Metals and Alloys

1.15 Metals have many effects on the human body

Virtually all metals exist as solids at room temperature. Mercury is the only metallic element that is a liquid under normal conditions. If cooled to −39°C, it does freeze to a solid. Liquid mercury is shiny and metallic-looking.

The word *vapor* is used to describe the gaseous form of a substance that is normally a liquid or solid.

You have probably heard a fair amount about the toxicity of mercury. As a liquid, it is not especially toxic when swallowed since most of it passes through the body unchanged. However, mercury vapor is highly toxic, as are all compounds of mercury that dissolve in water to form solutions. Once they enter the body, these forms of mercury can attack the brain and produce mental and physiological disturbances. An incident in Texarkana, on the Texas-Arkansas border, illustrated the hazards of handling mercury. Two teenagers stole 40 pounds of liquid mercury from a site where it had been used to make neon lights. They poured it over themselves and on floors in their homes, gave it out to friends, and even dipped cigarettes into the liquid and smoked them. Within days they began to exhibit the signs of mercury poisoning: coughing up blood, vomiting, breathing difficulties, and seizures. The end result was that eight contaminated homes were evacuated, a family dog was killed by the vapors, and more than 170 people in the town and surrounding areas received medical treatment for mercury exposure.

Mercury poisoning was much more common in the 19^{th} century when workers who used mercury to cure felt hats developed twitches, spoke incoherently, and drooled as a result of long-term exposure to mercury vapors. These workers provided Lewis Carroll with a model for the Mad Hatter in *Alice in Wonderland*. These days, most of the mercury that enters the environment comes from the incineration of waste and sewage sludge, and the burning of fuels. Recently, scrapping cars without removing the elemental mercury used in light switches and other components was identified as a significant source of the element to the environment.

▷ Discussion Point

Should we phase out the use of mercury?

Do you think we should continue to use mercury-containing products? Use the resources at the end of the chapter to identify mercury-containing products in common use. What are the advantages and disadvantages of their use? Develop arguments both for and against the use of mercury.

A Global/Local Perspective

Address: www.whfreeman.com/chemistryinyourlife → GO

Mercury in the Environment

Go to the website above and choose "Global/Local" to link to websites that will help you determine which human activities contribute to mercury pollution in *your* area. What human activities contribute to mercury pollution in other parts of the world? What steps could be taken by individuals, communities, and industries to minimize mercury pollution?

Other metals can have various effects, both bad and good, on the body. Sweat contains various chemicals that can react with nickel and copper in jewelry. These chemicals dissolve the metals and allow them to interact with cosmetics, detergents, or the components of sweat on the skin, forming new chemical compounds. These new compounds can, in turn, sometimes produce black, or rust-colored, or green discolorations on the skin surface.

Humans are amazingly sensitive to nickel, which can be carried into the body from the skin when even a small amount of it dissolves in sweat. Sensitivity to nickel is the main reason that some people develop rashes when they pierce some part of their body and attach stainless steel or gold-plated objects such as studs. These objects usually contain a tiny proportion of nickel, especially in the metal that lies below the surface. Once a human body has been sensitized to nickel, lifelong reaction to even tiny amounts can occur. For more information about nickel sensitivity and the use of hypoallergenic jewelry, visit the website listed at the end of the chapter.

Gold, silver, and copper have all been used to treat diseases. Copper bracelets are sold to people suffering from arthritis. Silver present as a colloid in a liquid mixture is reputed to kill microorganisms such as bacteria (antibiotic effect) when ingested or applied to the skin. The established medical community does not agree that these treatments actually work, and the products containing them generally have not been subjected to tests by agencies such as the U.S. Food and Drug Administration (FDA).

(a)

(b)

Figure 1.17 (a) A human-made alloy. Frames for racing bicycles are built from lightweight, high-strength steel alloys that combine metals such as magnesium, molybdenum, and titanium with iron. (b) A natural alloy. This meteorite, composed primarily of iron and nickel, was found in Australia. *(Part a, courtesy of Trek Bicycle Corporation; part b, Paul Bierman/Visuals Unlimited)*

1.16 Alloys are mixtures of metals

Many metals, when melted, mix together easily in various proportions; such mixtures are called **alloys.** For example, stainless steel is an alloy consisting of 74% iron, 18% chromium, and 8% nickel. The properties of alloys are usually intermediate between those of their component metals, though

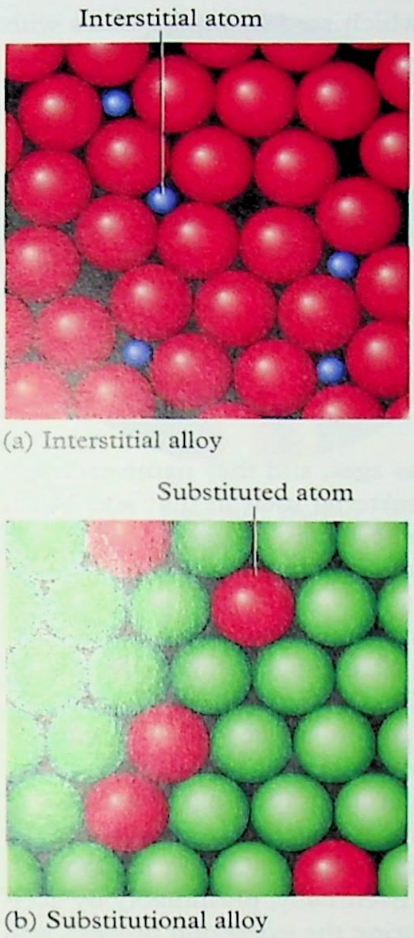

Figure 1.18 Atomic structure of two types of alloys. (a) In interstitial alloys, small atoms lie between larger ones. (b) In substitutional alloys, atoms of one element replace those of another since they are of similar size.

View the structure of a stainless steel alloy at Chapter 1: Visualizations: Media Link 9.

this is not always true of characteristics such as hardness. Most alloys, including some of our most common industrial materials, are human-made (see Figure 1.17a). However, some do occur naturally, such as the meteorite in Figure 1.17b.

The presence of atoms of different size from the main metal in an alloy allows alloys to resist deforming if a force is applied to them. Thus, relatively soft elemental metals can be hardened by alloying them with another element. This is easy to understand for **interstitial alloys** such as steel, where small atoms such as those of carbon fit in the spaces *between* the rows of the main metal, iron, and prevent the iron atoms from gliding past each other. Iron has a structure in which there is room for small atoms of other elements to fit in the "holes" formed between the four adjacent atoms in any plane. A symbolic representation of the presence of such atoms in iron is illustrated in Figure 1.18a.

In many alloys, such as those formed between gold and silver or copper, atoms of the minority metal simply replace a few of those in the regular structure of the majority metal when the substance solidifies. Thus in an alloy consisting of 80% gold atoms and 20% silver atoms, on the average every fifth atom along any row in any direction in the structure is one of silver rather than gold. The substitution of one atom for another does not disrupt the structure of the original metal significantly if the two types of atoms do not differ much in size, as is illustrated schematically in Figure 1.18b. Such so-called **substitutional alloys** have a uniform composition throughout their structure and consequently they are solutions. However, unlike compounds, it is possible to prepare alloys with other proportions of the constituents—say 85% gold and 15% silver, or 95% gold and 5% silver. Also unlike compounds, the original pure components can be readily recovered by melting the alloy and separating the layers. Examples of substitutional alloys include:

- *Brass:* an alloy of zinc (up to 40%) in copper
- *Bronze:* an alloy of metals such as tin and lead in copper
- *Coinage metals:* various alloys of gold, silver, copper, and nickel

Some alloys are not homogeneous, but consist instead of small crystals of different compositions packed together. Such alloys are not solutions but are heterogeneous mixtures. An example is the "solder" alloy formed by tin and lead that is used to join other metals, such as piping, together.

Until quite recently, an alloy that most people had an intimate acquaintance with was the material used to fill cavities in decayed teeth. You may be surprised to learn that mercury was one of the metals used to fill teeth. Although mercury is a liquid at room and body temperatures, it forms many alloys, called *amalgams,* that are solid at normal temperatures. Those having melting points in the 60°C range are useful for fillings, since they can be placed in the decay cavity as a warm liquid metal without causing the patient pain. The liquid assumes the cavity shape as it cools and solidifies in place. Dental amalgam combines mercury with silver, which imparts resistance to tarnishing and mechanical strength, and about half as much tin, which readily amalgamates with mercury. There are also minor amounts of copper, which provides additional strength, and zinc.

Recently, amalgams have been replaced by mercury-free materials such as composite resins, porcelain and ceramic overlays, and gold. The trend toward using alternative materials stems from concerns about the potential negative health impact of mercury fillings and from the more aesthetically pleasing look of tooth-colored composites. For more information and discussion about the issues surrounding mercury amalgams, visit the websites listed at the end of the chapter.

1.17 The ages of history are named after the principal materials that were used

Historians refer to long blocks of time as ages, and they name each age to indicate the principal technological material used in that era. Much of prehistory consisted of the Stone Age. Near its end, people began to make some use of the gold, silver, and copper that they found in the elemental state here and there.

Copper sometimes was found in huge masses and was probably the first metal to be widely used. Although pure copper is relatively soft, it hardens when beaten and hammered. Knowledge of these characteristics allowed people in the late Stone Age to make objects including primitive blades, sickles, and daggers. Much greater amounts of copper became available when people learned, around 4000 B.C., to extract it from the naturally occurring compounds in which it is combined with oxygen or with sulfur. Rock mixtures of metal-containing compounds with other components are called ores. Eventually, presumably by accident, copper and tin ores were mixed during the extraction process, and consequently the copper-tin alloy called bronze was first produced (about 3000 B.C.). Trial and error eventually led to the optimum composition for the alloy, which is 11% tin. Because bronze is harder than copper but is easier to melt and cast into shapes, it became the preferred material (see Figure 1.19). The Bronze Age began about 2000 B.C.

Figure 1.19 A Bronze Age artifact. *(The Granger Collection)*

The extensive use of a metal for the practical fabrication of large objects requires the use of its liquid form. Copper melts at 1083°C and brass at a lower temperature still; these temperatures were accessible using rudimentary expertise in building fires. However, iron, which is a superior structural metal, does not become liquid until 1535°C. Eventually the technology required to produce and use iron was discovered, and at about 1200 B.C., the Iron Age began. At some point, the discovery—again presumably by accident—was made that if some charcoal was added to the iron, a much superior alloy, steel, could be obtained.

1.18 Gold is a valuable and versatile element

Because it occurs in nature as the metal, in pieces that are as heavy as 90 kilograms, gold was one of the first elements to be discovered by humans. Gold jewelry manufactured about 3500 B.C. has been discovered in Mesopotamia (modern-day Turkey); not much later than this date, gold was used as currency. There are references to gold in the Old

Testament. Alexander the Great invaded Persia (modern-day Iran) for gold, and later Cortes was willing to wipe out the Aztec civilization for it. Since gold does not tarnish and has always been valuable, it is recycled endlessly. Some of the gold in any piece of modern jewelry was probably first mined thousands of years ago!

Figure 1.20 Liquid gold. *(Georg Gerster/Photo Researchers)*

The gold that is found in nature is not the pure element, but an alloy that contains some other metals. Some of the metallic impurities can be removed simply by melting the mixture. Other impurities require that air be blasted over the hot liquid, which converts the impurities into compounds that are not soluble in metal and that consequently can be skimmed off the pure, liquid gold (see Figure 1.20).

Because the atoms in metals can readily be displaced relative to each other, solid metals can often be drawn into long wires and/or hammered into thin sheets. Very thin gold sheets, corresponding to only a few hundred layers of gold atoms, can be made (see Figure 1.21a). Such thin sheets of gold, called "gold leaf," are used for decoration on buildings, books, and other objects (see Figure 1.21b). Very thin gold coatings are used on the windows of some office buildings. In addition to being visually attractive, the coating reflects radiative heat, so it keeps the offices cool in the summer by reflecting incoming sunlight and warm in the winter by retaining heat inside the building. You may be surprised to learn that edible gold foil is sometimes used to decorate elegant desserts. The ingestion of a very small amount of gold seems to have no negative effect on the body. In fact, gold is sometimes used as a therapeutic agent to treat arthritis.

Commercial gold is an alloy of gold with silver and usually copper and other metals such as nickel. These alloys are much stronger than the pure metal, which is too soft to use alone for most items of jewelry. The relative proportions of silver and copper in the alloys must be carefully controlled if the color of the "gold" is to be the right shade of yellow. Too much silver gives gold a pale, whiteish look whereas too much of the reddish-brown metal copper makes it too reddish.

The term *carat* also is used in a different sense to specify the mass, rather than purity, of diamonds.

Gold alloys are classified using the **carat** system, invented by the British about A.D. 1300, which gives the proportion of gold in the combination. The carat scale is based upon the number 24—pure gold is called 24-carat, whereas an alloy having 50% gold by mass is 12-carat. Although spelled "carat" rather than the European "karat," the number of carats is always indicated by the capital letter K following the number. The formula by which the number of carats for a sample of any gold alloy can be obtained is:

$$\text{carats of gold} = 24 \times \text{the fraction of mass of the sample that is gold}$$

In other words,

$$\text{carats of gold} = 24 \times (\text{mass of gold in a sample / mass of the entire sample})$$

If a ring, for example, is 75% gold by mass, the fraction is 0.75 and the number of carats is $24 \times 0.75 = 18$. The ring is 18K gold. Most of the

Taking It Further *with Math*

For information and problems on significant figures, go to Taking It Further with Math at www.whfreeman.com/chemistry in your life.