12.4 Properties of the Elements

Elements have a wide variety of physical and chemical properties. Physical properties include their state, temperatures of melting or boiling, solubility, and whether or not they conduct electricity or heat. Chemical properties include how elements react to form new compounds. In this section, you will learn about some of the properties of elements and how the periodic table helps you predict the properties of elements. You will also learn interesting fact about specific elements.

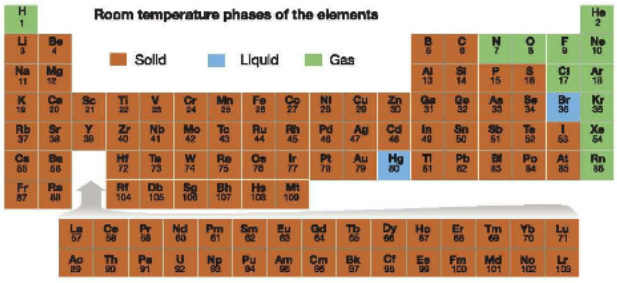
State of matter at room temperature

Most elements are solid at room temperature

Most of the pure elements are solid at room temperature. Only 11 of the 92 naturally occurring elements are a gas, and 10 of the 11 are found on the far right of the periodic table. Only two elements (Br and Hg) are liquid at room temperature.

What this tells us about intermolecular forces

An element is solid when intermolecular forces are strong enough to overcome the thermal motion of atoms. At room temperature, this is true for most of the elements. The noble gases and elements to the far right of the periodic table are the exceptions. These elements have completely filled or nearly filled energy levels (Figure 12.23). When an energy level is completely filled, the electrons do not interact strongly with electrons in other atoms, reducing intermolecular forces.



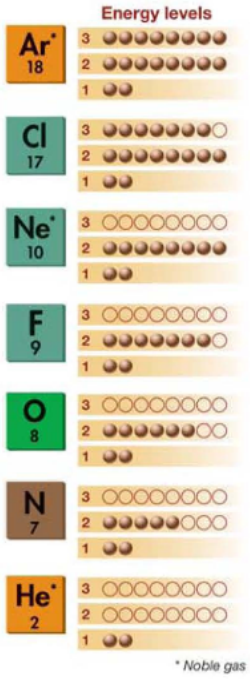


Figure 12.23: *The noble gases have completely filled energy levels. All of the elements that are a gas at room temperature have filled or nearly filled energy levels.*

Periodic properties of the elements

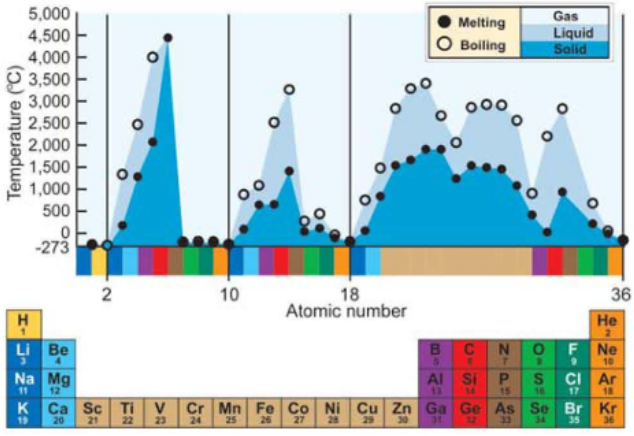
The pattern in melting and boiling points

We said earlier that the periodic table arranges elements with common properties into groups (columns). The diagram below shows the melting and boiling points for the first 36 elements. The first element in each row (Li, Na, K) always has a low melting point. The melting (and boiling) points rise toward the center of each row and then decrease again.

Periodicity

The pattern of melting and boiling points is an example of **periodicity**. Periodicity means the pattern or trend in properties repeats for each period (row) of the periodic table (Figure 12.24). Periodicity tells us a property is strongly related to the filling of electron energy levels. Melting points reflect the strength of intermolecular forces. The diagram below shows that intermolecular forces are strongest when energy levels are about half full (or half empty). Elements with half-filled energy levels have the greatest number of electrons that can participate in bonding.

Melting and Boiling Points for Elements 1 – 36



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periodicity - the repeating pattern of chemical and physical properties of the elements.

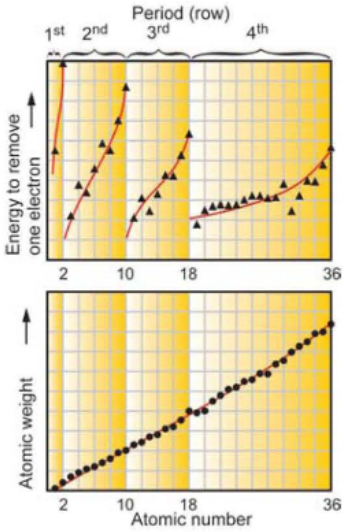

Figure 12.24: *One of these graphs shows periodicity and the other does not. Can you tell which one is periodic? The top graph shows the energy it takes to remove an electron. The bottom graph shows the atomic weight.*

Thermal and electrical conductivity

Metals are good electrical conductors

Copper wire

Electricity is something we often take for granted because we use it every day. Fundamentally, *electricity* is the movement of electric charge, usually electrons. Some materials allow electrons to flow easily through them. If you connected a battery and a light bulb through one of these materials, the bulb would light. We call these materials **electrical conductors**. Copper and aluminum are excellent electrical conductors. Both belong to the family of metals, which are elements in the center and left-hand side of the periodic table (Figure 12.25). Copper and aluminum are used for almost all electrical wiring.

VOCABULARY

electrical conductor - a material that allows electricity to flow through it easily.

thermal conductor - a material that allows heat to flow through it easily.

insulator - a material that slows down or stops the flow of either heat or electricity.

Metals are good conductors of heat

If you hold one end of a piece of copper wire and put the other end in hot water, the wire will quickly become warmer. This is because copper is a good conductor of heat as well as of electricity. Like copper, most metals are good **thermal conductors**. That is one reason pots and pans are made of metal. Heat from a stove can pass easily through the metal walls of a pot to transfer energy (heat) to the food inside.

Nonmetals are typically insulators

Elements to the far right of the periodic table are not good conductors of electricity or heat, especially since many of them are gases. Because they are so different from metals, these elements are called *nonmetals*. Nonmetals make good insulators. An **insulator** is a material that slows down or stops the flow of either heat or electricity. Air is a good insulator. Air is made of oxygen, nitrogen, and argon.

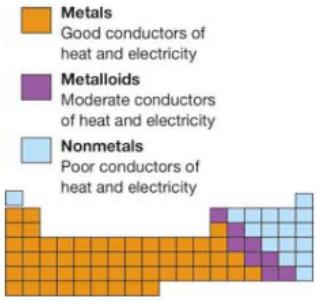

Figure 12.25: *Dividing the periodic table into metals, metalloids, and nonmetals.*

Metals and metal alloys

Steel is an alloy of iron and carbon

When asked for an example of a metal, many people immediately think of **steel**. Steel is made from iron, which is the fourth most abundant element in Earth's crust. However, steel is not pure iron. Steel is an *alloy*. An alloy is a solid mixture of two or more elements. Most metals are used as alloys and not in their pure elemental form. Common steel contains mostly iron with a small percentage of carbon. Stainless steel and high-strength steel alloys also contain small percentages of other elements such as chromium, manganese, and vanadium. More than 500 different types of steel are in everyday use (Figure 12.26).

VOCABULARY

steel - an alloy of iron and carbon.

Stainless steel kitchen knife (will not rust)

Ordinary steel nails (will rust)

Figure 12.26: *Nails are made of steel that contains 95% iron and 5% carbon. Kitchen knives are made of stainless steel that is an alloy containing vanadium and other metals.*

Aluminum is light

Aluminum is a metal widely used for structural applications. Aluminum alloys are not quite as strong as steel, but aluminum has one-third the density of steel. Aluminum alloys are used when the product, such as an airplane, needs to be lightweight. The frames and skins of airplanes are built of aluminum alloys (Figure 12.27).

Figure 12.27: *This aircraft is made mostly from aluminum alloys. Aluminum combines high strength and light weight.*

Titanium is both strong and light

Titanium combines the strength and hardness of steel with the light weight of aluminum. Titanium alloys are used for military aircraft, racing bicycles, and other high-performance machines. Titanium is expensive because it is somewhat rare and difficult to work with.

Brass

Brass is a hard, gold-colored metal alloy. Ordinary (yellow) brass is an alloy of 72 percent copper, 24 percent zinc, 3 percent lead, and 1percent tin. Hinges, door knobs, keys, and decorative objects are made of brass because brass is easy to work with. Because it contains lead, however, you should never eat or drink from anything made of ordinary (yellow) brass.

Carbon and carbon-like elements

Carbon is an important element for life

Carbon represents less than 1/100th of a percent of Earth's crust by mass, yet it is the element most essential for life on our planet. Virtually all the molecules that make up plants and animals are constructed around carbon. The chemistry of carbon is so important, it has its own name: *organic chemistry* (Figure 12.28).

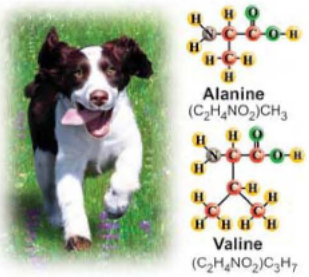

Figure 12.28: *Organic chemistry is the chemistry of living organisms and is based on the element carbon.*

Diamond and graphite

Pure carbon is found in nature in two very different forms. Graphite is a black solid made of carbon that becomes a slippery powder when ground up. Graphite is used for lubricating locks and keys. Diamond (shown left) is also pure carbon. Diamond is the hardest natural substance known and also has the highest thermal conductivity of any material. Diamond is so strong because every carbon atom is bonded to four neighboring atoms in a tetrahedral crystal.

Silicon

Directly under carbon on the periodic table is the element silicon. Silicon is the second most abundant element in Earth's crust, second only to oxygen. Like carbon, silicon has four electrons in its outermost energy level. This means silicon can also make bonds with four other atoms. Sand, rocks, and minerals are predominantly made of silicon and oxygen (Figure 12.29). Most gemstones, such as rubies and emeralds, are compounds of silicon and oxygen with traces of other elements. In fact, when you see a glass window, you are looking at (or through) pure silica (SiO_2).

Figure 12.29: *Sand and glass are two common materials made of silicon.*

Silicon and semiconductors

Perhaps silicon's most famous application today is for making semiconductors. Virtually every computer chip and electronic device uses crystals of very pure silicon. The area around San Jose, California, is known as Silicon Valley because of the electronics companies located there. Germanium, the element just below silicon on the periodic table, is also used to make semiconductors.

Nitrogen, oxygen, and phosphorus

Nitrogen and oxygen make up most of the atmosphere

Nitrogen is a colorless, tasteless, and odorless gas that makes up about 77 percent of Earth's atmosphere. Oxygen makes up 21 percent of the atmosphere (Figure 12.30). Both oxygen and nitrogen gas consist of molecules with two atoms (N_2, O_2).

Oxygen in rocks and minerals

Oxygen makes up only 21 percent of the atmosphere, however, oxygen is by far the most abundant element in Earth's crust. Almost 46 percent of Earth's crust is oxygen (Figure 12.31). Because it is so reactive, all of this oxygen is bonded to other elements in rocks and minerals in the form of oxides. Silicon dioxide (SiO_2), calcium oxide (CaO), aluminum oxide (Al_2O_3), and magnesium oxide (MgO) are common mineral compounds. Hematite (Fe_2O_3), an oxide of iron, is a common ore from which iron is extracted.

Liquid nitrogen

With a boiling point of –196°C, liquid nitrogen is used for rapid freezing in medical and industrial applications. A common treatment for skin warts is to freeze them with liquid nitrogen.

Oxygen and nitrogen in living organisms

Oxygen and nitrogen are crucial to living animals and plants. For example, proteins and DNA both contain nitrogen. Nitrogen is part of a key ecological cycle. Bacteria in soil convert nitrogen dioxide (NO_2) in the soil into complex proteins and amino acids. These nutrients are taken up by the roots of plants and later eaten by animals. Waste and dead tissue from animals are recycled by the soil bacteria that return the nitrogen to begin a new cycle.

Phosphorus

Directly below nitrogen in the periodic table is phosphorus. Phosphorus is a key ingredient of DNA, the molecule responsible for carrying the genetic code in all living creatures. One of phosphorus's unusual applications is in glow-in-the-dark plastic. When phosphorus atoms absorb light, they store energy and give off a greenish glow as they slowly re-emit the energy.

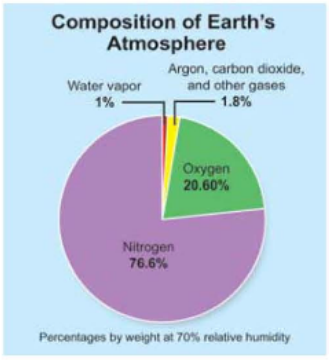

Figure 12.30: *Earth's atmosphere is predominantly made up of nitrogen and oxygen.*

Figure 12.31: *Oxygen makes up 46% of the mass of Earth's crust. This enormous quantity of oxygen is bound up in rocks and minerals.*

Section 12.4 Review

1. Name two elements that are liquid at room temperature.
2. Which of the following is NOT true about the noble gases?
   a. They have completely filled energy levels.
   b. They have weak intermolecular forces.
   c. They do not bond with other elements in nature.
   d. They have boiling points above room temperature.
3. Describe what it means if a chemical or physical property is periodic.
4. Name three elements that are good conductors of electricity.
5. Name three elements that are good conductors of heat.
6. A metalloid is an element that:
   a. has properties between those of a metal and a nonmetal
   b. is a good thermal conductor but a poor electrical conductor
   c. is a good electrical conductor but a poor thermal conductor
   d. belongs to the same group as carbon in the periodic table
7. Steel is a metallic-like material but is not a pure element. What is steel?
8. Almost all of the oxygen on the planet Earth is found in the atmosphere. Is this statement true or false?
9. This element is abundant in Earth's crust and combines with oxygen to form rocks and minerals. Which element is it?
10. An element that has strong intermolecular forces is most likely to have:
    a. a boiling point below room temperature
    b. a melting point below room temperature
    c. a boiling point very close to its melting point
    d. a very high melting point
11. Which element in Figure 12.32 is likely to be the best conductor of electricity?
12. Which element in Figure 12.32 is likely to be the best insulator?

CHALLENGE

One of the elements with an atomic number less than 54 has the honor of being the first man-made element. Which element is this, and how was it discovered?

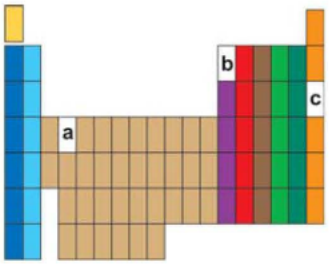

Figure 12.32: *Questions 11 and 12.*