Section Preview of the Student Book for

The Chemistry of Materials, *Issues and Physical Science, 2nd Edition*

Activities 15-17

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15 Families of Elements

In the last activity, you grouped selected materials based on their properties. Some of those materials were elements, while others were made of combinations of elements. An **element** is a substance that cannot be broken down into simpler substances by heating it or causing it to react with other chemicals.

Did you know that there are only 90 naturally occurring elements in our world, and scientists have made about 25 more elements in laboratories? That may seem like a lot, but think of it this way: everything—yes, everything—around you is made from one or more of these elements. In this activity you will investigate 14 of the 90 naturally occurring elements and think of ways to group them based on their chemical and physical properties.

How can elements be grouped based on their physical and chemical properties?

Samples of elements. Clockwise from upper center, they are chlorine (Cl), sulfur (S), mercury (Hg), copper (Cu), and silicon (Si).

MATERIALS

For each group of four students

- **1 set of 14 Element Cards**
- **4 half-sheets of paper of various colors**

PROCEDURE

1. With your group, spread the Element Cards out on a table. Each card provides the following information about an element:
   - Element symbol
   - Element name
   - Whether the element is a metal or nonmetal
   - Whether the element is solid, liquid, or gas at room temperature
   - Color
   - Atomic mass: the mass of the smallest particle (an atom) of the element
   - Reactivity: how likely the element is to react chemically with other elements
   - Number of bonds to hydrogen: the number of hydrogen atoms that usually combine chemically with this element when they react
2. Examine the information on each card carefully, noting similarities and differences among the elements.
3. Working together, sort the elements into at least three groups. Each group should have at least two similar properties. Agree on a classification system. As you work remember to:
   - Listen to and consider the explanations and ideas of your group.
   - If you disagree with other members of your group, explain why you disagree.
4. In your science notebook, list the groups you made and the common features of each. Be sure to record all the elements in each group.
5. Present your classification system to the class. As you look at other students' systems, observe similarities and differences between theirs and yours. Discuss your observations with your group.
6. Your group will receive four Element Family Cards. Each card describes a group of elements called a **family.** Based on the information on the Family Cards, place each element under a card.

7. Arrange the elements in each family in order from lowest atomic mass at the top to highest atomic mass at the bottom. Place the column on a half-sheet of paper.
8. Line up the four columns of elements to form a table, so that the elements are in columns and rows. Use the atomic masses of the elements to decide on an order for the holders.
9. In your notebook, record your new classification system, complete with:
   - family names
   - similar properties within each family
   - elements in each family in order of increasing atomic mass

ANALYSIS

1. Which of the properties listed on the Element Cards are:
   a. physical properties?
   b. chemical properties?

2. How did your first classification system compare to the second classification with the Element Family Cards?

3. In what ways could grouping elements help scientists understand their properties?
4. Use the table of elements you constructed to find the family or families of elements that are:
   a. not usually reactive.
   b. highly reactive.
   c. all metals.
   d. all solids.
   e. all gases.

5. The element strontium (Sr) is below calcium (Ca) in Column 2 on the periodic table. Design an Element Card that shows the properties you predict for strontium.

EXTENSION

Visit the *Issues and Physical Science* page of the SEPUP website for:

- links to different versions of the periodic table.
- the latest update on the number of elements.

16 Elements and the Periodic Table

READING

Materials—both natural and human made—have unique properties. Some are made of one type of element, and some are made of combinations of elements. But what are elements made of, and how do they differ from each other?

Each element is made of tiny particles called **atoms.** A pure sample of an element contains many atoms of the same type. For example, the millions of iron atoms that make up a piece of iron metal are of the same type and have the characteristics of iron. Iron atoms, however, are very different from atoms of other elements, such as gold or oxygen. The properties of each element depend on its atoms.

Some elements are rarely found in a pure form. They tend to combine chemically, or **react,** with other elements. Scientists say that these elements are **reactive.** When elements react, they can form substances called **compounds.**

CHALLENGE

What are elements, and how do they relate to compounds?

Think of the world around you. Everything—from the air you breathe to the shoes you walk in—is made from elements or combinations of elements.

MATERIALS

For each student

1 **Student Sheet 16.1, "Periodic Table of the Elements"**

READING

Discovering Elements

When reading, answer the Stopping to Think questions in your mind. They can help you find out whether you understand the main ideas.

Laboratory investigations in the 1700s similar to those shown in this illustration led to discoveries about the properties of elements.

The idea that everything on the earth is made of a basic set of elements began with the ancient Greeks more than 2,000 years ago. Greek philosophers thought that fire, earth, air, and water combined to make everything in the world.

Starting in the 1600s, early chemists realized that fire, earth, air, and water were not the basic building blocks of matter. They looked instead for substances that they could not break down into simpler substances. These substances are known today as the elements.

Some of the earliest known elements were carbon, gold, silver, copper, sulfur, tin, lead, mercury, and iron—all of them elements that occur in nature. Until the 1700s, very few new elements were discovered. But in the mid 1700s through the 1800s, chemists learned how to create chemical reactions and physical ways to separate pure elements. With these new techniques, they found dozens more elements. By 1869, approximately 63 elements were known. These included hydrogen, nitrogen, oxygen, sodium, and aluminum.

STOPPING TO THINK 1

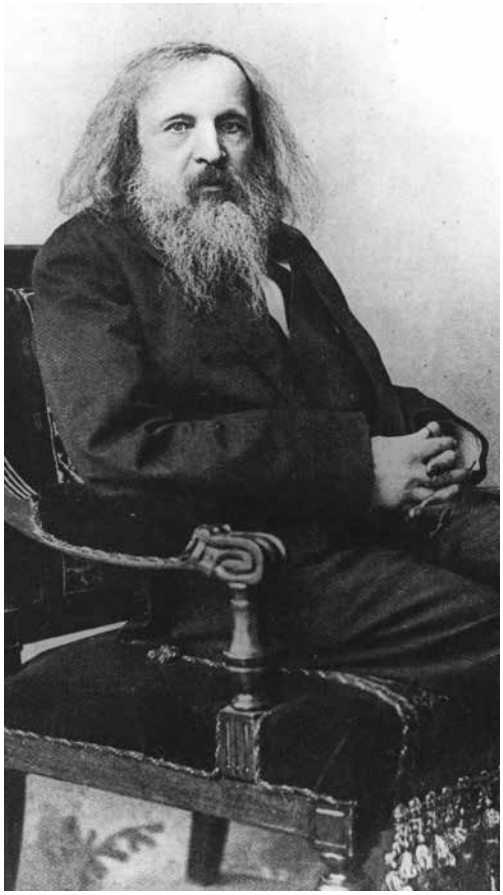
In what way were the ancient Greek philosophers right about elements?

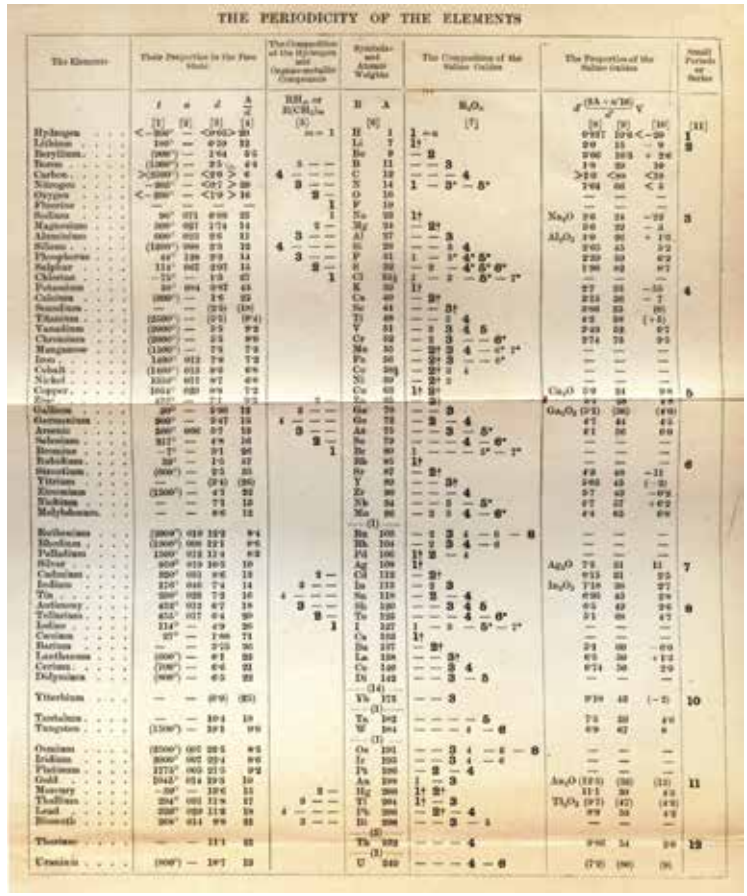
In what way were the ancient Greek philosophers wrong?

Mendeleev and the Periodic Table of the Elements

In 1869 the Russian scientist Dmitri Mendeleev (men-deh-LAY-eff) developed the ideas that led to the modern periodic table. Other scientists had some similar ideas, but Mendeleev made the most progress and published the first version of a table of the 63 elements known at the time.

Mendeleev collected information on the properties of those 63 elements and grouped them in a way similar to what you did in Activity 15, "Families





THE PERIODICITY OF THE ELEMENTS

Photo (left) of Russian chemist Dmitri Ivanovich Mendeleev (1834–1907) and a table (right) he developed based on the properties of elements. This reference was translated into English in 1891.

of Elements." He used data that many other scientists had collected about the properties of each of the elements. When he arranged the elements according to their atomic masses and their physical and chemical properties, he noticed that there was a repeating—or periodic—pattern. For example, as the atomic mass increased from lithium to fluorine, the elements in between changed from metals to nonmetals and from solids to gases. He saw a similar pattern repeated from sodium to chlorine and again from potassium to bromine. Mendeleev predicted that there were more elements that would fit into gaps in his chart, the first version of what came to be known as a periodic table. He even used the patterns in the table to predict the properties of new elements.

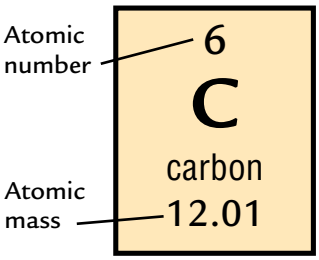
Other scientists used Mendeleev's ideas and built on them to identify the elements he predicted. Later scientists found many more elements that follow the patterns he found. The modern version of the table is called the **Periodic Table of the Elements.** Based on new data about the elements, scientists around the world have agreed on some changes to the arrangement of the table.

STOPPING TO THINK 2

How did Mendeleev build on other scientists' work?

How did other scientists build on Mendeleev's work?

The Modern Periodic Table



Today, there are more than 115 identified elements, and everything on earth is made of these elements. Look at the current periodic table shown below. Each element is represented by a symbol that includes either one uppercase letter, such as C for carbon, or an uppercase and a lowercase letter, such as Ca for calcium or Cu for copper. Each element shows an **atomic number** that corresponds to its order in the periodic table and an atomic mass, as shown in the example of the element carbon to the left.

Periodic Table of the Elements

SHADING KEY
- A — solid at room temperature
- A — liquid at room temperature
- A — gas at room temperature

1																	18
1 H hydrogen 1.008	2											13	14	15	16	171	2 He helium 4.003
3 Li lithium 6.941	4 Be beryllium 9.012											5 B boron 10.81	6 C carbon 12.01	7 N nitrogen 14.01	8 O oxygen 16.00	9 F fluorine 19.00	10 Ne neon 20.18
11 Na sodium 22.99	12 Mg magnesium 24.31	3	4	5	6	7	8	9	10	11	12	13 Al aluminum 26.98	14 Si silicon 28.09	15 P phosphorus 30.97	16 S sulfur 32.07	17 Cl chlorine 35.45	18 Ar argon 39.95
19 K potassium 39.10	20 Ca calcium 40.08	21 Sc scandium 44.96	22 Ti titanium 47.87	23 V vanadium 50.94	24 Cr chromium 52.00	25 Mn manganese 54.94	26 Fe iron 55.85	27 Co cobalt 58.93	28 Ni nickel 58.69	29 Cu copper 63.55	30 Zn zinc 65.39	31 Ga gallium 69.72	32 Ge germanium 72.64	33 As arsenic 74.92	34 Se selenium 78.96	35 Br bromine 79.90	36 Kr krypton 83.80
37 Rb rubidium 85.47	38 Sr strontium 87.62	39 Y yttrium 88.91	40 Zr zirconium 91.22	41 Nb niobium 92.91	42 Mo molybdenum 95.94	43 Tc technetium (98)	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3
55 Cs cesium 132.9	56 Ba barium 137.3	71 Lu lutetium 175.0	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium (209)	85 At astatine (210)	86 Rn radon (222)
87 Fr francium (223)	88 Ra radium (226)	103 Lr lawrencium (262)	104 Rf rutherfordium (267)	105 Db dubnium (268)	106 Sg seaborgium (271)	107 Bh bohrium (272)	108 Hs hassium (277)	109 Mt meitnerium (276)	110 Ds darmstadtium (281)	111 Rg roentgenium (280)	112 Cn copernicium (285)	113 Uut ununtrium (284)	114 Uuq ununquadium (289)	115 Uup ununpentium (288)	116 Uuh ununhexium (293)	117 Uus ununseptium ( )	118 Uuo ununoctium (294)

Lanthanides	57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.2	61 Pm promethium (145)	62 Sm samarium 150.4	63 Eu europium 152.0	64 Gd gadolinium 157.3	65 Tb terbium 158.9	66 Dy dysprosium 162.5	67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.0
Actinides	89 Ac actinium (227)	90 Th thorium 232.0	91 Pa protactinium 231.0	92 U uranium 238.0	93 Np neptunium (237)	94 Pu plutonium (244)	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)

From the periodic table you can find out a lot about an element. For example, if you look at the element cesium (atomic number 55) on the periodic table shown on the next page, you will see that it is in the alkali metal column. From this you can assume that cesium is a highly reactive, soft metal. On this periodic table, you can also tell if an element is a metal or nonmetal, because a dark "stepped line" divides the table into metals to the left of the stepped line and nonmetals to its right.

Most of the elements that border the stepped line between metals and nonmetals are called metalloids. Metalloids have chemical and physical properties intermediate between those of metals and nonmetals. Aluminum is not classified as a metalloid because it has metallic properties. Metalloids are often called semiconductors because they conduct electricity better than nonmetals but not as well as metals. Semiconductors, especially silicon, are essential components of electronic products.

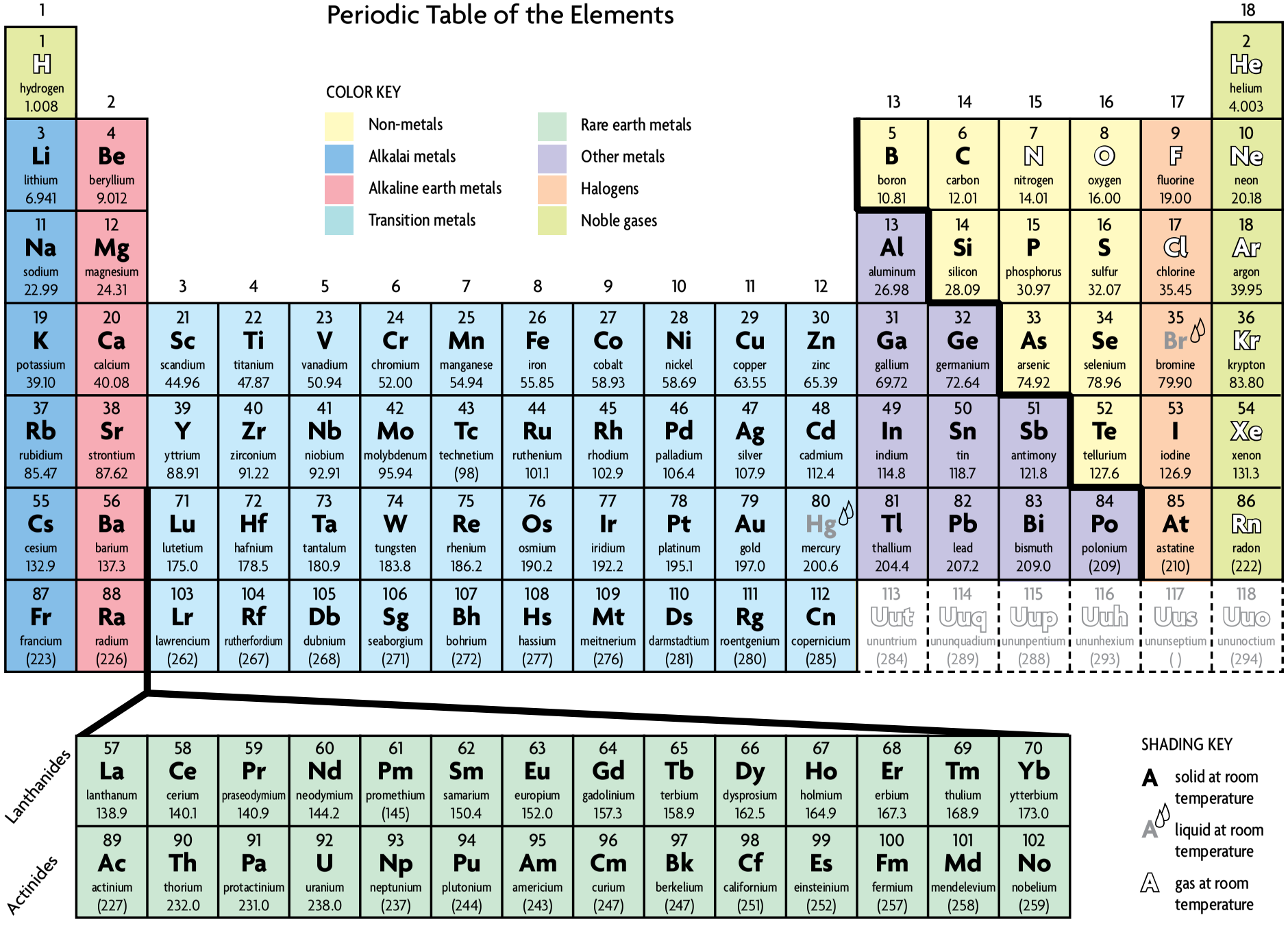
STOPPING TO THINK 3

Use the Periodic Table of the Elements on the next page to decide whether each of the following is a metal or a nonmetal: lithium (Li), carbon (C), sulfur (S), calcium (Ca), titanium (Ti), and bromine (Br).

Most elements are solid at room temperature. The 11 elements that are gases tend to appear on the right and near the top of the periodic table. Their symbols are white. There are two elements that are liquid at room temperature—mercury and bromine. Their symbols are shaded in gray.

You can also predict the chemical reactivity of an element based on its position in the periodic table. The **reactivity** of an element describes how likely it is to **react,** or combine, with other elements. An element that is very likely to react with other elements is described as highly **reactive.** This means that they will react with many other substances. The least reactive elements are the noble gases to the right. The most reactive metals are in the two columns to the far left of the periodic table. The most reactive nonmetals are in the halogen family in column 17.

Periodic Table of the Elements



STOPPING TO THINK 4

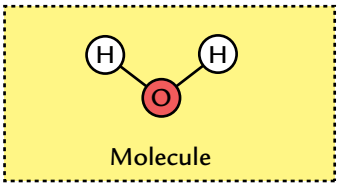
Find magnesium on the periodic table.

- What is magnesium's chemical symbol?
- What family does magnesium belong to?
- Is magnesium a solid, a liquid, or a gas?

Based on its family, would you expect magnesium to be very reactive, somewhat reactive, or not reactive at all?

Forming Compounds

Elements contain only one kind of atom. Other substances contain two or more types of atoms held together by chemical bonds. Bonds form when the atoms of one element are attracted to the atoms of one or more other elements. Substances with two or more types of atoms held together by bonds are called compounds. For example, the compound water forms when the elements hydrogen and oxygen react together. Sugars are chemical combinations of the elements carbon, hydrogen, and oxygen. Groups of differing atoms that are held together by chemical attraction are called **molecules.** The diagram below shows a water molecule, made of two hydrogen atoms and one oxygen atom.



Water molecule

There are more than 115 elements, and these elements can combine to form millions of compounds. To get an idea of how many, just look at a dictionary of the English language and think about how many words are formed from just 26 letters!

Compounds have different properties than the elements that form them. For example, the compound we call water is a liquid formed from two gases—hydrogen and oxygen. Table sugar is an edible white solid formed from a black solid (carbon) and the gases hydrogen and oxygen.

STOPPING TO THINK 5

What are two ways that compounds are different from the elements that form them?

Commonly referred to as salt, this naturally-occurring compound is sodium chloride, NaCl.

Chemical Names and Formulas

Scientists have created a system for naming compounds. These names often identify the elements that make up the compound. For example, the full chemical name for table salt is "sodium chloride." This name tells you table salt contains sodium and chlorine. This is information about the compound that you would not have if you called it "table salt." Notice that the ending of "chlorine" is changed to "–ide" in the name of the compound. A **chemical formula** is a shorthand way to identify the kind and number of atoms that make up a compound. For example, the symbol for sodium is **Na**, and the symbol for chlorine is **Cl.** So you can write the formula for the compound sodium chloride like this: **NaCl.** This tells you that there is one chlorine atom for every sodium atom in sodium chloride.

Not all chemical formulas are as simple as **NaCl.** For instance, water is made up of the elements hydrogen (H) and oxygen (O), and its chemical formula is **H_2O.** (You say this "H-two-O.") That is because each water molecule is made up of two hydrogen atoms bonded to one oxygen atom. The number "2" below and to the right of the "H" shows that there are two hydrogen atoms in a water molecule. When there is no number written below and to the right of the element symbol, then there is only one of that type of atom.

STOPPING TO THINK 6

The chemical formula for baking soda is **$NaHCO_3$.** What elements are in baking soda? How many of each kind of atom is represented by the formula for baking soda?

Ocean water is a mixture of compounds, including water (H_2O), salt (NaCl), and others.

Classifying Matter: Elements, Compounds, and Mixtures

Everything around you is an element, a compound, or a mixture of both. The oxygen in the air you breathe and the copper in pennies are examples of elements. The water you drink and the salt and sugars in the foods you eat are examples of compounds. So are the proteins, fats, and carbohydrates that make up the cells in your body. Everything that is not a pure element or compound is a mixture of elements, compounds, or both. Even air is a mixture of several elements and compounds, including the elements nitrogen and oxygen and the compounds carbon dioxide and water.

ANALYSIS

1. Make a copy of the table below in your science notebook. Use the Periodic Table of Elements to find out which atoms make up a molecule for each of the substances listed. The first row has been completed for you.

Chemical Formulas of Common Substances

Substance	Chemical Formula	Atoms that make up the molecule
Water	H_2O	2 hydrogen atoms, 1 oxygen atom
Hydrogen peroxide	H_2O_2	
Carbon dioxide	CO_2	
Sucrose (table sugar)	$C_{12}H_{22}O_{11}$	
Alanine (an amino acid)	$C_3H_7O_2N$	
Oleic acid (a fat)	$C_{12}H_{24}O_2$	

2. Sodium is a metallic solid, and chlorine is a poisonous yellow-green gas. Sodium and chlorine react to form sodium chloride, which is common table salt.
   a. Is table salt an element or a compound? Explain.
   b. Describe the physical properties of table salt.
   c. How do the properties of table salt compare with those of sodium and chlorine?
3. Is seawater an element, compound, or mixture? Explain your answer.
4. Explain the relationship between an atom and a molecule.

EXTENSION

Visit the *Issues and Physical Science* page of the SEPUP website for links to learn more about Dmitri Mendeleev's work and the work of other chemists.

17 Modeling Molecules

Most substances on earth are not pure elements made up of a single type of atom. "Energy connections" called **chemical bonds** can hold atoms together to form molecules. Molecules are composed of two or more atoms held together with chemical bonds. Atoms can combine with atoms of the same element, with atoms of another element, or even with atoms of several elements through chemical bonds. When the atoms of more than one element bond in specific, regular proportions they form a substance called a compound. Water, for example, is a compound because its molecules are made from atoms of hydrogen and oxygen in exact proportions. These proportions (2:1) are shown in its chemical formula, H_2O.

Compounds can be found everywhere. Many everyday materials—from wood to gasoline to aspirin—are made of compounds. In this activity, you will build molecules of several compounds.

CHALLENGE

How do atoms combine to form molecules?

The Atomium, a building modeled after the crystal structure of metal, was built in Brussels, Belgium for the 1958 World's Fair.

MATERIALS

For each pair of students

- **1 molecular model set containing:**
- **32 white "atoms"**
- **18 black "atoms"**
- **14 red "atoms"**
- **4 blue "atoms"**
- **54 white "bonds"**

For each student

- **1 Student Sheet 16.1, "Periodic Table of the Elements"**

PROCEDURE

Part A: Making Simple Molecules

COLOR	ELEMENT	SYMBOL
	hydrogen	H
	carbon	C
	oxygen	O
	nitrogen	N

1. Build a model of a molecule of water with two hydrogen (white) atoms and one oxygen (red) atom. Use the white bonds (tubes) to make the connections that represent chemical bonds.
2. Follow your teacher's directions to draw a diagram of this molecule in your science notebook.
3. What do you think is the name and chemical formula of this molecule? Record these on your diagram.
4. Pull the model apart.
5. Every time you make a molecule, all of the bonding sites (the "sticks" on the atom models) must be connected to the sites on another atom.
   a. Using this rule, make two models: a molecule of hydrogen and carbon and a molecule of hydrogen and nitrogen.
   b. Draw each molecule that you construct.
   c. Record next to each drawing the chemical formula for the molecule.
6. Follow your teacher's demonstration to construct a molecule using two oxygen atoms. Remember, all the bonding sites must be connected.
7. Construct two molecules: one using 2 hydrogen atoms and one using 2 nitrogen atoms.
8. Draw a diagram of each of the molecules you made for Steps 6 and 7.
9. Next to each diagram record the chemical formula for the molecule.
10. Take apart all of the models, and return all of the pieces to the set.

Part B : Making More Complex Molecules

11. Construct and draw at least four more molecules according to the following two rules:
    - Each molecule must contain between two and five atoms.
    - All the bonding sites (the protruding "sticks") of an atom must be connected to those of another atom.

    After drawing each molecule, pull it apart before constructing the next.
12. Construct and draw two more molecules following only one rule:
    - All the bonding sites must be connected to those of another atom.
13. Take all the molecules apart, and return all the pieces to the set.
14. Compare your drawings with those of the other pair in your group.
15. Construct and draw a model of a molecule with the formula CO_2.

ANALYSIS

1. How many different elements were you working with?
2. What was the role of the "sticks" on each atom model?
3. Was it possible for an atom to make more than one bond? Explain and give an example.
4. How many bonds could each of the following make with hydrogen? Copy the table below into your science notebook. Use the atomic numbers to help you find the elements on the periodic table.

Bonds with Hydrogen

Element	Atomic Number	Number of Bonds with Hydrogen
Si	14	
Se	34	
I	53	
As	33	

5. If you had two oxygen atoms and one hydrogen atom, could you form a molecule? Explain.
6. Make a drawing to show the difference between an atom and a molecule.
7. Which model provides more information—a chemical formula or a sketch of the molecule?