CHAPTER

2

Matter

SECTION

2.1 Matter: Pure Substances and Mixtures

Matter can be classified in yet other ways. For example, we can subdivide matter into pure substances and mixtures (Figure). **Pure substances** have a definite, or fixed, composition. The composition of **mixtures** may vary. Water is a pure substance; it always contains 11% hydrogen and 89% oxygen by weight. Similarly, pure gold is pure gold, that is, 100% gold. A milk shake, on the other hand, is a mixture. The proportions of milk, ice cream, and flavorings change depending on who is preparing the shake. Mixed nuts are a mixture; the ratio of peanuts to pecans depends on how much you are willing to pay per pound.

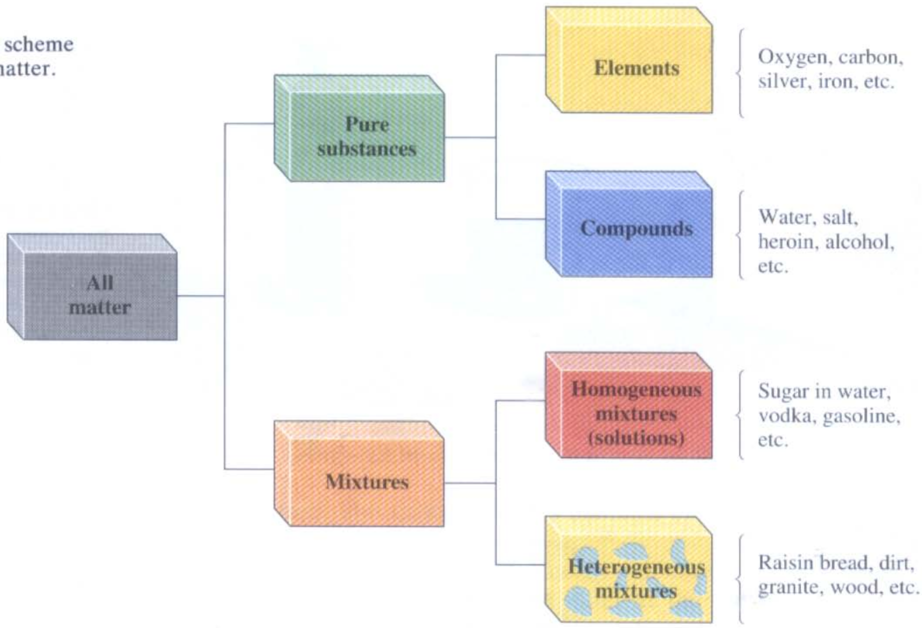


Figure A scheme for classifying matter.

Elements and Compounds

Pure substances may be either elements or compounds. **Elements** are those fundamental substances from which all material things are constructed. **Compounds** are pure substances that are made up of two or more elements chemically combined in constant or fixed proportions. Our ideas about elements have changed during historical times. Fire was once considered an element, but it is now regarded as nonmaterial, that is, as a form of energy. Water was once thought to be an element, but we now know it to be a compound composed of two elements, hydrogen and oxygen. We presently regard as elements a few more than 100 pure substances that cannot be broken down by chemical means into simpler substances. Sulfur, oxygen, carbon, and iron are elements. Sulfur dioxide, carbon disulfide, and iron sulfide are compounds.

Because elements are so fundamental to our study of chemistry, we find it useful to refer to them in a shorthand form. Each element can be represented by a **chemical symbol** made up of one or two letters derived from the name of the element (or, sometimes, from the Latin name of the element). The first letter of the symbol is always capitalized; the second is always lowercase. (It makes a difference. For example, Hf is the symbol for hafnium, an element, but HF is the formula for hydrogen fluoride, a compound. Similarly, Co is cobalt, an element; CO is carbon monoxide, a compound.)

Symbols are the alphabet of chemistry. Symbols for the more important elements studied in this book are given in Table . Memorization of the names and symbols of the elements shown in that table is well worth your time. You will find that discussion much easier to follow if you are familiar with some of the more common elemental symbols.

A chemical symbol in a formula stands for one atom of the element. If more than one atom is to be indicated in a formula, a subscripted number is used after the symbol. For example, the formula Cl_2 represents two atoms of chlorine, and the formula CCl_4 stands for one atom of carbon and four atoms of chlorine. Table gives actual formulas (Br_2, P_4, S_8, and so on) for some of the elements as they occur when in the elemental form. You need not concern yourself with such formulas now; they are included in the table for your future reference.

Table Names, Symbols, and Physical Characteristics of Some Common Elements

Name (Latin name)	Symbol	Selected Properties
Aluminum	Al	Light, silvery metal
Argon	Ar	Colorless gas
Arsenic	As	Grayish white solid
Barium	Ba	Silvery white metal
Beryllium	Be	Steel gray, hard, light solid
Boron	B	Black or brown powder; several crystal forms
Bromine	Br	Reddish brown liquid (Br_2)
Calcium	Ca	Silvery white metal
Carbon	C	Soft black solid (graphite) or hard, brilliant crystal (diamond)
Chlorine	Cl	Greenish yellow gas (Cl_2)
Copper (Cuprum)	Cu	Light reddish brown metal
Fluorine	F	Pale yellow gas (F_2)
Gold (Aurum)	Au	Yellow, malleable metal
Helium	He	Colorless gas
Hydrogen	H	Colorless gas (H_2)
Iodine	I	Lustrous black solid (I_2)
Iron (Ferrum)	Fe	Silvery white, ductile, malleable metal
Lead (Plumbum)	Pb	Bluish white, soft, heavy metal
Lithium	Li	Silvery white, soft, light metal
Magnesium	Mg	Silvery white, ductile, light metal
Mercury (Hydrargyrum)	Hg	Silvery white, liquid, heavy metal
Neon	Ne	Colorless gas
Nickel	Ni	Silvery white, ductile, malleable metal
Nitrogen	N	Colorless gas (N_2)
Oxygen	O	Colorless gas (O_2)
Phosphorus	P	Yellowish white waxy solid or red powder (P_4)
Plutonium	Pu	Silvery white, radioactive metal
Potassium (Kalium)	K	Silvery white, soft metal
Silicon	Si	Lustrous gray solid
Silver (Argentum)	Ag	Silvery white metal
Sodium (Natrium)	Na	Silvery white, soft metal
Sulfur	S	Yellow solid (S_8)
Tin (Stannum)	Sn	Silvery white, soft metal
Uranium	U	Silvery, radioactive metal
Zinc	Zn	Bluish white metal

SECTION

2.2 Electron Configurations and the Periodic Table

The modern periodic table (inside front cover) has vertical columns called **groups** or (sometimes) *families*. The horizontal rows of the periodic table are called **periods**. Elements in a group have similar chemical properties. The properties of elements vary periodically across a period.

In the United States, the groups are usually indicated by a Roman numeral followed by the letter A or B. The International Union of Pure and Applied Chemistry (IUPAC) recommends numbering the groups from 1 to 18. Both systems are indicated on the periodic table on the inside front cover, but we follow the traditional U.S. method in this book.

In the United States, the letter A indentifies the **main group elements** and B indicates the **transition elements**. (Nearly opposite usage prevailed in Europe, leading IUPAC to develop the new system.)

Metals, Nonmetals, and Metalloids

Elements also are divided into two classes by a heavy, stepped diagonal line. Those to the left of the line are **metals**, elements that have a characteristic luster and generally are good conductors of heat and electricity. Except for mercury, which is a liquid, all the metals are solids at room temperature. Metals generally are **malleable**; that is, they can be hammered into thin sheets. Most also are **ductile**; they can be drawn into wires.

Elements to the right of the stepped line are **nonmetals**. These elements lack metallic properties. Several are gases (oxygen, nitrogen, fluorine, chlorine). Others are solids (carbon, sulfur, phosphorus, iodine). Bromine is the only nonmetal that is a liquid at room temperature.

Some of the elements bordering the stepped line are **metalloids**, elements that have intermediate properties. Metalloids have properties that resemble those of both the metals and the nonmetals.

Family Groups

Elements within a group have similar properties. For example, the elements in Group IA are all (except hydrogen) soft, highly reactive metals. These elements, often called the **alkali metals**, react vigorously with water to evolve hydrogen gas. There are important *trends* within a family. For example, lithium is the hardest metal of the group. Sodium is softer than lithium; potassium is softer still, and so on down the group. Lithium is also the least reactive toward water. Sodium, potassium, rubidium, and cesium are progressively more reactive. (Francium is highly radioactive and extremely rare; few of its properties have been measured.) Hydrogen is the odd one of Group IA. It is *not* an alkali metal. Indeed, it is a rather characteristic nonmetal. As far as its properties are concerned, hydrogen probably should be put in a group of its own.

Group IIA elements are sometimes known as the **alkaline earth metals**. The metals in this group are fairly soft and moderately reactive with water. Beryllium is an odd member of the group in that it is rather hard and does not react with water. There are trends in properties within the group—as there are in the other families. For example, magnesium, calcium, strontium, barium, and radium are progressively more reactive toward water.

Group VIIA elements, often called **halogens**, also consists of reactive elements. For example, the halogens react vigorously with the alkali metals to form crystalline solids (more about this in Chapter). There are trends in the halogen family. Fluorine is the most reactive of the halogens toward the alkali metals, chlorine next, and so on. Fluorine and chlorine are gases at room temperature, bromine is a liquid, and iodine is a solid. (Astatine, like francium, is highly radioactive and extremely rare; few of its properties have been determined.)

The group to the far right of the periodic table (sometimes called Group VIIIA) is known as the **noble gases**. The noble gases are known for their lack of chemical reactivity; their main chemical property is that they undergo few chemical reactions.

Family Features: Outer Electron Configurations

The electrons in the highest energy level of an atom are called the **valence electrons**. The number of valence electrons is the same for each element in a group. We can now demonstrate this with electron configurations using sublevel notations.

All the elements in Group IA (the alkali metals) have their single outermost electron in an *s* orbital. The outer electron in lithium (Li) is denoted $2s^1$, that in sodium (Na) as $3s^1$, that in potassium (K) as $4s^1$, and so on. We can say, then, that all Group IA metals have the outer electron structure ns^1, where n denotes the main energy level. Similarly, all the Group IIA elements have the outer electron structure ns^2; that is, the two outermost electrons in any Group IIA atom are in an *s* orbital. All Group VIIA elements have their seven outermost electrons in the ns^2np^5 configuration. Helium has the electron configuration $1s^2$, a filled first energy level. Neon has the configuration $1s^22s^22p^6$, a filled second energy level. All the other noble gases have the valence electron configuration ns^2np^6. All the noble gases have either filled outer energy levels (helium and neon) or a filled outer *p* sublevel. These are especially stable configurations and account for the lack of reactivity of these elements.

In general the properties of all the elements can be correlated with their electron configurations.

Table Electron Structures for Atoms of the First 20 Elements

Name	Atomic Number	Electron Structure
Hydrogen	1	$1s^1$
Helium	2	$1s^2$
Lithium	3	$1s^22s^1$
Beryllium	4	$1s^22s^2$
Boron	5	$1s^22s^22p^1$
Carbon	6	$1s^22s^22p^2$
Nitrogen	7	$1s^22s^22p^3$
Oxygen	8	$1s^22s^22p^4$
Fluorine	9	$1s^22s^22p^5$
Neon	10	$1s^22s^22p^6$
Sodium	11	$1s^22s^22p^63s^1$
Magnesium	12	$1s^22s^22p^63s^2$
Aluminum	13	$1s^22s^22p^63s^23p^1$
Silicon	14	$1s^22s^22p^63s^23p^2$
Phosphorus	15	$1s^22s^22p^63s^23p^3$
Sulfur	16	$1s^22s^22p^63s^23p^4$
Chlorine	17	$1s^22s^22p^63s^23p^5$
Argon	18	$1s^22s^22p^63s^23p^6$
Potassium	19	$1s^22s^22p^63s^23p^64s^1$
Calcium	20	$1s^22s^22p^63s^23p^64s^2$

Figure relates the sublevel configurations to the various groups of the periodic table.

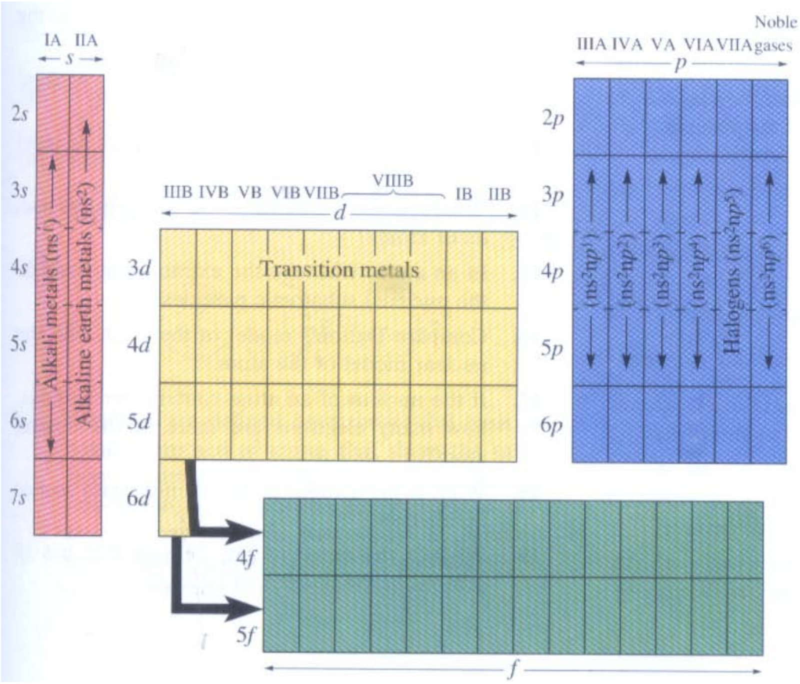


Figure Electron configurations and the periodic table.

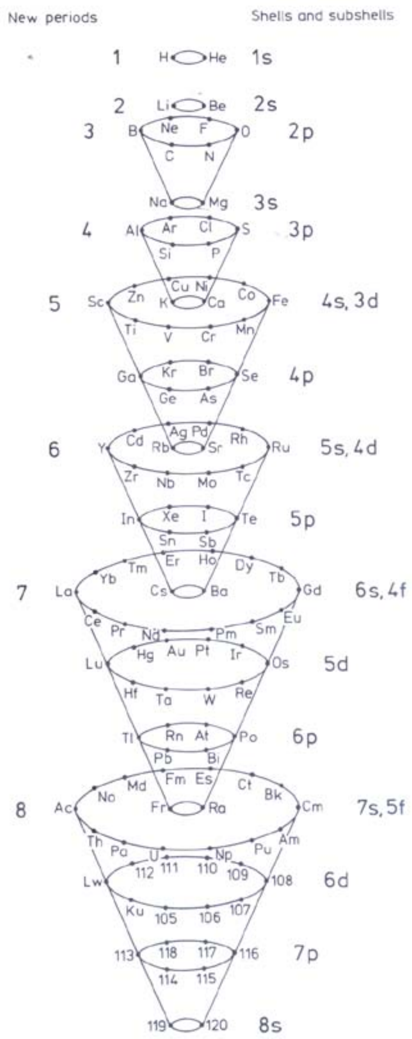
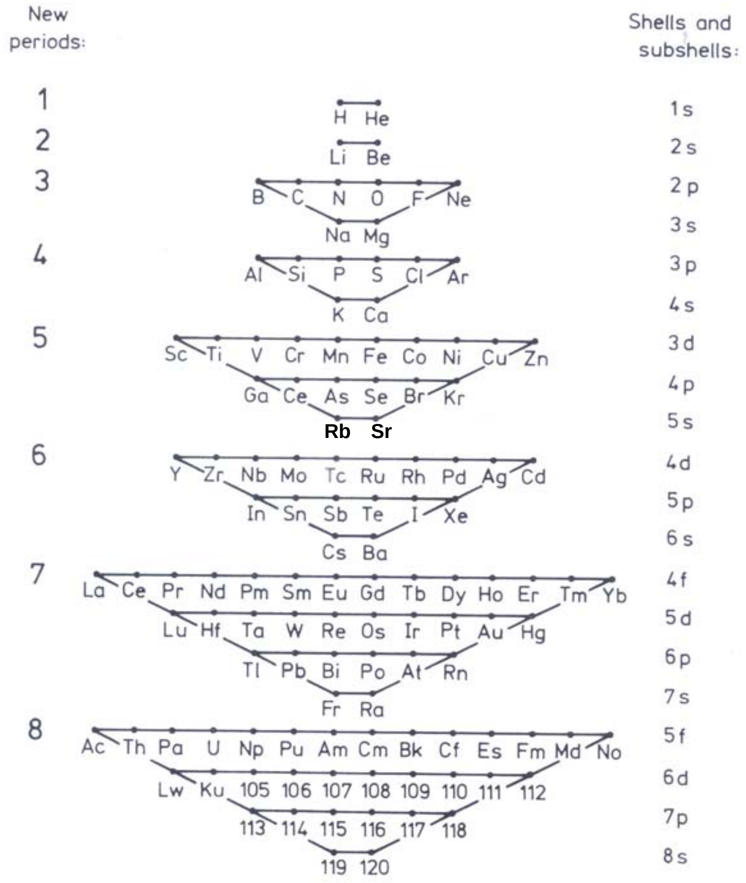


Figure
Periodic system by Mazurs [1-15] with concentric circles in space representing the subshells with 2, 6, 10, and 14 elements on them, and with period cones stretched vertically. From *Graphic Representations of the Periodic System During One Hundred Years,* Revised (2nd) edition, © 1974 by The University of Alabama Press. Used by permission.

Figure 2.4
Periodic system by Mazurs [1-15] with parallel lines and bilateral symmetry. The subshell lines are arranged in the order in which they are filled by electrons. The subshell lines of each period are connected to form inverted trapezoids. From *Graphic Representations of the Periodic System During One Hundred Years*, Revised (2nd) edition, © 1974 by The University of Alabama Press. Used by permission.



Exercises

Write out the sublevel notation for the electrons in the highest main energy level for strontium (Sr) and arsenic (As).