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

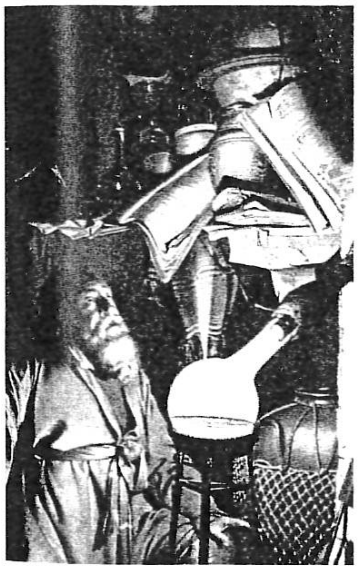
For each student

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 of

THE PERIODICITY OF THE ELEMENTS

The Elements	Their Properties in the Free State				The Composition of the Hydrogen and Organo-metallic Compounds	Symbols and Atomic Weights	The Composition of the Saline Oxides	The Properties of the Saline Oxides			Small Periods or Series
	t	a	d	$\frac{A}{n}$	RH_m or $R(CH_3)_m$	R A	R_2O_n	d	$\frac{(2A-n\cdot16)}{n}$	V	
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]
Hydrogen	<−200	—	<0·05	20	$m=1$	H 1	1 $n=8$	0·917	19·6	<−20	1
Lithium	186	—	0·59	12		Li 7	1†	2·0	15	− 9	2
Beryllium	(900°)	—	1·64	5·5		Be 9	— 2	3·06	16·3	+ 2·6	
Boron	(1500°)	—	2·5	4·4	3 — —	B 11	— — 3	1·8	39	10	
Carbon	>(2500°)	—	<2·0	> 6	4 — — —	C 12	— — — 4	>1·0	<88	<19	
Nitrogen	−205°	—	<0·7	> 20	3 — —	N 14	1 — 3* — 5*	1·04	66	< 5	
Oxygen	<−200	—	<1·0	> 16	2 —	O 16	— — —	—	—	—	
Fluorine	—	—	—	—	1	F 19	— — —	—	—	—	
Sodium	96°	071	0·98	23	1	Na 23	1† — —	Na_2O	2·6	24	−2·2	3
Magnesium	500	027	1·74	14	2 —	Mg 24	— 2† —		3·6	22	− 2	
Aluminium	600°	023	2·6	11	3 — —	Al 27	— — 3 —	Al_2O_3	4·0	26	+ 1·3	
Silicon	(1200°)	008	2·5	12	4 — — —	Si 28	— — 3 4		2·65	45	5·2	
Phosphorus	44°	128	2·2	14	3 — —	P 31	1 — 3* 4* 5*		2·29	59	6·2	
Sulphur	114°	097	2·07	15	2 —	S 32	— 2 — 4* 5* 6*		1·96	82	8·7	
Chlorine	−73°	—	1·3	27	1	Cl 35½	1 — 3 — 5* — 7*		—	—	—	
Potassium	58°	084	0·87	45		K 39	1† — — —		2·7	85	−5·5	4
Calcium	(800°)	—	1·6	25		Ca 40	— 2† — —		3·15	86	− 7	
Scandium	—	—	(2·5)	(18)		Sc 44	— — 3† —		3·86	85	(0)	
Titanium	(2500°)	—	(5·3)	(9·4)		Ti 48	— — 3 4		4·2	88	(+ 5)	
Vanadium	(2000°)	—	5·5	9·2		V 51	— 2 3 4 5		3·49	53	6·7	
Chromium	(2000°)	—	5·5	8·0		Cr 52	— 2 3 — — 6*		2·74	78	9·5	
Manganese	(1500°)	—	7·5	7·3		Mn 55	— 2† 3 4 — 6* 7*		—	—	—	
Iron	1400°	012	7·8	7·2		Fe 56	— 2† 3 — — 6*		—	—	—	
Cobalt	(1400°)	013	8·6	6·8		Co 58½	— 2† 3 4		—	—	—	
Nickel	1450°	017	8·7	6·8		Ni 59	— 2† 3		—	—	—	
Copper	1054°	023	8·8	7·2		Cu 63	1† 2† —	Cu_2O	5·9	34	5·5	5
Zinc	422°	—	7·1	9·2	2	Zn 65	— 2† —		6·7	28	4·8	
Gallium	30°	—	5·96	12	3 — —	Ga 70	— — 3	Ga_2O_3 (5·1)		(36)	(4·0)	
Germanium	900°	—	5·47	13	4 — — —	Ge 72	— — 3 — 4		4·7	44	4·5	
Arsenic	500°	006	5·7	13	3 — —	As 75	— — 3 — 5*		4·1	56	6·0	
Selenium	217°	—	4·8	16	2 —	Se 79	— — — 4 — 6*		—	—	—	
Bromine	−7°	—	3·1	26	1	Br 80	1 — — — 5* — 7*		—	—	—	
Rubidium	39°	—	1·5	57		Rb 85	1† — — —		—	—	—	6
Strontium	(600°)	—	2·5	35		Sr 87	— 2† — —		4·3	48	+ 1·1	
Yttrium	—	—	(3·4)	(26)		Y 89	— — 3† —		5·05	45	(− 2)	
Zirconium	(1500°)	—	4·1	22		Zr 90	— — — 4		5·7	43	+0·2	
Niobium	—	—	7·1	13		Nb 94	— — 3 — 5*		4·7	57	+ 0·2	
Molybdenum	—	—	8·6	12		Mo 96	— 2 3 4 — 6*		4·4	65	6·8	
					(1)							
Ruthenium	(2000°)	010	12·2	8·4		Ru 103	— 2 3 4 — 6 — 8		—	—	—	
Rhodium	(1900°)	008	12·1	8·6		Rh 104	— 2 3 4 — 6		—	—	—	
Palladium	1500°	012	11·4	8·3		Pd 106	1† 2 — 4		—	—	—	
Silver	950°	010	10·5	10		Ag 108	1†	Ag_2O	7·5	31	11	7
Cadmium	320°	031	8·6	13	2 —	Cd 112	— 2† —		8·15	31	9·5	
Indium	176°	046	7·4	14	3 — —	In 113	— — 3	In_2O_3	7·18	38	9·7	
Tin	230°	023	7·2	16	4 — — —	Sn 118	— 2 — 4		6·95	43	9·8	
Antimony	432°	012	6·7	18	3 — —	Sb 120	— — 3 4 5		6·5	49	9·6	8
Tellurium	455°	017	6·4	20	2 —	Te 125	— — — 4 — 6*		5·1	63	9·7	
Iodine	114°	—	4·9	26	1	I 127	1 — 3 — 5* — 7*		—	—	—	
Cæsium	27°	—	1·88	71		Cs 133	1†		—	—	—	
Barium	—	—	3·75	36		Ba 137	— 2†		5·1	69	6·0	
Lanthanum	(920)	—	6·1	23		La 138	— — 3†		6·5	50	+ 1·3	
Cerium	(700°)	—	6·6	21		Ce 140	— — 3 4		6·74	50	2·0	
Didymium	(800°)	—	6·5	22		Di 142	— — 3 — 5		—	—	—	
					(14)							
Ytterbium	—	—	(6·9)	(25)		Yb 173	— — 3		9·18	43	(− 2·	10
					(1)							
Tantalum	—	—	10·1	18		Ta 182	— — — — 5		7·5	59	4·6	
Tungsten	(1500°)	—	19·1	9·6		W 184	— — — 4 — 6		6·9	67	8	
					(1)							
Osmium	(2500°)	007	22·5	8·5		Os 191	— — 3 4 — 6 — 8		—	—	—	
Iridium	2000°	007	22·4	8·6		Ir 193	— — 3 4 — 6		—	—	—	
Platinum	1775°	005	21·5	9·2		Pt 196	— 2 — 4		—	—	—	
Gold	1045°	014	19·3	19		Au 198	1 — 3	Au_2O	(12·5)	(33)	(13·	11
Mercury	−39°	—	13·6	15	2 —	Hg 200	1† 2†		11·1	29	4·5	
Thallium	294°	031	11·8	17	3 — —	Tl 204	1† — 3	Tl_2O_3	(9·7)	(47)	(4·3)	
Lead	326°	029	11·3	18	4 — — —	Pb 206	— 2† — 4		8·9	53	4·2	
Bismuth	268	014	9·8	21	3 — —	Bi 208	— — 3 — 5		—	—	—	
					(5)							
Thorium	—	—	11·1	21		Th 232	— — — 4		9·86	54	2·0	12
					(1)							
Uranium	(800°)	—	18·7	13		U 240	— — — 4 — 6		(7·2)	(80)	(0·	

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.

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.

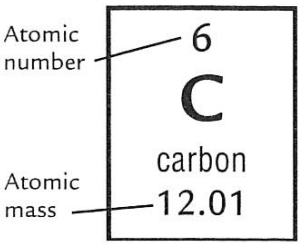
Other scientists used Mendeleev's ideas and built on them to identify the elements he predicted. Later scientists found many more elements that follow the patterns he found. The modern version of the table is called the **Periodic Table of the Elements**. Based on new data about the elements, scientists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

1																	18
1 H hydrogen 1.008	2											13	14	15	16	17	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 47.88	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 72.58	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)	45 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	57 La* lanthanum 138.9	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.9	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 190.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.5	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 208.9	84 Po polonium (209)	85 At astatine (210)	86 Rn radon (222)
87 Fr francium (223)	88 Ra radium (226)	89 Ac~ actinium (227)	104 Rf rutherfordium (257)	105 Db dubnium (260)	106 Sg seaborgium (263)	107 Bh bohrium (262)	108 Hs hassium (265)	109 Mt meitnerium (266)	110 Ds darmstadtium (271)	111 Uuu (272)	112 112 (277)		114 Uuq (296)		116 Uuh (298)		118 Uuo (?)

*Lanthanide Series	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd nenodymium 144.2	61 Pm promethium (147)	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	71 Lu luteium 175.0
~Actinide Series	90 Th thorium 232.0	91 Pa protactinium (231)	92 U uranium (238)	93 Np neptunium (237)	94 Pu plutonium (242)	95 Am americium (243)	96 Cm curium (247)	97 Bk berkelium (247)	98 Cf californium (249)	99 Es einsteinium (254)	100 Fm fermium (253)	101 Md mendelevium (256)	102 No nobelium (254)	103 Lr lawrencium (257)

Shading Key
- A Solid at room temperature
- A Liquid at room temperature
- A Gas at room temperature

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.

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 might also notice that one of the newer synthesized elements, 112, is a liquid. This is interesting to note because it falls below the element mercury (atomic number 80), which is a liquid at room temperature.

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.

STOPPING TO THINK 4

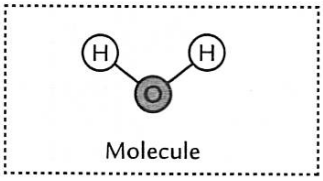
Find magnesium on the periodic table.

- 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!

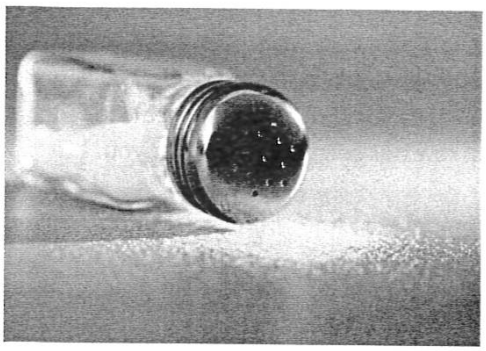
Compounds have different properties than the elements that form them. For example, the compound we call water is a liquid formed from two gases—hydrogen and oxygen. Table sugar is an edible white solid formed from a black solid (carbon) and the gases hydrogen and oxygen.

STOPPING TO THINK 5

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

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



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

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 $\mathbf{H_2O}$. (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.

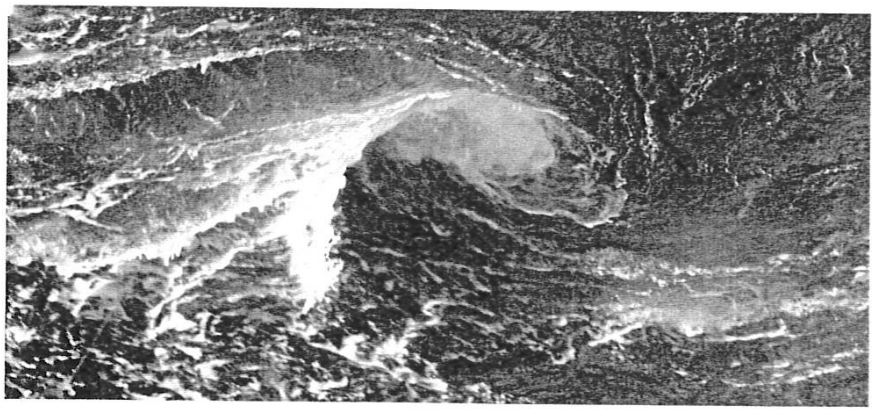
STOPPING TO THINK 6

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

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.

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



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.

Periodic Table of the Elements