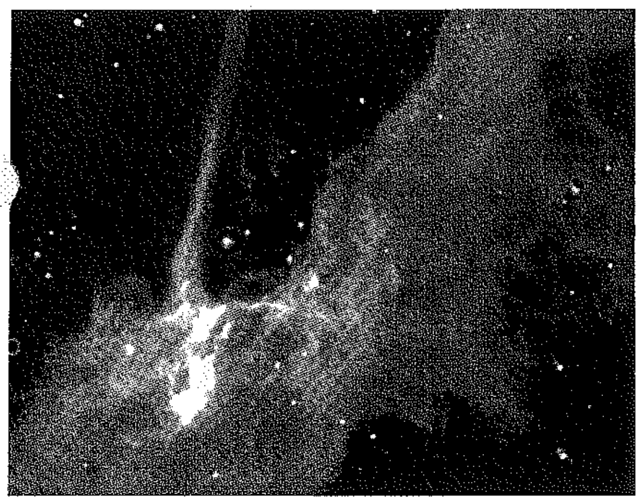


Figure 28 When massive stars explode in a supernova, enough energy is released to form the heavier elements.

How are elements heavier than iron produced? In the final hours of the most massive stars, scientists have observed an event called a supernova. A **supernova** is a tremendous explosion that breaks apart a massive star, producing temperatures up to one billion degrees Celsius. A supernova provides enough energy for the nuclear fusion reactions that create the heaviest elements.

Most astronomers agree that the matter in the sun and the planets around it, including Earth, originally came from a gigantic supernova that occurred billions of years ago. If this is true, it means that everything around you was created in a star. So all matter on Earth is a form of stardust.

Section 5 Review

1. How does nuclear fusion produce new elements?
2. What nuclear fusion reaction occurs in stars like the sun?
3. How do the fusion reactions in the sun compare to the fusion occurring in larger stars and supernovas?
4. **Thinking Critically Inferring** Plasma is not found naturally on Earth. Why do you think this is so?

CHAPTER PROJECT

Check Your Progress

With your teacher's approval, begin testing the metal samples. Record the results of each test. If you cannot measure a property with exact numbers, use a more general rating system. For example, you could describe each metal as showing a particular property very well, somewhat, poorly, or not at all.

CHAPTER 3 STUDY GUIDE

SECTION 1 Inside the Atom

Key Ideas

- An atom consists of a nucleus of protons and neutrons, surrounded by electrons.
- Chemical bonds form when electrons are transferred or shared between atoms.

Key Terms

nucleus	atomic number
proton	atomic mass unit (amu)
neutron	valence electron
electron	electron dot diagrams

SECTION 2 Organizing the Elements

Key Ideas

- Mendeleev developed the first periodic table of the elements. An element's properties can be predicted from its location in the table.
- Each square of the periodic table may contain the atomic number, chemical symbol, name, and atomic mass of an element.

Key Terms

atomic mass	family
periodic table	period
group	

SECTION 3 Metals

Key Ideas

- Most elements are metals, found to the left of the zigzag line in the periodic table.
- Metals are usually shiny, ductile, malleable, and good conductors of heat and electricity.

Key Terms

malleable	alkali metal
ductile	alkaline earth metal
conductor	transition metal
magnetic	lanthanide
corrosion	actinide

SECTION 4 Nonmetals and Metalloids

Key Ideas

- Nonmetals, found to the right of the zigzag line, are often gases or dull, brittle solids with low melting points.
- Metalloids have characteristics of both metals and nonmetals.

Key Terms

nonmetal	noble gas
diatomic molecule	metalloid
halogen family	semiconductor

SECTION 5 Elements From Stardust

INTEGRATING SPACE SCIENCE

Key Ideas

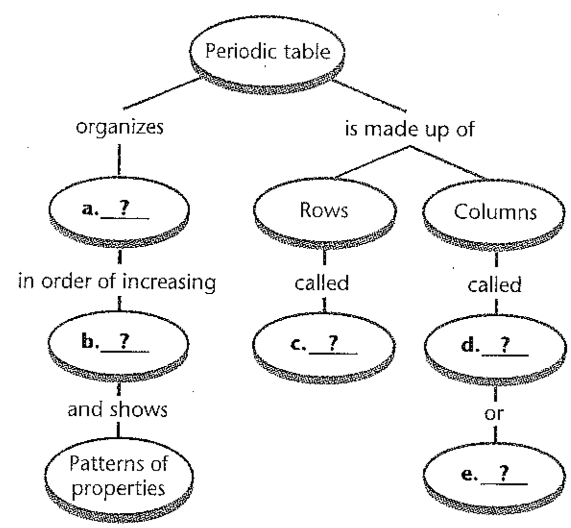
- Nuclear fusion inside stars produces the nuclei of different light elements, such as helium.
- Elements heavier than iron are produced in a supernova, the explosion of a very massive star.

Key Terms

plasma   nuclear fusion   supernova

Organizing Information

Concept Map Copy the concept map about the periodic table onto a separate sheet of paper. Then complete it and add a title. (For more on concept maps, see the Skills Handbook.)



Reviewing Content

For more review of key concepts, see the Interactive Student Tutorial CD-ROM.

Multiple Choice

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

1. The atomic number of an atom is determined by the number of
   a. protons. b. electrons.
   c. neutrons. d. valence electrons.
2. In the current periodic table, elements are arranged according to
   a. atomic mass.
   b. atomic number.
   c. their melting and boiling points.
   d. the number of neutrons in their nuclei.
3. Of the following, the group which contains the most reactive elements is the
   a. alkali metals.
   b. alkaline earth metals.
   c. transition metals.
   d. noble gases.
4. Unlike metals, many nonmetals are
   a. good conductors of heat and electricity.
   b. malleable and ductile.
   c. gases at room temperature.
   d. shiny.
5. Inside the sun, nuclear fusion creates helium nuclei from
   a. oxygen nuclei. b. neon nuclei.
   c. carbon nuclei. d. hydrogen nuclei.

True or False

If the statement is true, write true. If it is false, change the underlined word or words to make it a true statement.

6. The particles that move around outside an atom's nucleus are <u>electrons</u>.
7. Dmitri Mendeleev is credited with developing the first <u>periodic table</u>.
8. The <u>alkali metals</u> include iron, copper, silver, and gold.
9. Noble gases usually exist as <u>compounds</u>.
10. At the hot temperatures of stars, electrons are stripped away from nuclei. This forms a dense phase of matter called <u>a gas</u>.

Checking Concepts

11. Why did Mendeleev leave three blank spaces in his periodic table? How did he account for the blank spaces?
12. Why do elements in a group of the periodic table have similar properties?
13. List five different metals. Give examples of how each metal is used.
14. List five different nonmetals. Give examples of how each nonmetal is used.
15. Why would you expect to find the element argon in its pure, uncombined form in nature?
16. **Writing to Learn** Imagine that you are Dmitri Mendeleev, and you have just published the first periodic table. Write a letter to a fellow scientist describing the table and its value.

Thinking Critically

17. **Interpreting Diagrams** An atom contains 74 protons, 74 electrons, and 108 neutrons. Which element is it?
18. **Comparing and Contrasting** Draw one electron dot diagram for an alkali metal and another for a halogen. What do the two diagrams have in common? How are they different?
19. **Drawing Conclusions** A chemistry student claims to have isolated a new element. The student states that the new element has properties similar to fluorine and chlorine, and he argues that it should be placed between fluorine and chlorine in the periodic table. Could the student have discovered a new element? Explain.
20. **Making Models** Draw a model of a carbon nucleus (6 protons, 6 neutrons) fusing with a helium nucleus (2 protons, 2 neutrons). Assuming all the protons and neutrons combine into the new nucleus, what is the identity of the new element?

Applying Skills

The table on the right lists properties of five elements. Use the information to answer Questions 21–26.

21. Classifying Classify each element in the table as a metal or nonmetal. Explain your answers.

22. Inferring Both elements B and C have an atomic mass that is close to 40. Why can two different elements have very similar atomic masses?

23. Drawing Conclusions Use the periodic table to identify the five elements.

24. Predicting Would you expect elements A and B to have similar chemical properties? Why or why not?

25. Predicting Would you expect to find element C uncombined in nature? Explain.

26. Designing Experiments Which of the metals you identified is the most reactive? Describe an experiment that would support your answer.

Properties of Five Elements

Element	Appearance	Atomic Mass	Conducts Electricity
A	Invisible gas	14.0	No
B	Invisible gas	39.9	No
C	Hard, silvery solid	40.0	Yes
D	Silvery liquid	200.6	Yes
E	Shiny, bluish-white solid	207.2	Slightly

Performance Assessment (Chapter Project)

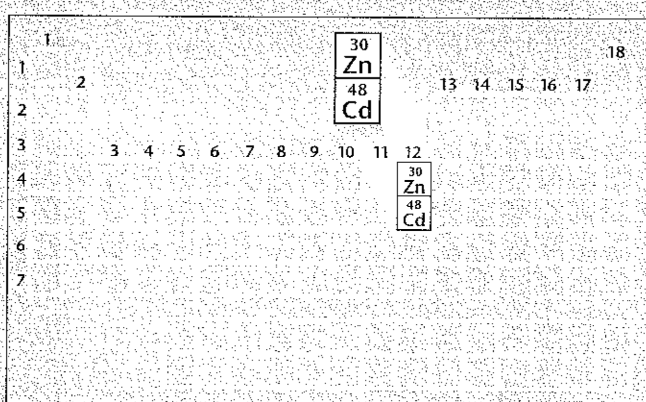
Present Your Project Display the chart showing the metals you studied. Be ready to discuss which properties are common to all metals. Try to predict the types of questions that others might ask you.

Reflect and Record In your journal, describe other properties of metals you could not test. List all the properties that could be used to find out whether an unknown element is a metal.

Test Preparation

Use these questions to prepare for standardized tests.

Use the diagram to answer Questions 27–32.



27. What is the atomic number for zinc (Zn)?
- **a.** 12 **b.** 30
- **c.** 15 **d.** 65.39

28. How many electrons does a zinc atom contain?
- **a.** 0 **b.** 15
- **c.** 30 **d.** 60

29. In what group of the periodic table is zinc located?
- **a.** 3 **b.** 4
- **c.** 11 **d.** 12

30. In what period of the table is zinc located?
- **a.** 3 **b.** 4
- **c.** 11 **d.** 12

31. In what way is zinc similar to cadmium (Cd), which is located just below it in the periodic table?
- **a.** They have the same number of electrons.
- **b.** They have the same number of valence electrons.
- **c.** They have the same number of protons.
- **d.** They are members of the same period.

32. From their location in the periodic table, you know that zinc and cadmium are
- **a.** alkali metals. **b.** lanthanides.
- **c.** noble gases. **d.** transition metals.