3.7: Completing the 20-Element Periodic Table

So far in this chapter 10 elements have been defined and discussed. A total of 10 more are required to complete the 20-element abbreviated periodic table. Their names and properties are summarized briefly here. The periodic table is given in Figure 3.9.

Sodium, **Na**, atomic number 11, atomic mass 22.99, comes directly below lithium in the periodic table and is very similar to lithium in being a soft, chemically very reactive metal. There is one major isotope of sodium containing 12 neutrons in the atom's nucleus. Sodium has 10 inner-shell electrons contained in its first inner shell of 2 electrons and its second one of 8 electrons. The 11th electron in the sodium atom is in a third shell, which is an outer shell. This is shown as a single dot in the Lewis symbol of Na in Figure 3.7. The electrons in sodium can be represented as shown in Figure 3.7.

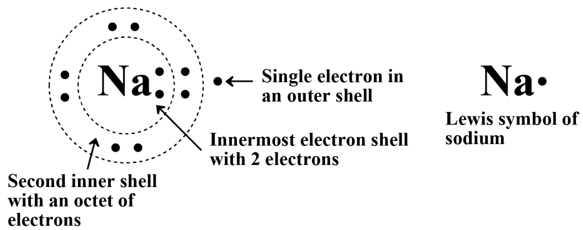

Figure 3.7. Representation of the electrons in 2 inner shells and 1 outer shell of sodium and the Lewis symbol of sodium.

Magnesium, **Mg**, atomic number 12, atomic mass 24.31, has 12 electrons per atom so it has 2 outer shell electrons. There are three isotopes of magnesium containing 12, 13, and 14 neutrons. Magnesium is a relatively strong, very lightweight metal that is used in aircraft, extension ladders, portable tools, and other applications where light weight is particularly important.

Aluminum, **Al**, atomic number 13, atomic mass 26.98, has 3 outer-shell electrons in addition to its 10 inner electrons. Aluminum is a lightweight metal used in aircraft, automobiles, electrical transmission lines, building construction and many other applications. Although it is chemically reactive, the oxide coating formed when aluminum on the surface of the metal reacts with oxygen in air is self-protecting and prevents more corrosion.

In some important respects aluminum can be regarded as a green metal. This is because aluminum enables construction of strong lightweight components which, when used in aircraft and automobiles, require relatively less energy to move. So aluminum is important in energy conservation. Aluminum cables also provide an efficient way to transmit electricity. Although the ores from which aluminum is made are an extractive resource dug from the earth, aluminum is an abundant element. And there are alternative resources that can be developed, including aluminum in the fly ash left over from coal combustion. Furthermore, aluminum is one of the most recyclable metals, and scrap aluminum is readily melted down and cast into new aluminum goods.

If an "element of the century" were to be named for the 1900s, humble **silicon**, **Si**, atomic number 14, atomic mass 28.09, would be a likely candidate. This is because silicon is the most commonly used of the semiconductor elements and during the latter 1900s provided the basis for the explosion in electronics and computers based upon semiconductor devices composed primarily of silicon. Despite the value of these silicon-based products, silicon is abundant in soil and rocks, ranking second behind oxygen as a constituent of Earth's crust. The silicon atom has 4 outer-shell electrons, half an octet, and it is a metalloid, intermediate in behavior between the metals on the left of the periodic table and the nonmetals on the right.

By vastly reducing the bulk of electronic components relative to performance, silicon has contributed to a huge saving of materials used in radios, televisions, communications equipment, and other electronic devices. Furthermore, the silicon-based semiconductor devices used in solid-state electronics consumes only a fraction of the electricity once used by vacuum tube based devices. The bulky wires made of relatively scarce copper formerly employed for transmitting communications signals electrically have been largely replaced by fiber optic devices consisting of transparent silica, SiO2, which transfer information as pulses of light. A hair-like optical fiber can transmit many times the amount of information per unit time as the thick copper wire that it replaces. And the energy required for transmission of a unit of information by a fiber optic cable is minuscule compared to that required to send the same information by electrical impulse over copper wire. So silicon is truly a green element that, although cheap and abundant, performs electronic and communications functions much faster and better than the copper and other metals that it has replaced.

Phosphorus, **P**, atomic number 15, atomic mass 30.97, has 5 outer-shell electrons. So it is directly below nitrogen in the periodic table and resembles nitrogen in its chemical behavior. Pure elemental phosphorus occurs in several forms, the most abundant of which is white phosphorus. White phosphorus is a chemically very reactive nonmetal that may catch fire spontaneously in the atmosphere. It is toxic and causes deterioration of bone. The jawbone is especially susceptible to the effects of phosphorus and develops a condition known as "phossy jaw" in which the bone becomes porous and weak and may break from the strain of chewing. Chemically combined phosphorus is an essential life element, however, and is one of the components of DNA, the basic molecule that directs molecular life processes. Phosphorus is also an essential plant fertilizer and is an ingredient of many industrial chemicals including some pesticides.

Arsenic is in the same group of the periodic table as phosphorus and occurs as an impurity with phosphorus processed from ore. If this phosphorus is to be used for food, the arsenic has to be removed.

Sulfur, **S**, atomic number 16, atomic mass 32.06, has 6 outer-shell electrons. It is a brittle, generally yellow nonmetal. It is an essential nutrient for plants and animals occurring in the amino acids that compose proteins. Sulfur is a common air pollutant emitted as sulfur dioxide, SO2, in the combustion of fossil fuels that contain sulfur. Much of the large quantities of sulfur required for industrial production of sulfuric acid and other sulfur-containing chemicals is reclaimed from the hydrogen sulfide, H2S, that contaminates much of the natural gas (methane, CH4) that is such an important fuel and raw material in the world today. In keeping with the best practice of green chemistry, the hydrogen sulfide is separated from the raw natural gas and about 1/3 of it is burned,

$$2\,H_2S + 3\,O_2 \rightarrow 2\,SO_2 + 2\,H_2O \tag{3.7.1}$$

producing sulfur dioxide, SO2. The sulfur dioxide produced is then reacted with the remaining hydrogen sulfide through the Claus reaction, below, yielding an elemental sulfur product that is used to synthesize sulfuric acid and other sulfur chemicals.

$$2\,H_2S + SO_2 \rightarrow 3\,S + 2\,H_2O \tag{3.7.2}$$

Chlorine, **Cl**, atomic number 17, atomic mass 35.453, has 7 outer-shell electrons, just 1 electron short of a full octet. Elemental chlorine is a greenish-yellow diatomic gas consisting of Cl2 molecules. In these molecules the Cl atoms attain stable octets of outer-shell electrons by sharing two electrons in a covalent bond as illustrated in Figure 3.8. The chlorine atom can also accept an electron to attain a stable octet in the Cl- anion as shown in the ionic compound sodium chloride, NaCl, in Figure 3.8.

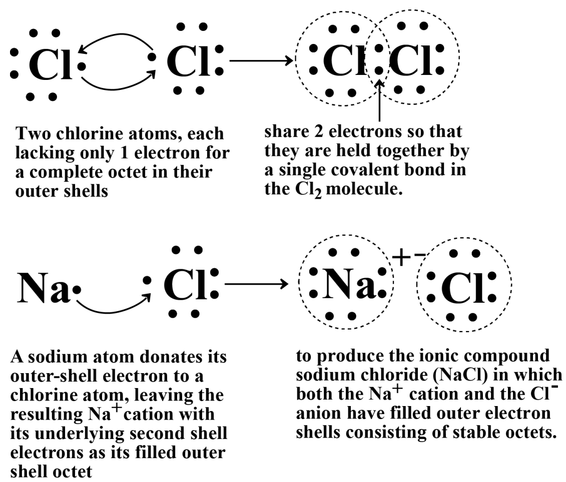

Figure 3.8. Chlorine atoms can attain a stable octet of outer-shell electrons by sharing electrons in covalent bonds, as shown for molecular diatomic elemental Cl2, or by accepting electrons to produce Cl- anion as shown for ionic sodium chloride, NaCl.

Elemental chlorine can be deadly when inhaled and was the first military poison gas used in World War I. Despite its toxic nature, chlorine gas has saved many lives because of its use for approximately the last 100 years as a drinking water disinfectant that has eradicated deadly water-borne diseases, such as cholera and typhoid. Chlorine is an important industrial chemical that is used to make plastics and solvents. There is no possibility of a shortage of chlorine and it can even be made by passing an electrical current through seawater, which contains chlorine as dissolved sodium chloride.

The green aspects of chlorine depend upon its application. Elemental chlorine is certainly a dangerous material whose manufacture and use are generally to be avoided where possible in the practice of green chemistry. But, as noted above, elemental chlorine has saved many lives because of its uses to disinfect water. A number of persistent pesticides including DDT are organic compounds composed of chlorine along with carbon and hydrogen. In addition to the ecological damage done by these pesticides, the waste byproducts of their manufacture and of the production of other organochlorine compounds are among the most abundant contaminants of troublesome hazardous waste chemical dumps. A common plastic, polyvinyl chloride (PVC), contains chlorine. This plastic is widely used in water pipe and drain pipe, in the former application replacing relatively scarce and expensive copper metal and toxic lead. But the material used to make PVC is volatile vinyl chloride. It is one of the few known human carcinogens, having caused documented cases of a rare form of liver cancer in workers formerly exposed to very high levels of vinyl chloride vapor in the workplace. Because of the dangers of elemental chlorine and the problems caused by organochlorine compounds, the practice of green chemistry certainly tries to minimize the production and use of elemental chlorine and generally attempts to minimize production of organochlorine compounds and their dispersion in the environment.

Element number 18, **argon**, **Ar**, atomic mass 39.95, brings us to the end of the third period of the abbreviated periodic table. It has a complete octet of outer-shell electrons and is a noble gas. No true chemical compounds of argon have been isolated and no chemical bonds involving this element were known until formation of a very unstable transient bond involving Ar atoms was reported in September, 2000. Argon composes about 1% by volume in the atmosphere. Largely because of its chemically inert nature, argon has some uses. It is employed as a gas to fill incandescent light bulbs. In this respect it helps prevent evaporation of white-hot tungsten atoms from the glowing lamp filament, thus significantly extending bulb life. It is also used as a plasma medium in instruments employed for inductively coupled plasma atomic emission analysis of elemental pollutants. In this application a radiofrequency signal is used to convert the argon to a gaseous plasma that contains positively charged Ar+ ions and negatively charged electrons and is heated to an incredibly hot 10,000˚C.

Completing the Periodic Table

The next element to be added to the abbreviated periodic table is element number 19. This begins a fourth period of the periodic table. This period actually contains 18 elements, but we will take it only as far as the first two. That is because element number 21 is the first of the transition metals and to explain their placement in the periodic table on the basis of the electrons in them gets a little more complicated and involved than is appropriate for this book. The reader needing more details is referred to other standard books on beginning chemistry.2,3

The element with atomic number 19 is **potassium**, **K**, having an atomic mass of 39.10. Most potassium consists of the isotope with 20 neutrons, $^{39}_{19}K$. However, a small fraction of naturally occurring K is in the form of $^{40}_{19}K$. This is a radioactive isotope of potassium and since we all have potassium (an essential element for life) in our bodies, we all are naturally radioactive! Muscle mass contains more potassium than adipose (fat) tissue, so more muscular people are more radioactive. But not to worry, the levels of radioactivity from potassium in the body are too low to cause concern and, under any circumstances, cannot be avoided. (One proponent of nuclear energy has pointed out that sleeping with a muscular person exposes one to more radioactivity than does living close to a nuclear power reactor.)

The same things that can be said of sodium, element number 11, are generally true of potassium. In the pure elemental state, potassium is a very reactive *alkali metal*. As an essential element for life, it is a common fertilizer added to soil to make crops grow well. Chemically, potassium loses its single outer-shell electron to produce K+ ion.

Calcium, **Ca**, atomic number 20, atomic mass 40.08, has 2 outer-shell electrons, two beyond a full octet. The calcium atom readily loses its 2 “extra” electrons to produce Ca2+ cation. Like other elements in its group in the periodic table, calcium is an alkaline earth metal. Elemental calcium metal is chemically reactive, though not so much so as potassium. Calcium has chemical properties very similar to those of magnesium, the alkaline earth metal directly above calcium in the periodic table.

Calcium is essential for life, although most soils contain sufficient calcium to support optimum crop growth. Calcium is very important in our own bodies because as hard mineral hydroxyapatite, Ca5OH(PO4)3, it is the hard material in teeth and bones. Calcium deficiency can cause formation of poor teeth and the development of disabling osteoporosis a condition characterized by weak bones that is especially likely to afflict older women.