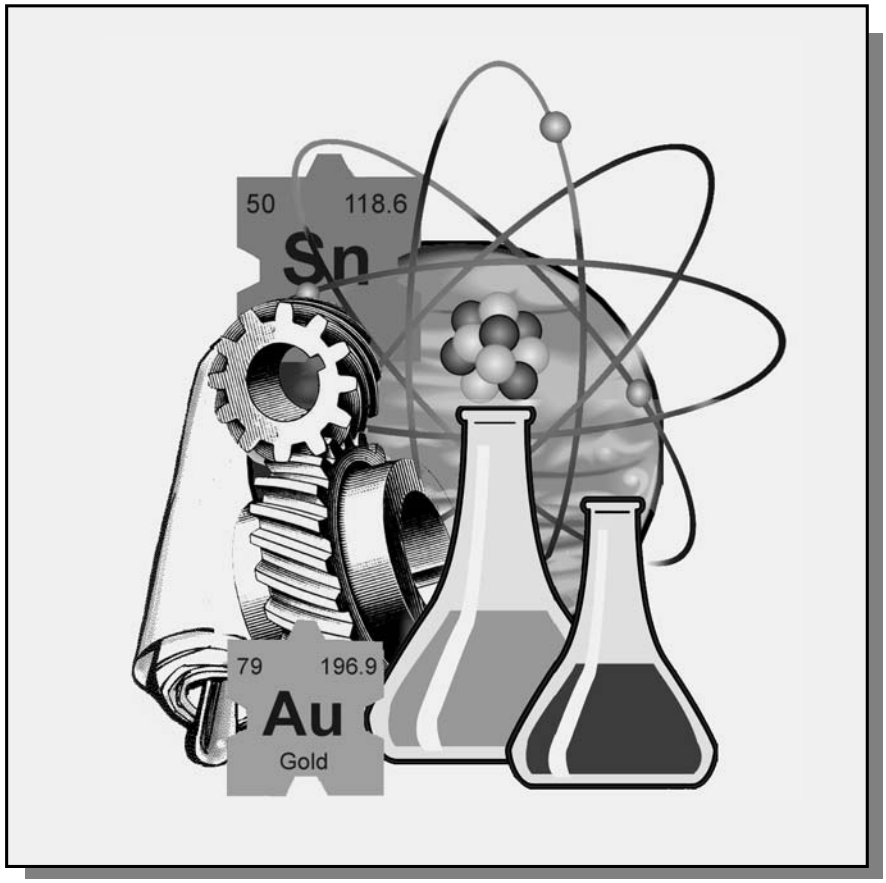
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This chapter requires a companion activity book in which students respond to questions on text content. Answers are found in the *Teacher's Resource Kit*.



Chapter 11

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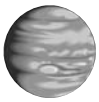
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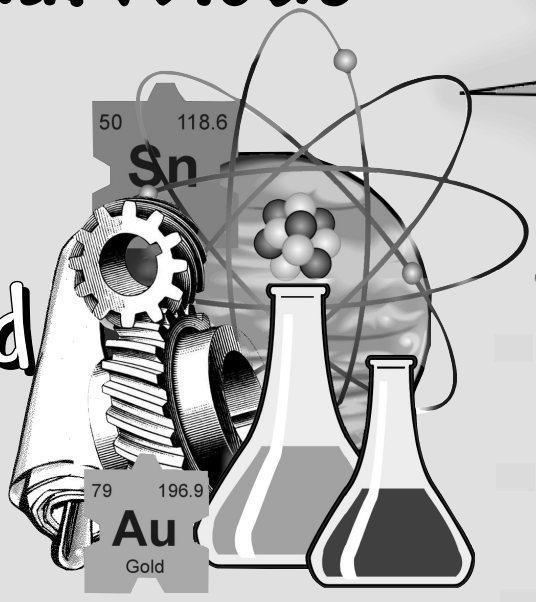
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"The study of science is the chronicle of man's quest to discover the essence of life and how the marvelous laws of creation are applied to human needs."



—Ronald Johnson, Ph.D.

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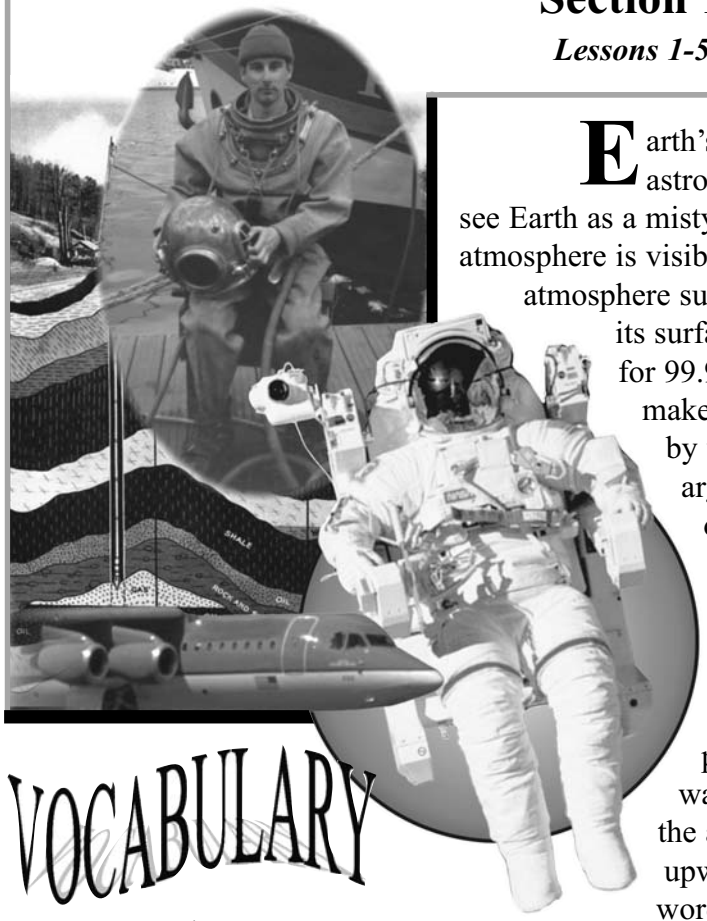
Lesson 1
Planets

Chapter 11

THE EARTH

Section 1

Lessons 1-5



Earth's sphere of air is the *atmosphere*. When astronauts look down from a high orbit, they see Earth as a misty blue-green ball. Only a thin layer of the atmosphere is visible, although they know the gases of the atmosphere surround the Earth and extend miles above its surface. Nitrogen, oxygen and argon account for 99.9 percent of the atmosphere. Nitrogen makes up about 78 percent of the atmosphere by volume; oxygen is about 21 percent and argon slightly less than one percent. Carbon dioxide, water vapor, ozone and hydrogen are found in trace amounts.

Astronauts looking straight down toward Earth see the atmosphere, so transparent that it is hardly noticeable. It is visible only around the rim of the planet or when the atmosphere is carrying water vapor as clouds. The lowest level of the atmosphere from sea level on Earth upward about 7.5 miles is the *troposphere,* a word meaning *changing sphere*. The troposphere grows less dense with elevation. Most living organisms extract oxygen from the troposphere. As the air grows thinner in the upper troposphere fewer organisms can survive. Only a few species of hardy trees are found above 14,000 feet. Most people have difficulty breathing at about 15,000 feet and need extra oxygen. Only a few experienced mountain climbers can survive without extra oxygen at the height of Mt. Everest, approximately six miles above sea level. Climbers must carry extra oxygen in bottles to remain at that elevation of the troposphere for more than a few hours.

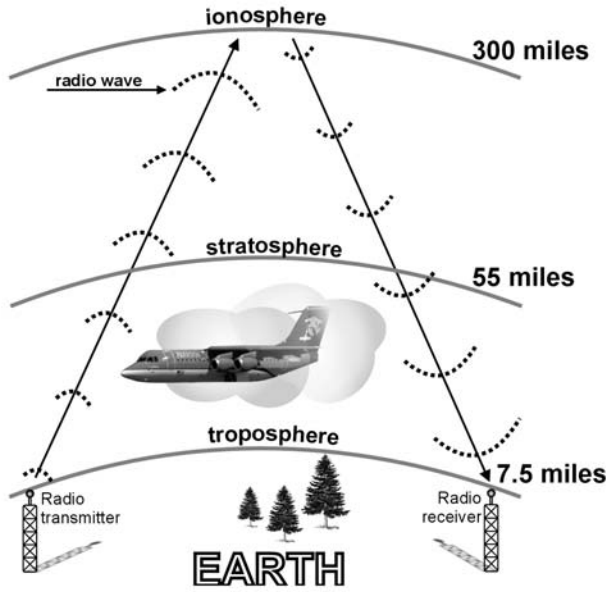
A meteorologist is a scientist who studies weather and the atmosphere. Clouds and most weather conditions form in the troposphere. The next layer of the atmosphere above the troposphere is the *stratosphere* (7.5 miles to 55 miles) where jet

VOCABULARY

Hydrosphere: the water on or around the Earth; includes water in the atmosphere and oceans; the four most abundant elements by weight in the hydrosphere are oxygen (85 percent), hydrogen (11 percent), chlorine (two percent) and sodium (one percent)
Minesweeper: a ship designed to locate and render harmless underwater explosive mines that during time of war have been placed in harbors and shipping lanes

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aircraft cruise. The third major layer is the *ionosphere* (55 miles to 300 miles) where charged particles reflect radio waves. The ionosphere is the home of the northern lights. Although the ionosphere is thin, meteorites that crash into it generate enough heat by friction to vaporize.



The Earth's sphere of water is the ***hydrosphere***. An astronaut in orbit sees water as clouds in great swirling tropical storms over the oceans or as puffy thunderheads over land. Northern glaciers appear dazzling white as they reflect sunlight. Greenland, the Arctic region and the continent of Antarctica are covered by deep blankets of ice. As astronauts orbit Earth and pass over the Pacific Ocean, they see mostly liquid water. The Pacific is a giant circular ocean that covers almost half of Earth's surface.

Four major oceans (Arctic, Atlantic, Indian, Pacific) cover almost three-fourths of the Earth's surface. Snow and clouds can obscure even more portions of Earth's surface. At times, the entire planet seems to be covered with water in one form or another.

An *oceanographer* is a scientist who studies the hydrosphere and the oceans. One of the best known oceanographers was Jacques Yves Cousteau. He was not formally trained as a scientist. He graduated from France's Naval Academy in 1933 as an airplane pilot. That career was cut short by an automobile accident that broke both of Cousteau's arms. To recover from the accident, he began underwater diving and became fascinated with undersea exploration.



Cousteau enjoyed the freedom of diving with goggles, but he could stay underwater for only a few minutes while he held his breath. At that time, the only way to stay underwater for long periods of time was with a heavy, clumsy diving suit with cables and air hose that connected to a ship on the surface. Cousteau and a friend developed the *aqualung,* a cylinder of compressed air connected through a pressure-regulating valve to a facemask. The device was self-contained and did not require a lifeline to connect the diver to a ship on the surface. The invention also became known as *scuba* gear. The name *scuba* came from the letters of **S**elf-**C**ontained **U**nderwater **B**reathing **A**pparatus. Scuba equipment became available to the public after World War II, in 1946.

VOCABULARY

Crust: the top layer of the lithosphere, although only about 15 miles thick, it is the rocky layer that geologists know best
Seismic: relating to earthquake waves within the Earth
Molten: melted or liquefied by extreme heat such as the fusion (melting) of rocks or metal in molten lava

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In 1950, Cousteau became commander of the *Calypso*, a British military ***minesweeper*** that had been converted into an oceanographic research vessel. Cousteau developed sealed cases for cameras that could take pictures underwater. His documentary film, *The Silent World*, won the Academy Award in 1957. His films and television show, "The Undersea World of Jacques Cousteau," encouraged people to take up scuba diving. Even observers who stayed on land had a greater appreciation for the vast array of life in the sea.

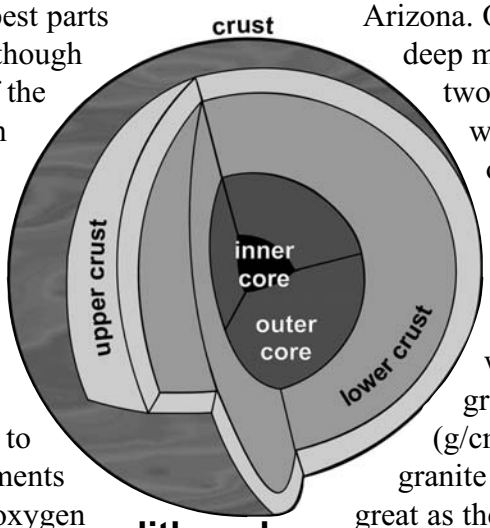
However, rather than a pristine ocean floor (untouched by human activity), Jacques Cousteau saw empty milk cartons, plastic bottles and tin cans in the deepest parts of the oceans. He warned, "Although water covers a large surface of the Earth, our water reserves are in reality really very small." Because of his documentary movies about the sea, people became more aware of the need to use oceanic resources wisely and to control pollution.

Mankind has been able to identify the most common elements in seawater. Water is made of oxygen and hydrogen. Seawater contains salt, and salt is made of sodium and chlorine. As you would expect, these four elements are most abundant in the ocean. Oxygen makes up about 85 percent by weight of a sample of seawater; hydrogen contributes about 11 percent; chlorine comprises a little under two percent, and sodium counts for about one percent. All other chemicals in the sea make up the remaining one percent.

Some elements are present in seawater only in small traces. Because the oceans are so vast, even a small percentage can add up to be a vast supply. For instance, chemists estimate that about eight tons of gold are dissolved in all the oceans of the world. Of course, the problem is separating gold from salt water; no one has found a profitable way to do it.

Gold and most other minerals are mined from the *lithosphere*. *Litho* is a word meaning *rock*. The lithosphere is the rocky, solid sphere of the Earth. A scientist who studies Earth's rocky sphere is a *geologist*. *Geo* is a Greek word meaning *Earth*.

The topmost layer of the lithosphere (the one geologists know best) is the ***crust***. In addition to studying its surface, geologists can trace out layers of rock as far as a mile deep in the Grand Canyon of Northern Arizona. On other surface areas, deep mine shafts go down about two miles. The deepest oil wells plunge to the depths of about five miles. Samples taken from below the surface show that the top part of the crust is composed of rock with a density of about 2.7 grams per cubic centimeter (g/cm^3). A cubic centimeter of granite has a mass 2.7 times as great as the same volume of water. Below the oceans, rock is slightly denser at about 3.0 g/cm^3.



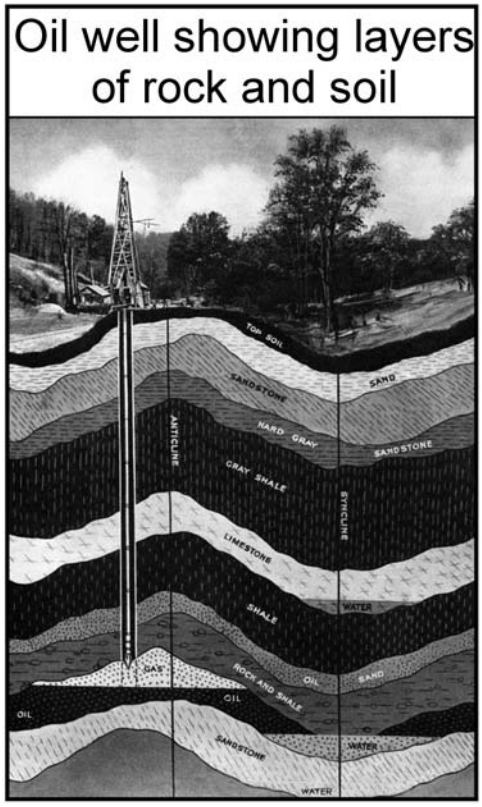
lithosphere

Compared to the total radius of Earth, the crust is very thin. With an average thickness of 15 miles, the crust is thickest under mountain ranges and thinnest under the deepest parts of the ocean. The crust is very thin compared to the distance from the surface of the Earth to the center of the Earth—3,959 miles. Suppose Earth were reduced to the size of a basketball that has a diameter of 9.96 inches. The tallest mountain, Mt. Everest, would stand only a little more than $^1/_{70}$ of an inch above the surface. The

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three top elements in the crust by weight and in order of abundance are oxygen (about 45%), silicon (27%) and aluminum (about 8%).

Geologists have never seen material from below the crust. To learn more about material located deeper in the Earth, scientists study earthquake waves and waves produced by artificial explosions. Waves change speed and direction when they encounter material of different density. Geologists have made a model of the interior of Earth based on the speed and direction of ***seismic*** waves. Waves change direction because of a change in density. A sharp reflection indicates a sudden change in density. From the unmistakable reflection of earthquake waves, geologists concluded that a definite boundary exists between the crust and the next layer. The division is named the *Moho discontinuity* for the geologist who discovered it, Andrija Mohorovicic. He was born in Croatia.

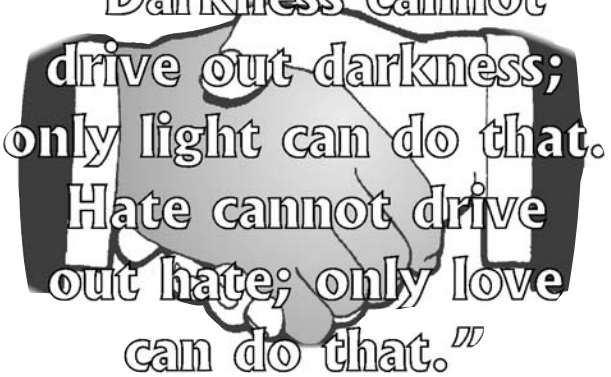


The *mantle*, Earth's second layer, is found below the crust. Geologists believe the mantle extends down about 1,800 miles. The crust and mantle do not blend into one another. Within the mantle, the change in direction of seismic waves is more gradual, indicating a continuous change in density. Near the top, density is about 3.3 g/cm^3. At its greatest depth, the mantle's density increases to about 6.0 g/cm^3.

The *core* is below the mantle and extends to the center of the Earth. Scientists have calculated that average density is 13 g/cm^3. Because Earth has a magnetic field, geologists believe the outer core is made of ***molten*** nickel and iron, about 1,300 miles thick with a temperature of several thousand degrees Fahrenheit. Seismic waves passing through the core indicate that the inner core is a very dense solid with a radius of about 850 miles.

Normally, pressure causes a substance to remain a solid. Pressure at the center of the Earth is very high. However, temperature increases with depth toward the core. Oil pumped from deep wells comes out at a temperature above the boiling point of water. Volcanoes spew out molten lava at about 2,200ºF. Geologists estimate that at the center of the Earth, the temperature may be as high as 12,000ºF, which is about the same temperature as the surface of the Sun.

Life Principle



—Martin Luther King, Jr.

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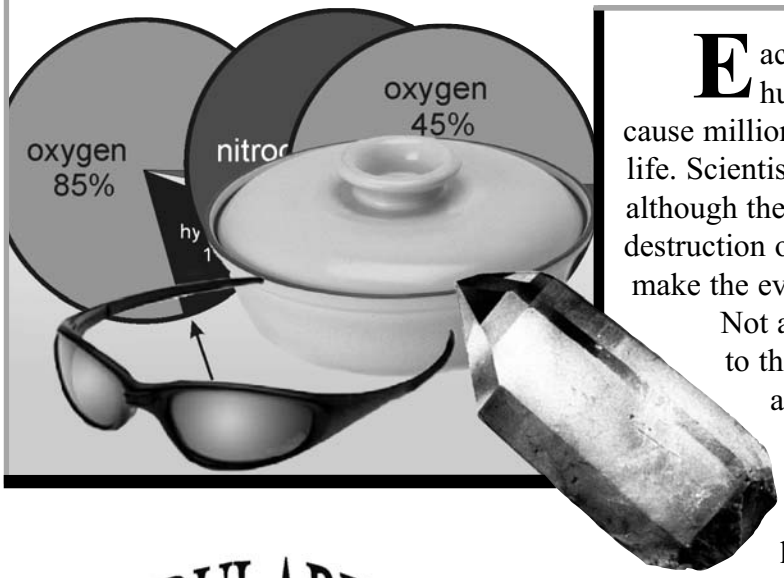
Lesson 2
Compounds

Chapter 11

MINERALS

Section 1

Lessons 1-5



Each year natural disasters such as hurricanes, tornadoes and earthquakes cause millions of dollars in damage and loss of life. Scientists cannot prevent natural disasters, although they can suggest ways to reduce destruction of buildings, crops and dams and make the events less dangerous to human life.

Not all natural disasters are due entirely to the forces of nature. Sometimes actions by human beings have a role in causing natural disasters. In the 1930s, a disaster known as the Dust Bowl caused considerable human misery in the United States, even though some negative consequences could have been prevented.

VOCABULARY

Contour: a line that follows the same elevation around a field, contour plowing of a field reduces erosion
Soil: the top layer of Earth's surface consisting of rock minerals and organic matter
Mineral: a naturally occurring inorganic compound that has a definite chemical composition
Inorganic: compounds produced by nonliving processes
Silicate: a mineral containing silicon, oxygen and one or more metals. Feldspar, mica and kaolin are silicates

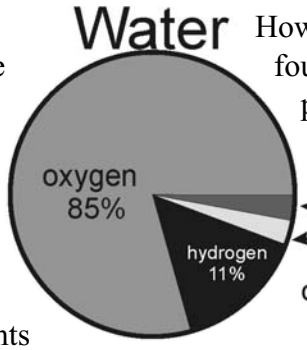
The Dust Bowl is a name given to the severe drought of the 1930s. Until settlers moved to the mid-west states of Kansas, Oklahoma and northern Texas in the late 1800s, the country was covered by native grasses. The soil was especially fine grained and prone to erosion, especially by the strong winds that blew across the prairie. The interlocking roots of native grasses held the soil in place. Settlers converted the prairie to cropland for growing grain. When average rainfall in the 1930s fell to near desert conditions and crops failed, strong winds carried away as much as four inches of topsoil. Blowing sand caused dunes that piled up nearly to the roofs of houses. The event became known as the Dust Bowl, and the land became too poor to grow crops. People moved away from their farms to find work. When the drought finally ended, the soil had been badly damaged.

Steps were taken to rebuild the soil. These efforts included letting the land recover with crop rotation and returning some of the area to grassland. To prevent wind and

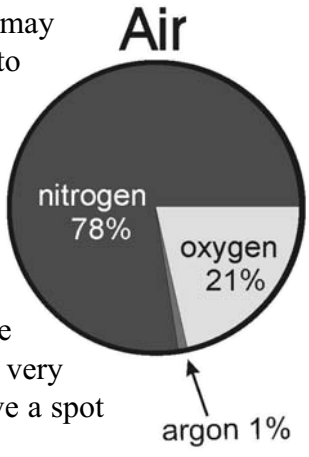
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water erosion, farmers used ***contour*** plowing and avoided excessive preparation of the soil to receive seeds. In some places, rows of trees were planted to slow the force of the wind. Despite efforts for almost 70 years, the soil has not yet been fully restored in some regions of the mid-western United States.

Soil is produced by fine particles of ***minerals*** mixed with organic material. Minerals are the building blocks from which soil and rocks of the lithosphere are produced. Unlike gases of the air and compounds of the ocean, minerals are composed of a far greater variety of elements.

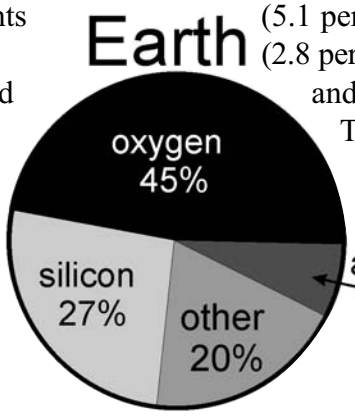


The most common elements in Earth's crust are not easily identified. The percentages are not as easy to arrive at as for the atmosphere and hydrosphere. The gases in the air are in constant motion and become well mixed. Although the carbon dioxide and water vapor may vary slightly from place to place, the proportion of nitrogen (78 percent), oxygen (21 percent) and argon (a little less than one percent) remains constant. A sample of air taken at one location on Earth will be very similar to one taken above a spot elsewhere on Earth.



Ocean water, too, contains elements that are well mixed. A unique feature of oceans is "the paths of the seas" identified in Psalm 8 of the Bible. Ship captains learned to follow these ocean highway streams. Warm streams such as the Gulf Stream in the Atlantic and the cold Humboldt stream off the coast of South America keep elements in ocean water mixed. The proportion of sodium and chlorine at the surface of the water is slightly higher because evaporation removes water but leaves salt behind. The proportion of salt is slightly less in those areas where freshwater from rivers pours into the oceans. For example, water flowing from the forceful Amazon River in Brazil is fresh for a hundred miles into the Atlantic Ocean. However, overall, the proportion of the four elements in ocean water oxygen (85 percent), hydrogen (11 percent), chlorine (about two percent) and sodium (about two percent) remains constant. A sample of ocean water taken in one ocean will be very similar to water samples taken from another ocean elsewhere in the world.

Elements are not uniformly distributed throughout Earth's crust. Salt (sodium and chlorine), coal (mostly carbon and hydrogen) and metals in their natural state, such as gold, can occur in great abundance in one place but be entirely absent in others. To figure out which elements are most abundant, geologists compute an average mixture. They analyze samples various depths around the world. This average for the crust of Earth shows that the three most common elements of the Earth's crust are oxygen (45.0 percent), silicon (27.0 percent) and aluminum (8 percent). Other elements found in the crust in abundance include iron (5.8 percent), calcium (5.1 percent), magnesium (2.8 percent), sodium (2.3 percent) and potassium (1.7 percent). The top three elements plus these five elements account for 97.7 percent of the minerals found in the crust.



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Oxygen is the second most abundant element in the atmosphere and the most abundant element in the hydrosphere and lithosphere. Oxygen is not combined with other elements in the atmosphere. In the ocean, oxygen is combined with hydrogen to produce water. In the rocky part of Earth, oxygen is found in combination with other elements. The three most abundant elements in the lithosphere — oxygen, silicon and aluminum — are never found in the free state. Instead, they are combined with each other and with other elements to produce minerals.

A mineral is a naturally occurring solid from an ***inorganic*** process and has a definite chemical composition. Because a slight variation in the composition gives rise to different minerals, identifying them usually requires a series of tests. Geologists test the hardness, density and color. The shape of the crystal and how the crystals break when struck are examined. Some minerals break along a crystal plane and leave a smooth surface. Others flake off and leave a rough surface.

Feldspar is the term applied to a group of minerals with very similar chemical compositions. Feldspar is the most abundant mineral. One type of feldspar is potassium aluminum silicate ($KAlSi_3O_8$). It has one potassium atom (K), one aluminum atom (Al), three silicon atoms (Si) and eight oxygen atoms (O). Other varieties of feldspar may have the potassium replaced with sodium (Na) or lithium (Li). Each one is considered a different mineral because the chemical composition is different. Feldspars form the most common group of minerals in Earth's crust. They comprise nearly half of Earth's crust. Most feldspars have a hardness of about 6 (which is harder than a knife blade) and a density of 2.6 grams per cubic centimeter.

Quartz is the second most abundant mineral. Quartz is *silica*, which contains only silicon and oxygen—silicon dioxide or (SiO_2). Of all the minerals, quartz has one of the simplest chemical formulas. It has a hardness of 7 and will scratch feldspar. Pure quartz is colorless and transparent. However, when colored by impurities, quartz is considered a gem. The purple or violet gemstone, amethyst, is quartz with impurities of iron or manganese. Rose quartz has a pink color from titanium. One important application of quartz is in electronic equipment. A quartz crystal vibrates at a very precise rate and is used to regulate electronic circuits. Most high-grade quartz crystals come from Brazil.



Mica is another abundant mineral in Earth's crust. Mica's most common form has the complicated chemical formula of $KAl_3Si_3O_{10}(OH)_2$. Mica is recognized by the way that it splits into thin, almost transparent sheets. Large sheets of mica are used as electrical insulators. Mica is also a good insulator of heat. Small flakes of it are used in roofing material and have the added advantage of being fire resistant. Because of its flat surface, small sheets of mica will slide over one another. Broken sheets and small flakes are recovered from other manufacturing processes and mixed with oil to make a lubricant. Mica is a soft mineral with a hardness of about 3. A coin will scratch mica.

Kaolinite ($Al_2Si_2O_5(OH)_4$) is another common mineral and the chief ingredient in kaolin, a fine white clay. Kaolin is used in the manufacture of ceramics, porcelain and china



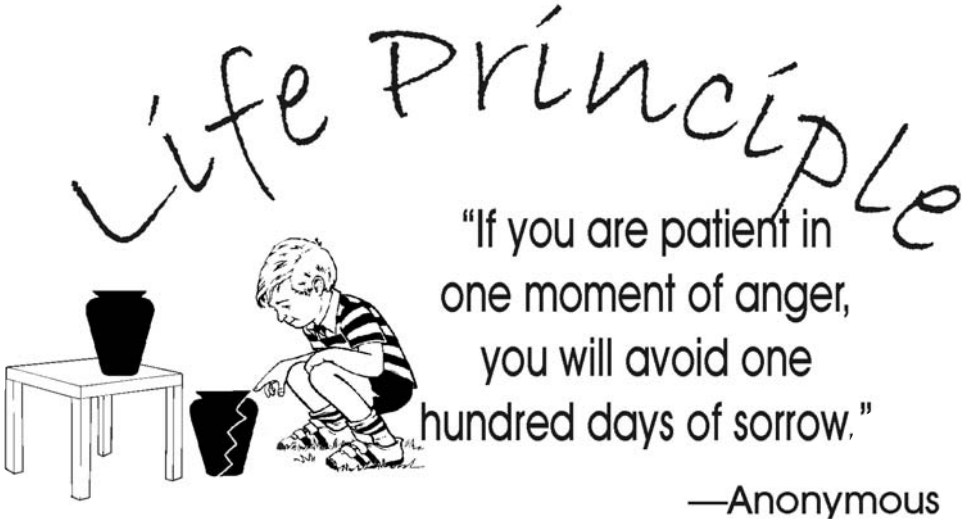
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products. Kaolin is added to pigments to give them body. Heavy papers coated with kaolinite have a glossy white surface. Feldspar, mica and kaolinite are ***silicates***. They contain silicon, oxygen and one or more metals.

Calcite ($CaCO_3$) is the chief mineral found in limestone and marble. Calcite is used commercially as a source of lime for mortar and cement. The purest form of calcite is Iceland spar. Calcite is a *carbonate* and contains carbon, oxygen and a metal. First discovered in Iceland, scientists of the 1800s noticed that when light passed through calcite the light was separated into two rays. This was the first evidence that light can be *polarized*.

Polarized light vibrates in only one plane. Light waves could vibrate up or down, left or right, and all the angles in between. When light becomes polarized, waves vibrating in only one plane are allowed to pass. Calcite in the form of Iceland spar was the first crystal discovered that could polarize light. Airplane pilots found that sunglasses made with lenses of Iceland spar reduced glare. However, crystals large enough to fit in eyeglasses were expensive. An American inventor, Edward Land, found he could use smaller crystals, aligned and sandwiched between sheets of plastic, rather than a single large crystal. Land gave his invention the name *Polaroid*. Polaroid glasses reduce glare by eliminating rays of light that are vibrating in one direction but let rays pass that are vibrating in the other direction.





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Lesson 3
Geology

Chapter 11

SEDIMENTARY, IGNEOUS AND METAMORPHIC ROCK

Section 1

Lessons 1-5





Along the coast of California near the city of San Diego is Torrey Pines Nature Preserve. Although a part of San Diego, the park has been left in its wild state. High bluffs overlook the Pacific Ocean. Visitors who walk the trails can stop in the shade of Torrey Pines, some of the rarest pine trees in the world, which grow in this area and no where else. Geologists, however, are not interested in the pines. Instead, the scientists examine the 300-foot high bluff that overlooks the beach and the Pacific Ocean. The action of waves and tides has cut away at the land. The sheer face of the bluff reveals two of the ways ***sedimentary*** rocks are formed.

Sedimentary rocks contain small mineral fragments that are worn away from other rocks. Most sedimentary rocks are in layers that reveal how they were laid down. At the top of the bluff at Torrey Pines Park, the sandstone layers are not straight. They rise and fall along the curves that once were sand dunes. Wind or water action shaped the sand into dunes. The sand was compacted as the grains stuck together and changed into sandstone.

Part way down the bluff, the layers become more regular. Here the sediment grains were clearly deposited by the action of water and became sedimentary rock, but their layers are straighter and parallel to one another. They do not have the distinctive rise and fall of wind-formed sand dunes. The bluffs obviously were produced by the action of water and not wind. Sedimentary rocks are common in the top layers of the crust because they are formed by the action of wind, water and ice.

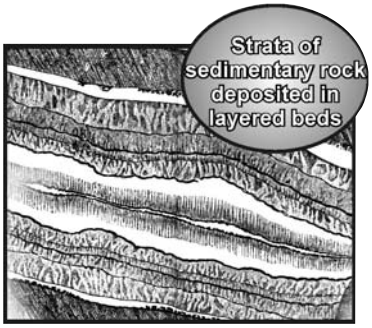
VOCABULARY

Sedimentary: rock from sediment, laid down in layers
Weathering: the process of wind and water breaking down large rocks into smaller fragments
Fossils: the remains or traces of prehistoric plant or animal life once buried in the Earth and now hardened like rock
Magma: molten (melted) material that cools to form igneous rock
Basalt: a hard and dense igneous rock with a fine crystalline structure

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Weathering breaks down larger rocks into smaller fragments. Wind and water transport the fragments great distances. The farther the particles travel, the smoother they become because of wear. The particles also become sorted. The coarser and heavier ones fall out first as the wind dies or speed of the water current slows. The finer and lighter grains travel greater distances. The natural sorting gives rise to sediment that is rich in minerals of a particular density.

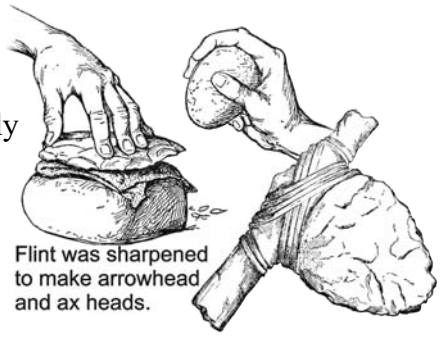
Rushing water can extract gold or diamonds over an extensive area and then concentrate them in the location where the speed of the current can no longer support the heavier minerals.



Usually, a distinct boundary is evident between the layers of sedimentary rock. One year a river will flood and lay down a layer of sediment. The next year it will put down another layer. Between the two floods, however, winds deposit smaller particles that form a boundary between the two layers. The single most common feature of sedimentary rocks is that they form in layers. The layers are sometimes called beds or *strata*.

Sandstone is one of the most common sedimentary rocks. Used as paving and building materials and grinding stones, sandstone contains coarse particles of quartz held together by natural cement. Iron oxide cements red sandstone together. Calcium carbonate holds white or gray sandstone together. Silica is another natural cement. In spite of these natural "glues," sandstone is weathered by winds faster than other types of rock.

Flint is a sedimentary rock made of quartz. However, unlike sandstone, the grains are finer, and the rock is heavy and hard. When struck properly, flint breaks into smooth flakes with very sharp edges. Ancient people used flint for ax heads, arrowheads and knives. Because of their value, locations of flint deposits were kept secret. As early civilizations depleted sources of flint, warriors and hunters used bronze and iron to make tools. Flint became one of the first natural resources to fall into short supply.



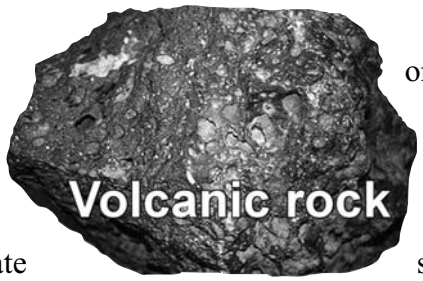
Flint gives off a spark when struck against iron. Flint was used to start fires and to supply the spark to set off gunpowder. A flintlock rifle had a piece of flint held in the striker. As the striker fell, the flint struck a metal plate, causing a spark to ignite the powder charge.

Shale is a gray sedimentary rock formed of mica, quartz and clay minerals. The fragments are so fine they can be seen only with the aid of a microscope. Shale looks as if mud or clay hardened to produce it. It is a soft rock and easily separates into layers. Shale often contains oil, which can be extracted by heating the rock. Taking oil from rock is more expensive than pumping it from wells. Despite the expense, some countries with extensive shale oil deposits prefer that source rather than depending on uncertain energy supplies from other countries.

Conglomerate is a sedimentary rock made of a jumble of pebbles and gravel. The size of particles can range from fine grains to round pebbles the size of baseballs. The



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large rocks are carried by fast running streams or washed by countless waves against rocky shores. Sometimes ***fossils*** or shells are in conglomerate rock. Fossils are often found in other sedimentary rocks, too. Archeologists searching the high regions of the Pacific Coast range above seven thousand feet. have discovered fossilized remains of great sharks and whales just like modern sea creatures. Scientists also found where water deposits of oxide of iron, zinc or lead formed exquisite moss agates. One such agate included a trapped mosquito exactly like mosquitoes found today.

Limestone (calcium carbonate, $CaCO_3$) is a sedimentary rock produced by chemical action. Sandstone, shale and conglomerate are produced by mechanical action. Very little chemical change takes place. Limestone is made as water percolates through the soil. The water chemically dissolves some of the minerals. As the water evaporates, it deposits limestone.

Water flowing into a lake is another example of chemically produced sedimentary rock. The water began as rain that fell on soil and dissolved minerals. Then water flowed into streams, rivers and then into lakes. As the water evaporated, the minerals were left behind and fell to the lakebeds as sediment. Eventually, it hardened into sedimentary rock. Should the source of the water be reduced, the entire lake could go dry. In the state of Oklahoma, the Great Salt Plains is a dry lake where water has evaporated and left behind both salt and the sedimentary rock *gypsum* ($CaSO_4 \cdot H_2O$), used in the manufacture of plaster of Paris.

Igneous rocks are formed when molten rock cools and becomes solid. Igneous rocks were once molten. The word *igneous* is from a Greek word meaning *fire*.

Magma is molten material produced from rock by heat deep in the Earth. It can cool and become solid underground, or it may come to the surface as lava. Magma contains the same elements as rocks in the crust: oxygen, silicon, aluminum, iron, magnesium, calcium, sodium and potassium. Once magma cools, it forms mineral crystals of quartz, feldspar, mica and other minerals made of silicon, oxygen with two or more metals. A variety of different minerals can form. Rather than classifying minerals according to their chemical composition, geologists classify them based on the size of the rocks' crystal formation.

The primary difference in types of igneous rocks is the size of the crystals. Magma, cooled underground, is insulated by surrounding rocks and does not cool as quickly as it would on the surface of the ground. The slow cooling gives the crystals time to grow; therefore igneous rocks formed beneath the surface have larger crystals. Magma, which flows to the surface as lava, cools more rapidly and becomes solid while the crystals are still small. Thus, igneous rocks formed on the surface contain smaller crystals.

Obsidian is a glass-like igneous rock with a shiny surface, which is produced when lava cools rapidly with no time for crystals to form. The resulting rock has a smooth texture. Obsidian is usually black. Because obsidian produces edges as sharp as broken glass, early people prized obsidian for the cutting edges that could be made. One Native American tribe in Mexico had a strong economy built on making and trading stone knives made of obsidian. Today, visitors to Yellowstone National Park in Wyoming can see the imposing



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geological feature, Obsidian Cliff. This mountain of black glass is one of the largest deposits of obsidian in North America.

Basalt, a hard and dense igneous rock with a fine structure, is produced by lava that cools more slowly than obsidian. Crystals form, but they are small. The surface has a glassy appearance. Sometimes gases trapped in the basalt produce tiny bubbles in the rock. Basalt usually forms from lava that flows out on the surface of the Earth or under the ocean, but it can form underground. When basalt cools beneath Earth's surface, distinct columns like rocky posts may be formed. The imposing Devil's Tower in Wyoming is a pillar of basalt. Another example is Giant's Causeway in Northern Ireland, which consists of thousands of polygonal shaped columns of basalt like giant stepping-stones.


Devil's Tower

Pumice is a lava rock filled with pores caused by gas bubbles, giving the appearance of a rock sponge. The air holes make pumice so light it will float in water.

Granite forms from magma that cools slowly deep below Earth's surface. Granite has crystals so coarse they can be seen with unaided eyes. The rock is light colored and contains quartz, feldspar and mica. Granite resists weathering more than sedimentary rock such as sandstone and limestone, so it is preferred as a building material.

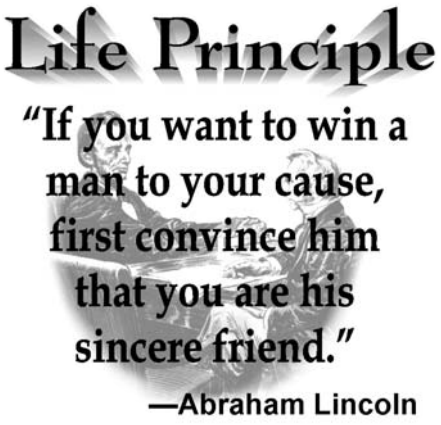
Metamorphic rocks are the third category of rocks. *Metamorphic* is from two Greek words meaning *to change shape*. Metamorphic rocks are sedimentary or igneous rocks that have been changed by heat or pressure or both. The composition and texture of metamorphic rock depends upon the starting material. Each of the sedimentary rocks and igneous rocks forms a type of metamorphic rock when they are exposed to heat, pressure or both.

Quartzite is metamorphic rock formed from sedimentary sandstone put under heat and pressure.

Slate is metamorphic rock produced from shale. The primary change is caused by pressure, and heat is not an important factor. When shale is buried deep, the overlaying rock becomes so heavy the added pressure changes shale into slate. Slate is hard and resists weathering. Like shale, slate will split into thin, smooth surfaced layers. For decades, slate was used for making chalkboards and for shingles on houses. Polished slate is still used as a building material.

Marble is metamorphic rock produced from limestone by heat. The primary change is caused by heat, and pressure is not an important factor. Marble takes a high polish and is the material of choice for finishing buildings that reflect a prosperous lifestyle. Sculptures chisel and polish statues from marble. Its only defect is, that unlike most other metamorphic rocks, marble weathers when exposed to sulfur and moisture.

The three types of rock are sedimentary, igneous and metamorphic. Magma, because it is a liquid, is not a type of rock. Because of the destruction caused by the heat and pressure that forms them, neither metamorphic nor igneous rocks contain fossils. Only sedimentary rocks contain fossils.



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Integrated Physics & Chemistry



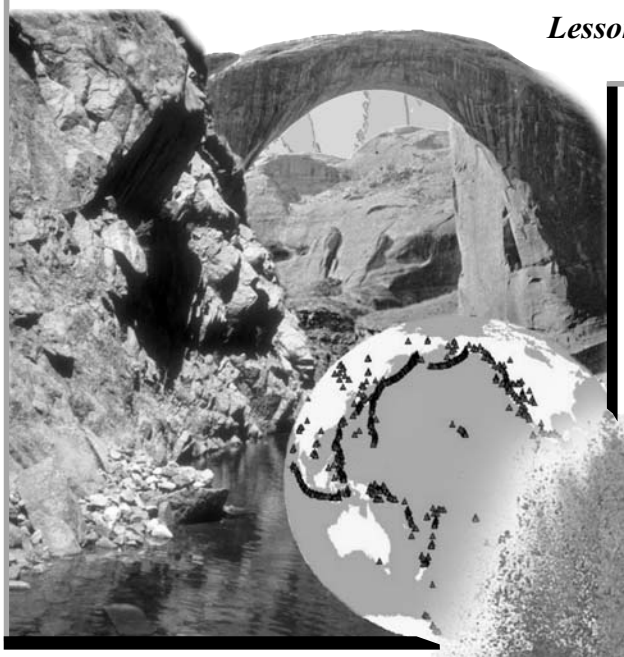
Lesson 4
Geology

Chapter 11

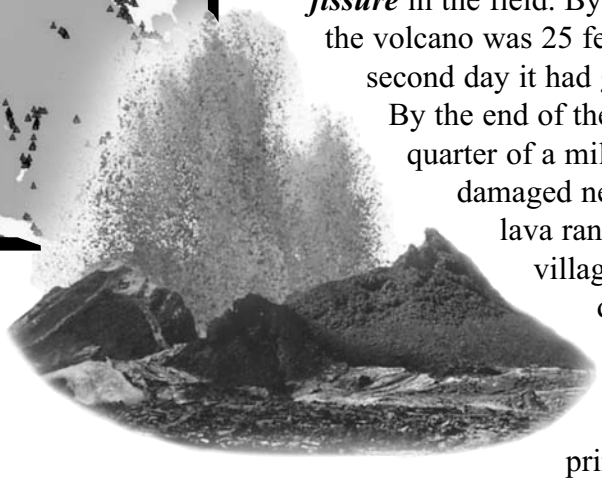
VOLCANOES, WEATHERING AND EROSION

Section 1

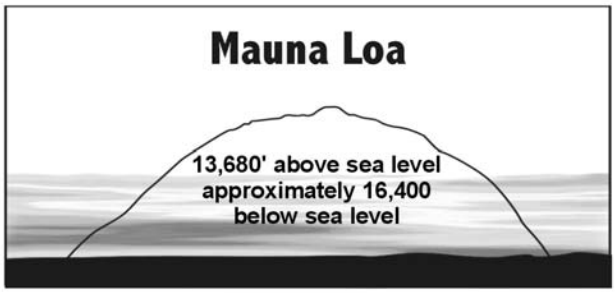
Lessons 1-5



The Mexican farmer working in his cornfield thought February 20, 1943 would be like any other day. He lived near Paricutín, a small village about 200 miles west of Mexico City. However, before the day was over, the cornfield had become an active volcano. Lava and ash began pouring from a ***fissure*** in the field. By the end of the day, the volcano was 25 feet high. By the second day it had grown to 164 feet. By the end of the year, it was a quarter of a mile high. The ash damaged nearby farmland, and lava ran through the local village and buried it to a depth of thirty feet.



Lava and ash from volcanoes are the primary way that new crust is produced. All of the Hawaii islands are a gift of volcanoes. Most volcanoes end up as mountains, and some reach enormous heights. Mauna Loa, rising almost 13,680 feet above the surface of the sea, is an active volcano on the big island of Hawaii in the Pacific Ocean. That height is only part of the entire volcanic cone. It was built up from the ocean floor, a distance of 16,400 feet below the sea. Overall, then, Mauna Loa is one of the largest mountain peaks in the world.



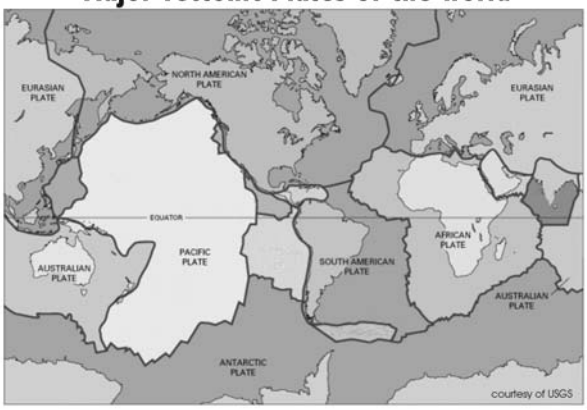
VOCABULARY

Fissure: a long narrow opening, a crack
Glacier: a huge mass of slowly flowing ice
Debris (deb-bree): remains of anything destroyed; ruins, rubble, accumulated fragments of what was once whole
Disintegration: the physical (or mechanical) reduction of a substance into parts, fragments or particles; the destruction of the cohesiveness of a thing
Decomposition: the weakening or destruction of substances by chemical means

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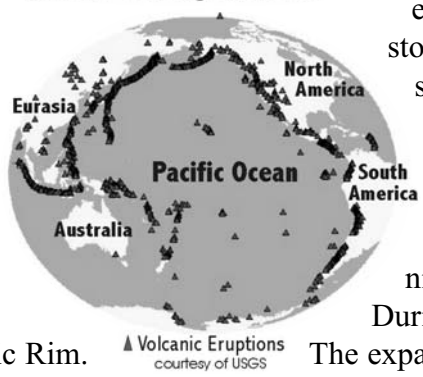
Volcanoes can and do erupt underwater. South of Hawaii, oceanographers have detected a volcano that has not yet built itself up high enough to reach the surface of the water. Volcanoes build their volcanic cones during eruptions. The action of pouring out lava and ash generates the mountains. The undersea volcano and Paricutín, the active volcano that erupted in the farmer's cornfield, show that volcanoes are still at work building mountains.

Major Tectonic Plates of the World



Geologists have noticed that volcanoes occur along the edges of *tectonic plates*. Geologists have a theory that Earth's crust is not a continuous sheet of rock. Instead, it is made of seven large tectonic plates as well as several smaller ones. A tectonic plate is a section of Earth's crust. Measurements show that the plates seem to move about. Some move as much as 10 centimeters per year. The cause of the motion is not clear. Volcanoes form where two moving tectonic plates meet. Along the border of the Pacific plate between North America and Japan is an especially active area of volcanic activity. Of the world's active volcanoes, about 80 percent are along the Pacific Rim.

Volcano's along the Pacific Rim



As volcanoes build mountains, weathering and erosion also work against the mountains. Weathering is the process of breaking rock into smaller fragments. Erosion is the action of wind or water moving the fragments to new locations. Weathering and erosion work together. Rocks that have been weathered are broken into smaller pieces that are more easily transported. Erosion of the fragments exposes new rock to weathering. Because the two usually occur at the same time, geologists often use the two terms weathering and erosion interchangeably.

The various actions of water are important agents in weathering. Falling rain, rushing water, waves crashing against the shore, and the freezing and thawing of ice all weather rock. Slow moving ***glaciers*** can mechanically rip apart rock. Water also produces erosion by carrying away the fragments. River currents, glaciers and the action of waves and tides transport the smaller fragments.

Erosion removes materials of soil and rock from one place to another. Barrier islands are formed along the coast when waves and currents pile up sand. Sandbars may grow until they become large enough to support plants and serve as locations for buildings. The Outer Banks of North Carolina and Padre Island in Texas are examples of barrier islands. Unfortunately, the same wind and water that deposited the sand can also take it away. Beach erosion caused by strong tropical storms or by hurricanes poses a serious problem for barrier islands.

Gravity is also a factor in erosion. Suppose weathering causes small rocks and boulders to loosen on the side of a slope. At night, the rocky slope is cool. During the day, it warms and expands. The expansion is at right angles to the

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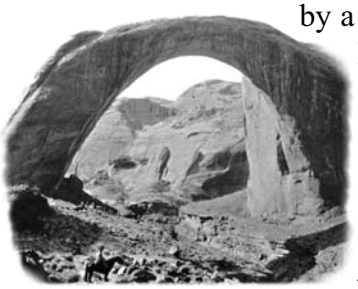
slope. The rock is pushed away from the slope. As the slope cools at night, gravity pulls down on the rocks. When the rocks cool, they settle slightly further down hill than they were the day before. This creep is imperceptible, but over several years, a mass of rock ***debris*** forms at the base of the slope. Such a collection of rocks caused by temperature changes and gravity is called a *talus slope*.



A landslide is caused by a large mass of rock that slides into a valley. Landslides along a slope normally occur where layers of two different kinds of sedimentary rock meet. The top layer is porous enough to be weakened by the action of the water. Then, the water encounters a harder and less porous layer that is tilted toward the valley. The top layer rests on a tilted, slippery surface. Eventually, the ground gives way, and loosened rocks slide down the slope into the valley.

As an example, suppose the top layer is sandstone, which is easily weakened by the action of water. Below the sandstone is a layer of clay or shale. Those less-porous layers of clay or shale do not let water penetrate. The top soggy layer rests on a slippery hard surface. Eventually the top layer slides down into the valley. Rockslides mixed with water can be deadly because the material can reach speeds of 40 miles per hour.

Wind mixed with sand is another agent of weathering and erosion. Sand blown by wind can grind away at rock and then carry away the fragments. Sometimes the action produces unusual natural features. Arches Natural Park in Utah contains Delicate Arch, Double Arch, Landscape Arch and a variety of other features in which wind has played a major role. Although water probably generated the basic shapes in the sandstone, the action of grit in wind has given the features a smooth look as if sanded by a giant human hand.



Landscape Arch is the largest natural arch in the world. At 306 feet long, the arch is long enough to bridge a football field.

Changes in temperature can cause physical weathering. Rocks exposed to hot sunlight expand. The expansion is not uniform throughout the entire body. An outer flake may pop off. Or, as in sedimentary rock, an entire layer may separate. If water gets between cracks, expansion of ice causes a wider crack.

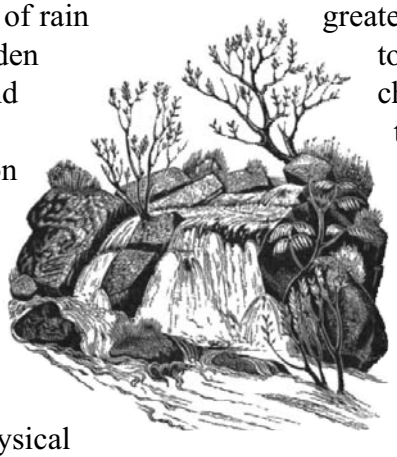
Living things also cause weathering. The roots of trees can separate rocks. Roots of plants have the same effect but on a smaller scale. They not only split rocks but also extract nutrients chemically. The chemical change weakens the rock.

The *lichen* is a very effective plant at breaking down rock. Lichens are combinations of algae and fungus living together. One variety of lichen forms a crust-like growth on bare rocks. Lichens secrete an acid that dissolves the material, which cements the rock particles together. In addition to chemical action, lichens grow outward in wet weather. They retract into smaller circles when the weather is dry. During periods of contraction, lichens pull particles loose from the host rocks.

Burrowing animals and the action of human beings are also agents of weathering. Overgrazing and clearing land of trees to plant crops are examples of changes caused

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by animals and human activity. When new shopping centers are constructed, the large areas of building roofs and asphalt parking areas cause a sudden runoff of rain during downpours. The sudden run off can swell streams and hasten erosion. Some cities now require that construction of buildings and parking lots also include runoff ponds. The ponds catch and slowly release the water that drains from parking lots and buildings.

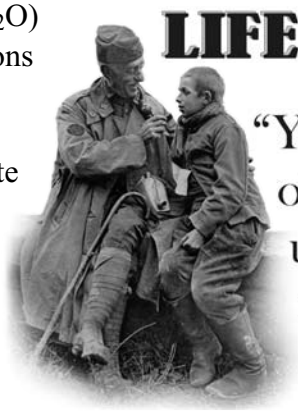


Disintegration is physical weathering. Smaller rock fragments have the same composition as the parent rock from which the fragments are loosened. Examples of agents of physical weathering include rushing waters, waves, tides, temperature changes, effects of gravity and the grinding effects of glaciers.

Decomposition is chemical weathering. Decomposition changes the chemicals found in rocks. Examples include the action of acid rain on limestone, the acid secreted by lichens on rocks, and water that seeps through and dissolves minerals. Water can become chemically combined with minerals (notated by a dot in the formula). For example, Epsom salts ($MgSO_4 \cdot 7H_2O$) is magnesium sulfate with seven water molecules. Alum is a combination of potassium and aluminum sulfate with 24 water molecules. Gypsum ($CaSO_4 \cdot H_2O$) has one water molecule. Other reactions that weaken minerals are oxidation (combining with oxygen) and carbonation (changing into a carbonate such as potassium carbonate, K_2CO_3).

Usually, decomposition results in rocks that are weaker than the original rock. Both mechanical and chemical weathering occur at the same time. One aids the other. Breaking apart rocks by mechanical disintegration exposes a greater surface area for chemical reactions to take place. Weakening the rocks by chemical decomposition increases their likelihood of being broken apart by physical forces.

Weathering is produced by running water, winds containing sand, glaciers, ground water, freezing and thawing of ice, rapid heating and cooling of the surface of rocks, gravitational forces, waves and tides, growing plants, burrowing animals and human activity. All play important roles in shaping Earth's surface. In wet climates, the action of water is the most effective weathering agent. In dry climates, wind and alternating temperatures are the most important. The powerful action of glaciers makes great changes in Earth's surface features. Rather than baseball sized boulders that fast-moving river currents can carry along, glaciers can carry boulders as large as houses. Moving glaciers erode and transport large quantities of rocks, sand and other particles along their paths.



LIFE PRINCIPLE

"You should never put off doing something useful for fear of evil that may never arrive."

—James D. Watson

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Integrated Physics & Chemistry



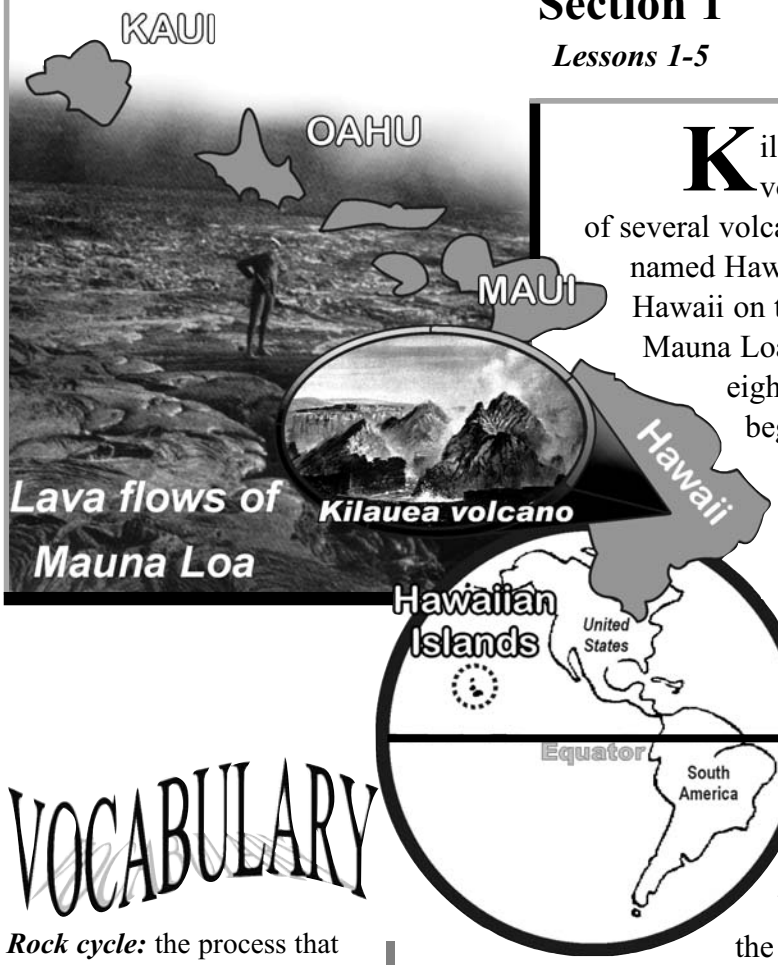
Lesson 5
Geology

Chapter 11

ROCK CYCLE

Section 1

Lessons 1-5



Kilauea is the world's most active volcano. The state of Hawaii consists of several volcanic islands. The largest island is also named Hawaii. Kilauea is on the big island of Hawaii on the side of a still larger volcano, Mauna Loa. During the 1900s, Kilauea erupted eight times. The longest-lasting eruption began in 1983 and has not yet concluded. Kilauea is constantly active, but the lava that flows through the crater often drains away through other passageways in the larger mountain. However, sometimes the lava overflows and streams down the mountain slope to the sea, causing a great vapor of steam.

In 1989, a lava flow set fire to the visitor's center at Volcanoes National Park, cut across the highway that circled the island, poured into the Royal Gardens subdivision and destroyed 65 houses before plunging into the sea. Lava remained a liquid for the entire seven-mile journey. Once in the sea, the lava cooled and added about 500 acres to the island. Eruptions in 1990 buried the entire coastal village of Kalapana.

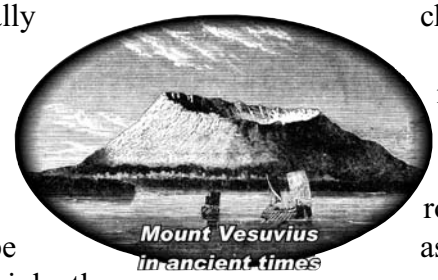
The eruptions have provided geologists with exceptional opportunities to understand how volcanoes work. Today, Kilauea is still being watched closely. Each day a geologist from the U.S. Geological Survey maps the location of the lava flows and estimates the location of the flows in the next 24 and 48 hours.

VOCABULARY

Rock cycle: the process that changes one type of rock into another
Soil: minerals with some organic matter capable of growing plants
pH: a measure of the number of hydrogen ions in a solution, pH readings are used to determine if a solution is acidic (pH less than 7.0), neutral (pH equal to 7.0) or basic (pH greater than 7.0)

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The surface of the Earth is constantly changing from a variety of forces. Sometimes the changes are visible from one season to the next. For instance, sandbars a few hundred feet out from a beach may be visible one year but may have disappeared by the next year. Other changes take a lifetime to occur. A great river may cut a new channel during an unusually high flood that occurs only once a century. Mount Vesuvius in Italy is the only active volcano in Europe and has erupted violently since ancient times. In 1806, Vesuvius erupted and closed roads that had been in use for almost 2,000 years. Still other changes take far longer than recorded history, such as the erosion of the Grand Canyon.



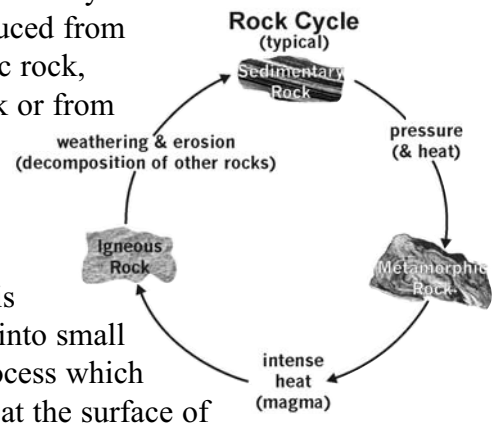
Gravitational attraction from the Sun and Moon also act as a force against Earth's crust. Gravitational attraction causes tides in water and puts stress on rocks. Tectonic plates that press against one another cause variations in the elevation of the land. Differences in temperature between the hotter magma deep in the Earth and the cooler crust also cause changes in Earth's surface. Rock is elastic, and responds to natural forces by warping and bending. Geologists call this warping and bending *folds*. Folds in Earth's surface form some types of mountains. *Faults* are breaks in Earth's crust where the stress is greater than the elasticity of the rock.



The lithosphere is constantly changing because of igneous processes, forces that produce folds and faults and by weathering and erosion. The changes do not create new material. Instead, rock is transformed into different forms. Forces that change rock are part of the ***rock cycle***.

If one sedimentary rock is changed into another sedimentary rock, then that is part of the rock cycle. For instance, sandstone, flint and limestone sedimentary rocks can be eroded and carried down stream as pebbles and gravel. The sediment collects when the current slows. Under the right conditions, the pebbles and gravel can be changed into conglomerate sedimentary rock.

If one type of rock, such as sedimentary, is changed into another type, such as metamorphic, that is part of the rock cycle. The agents that cause the changes are heat, pressure, weathering and erosion.



Sedimentary rock can be produced from metamorphic rock, igneous rock or from other sedimentary rock. Rock exposed to weathering is worn down into small grains, a process which occurs only at the surface of the Earth or very close to it. Erosion carries away the fragments and deposits them somewhere else. Their first stop might be only one part of the total journey. The sediment might be carried away during a flood and taken to the ocean. Eventually, however, the sediment reaches a place in the ocean where it accumulates to greater depth. As sediment is buried deeper and deeper, the

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small mineral grains are compacted and cemented together. Geologists believe sedimentary rock forms at a depth of about 0.5 to 2 miles. The overlying covering can become very deep. Instead of remaining as a shallow sea floor, sediment may be buried under tons of lava and ash from volcanoes. Conglomerate rock formed in this manner is often full of various types of fossilized sea life.

The Earth's crust is not stable. Because of heating, cooling and the movement of tectonic plates, rock that is on the surface may eventually be buried deep within the crust. If the sedimentary rock is buried deep enough, heat and pressure become great enough to change the sediment into metamorphic rock. During the process, the sedimentary rock does not melt. It remains a solid. The kind of metamorphic rock produced depends on the type of sedimentary rock, the amount of pressure and the amount of heat. Shale, a sedimentary rock that contains mica, quartz and clay minerals, may change into slate. Or, if the temperature is hot enough, the mica crystals may become larger. Heat and pressure can also change igneous rock into metamorphic rock. Geologists believe the pressure and temperature are high enough to form metamorphic rock at a depth between 6 to 18 miles below Earth's surface.

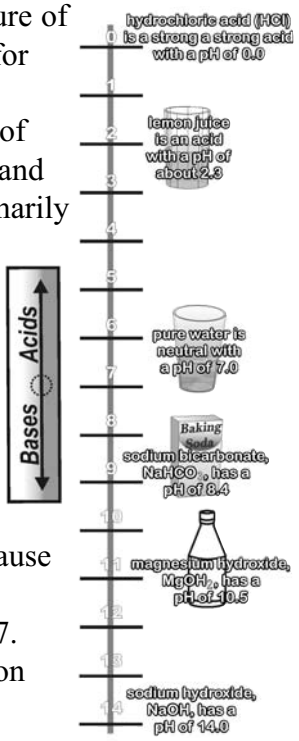
At a depth greater than about 18 miles, higher temperatures melt the rock. It becomes magma. Magma is a liquid that forms whenever any of the three types of rocks—sedimentary, metamorphic or igneous—become molten. Magma can form only deep within the crust. It may cool below the surface, or it may be released as lava from a volcano. In either case, once the magma cools, it produces igneous rock.

Weathering changes any one of the three types of rocks—sedimentary, igneous or metamorphic—into fine particles. These small particles are still considered rock despite being so small. When organic matter is mixed with the particles, the result is ***soil***.

For human beings, the top few inches of the Earth is most important. Except for fish and seafood, most of the world's food supply comes directly from plants or from animals that graze on plants. Plants draw resources from the soil, water, air and sunlight. About 10 percent of soil is *humus*, which is matter from decayed plants and animals. The partially decayed organic matter is an essential part of soil. Not only does humus provide nitrogen nutrients; humus keeps the soil porous and holds water and air.

The amount of water in soil has a great effect on agricultural usefulness of land. Sandy soils do not retain water. Instead, water soaks through the sand, removing some of the nutrients. Clay has the opposite reaction. Clay soils become gummy when wet due to water retention, and present difficulties for farm equipment in breaking the ground, planting seeds and controlling weeds.

Another measure of the suitability of soil for agriculture is its ***pH*** reading. In a solution of pure water, hydrogen and oxygen are found primarily as water molecules (H_2O). A few molecules disassociate into hydrogen ions (H^+) and hydroxide ions (OH^-). However, an equal number of each type of ion exists to cause water to be primarily neutral, with a pH of 7.



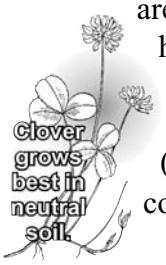
An acid solution contains an excess of

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hydrogen ions (H^+). Because of the way pH readings are taken, a high concentration of hydrogen ions results in a smaller number. Pure water is neutral and has a pH of 7.0. A weak acid such as acid rain has a pH reading of 5.6. Lemon juice is an acid with a pH of about 2.3. Hydrochloric acid (HCl) has a pH of 0.0. It is a strong, poisonous acid often used for cleaning stone or concrete.

A base solution contains an excess of hydroxide ions (OH^-). Sodium bicarbonate (baking soda, $NaHCO_3$) is a weak base with a pH of 8.4. Magnesium hydroxide (Milk of Magnesia, $MgOH_2$) is a stronger base with a pH of 10.5. Sodium hydroxide (NaOH) has a pH of 14.0 and is a strong base.

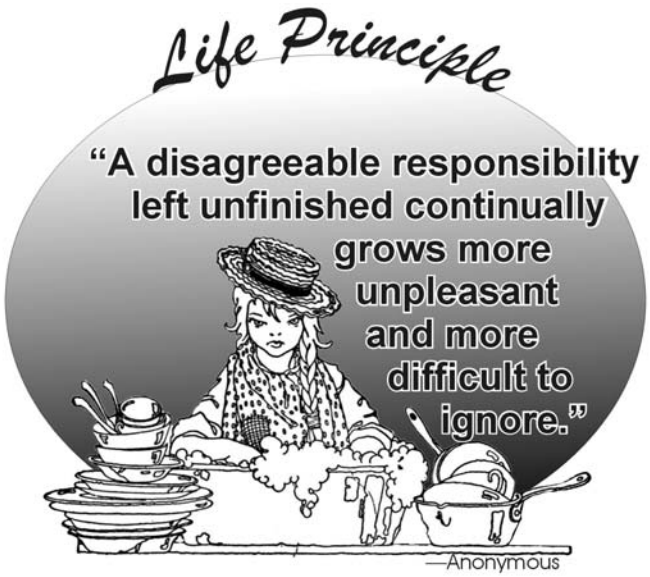
The pH reading of soils can vary considerably, from about 4.0 (moderately acidic) to 11.0 (highly basic). Deserts with low rainfall have basic soil, while well-watered land has a much higher pH reading. Rainfall changes the acid content. Calcium, potassium and sodium are in the soil in regions with little rainfall. These elements tend to react with what little moisture exists to form bases. In soils where water is more plentiful, the soil tends to be more acidic. Calcium, potassium and sodium are not as plentiful in the soil. They have been washed away by the rain. The water reacts with carbon dioxide to form weak carbonic acid (H_2CO_3). An acidic soil has a high concentration of hydrogen ions (H^+).



Some plants prefer one type of soil to another. Cranberries and wild flowers grow best in soils that are acidic. Other plants such as alfalfa and clover prefer neutral soils. Agricultural chemicals are used to modify the acidity of the soil. Lime (CaO) often is spread on fields that have soil which is too acidic. Lime reacts with water to produce calcium hydroxide ($Ca(OH)_2$), a base that neutralizes acid.



Chemistry plays a major role in food production. Fertilizers, insecticides, herbicides and fungicides are chemical compounds intended to restore nutrients to the soil, kill insects, destroy weeds and stop fungus. Developing chemicals to do the intended task without harmful side effects requires highly trained, skillful chemists.



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Integrated Physics & Chemistry



Lesson 6
Compounds

Chapter 11

SILICON

Section 2

Lessons 6-10





All of the following have something in common. An elderly patient complains of a constriction in her throat. Her doctor examines her throat and esophagus with a fiber optic device that shines light into the affected area and returns an image. An amateur mineralogist discovers an ordinary looking stone that is actually the gem, amethyst. A computer hobbyist connects his modem to a fiber optic cable to receive information over the Internet a hundred times faster than with a standard connection. An amateur radio operator purchases new crystals so his radio can receive signals on more channels. All of these activities make use of silicon and silicon minerals.

Silicon (Si) is second to oxygen as the most abundant element by weight in Earth's crust. Silicon never occurs in the native or free state. Silicon is always found in combination with other elements, and separating silicon from those other elements is not easy. Jons Jakob Berzelius discovered silicon in 1824. He separated it from silicon tetrafluoride (SiF_4) by heating it with potassium. Potassium has a greater chemical attraction for fluorine than does silicon, so potassium removes the fluorine and frees the silicon atoms. Today, pure silicon is produced by reacting silicon dioxide (SiO_2) with carbon to give carbon monoxide and pure silicon. The reaction requires heat that is provided by an electric furnace. Pure silicon is used as silicon chips to make semiconductor devices and as solar cells to convert sunlight into electricity.

VOCABULARY

Silicon: a nonmetallic element; the second most abundant element in Earth's crust, used in semiconductors; its compounds are used in the manufacture of glass
Quartz: a crystalline form of silica, silicon dioxide
Abrasive: a material such as diamond, Carborundum or sandstone that is capable of wearing down a substance by the friction of rubbing
Stained glass: glass that has been colored in specific ways by processing with certain metallic elements

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Pure silicon reacts readily with oxygen and highly active nonmetals such as fluorine and chlorine. Silicon does not dissolve in water or in acids but is attacked by sodium hydroxide (NaOH), a base. Silicon is in the same family as carbon in the periodic table. Silicon has four electrons in its outer shell and needs eight electrons to complete the shell. Silicon's valence is 4, the same as the valence of carbon. Just as carbon is added to iron to make strong steel, silicon can also be added to metals to produce better alloys.

Silica, another name for silicon dioxide (SiO_2), is the simplest naturally occurring silicon compound and one of the most common. The bonds are covalent because silicon and oxygen share the electrons. The atoms of silica form a tetrahedron, with silicon in the middle and an oxygen atom at each of the four-corners. Each oxygen atom is shared between two tetrahedrons forming a solid, strong, three-dimensional structure.

Quartz is the most common silica mineral. It is a hard mineral, although not as hard as diamond. Because of its hardness, quartz is used as a substitute for diamond as an ***abrasive***. Quartz is used in blades for stone cutting, as well as for sandblasting and glass grinding. Another silicon-based abrasive is silicon carbide (SiC) better known under its brand name of *Carborundum*. Edward Goodrich Acheson, an American inventor working for Thomas A. Edison, discovered Carborundum while trying to make synthetic diamond. Acheson heated carbon with various substances including clay. He produced a substance with hardness very nearly that of diamond but without its gem-like beauty. Acheson thought the substance was a compound of carbon and aluminum oxide. Later tests showed that it was silicon and carbon.

Silicon carbide is still one of the hardest minerals known. Grains of Carborundum are cemented together to make grind stones and glued to paper to make sandpaper. Amateur mineralogists tumble stones in a container with water and Carborundum. The process begins with coarse grains and proceeds to finer and finer ones. After several weeks of the treatment, rough stones become smoothed and polished into semiprecious stones and gems.

Silica glass is made from fused quartz. Pure quartz becomes molten at about 1,500ºC (2,732ºF). While still hot, it can be shaped into laboratory glassware. Quartz can withstand extreme and sudden temperature changes. Quartz can be heated red-hot and then plunged into cold water without shattering. Laboratory beakers and test tubes that must withstand extreme conditions of heat and cold are made of quartz.

Quartz is transparent to ultraviolet light. Tanning beds, which give a person an even tan, emit ultraviolet light. Most clear substances such as glass are opaque to ultraviolet rays. Ultraviolet light does not pass through ordinary glass. A tanning bed lamp inside a glass bulb would not emit ultraviolet rays because the glass would filter them out. Quartz, however, allows ultraviolet light to pass. Bulbs in tanning beds are made of quartz. The ultraviolet light can damage skin and cause skin cancer.



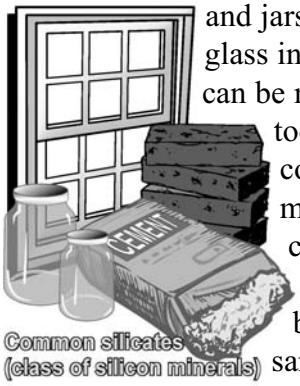
Quartz crystals are used because of their property of vibrating at a fixed rate when electricity flows through them. Quartz crystals control the frequency of electric circuits in computers and sensitive electronic equipment.

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Naturally occurring quartz crystals vary greatly in size. Some weigh as much as 2,000 pounds. Others are no larger than a grain of sand. In fact, sand is made of small crystals of quartz. Pure quartz is clear, and fine particles of it appear dazzling white in the Sun. Most quartz is not pure. Brown and tan sand comes from quartz that has impurities. Small fragments of pure quartz crystals produce white sand, although white sand can also be made of broken shells and of gypsum.

Silicates are another broad class of silicon minerals. A silicate contains silicon, oxygen and one or more metals. Silicate minerals make up the most common minerals of Earth's crust. About 90 percent of igneous rocks contain silicates and about 75 percent of all minerals are silicates. Common silicates include emerald, mica, gypsum, asbestos and talc. Most construction materials such as glass, ceramics, brick, concrete and building stone are silicates.

Glass such as that used in windows and jars is a silicate. Although glass in the form of fused quartz can be made from silica, it is much too expensive for most commercial purposes. Glass made from a mix of three chemicals is cheaper to produce. Glass production begins by mixing together sand (silicon dioxide, SiO_2), limestone (calcium carbonate, $CaCO_3$) and soda ash (sodium carbonate, Na_2CO_3). After the mixture melts, the reaction drives off carbon dioxide gas and converts the remaining materials to oxides of silicon, calcium and sodium.



Common silicates (class of silicon minerals)

As the mixture cools, it never becomes a true solid. Unlike quartz and other crystalline minerals, glass does not have an orderly internal pattern. Glass is *amorphous*, a term meaning *no shape*. Because it is a noncrystal, as the slow moving molten glass sets, it becomes harder and harder but never becomes truly solid. Glass panes in old buildings are slightly thicker at the bottom than at the top. During the many years they were in place, the glass has very slowly flowed toward the bottom. Crystalline minerals have a definite temperature at which they melt. When glass is heated, it becomes softer and softer without becoming a liquid at a specific temperature.

Occasionally, glass crystallizes spontaneously. Sometimes an automobile window or other sheet of glass will, without warning and for no apparent reason, develop a network of cracks and fall apart as small pieces of crystallized glass.

Glass has been made for several thousand years. Glass objects have been found in Egypt dating from about 1500 B.C. Glass made by mixing sand, limestone and soda ash normally has a green tint. Introducing manganese eliminates the green color. Some glassmakers concealed the fact they could not make glass perfectly transparent by giving it a definite color. Glassmakers intentionally gave the glass a definite color by introducing nickel, cobalt, iron and other metals into their mix. Iron gave glass a red color. Nickel gave a green color. Cobalt gave a beautiful blue color.

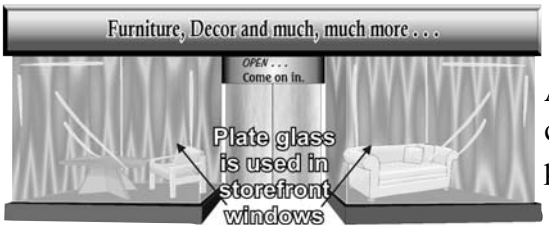
Pieces of different colored ***stained glass*** were put together to show designs or to make pictures. Many churches and cathedrals have stained glass windows. Today, people who visit European church buildings marvel at the beautiful stained glass. People who


Many cathedrals in Europe have stained glass windows that depict religious scenes

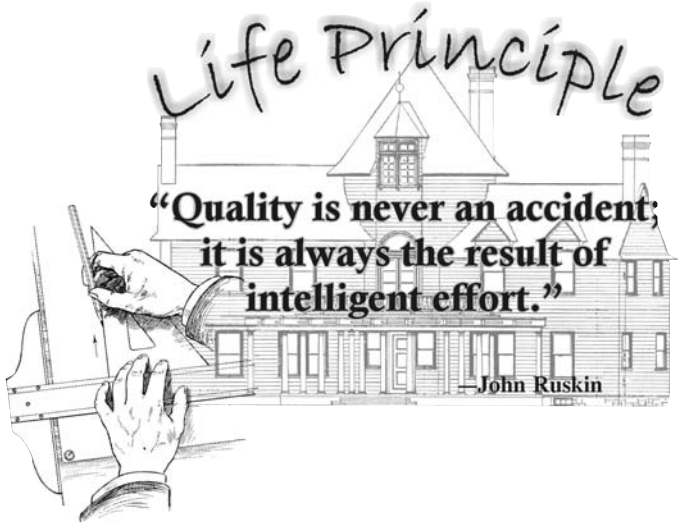
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lived four or five hundred years ago would have been as impressed with large pieces of clear glass.

Plate glass is a sheet of glass that is flat, clear and of uniform thickness. It is used for large storefront windows and glass doors. Making perfectly flat, transparent sheets of glass is difficult. Early glassmakers would take a four-foot long, small diameter pipe, then dip it in the molten glass and then blow through the pipe to form a large globe of glass. Then craftsmen would cut the glass globe and unfold it into a sheet. Such glass was not particularly flat, and it had imperfections of bubbles and streaks that can be seen in windows of very old houses. The next improvement was to use hot metal rollers to flatten the glass. The resulting glass had to be ground and polished so that it was parallel and transparent on each side. Today, the glass is floated on the surface of molten metal, which produces glass that does not need as much treatment to make it smooth.



Glass also has many applications in science and technology. Telescopes, microscopes, camera lenses and eyeglasses are made of optical glass. The glass is cooled at a controlled rate so it does not become strained, and steps are taken to prevent air bubbles and other imperfections. Although a single convex lens can produce an image, few optical devices are made of a single lens. A lens acts as a prism and introduces false color fringes around bright objects. The color defect can be overcome by using more than one type of glass. Some camera lenses have as many as 15 different lenses of various kinds of glass to improve the quality of photo images. Lenses are also coated with filtering material to eliminate reflections between the lens elements.



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Integrated Physics & Chemistry



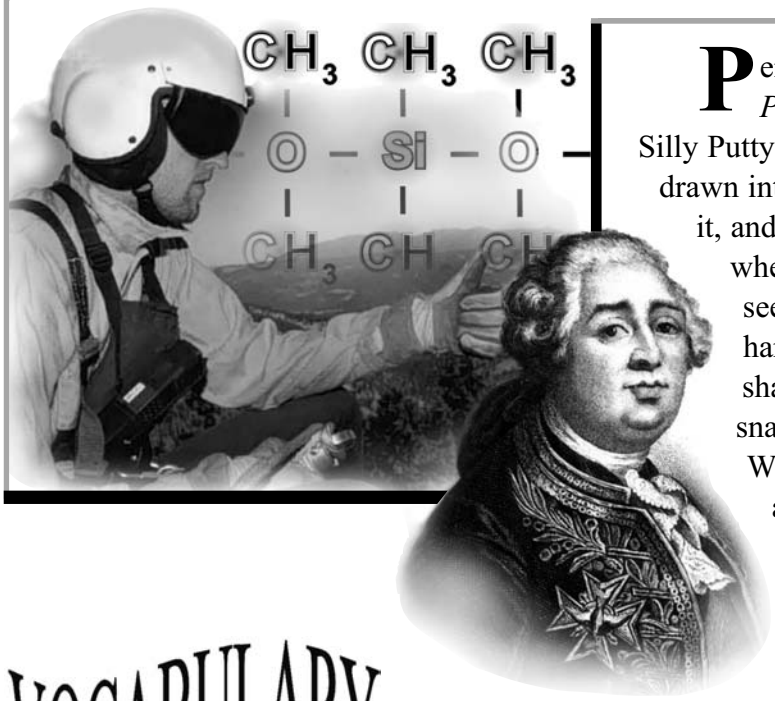
Lesson 7
Compounds

Chapter 11

SILICON COMPOUNDS

Section 2

Lessons 6-10



Perhaps you have played with *Silly-Putty*™. When acted upon slowly, Silly Putty can be rolled out into sheets or drawn into taffy-like strips. Press a thumb into it, and the material gives way; however, when acted upon quickly, its properties seem reversed. Strike it sharply with a hammer, and, instead of giving way, it shatters. If pulled upon briskly, the strip snaps as if a rubber band had broken. When rolled into a ball and thrown against a hard wall, it will bounce like a rubber ball. Silly-Putty is an example of some of the unusual properties of silicon compounds.

Silicon, like carbon, has a valence of four, which means that it has a variety of ways to form compounds. Even so, the number of different compounds containing silicon is far less than the number of different compounds containing carbon. Although fewer silicon compounds exist, the ones that occur naturally are found in greater abundance than the naturally occurring carbon compounds. Silicates make up a large proportion of Earth's crust.

Many ***gemstones*** are *silicates*, which are compounds containing silicon, oxygen and one or more metals. Various properties of a mineral make it a good candidate as a gemstone. A gemstone must be beautiful, hard, rare, carefully polished and attractively displayed.

The beauty of gemstones depends on their ***optical properties***—how they refract and disperse light so that the gems produce a variety of colorful effects. Some gems have fire and brilliance; others show different colors depending on how

VOCABULARY

Gemstones: precious gems; naturally occurring stones valued for their rarity, beauty or worth, such as diamonds, rubies, emeralds or sapphires used in jewelry
Optical properties: features that people can observe
Emery: a powder-like abrasive; aluminum oxide (Al_2O_3) used to polish gemstones
Silicone: a synthetic silicon compound consisting of chains of silicon and oxygen with side members of organic molecules

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they are held. Diamonds, for instance, are usually clear and produce prismatic colors. Rubies and emeralds have intense colors. Each star sapphire seems to posses a glowing white star in its midst. A "cat's eye" seems to have a shimmering golden light reminiscent of a tiger's eye.

The physical properties are important, too. A gemstone mineral must be hard to withstand wear and conditions encountered during everyday activity. A person would not pay a high price for a gem if it scratched easily or wore away while being worn on hands or garments. The gemstone must also be capable of being ground and polished. Many minerals are unimposing when first found. A diamond looks like a dull, oily stone. Agate looks like a piece of gravel. A gemstone must be able to take a high polish to bring out the beauty of the stone.

The third requirement for the gemstone is to be rare or difficult to obtain. A gem may be precious at one time during history but only semiprecious at another time. Amethyst is a form of quartz with a beautiful violet color. Europeans of the Middle Ages held the stone in high regard. However, explorers to South America and other parts of the world found large deposits of quartz that included amethyst, and it lost its value.

Rarity, hardness and beauty alone do not determine the value of a gem. A fourth factor applies—how well it is cut, polished and displayed. Shaping and polishing a gem enhances its value. The cost of a gem includes the expense of grinding, polishing and putting it into a setting.

The first step is to cut the stone to the approximate correct size. During the cutting, imperfections can be eliminated to improve the value of the stone. Cutting is done by means of thin metal disks embedded with diamond particles.

The next step is to grind away rough edges so the stone has a smooth surface. Sandstone, which contains quartz, can grind softer minerals. For harder stones, silicon carbide (SiC) is used. Several stones may be put in a revolving tumbler with water and silicon carbide. With tumbling, the shape cannot be controlled. To put flat surfaces on the stone, it is cemented to the end of a wooden stick and held against a revolving wheel covered with silicon carbide.

The final step is to polish the stone. Polishing is done with *optical rouge*, a fine, powder-like abrasive. Optical rouge is ferric oxide (Fe_2O_3), which has a red color. *Rouge* is a French word meaning *red*. Another mineral used for polishing is emery, a powdered mineral consisting of aluminum oxide (Al_2O_3). Next to the diamond, ***emery*** is the hardest natural substance. Once in finished form, the gem is put in a setting of silver, gold or other precious metal such as platinum.

Beauty, hardness, rarity and how it is polished and displayed all go together to make a stone valuable. Another factor is a human one. A gem may have additional value simply because of who previously owned it or because of a legend surrounding its history. The best known story is the mystery surrounding the blue Hope Diamond. It was once owned by King Louis XVI but disappeared during the French Revolution. The diamond was re-cut and appeared in London in 1792. Today the Hope Diamond is on display at the Smithsonian Museum. Another famous gem is the "Star of India" in the Morgan-Tiffany Collection at the American Museum of Natural History in New York City.



The Blue Hope Diamond

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Another common silicate, not as valuable as gems but still important, is glass. Glass has a variety of useful properties including the fact that it can be drawn out into long thin fibers. Fiber optics are an important application of total internal reflection. The fibers are so narrow that light rays that enter at one end cannot escape because the rays strike glancing blows along the sides of the fiber. Light rays are kept inside the fiber by total internal reflection. The light rays can escape only at the other end of the fiber.

At first, fiber optics were used to shine light into hard-to-reach areas. Then scientists discovered that a bundle of thousands of the thin fibers could transmit an image. A lens projects the image onto the end of the bundle. Each fiber carries a small section of the image to the other end. There it can be viewed with a magnifier. Doctors use optical fibers to see inside the human body. Fiber optics strands which help doctors to position a laser beam precisely for laser surgery, carry laser light.

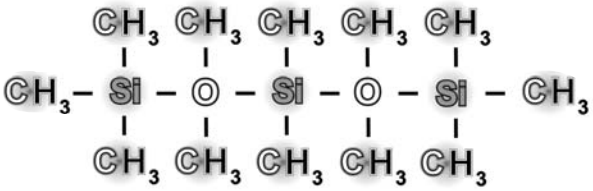
Communication specialists know the importance of bandwidth, the difference between the lowest frequency and the highest frequency that a communication line can carry. The bandwidth capacity increases with the frequency of signals. High frequency signals can carry more information than low frequency signals. Light has a higher frequency than radio waves, television waves and microwaves. Light traveling through fiber optics can carry vast amounts of information needed for the Internet and other computer applications. As it travels through a wire, electricity grows weaker with distance and eventually a repeater is needed to strengthen the signal. Light going through a fiber optic line can travel about 50 times as far before it must be amplified. Telephone and cable companies use fiber optics to transmit vast amounts of audio and video information on beams of light in fiber optic cables. Not all fiber optics are of glass. Some are a compound of glass and plastic.

Silicone is another category of silicon compounds. Silicones are synthetic and not found in nature. The first silicones were discovered in the 1800s, but they did not come into common usage until World War II as synthetic substitutes for oil and rubber.

Because of silicon's valence of 4, silicon and hydrogen can form chains like the hydrocarbon chains of carbon and hydrogen. However, the bonds between silicon and hydrogen are much weaker than the bonds between carbon and hydrogen. Silicon hydrides are not as strong as hydrocarbons and come apart easily.

Chemists build long silicon chains by alternating silicon atoms with oxygen atoms. The main silicon and oxygen chain has side units of other molecules, usually organic ones. The resulting compounds are silicones. An example of a silicone chain is methyl silicone. Silicon and oxygen atoms alternate with methyl (CH_3) as the side unit. Silicon and oxygen alone would be as brittle as quartz. The addition of the hydrocarbon units causes the chain to be flexible like hydrocarbon compounds.

A Silicone Chain



In the diagram, oxygen atoms could replace the *CH_3* units at each end, allowing the chain to be continued. The long chains can form bonds with side chains to produce large, strong polymers. Silicone molecules can form rings like carbon does in the benzene molecule. The overall properties of

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silicones depend upon their structure, length and type of side groups.

Silicone compounds of short chains produce synthetic oils. Silicone oils are good lubricants, and can be used in hydraulic systems with several advantages over hydrocarbon oils. Ordinary motor oil is as thick as molasses on a bitterly cold morning before the engine is started. Should the engine overheat, the oil becomes thin in the hotter temperature. If the engine is especially hot, the oil may come apart and lose its ability to lubricate the engine.



The ability of silicone oils to flow changes very little over a much greater range in temperature so that they flow as readily in both cold and hot temperatures. Also, they can withstand higher temperature than hydrocarbon oils and not burn as readily. They also resist the chemical action of oxygen and metals. Because of these qualities, silicone oils are used as lubricants and in the hydraulic systems of airplanes where temperatures can range over several hundred degrees.

Silicone compounds with longer chains produce synthetic rubber. Ordinary rubber becomes as hard as a board at cold temperatures. At high temperatures, rubber becomes gummy and easily catches fire. Silicone rubber remains flexible at a much lower temperature than regular rubber and can withstand higher temperatures without becoming sticky or catching fire. Jet aircraft use silicone hoses and tubing. The flight suits of military pilots are made of silicone rubber. Silly-Putty is a silicone with long polymer chains of molecules. The long molecules become twisted and intertwined, like a tangled ball of fishing line. If acted upon slowly, the chains sort themselves out and make slack so they do not break. If acted upon suddenly, the chains cannot give way quickly enough, and they break.


Military flight suit

Silicones are water repellant. They are added to car wax to shed rain and coated on automobile windshields to improve visibility during storms. Building materials are coated with silicones to make them waterproof.

Silicones are inert to the human body. Artificial heart valves and other replacement parts for damaged or diseased organs are made of silicones. Tubes of silicone carry the blood from patients to artificial kidney machines.

Life Principle

"Like rough gemstones, we must submit to the shaping, grinding and polishing processes of life to bring forth our true beauty and worth."

—Nancy Johnson

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Chapter 11

Lesson 8
Compounds

GEMS

Section 2

Lessons 6-10



Most silicon compounds found in nature contain impurities. Grains of brown and tan sand are small particles of quartz with iron or other metals as impurities. The impurities arise when the silicon compound is dissolved in water. Water will not dissolve silicon, but it will dissolve silica, which is another name for silicon dioxide (SiO_2). Sand is mostly silica. The amount of silica the water can dissolve depends on the temperature of the water and the pressure. Hot water can dissolve more silica than cooler water. Water under pressure can dissolve more silica than water at normal pressure.

Hot water under pressure is found below ground and comes to the surface in geothermal springs and geysers. At the surface the pressure is relieved, and the temperature cools. The dissolved silicon compounds come out of solution. Examples of geothermal areas include the geyser basins in Yellowstone National Park in Wyoming and Lassen Volcanic National Park in California. Geysers are also found on the North Island of New Zealand and on the island of Iceland.



Colorful rock formations are found around hot springs and geysers. The colors are caused by the precipitation of impure silicate minerals from the hot water. The colors come from metals or metal oxides that are dissolved along with the silicates. Atoms of other elements replace silicon atoms in the crystalline ***matrix*** of the mineral. Silicates with impurities form many gems and ***semiprecious stones***.

VOCABULARY

Matrix: the fine-grained part of a rock in which coarser crystals are embedded

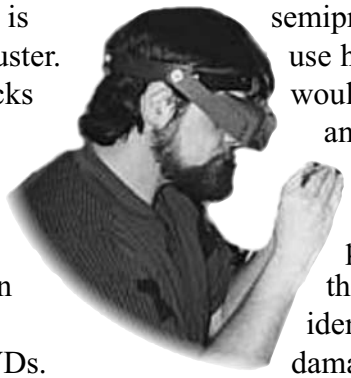
Semiprecious stones: composed of minerals of lesser worth than precious gemstones, but having commercial value such as jade, turquoise, amethyst

Synthetic gem: a manufactured gem with the same chemical composition and physical and optical properties as the real gem, synthetic gems can be identified because they are too perfect

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Silicate gems include opal, agate, onyx and jasper. These are made of very fine quartz crystals aligned in parallel bands. Chemists believe crystals form by the cooling and evaporating of mineral solutions in the cracks of rock formations. *Agate,* in its natural condition, looks ordinary; however, a slice of agate reveals colored bands. Each band is a different silicate mineral such as amethyst and jasper. *Onyx* is similar to agate, but its bands are white opal that alternate with a dark silicate mineral. *Jasper* is opaque and often has a red color.

Opal is the most valuable silicate gem. Opal forms from silicates that are deposited around hot springs and in veins where hot water flows. Opal is silicon dioxide with water as part of the chemical formula: $SiO_2 \bullet nH_2O$. The *n* in the formula shows that the number of water molecules can vary. A good quality opal gem is translucent and has an iridescent luster. The luster is produced by tiny cracks in the stone filled with silicon dioxide. When light passes through the stone, the tiny cracks act as a diffraction grating. Light waves interfere with one another in a way similar to the shimmering display of color across CDs or DVDs.



Aluminum is another element that is common in minerals and gems. After oxygen and silicon, aluminum is third in abundance in the Earth's crust. Aluminum, when combined with oxygen, creates aluminum oxide, a hard mineral. *Emery*, a hard mineral used in polishing gems, is a compound of aluminum and oxygen. *Sapphire* is aluminum oxide, too. It is usually blue, but impurities can produce other colors. Should the compound be red, it is not called sapphire. Instead it is *ruby*, a translucent gem with a beautiful red color. Ruby is the most valuable form of aluminum oxide. A ruby or a sapphire stone can have a brilliant star that seems to emit rays from below the translucent surface. Star rubies are the most highly regarded aluminum oxide gems.

Another large class of gems is based on the mineral *beryl*. Beryl is a combination of the metals beryllium (Be) and aluminum (Al) with silicon (Si) and oxygen (O). The chemical formula is $Be_3Al_2Si_6O_{18}$. The gem *emerald* is beryl with a trace impurity of chromium, which gives the gem a rich green color. Emerald is the most valuable form of beryl. The best emeralds often command higher prices than diamonds of the same weight. *Aquamarine* is beryl with a beautiful blue green color. *Aqua* means *water* and *marine* means *sea*. Aquamarine has the blue-green color of the ocean.

Gems are difficult to identify by sight alone. People who look for gems and semiprecious stones in the field often use hardness tests. However, a person would not use a hardness test on a cut and polished stone. To determine hardness, the gem must be scratched. A test that damages precious stones would not make the owner happy. Instead, a gem is identified by procedures that do not damage it.

If a person buying a gem wants to be assured the gem is not fake, it should be evaluated by someone who is knowledgeable about gemstones. A *gemologist* is trained in identifying gemstones. The gemologist does not rely on the hardness test or sight alone to identify a gem; rather, he makes a scientific study of the stone.

The first test is to measure the index of refraction. The index of refraction is the ratio of the speed of light in a substance compared to the speed of light in a vacuum. The index of refraction is also a measure of the angle through which light will bend when

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it enters the face of a gem at an angle. The greater the angle at which it refracts (bends), the greater the index of refraction. Each type of gem has a different index of refraction.

Second, the gemologist checks how the crystal polarizes light. To understand the effect of the crystal on light, think of a person making waves in a stretched rope. Briskly moving the rope up and down causes vertical waves in the rope. The crests and troughs of the rope will rise and fall in the same direction as the hand making the waves. Briskly moving the rope left and right causes horizontal waves in the rope. The crests and troughs of the rope swing left and right. Now suppose the rope passes through a picket fence. The picket fence has vertical gaps between wooden slats. A rope vibrating up and down will pass through the vertical gaps without being hindered. A rope vibrating left and right will be stopped by the vertical pickets.

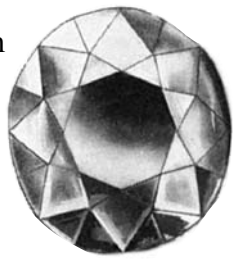


Light vibrates in all directions, up and down, left and right and all the angles in between. When light passes through certain crystals, the crystals act as the vertical slats in the picket fence, filtering out some light waves but letting the others pass. Polarized light contains waves that vibrate in only one plane. The other light rays have been filtered out. Some crystals, including gems, polarize light. Other gems separate light vibrating in one direction from light vibrating in the other direction. The gemologist looks for the polarizing effect a gem has upon light.

A third test is the density. Density is the mass of an object compared to its volume. In the metric system, density is measured in grams per cubic centimeter (g/cm^3). Water has a density of 1.0 g/cm^3. The geologist has liquids that range from the density of water to about 4.0 g/cm^3. If the mineral floats in a liquid with a density of 4.0 but sinks in one with a density of 3.0, then its density is between 4.0 and 3.0. A more exact value can be found by weighing the mineral when dry and when immersed in water. Its density can be calculated by the amount of weight that it loses when immersed in the water.

Some chemists have attempted to make valuable fake gems. But experts are not fooled. An *imitation gem* is glass or other cheaper material that has been made to look like a more expensive gem. Imitation gems are made of glass or plastic. However, a gemologist can easily detect imitation gems.

A ***synthetic gem*** is one that has been manufactured. The natural gemstone has been duplicated almost exactly; however the perfections of synthetic gems are revealed under a microscope. These gems are more regular than natural gemstones and contain no impurities or flaws. If a gem has no flaws, it is most likely synthetic.



One of the reasons synthetic gems are manufactured is not for jewelry but for industrial uses. The properties that make a mineral attractive as a gem may also make it useful in industry.

The General Electric Company made the first synthetic diamonds in 1955. Scientists subjected carbon to intense pressure, about 100,000 times normal atmospheric pressure, and intense heat or approximately about 5,000ºF. The resulting tiny diamonds were adequate for industrial purposes. The hardness of diamond is employed for cutting tools. Other methods of making diamonds have been developed, but the cost of the synthetic diamond is greater

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than the natural variety. Some synthetic compounds have one of the properties of diamond but not another. Silicon carbide is nearly as hard as diamond, but it has a dirty gray surface. A compound of strontium has been made that is as clear as diamond and has a higher index of refraction. It sparkles even better than diamond. The problem is that it is too soft and scratches easily.

Synthetic rubies were produced as far back as the early 1800s. They are made from powdered aluminum oxide with a small proportion of powdered chromium oxide. The powder is carried by oxygen gas that ignites with hydrogen gas. The reaction inside a furnace produces a pear shaped droplet of ruby. A star ruby cut from the droplet is as brilliant as the natural variety. The only way it differs is that the synthetic star is clearer than the natural one. Rubies, both the natural and synthetic variety, are hard and offer low friction to moving parts. Mechanical watches and delicate scientific instruments use rubies as bearings. Synthetic ruby rods were used in the first visible light lasers, enabling the laser to emit a concentrated beam of red light.

LIFE PRINCIPLE

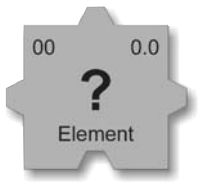


"Success comes not by a single great leap, but by persistent small steps toward a goal."

—Anonymous

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Integrated Physics & Chemistry



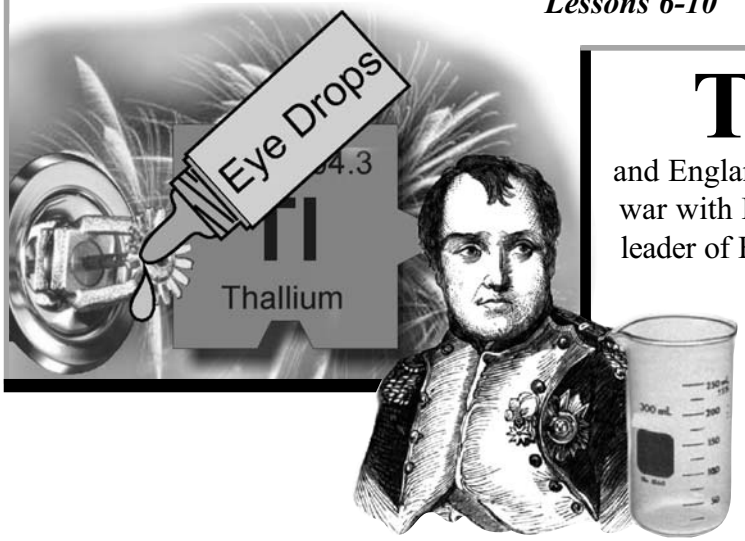
Lesson 9
Elements

Chapter 11

BORON AND ITS FAMILY OF ELEMENTS

Section 2

Lessons 6-10



The element, ***boron,*** was discovered because of a rivalry between France and England. Early in the 1800s, France was at war with England. Napoleon, the general and leader of France, believed scientific achievements were important to a country. Napoleon wanted his French chemists to triumph in the laboratory over rival British chemists. However, the most prominent English chemist at that time, Humphry Davy, was making world headlines with his discoveries of sodium, potassium and other elements. Napoleon wanted a French chemist to discover a new element, too. Napoleon encouraged the chemist, Joseph Gay-Lussac, to discover new elements. Napoleon gave money to Joseph Gay-Lussac to support his chemical researches.

Joseph Gay-Lussac and another French chemist, Louis Thenard, worked together to free the element in boric acid. First, they heated the acid to drive off hydrogen and produce boric oxide (B_2O_3). Humphry Davy had done the same experiment. Davy ran electricity through the boric oxide but did not succeed in freeing the element. Gay-Lussac and Thenard attempted to free the element by adding the highly active metallic element potassium that had been discovered by electrolysis. Potassium's strong chemical activity pried the oxygen from boric acid. In 1808, their reaction of boric acid with potassium generated a new element—boron—a dark brown powder, which gave France the chemical acclaim Napoleon desired.

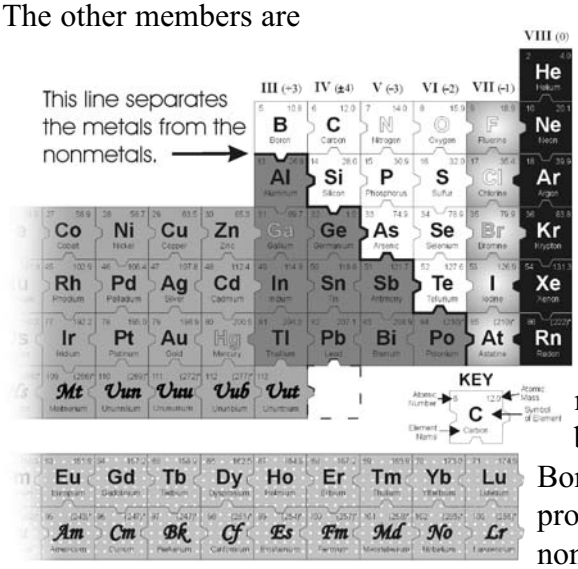
On most Periodic Table of the Elements, a zigzag line separates the metals from the nonmetals. Some of the families (vertical columns) begin as nonmetals at the top of the periodic table but end as metals at the bottom of the periodic table. An

VOCABULARY

Boron: a nonmetallic element with a valence of 3
Indium (In): a rare metallic element used in semiconductors in very small amounts

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example of a family that splits between the metals and nonmetals is the one that begins with boron (B). The other members are aluminum (Al), gallium (Ga), indium (In) and thallium (Tl). Boron, at the top of the family, is on the nonmetal side of the line, while aluminum and the others below it are on the metallic side of the line.



Compare the boron family with the sodium family on the far left of the periodic table. Lithium (Li), sodium (Na), potassium (K) and the other metals in that family have a strong family similarity. They share the same chemical and physical properties. Lithium, sodium and potassium are shiny, ductile (capable of being drawn out into wires) and malleable (capable of being beaten out into thin sheets). During chemical reactions, the sodium family has the metallic property of giving up an electron. These elements form strong bases with the hydroxide ion such as sodium hydroxide (NaOH). Like other metals, they readily conduct heat and electricity.

Now compare the boron family with the chlorine family on the right side of the periodic table. Fluorine (F), chlorine (Cl) and the others in that family have very similar chemical and physical properties. Their physical properties are opposite those of metals. Chlorine family members are brittle rather than being malleable and usually have a dull surface. During chemical reactions, they have the nonmetallic property of accepting an electron. Fluorine, chlorine and the others form strong acids such as hydrofluoric acid (HF) and hydrochloric acid (HCl).

On the right side of the periodic chart are elements that are very definitely metals and on the left side are elements that are very definitely nonmetals. Family characteristics are strong for the elements on each side of the periodic table.

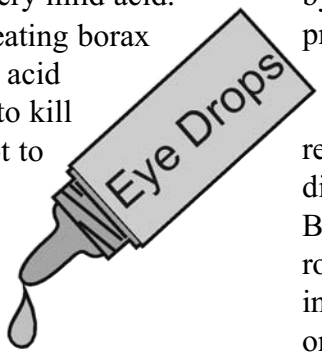
Family properties are not as consistent for members in the middle of the periodic chart. The boron family has many differences. Boron is a nonmetal. Its chemical properties are more like the nonmetals carbon and silicon than like aluminum. Many boron compounds are covalent; the atoms stay together by sharing electrons. Boron is never found in the free state and usually combines with oxygen. Boron is a nonmetal, but aluminum is a metal. Although aluminum forms the base aluminum hydroxide ($Al(OH)_3$), it is a weak base.

Each element is placed in the periodic table based on the element's atomic number (number of protons) and valence (chemical combining power). Boron, aluminum and others in the boron family have a valence of three. They have three electrons in their outer shell. Notice that the formula for aluminum hydroxide is *$Al(OH)_3$* with three of the *OH* groups. The formula for sodium hydroxide is *NaOH* with only one *OH* group. Aluminum has three times the chemical combining power of sodium. Sodium has a valence of 1; aluminum has a valence of 3. Despite their physical differences, boron, aluminum and the other elements in that family have a valence of 3.

Borax (sodium borate, $Na_2B_4O_7 \bullet 10H_2O$) is a naturally occurring compound that is the source for producing other useful boron compounds. Borax can be used to produce both mild acids and mild bases.

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Boric acid (H_3BO_3) is a very mild acid. The acid is prepared by heating borax with sulfuric acid. A boric acid solution is strong enough to kill germs but mild enough not to injure human tissue. The acid can be prepared so mildly that it can be used as disinfectant eye drops for newborn babies.



Borax dissolves readily in water and forms a mild base. It acts as a water softener by combining with the ions of calcium and magnesium and precipitating them (causing the heavy ions to settle out of the water).

In the United States, naturally occurring borax was discovered in the dry lakebeds of Death Valley, California. Starting in the 1870s, efforts were made to haul out the borax despite harsh desert conditions. Incredible heat, lack of water and shifting sand made the task especially difficult. Teams of mules hauled out the borax. As many as 20 teams were hitched together to haul out the borax and the water needed for mules and drivers during each trip.

Glass made of borax and silicon dioxide can withstand rapid temperature changes without cracking, because it does not expand or contract as much as regular glass during temperature changes. *Borosilicate glass* contains about 30 percent borax and is used in manufacture of cooking utensils and laboratory glassware. *Pyrex* is the brand name for one type of borosilicate glass.

Boron nitride (BN) is as hard as diamond and acts as a nonconductor of electricity. However, boron nitride is a good conductor of heat. The compound forms sheets that slide over each other easily, similar to the lubricating characteristics of graphite.

Gallium (Ga) is below aluminum in the periodic table. Gallium was first detected by the spectroscope in 1875 and then produced in a small amount the next year. Its name comes from Gall, the Roman name for France. Or, at least that is the official reason for the name. The French chemist who discovered gallium was Lecoq de Boisbaudran. His first name, Lecoq, means rooster in French, and Gallus means *rooster* in Latin. Lecoq de Boisbaudran used the play on words to name the element after himself. He later discovered two more elements.

Gallium was one of the three elements whose existence Mendeleev predicted from observing gaps in the periodic table. Upon reading Lecoq de Boisbaudran's report about the metal, Mendeleev instantly recognized the new metal as being one of the missing elements that he had called *eka-aluminum*.

Gallium is normally refined as a byproduct of the manufacture of aluminum and zinc. It is found in trace amounts in the aluminum ore, bauxite, and the zinc ore, zinc blende. Pure gallium has a beautiful, silvery appearance. Gallium atoms can work their way into the regular matrix of a silicon crystal. Gallium is one of the elements added to silicon to produce semiconductor devices and is also used in light emitting diodes (LEDs).

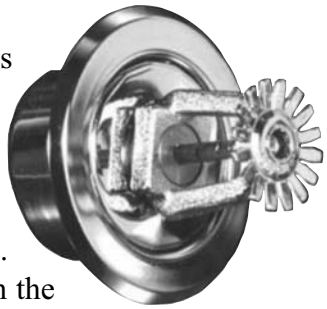
Gallium melts at the temperature of a warm summer day, 86ºF, but requires intense heat to boil. It remains a liquid to 4,250ºF, an incredible range to remain a liquid. It is used in high-temperature thermometers because of its low melting point and high boiling point. Mercury thermometers fail at 350ºC because mercury boils at that temperature. Gallium thermometers are made of quartz rather than glass so they can be used at temperatures hot enough to melt glass.

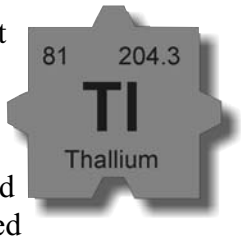
Indium (In) is a very soft metal with a brilliant silver luster. The name comes from its brilliant indigo line in its spectrum. Indium was discovered in 1863, only three

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years after the spectroscope came into use for identifying elements by their spectrum. When a bar of indium is bent, it gives a high pitched sound like a scream.

Indium is separated during the processing of zinc and lead. Mixing indium with other metals produces alloys that melt at lower temperatures. Indium alloy is used in fire sprinkler systems. Heat from a fire melts the indium plug and allows water to flow. Years ago industrial buildings had fire proof doors that closed in case of a fire. The doors were held in the open position by a chain with a link containing indium alloy. In case of a fire, the heat melted the link, and the door closed. Today, the doors are held open by electromagnets. During a fire a master switch cuts off the electricity and causes the doors to close.

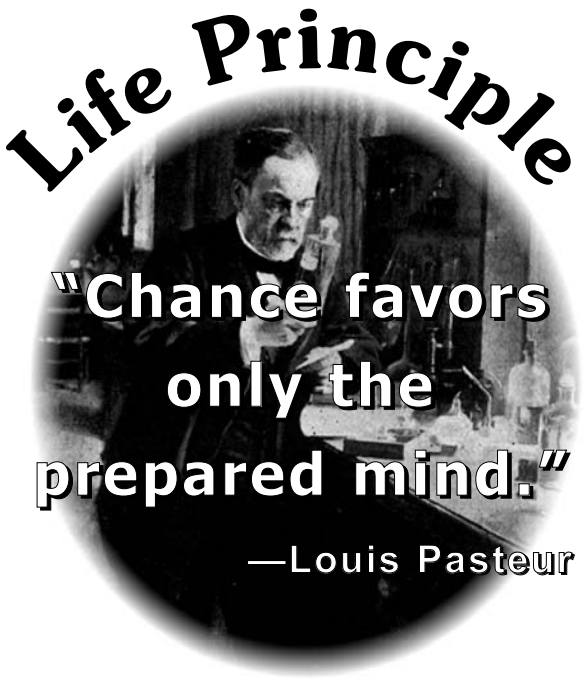




Thallium (Tl) is the last element in the boron family, located at the bottom of the periodic table. Englishman William Crookes, who invented the cathode ray tube, discovered thallium in 1861. While using a spectroscope to study an ore that was known to contain selenium (Se), Crookes noticed the brief flash of a green spectrum line. He named the new element thallium from the Greek word *thallos*, meaning *green twig*. Thallium is added to fireworks to produce a bright green glow during explosions.

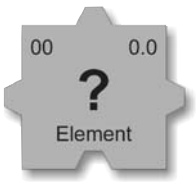
In pure form, thallium is soft and malleable. It can be cut with a knife. The element and many of its components are toxic, and can be absorbed into the skin. Thus, chemists who work with thallium wear protective suits or use rubber gloves and hold the chemical under a ventilating hood. Thallium sulfate (Tl_2SO_4) is odorless, tasteless and very poisonous. It is used to exterminate rodents and ants.





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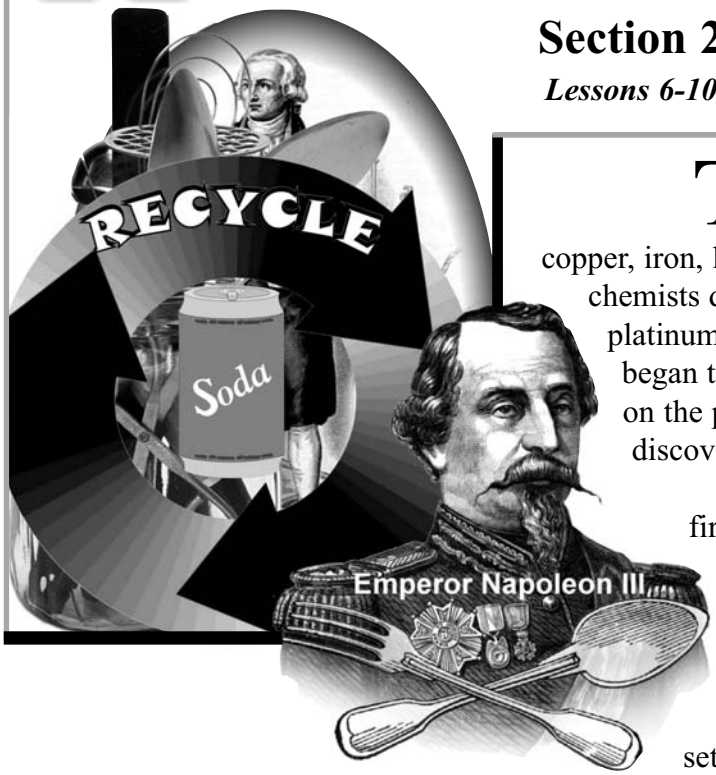
Lesson 10
Elements

Chapter 11

ALUMINUM

Section 2

Lessons 6-10



Two thousand years ago, people knew of only seven metals: gold, silver, copper, iron, lead, tin and mercury. As time passed, chemists discovered other metals, such as zinc, platinum and aluminum. Gradually, scientists began to discover and label metals and elements on the periodic table, which filled in as scientists discovered the hidden secrets of life.

Aluminum (Al) is a modern metal. It was first refined in the 1800s. At that time, aluminum cost more than silver and almost as much as gold. France's Emperor, Napoleon III, (nephew of Napoleon I who encouraged the discovery of boron) displayed a dinner setting made of the new and expensive metal. At a banquet, his important guests ate with aluminum spoons and forks. Less important officials ate with common silver utensils. No one knew then that ***ingested*** aluminum could be harmful to human tissue.

While aluminum is extremely useful in many ways externally, it has been linked with health problems such as Alzheimer's disease when taken internally. No one takes aluminum pills, but aluminum in antiperspirants and many cosmetics can be absorbed through the skin. Aluminum is also leached and ingested from cookware, beverage and food cans as well as foil in which acidic foods are cooked or wrapped. Additionally, aluminum is used as an additive in various food items such as processed cheese and pickles. Most brands of baking powder contain aluminum.

Aluminum is the most abundant metallic element in Earth's crust. Only the nonmetallic elements, oxygen and silicon, are more abundant. About eight percent of Earth's crust is aluminum, found primarily in clay and ***bauxite***.

VOCABULARY

Ingested: taken into the body, usually by mouth; inhaling or absorption
Bauxite: the primary ore of aluminum, containing aluminum with oxygen and various impurities
Coagulant: a substance, which aids in causing molecules in liquid to stick together to form a thickened mass, clump or clot

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Chemists saw that aluminum had high strength compared to its weight and conducted electricity well. Aluminum showed promise as an important metal if it could be refined in large amounts. However, separating aluminum from oxygen proved to be a difficult task.

Several chemists of great skill and fame attacked the problem of producing pure aluminum. Success came at the hands of a young and unknown chemist who was challenged to do so by his college chemistry professor who had read about the aluminum cap on the Washington Monument. The young chemistry student was Charles Martin Hall. In 1886, Charles Martin Hall studied chemistry at Oberlin College in Ohio. One of Hall's professors predicted, "The chemist who finds a cheap way to refine aluminum will become world famous and wealthy."

Charles Martin Hall decided to accept the challenge. After graduation, he built a laboratory in a woodshed. He began to learn about aluminum by repeating the work of other scientists. Hall conducted detailed research on the history of aluminum. He discovered that aluminum received its name from *alum*, meaning *sticky*. Alum is a complex molecule that contains aluminum, potassium, the sulfate group and water molecules: $Al_2(SO_4)_3 \bullet K_2SO_4 \bullet 24H_2O$. Fabrics to be dyed are soaked in alum, which clings to the fabrics and helps them to absorb the dyes. During the Middle Ages, chemists succeeded in converting alum into a compound called *alumina*, impure aluminum oxide (Al_2O_3).

French chemist, Lavoisier, thought alumina might be an element, and he listed it as one. An element is a substance with atoms all of the same kind. Humphry Davy, the English scientist, who used electricity to free sodium, potassium and other elements from their oxide, tried to separate a metal from alumina. None of his methods worked. Alumina would not break down.



Scientists did not know whether alumina was an element or a compound. If chemists could separate it into simpler substances, then alumina was a compound and not an element. Most chemists, including Humphry Davy, believed alumina to be a metal oxide. They should have been able to extract a metallic element from it. Yet, despite their best efforts they could not free the metal.

Another person who tested alumina was the respected Swedish chemist, Jons Jakob Berzelius. He is noted for his calculation of atomic weights and his proposal to use letters to identify elements. In 1824, Berzelius freed silicon from one of its compounds. Chemists can refine most metals by heating them with an element that reacts with the oxygen. Iron is separated from its oxide by carbon. Berzelius separated silicon by using the more active potassium. Another method to refine a metal is with electricity. Sodium and potassium were separated by electrolysis. Berzelius tried all of the known ways to separate the metal from its ore. Even the great Berzelius could not free aluminum from oxygen in the compound alumina.

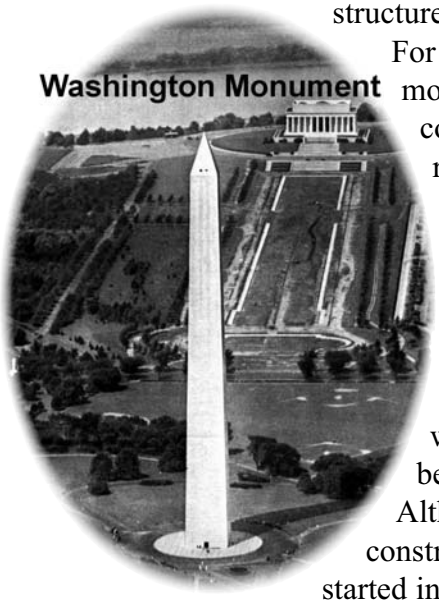
The first person to prepare aluminum metal was Hans Christian Oersted. He was the scientist who showed that an electric current is surrounded by a magnetic field. He proved this during a classroom lecture while his students watched. Oersted's method for making aluminum took many steps. He began with clay, which contains aluminum. He mixed clay with charcoal, heated the mixture white hot, and directed a stream of chlorine gas over it. Then he added

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potassium and mercury and heated it again. He got a very poor grade of aluminum.

Making aluminum this way was difficult and expensive. Oersted realized his method was too complex to be useful. Oersted did not pursue the matter because electrical investigations interested him more. One of Berzelius' students, Friedrich Wohler, produced aluminum by a less complex method. Wohler measured the density of aluminum. Wohler and not Oersted is often given credit for discovering aluminum for two reasons. First, chemists could repeat Wohler's method of making aluminum. Second, Wohler discovered many of the important properties of aluminum including the fact that it was lightweight and strong.

In 1855, a French chemist began producing aluminum in larger quantities. Even with the improved process, aluminum was expensive. In America, private citizens collected money to build a monument to honor George Washington. The design called for a 555-foot high stone shaft. It would be the largest man-made stone structure in the world.



For its top, the monument committee requested an expensive six-pound aluminum cap inscribed with the words, "Praise be to God." Although construction started in 1848, work temporarily stopped at the end of the 1850s because of a lack of money and the U.S. Civil War. The monument committee put the aluminum cap on display. Visitors could jump over the aluminum pyramid and later claim to have jumped over the top of the Washington Monument.

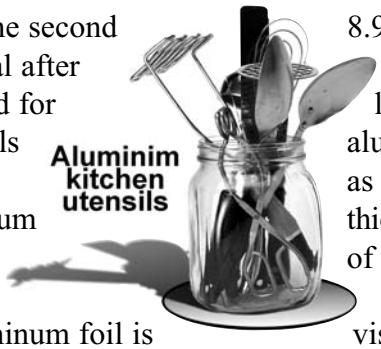
Work resumed on the Washington Monument in 1878, and was completed in 1884. The aluminum pyramid was put in place. The publicity of that event prompted Charles Martin Hall to begin working on making cheaper aluminum. Hall's father saw the importance of his son's efforts and helped him build a home laboratory.

After a year of trials, Charles Martin Hall discovered that aluminum oxide (Al_2O_3) would dissolve in molten cryolite (Na_3AlF_6). Hall ran electricity through the molten mixture. Aluminum was removed at the negative electrode, and oxygen came out at the positive terminal. The process operated at a much lower temperature than other methods.

At about the same time as Hall's discovery, the French chemist, Paul Héroult, developed essentially the same process. Rather than engage in long and costly court battles to determine who should be granted the patents, Charles Martin Hall and Paul Héroult became friends and worked together to perfect the process. The modern aluminum industry is based on the methods developed by Hall and Héroult. Only two years after the aluminum pyramid was placed on top of the Washington Monument, the price of aluminum became cheap enough to compete with other building materials.

Charles Martin Hall became rich and famous; but he never forgot the Ohio school that had set him on the road to discovery. Thus, Hall gave three million dollars to Oberlin College. Hall's refining process for aluminum was a commercial success. It is still used today. Bauxite, impure aluminum oxide, is the aluminum ore of choice. The Hall process releases aluminum a thousand times more cheaply than other methods.

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Aluminim kitchen utensils

Aluminum is the second most widely used metal after iron. Aluminum is used for kitchen cooking utensils because it readily conducts heat. Aluminum is malleable and can be rolled into thin sheets. A sheet of aluminum foil is less than $^{1}/_{100^{th}}$ of an inch thick. Aluminum foil is used to wrap food and has replaced tin for this purpose as well as for canning foods.

The density of aluminum is 2.7 g/cm^3, which is about one-third the density of iron at 7.87 g/cm^3. Aluminum is used in the construction of lightweight engines, aircraft frames and for building construction. Many homes have aluminum siding because it does not rust and acts as an insulator. Aluminum does react with oxygen in the air, forming a thin layer of aluminum oxide, which is transparent and protects the aluminum underneath from any additional oxidation. Aluminum resists seawater and is often used for the skin of boat hulls.

Aluminum oxide is the same color as the metal itself. Iron rust is red, and copper tarnish is green, but aluminum oxide is silver-colored like aluminum. The thin film of aluminum oxide does not blemish the beauty of the aluminum and is often used for decorative purposes.

Aluminum is a good conductor of electricity. Most wires for high voltage cross-country electrical transmission lines are made of aluminum. Copper conducts electricity better than aluminum, but aluminum is still the first choice. When comparing copper and aluminum wires of the same size, aluminum conducts only 63 percent as much electricity as the copper wire. For the tall transmission lines with their long distances from one tower to the next, weight is an important consideration. But copper has a density of 8.96 g/cm^3. Aluminum can be made thicker to carry more electricity and still weigh less than copper wire. Suppose the aluminum wire is made thicker so it carries as much electricity as the copper wire. The thicker aluminum wire has but half the weight of the copper wire and does not cost as much.

Aluminum is a good reflector of visible and infrared heat rays. Often, insulation is backed with aluminum foil to reflect infrared rays. Blankets of fireproof fabric alternating with aluminum foil are used as emergency shelters by forest fire fighters who are caught in fast moving fires. Premature infants are sometimes wrapped in aluminum blankets to conserve their body heat.

Because aluminum does not deteriorate with time, discarded aluminum cans and containers will not corrode. Rather than becoming an environmental eyesore, aluminum is recycled. About 20 percent of aluminum production comes from recycled aluminum, especially beverage cans.

In addition to its primary ore, bauxite, aluminum is found in emery, ruby, sapphire, mica, feldspar and clay. One of its important compounds is aluminum hydroxide ($Al(OH)_3$) that is used as a ***coagulant*** to purify water contaminated with solid particles, which make water cloudy. Because the particles are so small, they cannot be removed by standard filtering. By mixing in aluminum hydroxide, the particles coagulate and then settle to the bottom of the filtering tank.

Life Principle

"Development of the periodic table enlightened man's understanding of the design of life as scientists identified and predicted existence of undiscovered elements."

—Ronald Johnson

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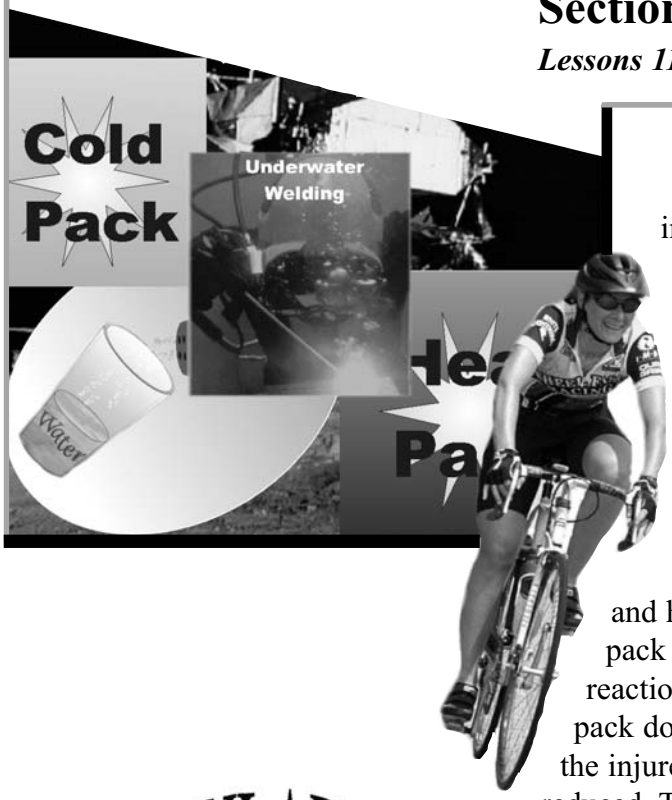
Lesson 11
Energy

Chapter 11

ENERGY AND CHEMICAL REACTIONS

Section 3

Lessons 11-15



Visualize a mountain biker taking a spill from his bicycle. He has injured his ankle and is in pain. The foot has grown warm to the touch and will soon become inflamed and sore. The injury has caused blood vessels to open wider, allowing more blood to rush to the site. The muscles have reacted by generating heat, and the injury has become inflamed. Nerve endings have sent out pain signals as the tissue swells.

A friend of the cyclist has a first aid kit and has taken out a cold pack. Bending the cold pack back and forth mixes two chemicals, and a reaction occurs which lowers the temperature of the pack down to about 32ºF. The cold pack is placed on the injured ankle, and the pain and swelling are reduced. The cold pack will stay at about 32ºF for five minutes or so before slowly warming to room temperature.

Thermochemistry is the study of heat associated with chemical reactions. Some chemical reactions, such as those that take place in cold packs, absorb heat. Other chemical reactions produce heat.

Usually, heat is produced by an *oxidation reaction* in which a metal combines with oxygen. The metal gives up one or more electrons to the oxygen. Iron rusting is an oxidation reaction. The iron gives up electrons and combines with oxygen. The burning of wood is oxidation because the carbon in the wood combines with oxygen to give carbon dioxide.

The opposite reaction is a *reduction reaction* in which a metal is freed from sharing electrons with oxygen or some other element such as sulfur. The reaction in which iron is freed from its ore is a reduction reaction. The metal gains electrons, becomes a free metal, and is no longer combined with oxygen.

VOCABULARY

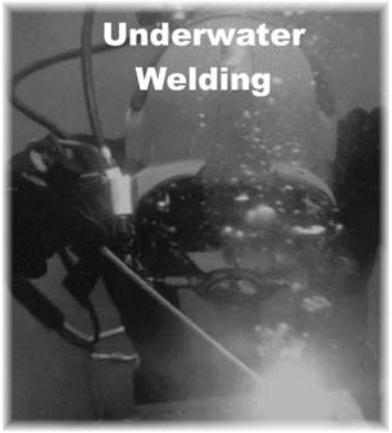
Thermite: a reaction in which aluminum combines with oxygen, usually the oxygen is provided by a metal oxide such as iron oxide (Fe_3O_3)
Exothermic: a chemical reaction that releases heat into the environment
Luminol: a complex organic compound that generates light when it oxidizes, luminol is one of the reactants in a glow light

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Oxidation and reduction take place in the same reaction. One of the reactants gains electrons (reduction), and the other reactant loses electrons (oxidation). For instance, when iron is freed from its ore by being heated with carbon, the iron is reduced but the carbon is oxidized.

Thermite is a spectacular example of an oxidation reaction. Thermite is a mixture of powdered aluminum with the oxide of a less active metal, such as iron oxide (Fe_2O_3). When thermite is ignited, the aluminum rapidly removes oxygen from the iron. Thermite gets very hot. The reacting chemicals heat to 3,600ºF and the heat of the reaction melts the iron.

Equipment operators at remote locations use thermite to repair cracks in broken equipment. In thermite welding, the heat generated melts the steel. The liquid steel enters the broken seam, cools and thereby welds together the sections. Thermite is used in the welding of railroad tracks. The reaction is vigorous enough to burn underwater. Divers can weld broken ship propeller shafts underwater.



Today, the primary use of the thermite reaction is to reduce metals from their oxide. To reduce a metal is to separate it from oxygen. Many metals can be reduced with carbon, but carbon impurities contaminate the metal. Other metals are not easily reduced by carbon or by electrolysis. In those cases, aluminum is used as the reducing agent, removing the oxygen and freeing the metal.

The thermite reaction is an example of ***exothermic*** reaction. *Exo* means *out* and *therm* means *heat*. An exothermic reaction generates and releases heat. The bonds of a chemical compound contain energy. The energy holds the electrons in position. During a chemical reaction, electrons rearrange themselves. If the new arrangement of electrons contains less energy than was previously contained, they then release excess energy. Usually, the extra energy is released as heat, although in some reactions electricity or light is generated.

For instance, glow sticks are sold at amusement parks. At night or in a dark room, the sticks glow with a pale light. The glow lights can also be used as temporary light in emergencies. Backpackers, cave explorers, hunters and mountain climbers carry the sticks for emergency use. They are light in weight, dependable and do not require matches to be ignited. The glow sticks are bent and snapped to mix the chemicals.

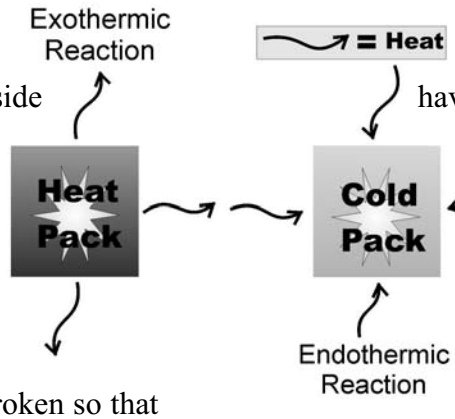
Most glow lights contain ***luminol,*** a complex organic compound. When combined with oxygen, luminol gives off light. The oxygen is present in the glow stick as the extra oxygen atom in hydrogen peroxide (H_2O_2). The light energy comes from the movement of electrons. In luminol, before the reaction, the electrons are at a higher energy state. During oxidation of luminol, electrons fall to a lower energy state, releasing excess energy as light. Once the oxidation is complete, no more light is emitted. A glow stick can emit light for only a few minutes or up to several hours depending on the speed of the reaction. A catalyst controls the speed. A metal such as copper is present in glow sticks. The amount of metal controls the length and brightness of the light.

Exothermic reactions are common. Most of the chemical reactions with which we are most familiar are exothermic ones.

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They generate heat. The burning is an exothermic reaction. Carbon in coal oxidizes with oxygen in the air to give carbon dioxide. The energy of the electrons forming the bonds of carbon dioxide is less than the energy of the electrons in the reactants, carbon and oxygen. Burning coal releases the energy as heat. At the end of the reaction, the amount of heat in the carbon dioxide is less than the energy in the carbon and oxygen atoms separately before the reaction. Heat flows out of the reaction that converts coal to carbon dioxide. In an exothermic reaction, heat flows from the reactants into the environment. A test tube would feel warm to your touch during an exothermic reaction.

Heat packs are examples of exothermic reactions. People who attend winter football games use heat packs to warm their hands. Hunters and others who are outside during cold weather carry heat packs to keep their hands warm. Chemical heat packs are activated in the same way as cold packs or glow sticks. A seal is broken so that chemicals mix. The packs cause the temperature to rise to about 115ºF, and remain warm for 20 minutes or longer. The chemical reaction is a simple one. Powdered iron oxidizes rapidly. The other chemicals are salt, water and charcoal. The water provides the oxygen and the salt and charcoal remove the hydrogen. The water absorbs the heat and helps prolong the heating effect.



Heat can go the other way, too—out of the environment and into a reaction. Cold packs are an example of such a reaction. An *endothermic* reaction is one that absorbs heat. The prefix *endo* means *within*.

During an endothermic reaction, heat flows from the environment into the products of the reaction. During an endothermic reaction, a test tube feels cold.

Energy must continually flow into an endothermic reaction. Photosynthesis is an example of an endothermic reaction. For photosynthesis to occur, energy in the form of sunlight must be continually supplied. Other chemicals will naturally react in the presence of light. Hydrogen peroxide is stored in dark opaque bottles to prevent light from breaking down the peroxide.



Another well-known endothermic reaction is the chemical action of salt dissolving in water. In a salt crystal, sodium and chlorine atoms are found in a regular array. Their electron bonds have a certain amount of energy. When salt is stirred in water, the sodium and chlorine atoms dissociate and become ions (Na^+ and Cl^-). Although this is a simple reaction, breaking the bonds requires energy. The energy is absorbed from the water and lowers its temperature. A home ice cream maker uses this principle. Water, ice and salt are mixed in an outer bucket. The ice cream is in an inner bucket. The endothermic reaction lowers the temperature of the mixture in the container and produces hard ice cream.

A *spontaneous reaction* takes place of its own accord without the addition of heat, light or a spark to set it off. Some reactions begin immediately as soon as the two reactants mix. For instance, astronauts Neil Armstrong and Buzz Aldrin depended on a spontaneous reaction to blast them safely from the Moon's surface. On July 20, 1969,

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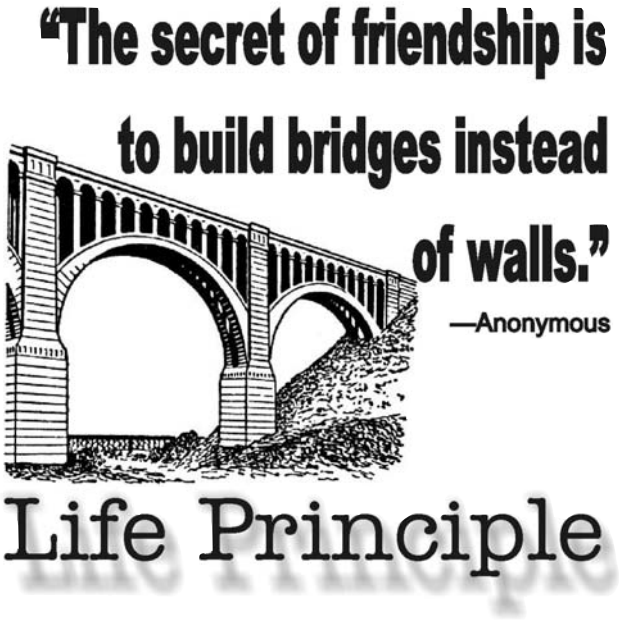
they had become the first people to walk on the Moon. After a total of almost 22 hours on the Moon, the astronauts were ready to lift off to join the lunar orbiter circling the Moon for the return trip to Earth. A fuel and oxidizer that ignited spontaneously on contact with each other powered the ascent engine. Methyl hydrazine (CH_6N_2) was the fuel, and oxygen was provided by nitrogen tetroxide (NO_4). Inert helium provided the pressure to force the fuels into the combustion chamber. Ignition took place as soon as the valves opened and the fuel and oxidizer mixed, causing a burst of energy.



The energy needed to start a chemical reaction is *activation energy*. A spontaneous reaction requires no activation energy. It is like a car that is sitting at the top of a hill. When the parking break is released, the car begins rolling down hill. In the case of the spontaneous reaction, the electrons immediately start moving from their region of greater energy to a region of lower energy and release the excess energy, usually as heat.

Some reactions are not spontaneous. For these reactions, energy must be added to produce motion. In the example of the car that is at the top of a hill, suppose the same car is in a shallow depression. Although it may be at the top of a tall mountain, the car cannot start rolling until it is pushed out of the shallow hole that keeps it from rolling downhill. Some chemical reactions are like this. They have to be given a shove to get them going.

For instance, paper will not burn until it is heated to its kindling temperature. The combustion of paper requires activation energy. Once ignited, the burning supplies activation energy for the rest of the paper. Oxygen gas and hydrogen gas can be mixed together, but no reaction results. They, too, require activation energy. A spark can supply the energy. Once the reaction starts, oxygen and hydrogen combine instantly with a flash of light and an explosion.



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Integrated Physics & Chemistry

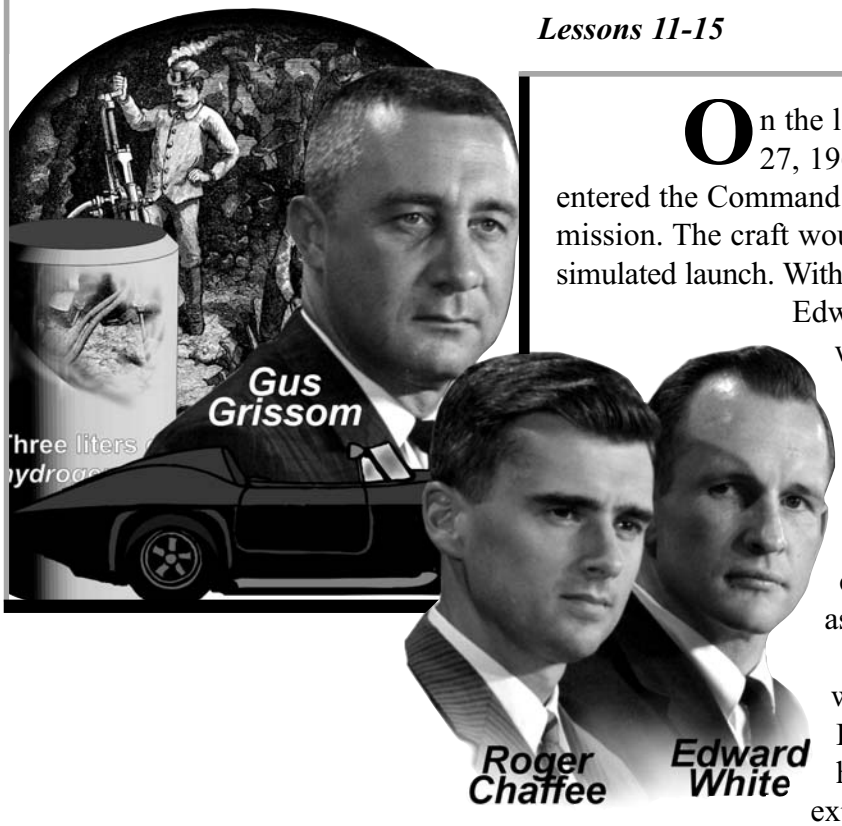
Lesson 12
Energy

Chapter 11

OXIDIZERS

Section 3

Lessons 11-15



On the last day of their lives, January 27, 1967, three Apollo I astronauts entered the Command Module on a routine test mission. The craft would not leave Earth during a simulated launch. With the hatch locked, Gus Grissom, Edward White and Roger Chaffee wore space suits. For five hours, they did their jobs and tested the launch sequence for their scheduled flight the next month. Suddenly, a fire engulfed the inside of the command module. All three astronauts died.

A spark from exposed wiring probably started the fire. But it burned far faster and hotter than anyone would expect. The paper, Velcro, the fabric of the spacesuits and other materials burned rapidly.

Burning is a type of chemical reaction known as oxidation. Burning proceeds at a fast rate. Rusting is a type of oxidation, too, but it proceeds at a much slower rate. Some chemical reactions go fast and others go slowly. The rates of chemical reactions are affected by several factors. Even material that normally will not burn, such as iron and aluminum, will support combustion under unique conditions.

Concentrating the reactants increases the speed of the reaction. Molecules react with one another only when they come in contact. If two molecules that normally react are kept apart by inert molecules, then the reaction proceeds at a much slower rate. One of the best known examples of this is the Earth's atmosphere. Nitrogen gas makes up the greater part of Earth's atmosphere (78 percent). Oxygen is a smaller

VOCABULARY

Catalyst: a chemical that speeds a chemical reaction but is unchanged by the reaction

Inhibitor: a chemical that slows a chemical reaction but is unchanged by the reaction, sometimes called a negative catalyst

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proportion (21 percent). If the atmosphere were pure oxygen, fires would rage with blinding speed. The presence of relatively inert nitrogen gas slows combustion of other materials with oxygen. The unique, precise balance of nitrogen and oxygen allows life to exist on Earth.

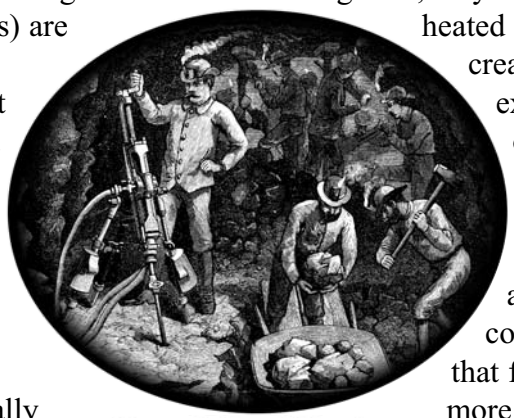
Concentration of oxygen was partially responsible for the disastrous fire aboard the Apollo command module while it was being tested. Normally, when a module is in space, astronauts breathe pure oxygen but at a greatly reduced pressure of about three pounds per square inch. During the ground testing of the spacecraft, the oxygen was pure and at a pressure slightly above normal atmospheric pressure of 14.7 pounds per square inch. At that pressure and concentration, a fire swept through the command module so quickly that the three astronauts could not escape.

Concentration of the reactants is directly related to the rate of the reaction. Increasing the concentration increases the rate of the reaction.

The nature of the reactants is another factor that affects the speed of a reaction. During a chemical reaction, electrons are gained, lost or shared. Some atoms have a greater tendency to lose, gain or share electrons than other atoms. For instance, electrons around the nuclei of inert gases (helium, neon, argon and others) are in an especially stable arrangement. Inert gases do not take part in chemical reactions. The fluorine family of elements (fluorine, chlorine, bromine and others) has an electron arrangement that becomes more stable by an element gaining an electron. Fluorine is very active chemically because of its tendency to accept an electron from other atoms. The sodium family of elements (lithium, sodium, potassium and others) has an electron arrangement that becomes more stable by an element giving up an electron. Sodium is very active chemically because of its tendency to release an electron to other atoms.

Increasing the surface area also increases the speed of a reaction. The reaction of a solid takes place on its surface. If you place an iron bar in a fire, it can become hot enough to glow. Oxidation takes place on its surface. However, it does not burst into flames. Suppose the iron bar is filed into fine iron particles. Iron particles sprinkled over an open flame, burn as tiny sparkles of light. When a solid is divided into small pieces, total mass and volume remain unchanged. However, the surface area increases tremendously.

Surface area and rate of a reaction are directly related. An increase in surface area causes an increase in the rate of the reaction. Imagine a metal shop in which a small explosion caused the building to shake. A moment later a tremendous explosion destroyed the building. The first explosion shook loose small metal particles that had collected during the normal operation of the metal working shop. When the small particles ignited, they burned fiercely. The heated air expanded rapidly, creating the secondary explosion. In mines, one of the great problems is the build-up of coal dust. A small explosion can shake mineshafts and fill them with fine coal dust. The explosion that follows will be much more severe and dangerous. Increasing the speed at



Miners labored long hours in the dark coal mines

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which molecules collide increases the rate of a chemical reaction. Temperature is the average kinetic energy of molecules. The hotter the temperature the faster molecules move. When molecules collide, they may not react if the collision is too gentle. The molecules simply rebound unchanged from one another. By increasing the temperature, the molecules zoom about more quickly. They strike each other more often and with greater force. Increasing the temperature not only increases the number of collisions but increases the energy of the collision.

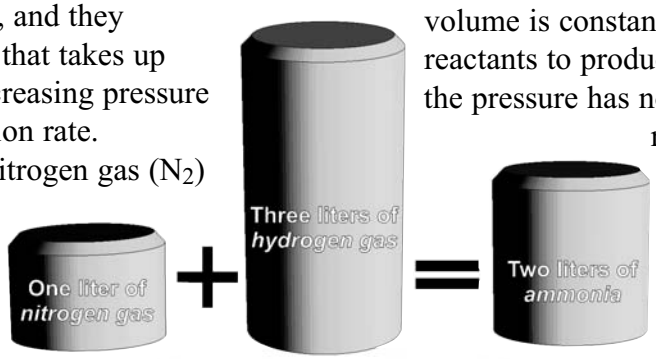
Temperature and the rate of a reaction are directly related. An increase in temperature causes an increase in the rate of the reaction.

Pressure has little effect on chemical reactions among solids or liquids. Increasing the pressure does not push the molecules any closer together or make other changes, so the reaction does not change. However, pressure does have an effect on gases. The effect is more complicated because it depends on how the volume changes. Suppose equal volumes of reactants are mixed, and they combine to give a gas that takes up less volume. Then, increasing pressure will increase the reaction rate.

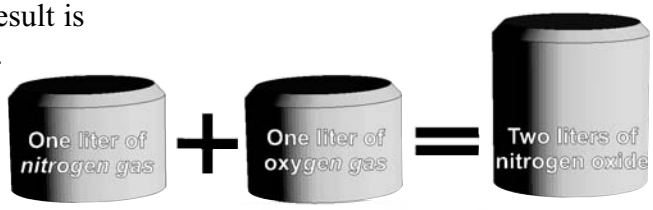
For instance, nitrogen gas (N_2) and hydrogen gas (H_2) can be made to react to give ammonia (NH_3). If one liter of nitrogen gas reacts with three liters of hydrogen gas, the result is two liters of ammonia. The reactants occupy four liters: 1 liter of nitrogen + 3 liters of hydrogen = 4 liters. The product occupies two liters. In this case, increasing the pressure increases the reaction rate. This makes sense because the increased pressure tends to reduce the volume, and the chemical reaction goes toward reduced volume.

Suppose, however, that the reaction causes the volume to stay the same. Increasing the pressure has no effect on the speed of the reaction. For instance, nitrogen gas (N_2) and oxygen gas (O_2) can be combined to produce two molecules of nitrogen oxide: $N_2 + O_2 \rightarrow 2NO$. If one liter of nitrogen gas reacts with one liter of oxygen gas, the result is two liters of nitrogen oxide. Both the reactants and products occupy the same amount of space. An increase in pressure has no effect on the reactants because the volume before and after the reaction does not change.

Pressure affects the rate of a reaction only for those reactions where the volume is different before and after the reaction. If the volume decreases while going from reactants to products, then increasing the pressure increases the rate of the reaction. If the volume is constant while going from reactants to products, then increasing the pressure has no effect on the reaction. If the volume increases while going from reactants to products, then increasing the pressure slows the reaction.



Increasing the pressure increased the reaction rate but reduced the volume.



In this case pressure was not required to produce the chemical reaction, therefore pressure did not reduce the volume.

Teflon is a chain of small units of tetrafluorethylene (C_2F_4). Teflon was produced as a natural reaction when smaller molecules were left in a tank under

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pressures. Because of the pressure, the molecules formed solid polymers that took up much less space. Teflon is used to coat cooking utensils to reduce sticking of food to pans.

A ***catalyst*** speeds a chemical reaction. Normally, a certain amount of energy is needed to start a reaction. Like the car sitting in a depression on top of a hill, the reaction needs a shove to get it going. The catalyst provides the shove in the form of an alternate reaction that does not require as much energy as sustained motion. The catalyst combines with one of the reactants to form an intermediate compound that reacts more readily with the other reactant. Instead of a single reaction that requires a lot of energy, the catalyst produces two or more reactions. Each one requires less energy.



A catalyst provides the extra *shove* or *energy* necessary to start the reactions needed to get the car over the last hill.

Many commercial processes depend on catalysts. The catalytic action of aluminum oxide promotes the cracking of petroleum hydrocarbons into different grades of oil and gasoline. Wood alcohol is made by the direct combination of hydrogen and carbon monoxide. Normally, they would not react except at a very slow rate. The presence of zinc oxide, the catalyst, speeds the reaction. Platinum is a catalyst found in catalytic converters in automobiles. Platinum promotes the complete burning of hydrocarbons so that carbon monoxide and other harmful auto emissions are not produced. Chemists believe that oxygen gas (O_2) is absorbed on the surface of the platinum. To fit on the surface of the platinum, the two oxygen atoms are pulled further apart, which weakens their bonds with one another. The oxygen atoms more readily react with carbon atoms.

In living tissue, reactions go faster because of organic catalysts known as enzymes. Some people ingest supplemental enzymes after meals to increase the digestive process of proteins, carbohydrates and fats.

An ***inhibitor*** slows the rate of a chemical reaction. For example, hydrogen peroxide will decompose into water and oxygen gas. To slow the rate of decomposition, sulfuric acid is mixed with the hydrogen peroxide. The sulfuric acid acts as an inhibitor in this case.

In this lesson you have learned about the five factors that can affect the rate of a reaction. They are the concentration, surface area, temperature, pressure and the presence of a catalyst or inhibitor.

Life Principle



"The way for a young man to rise is to improve himself in every way he can."

—Abraham Lincoln

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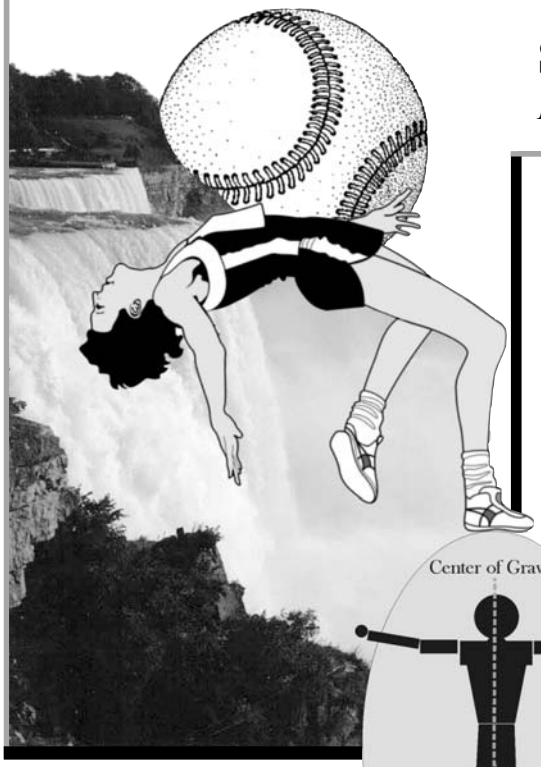
Lesson 13
Motion

Chapter 11

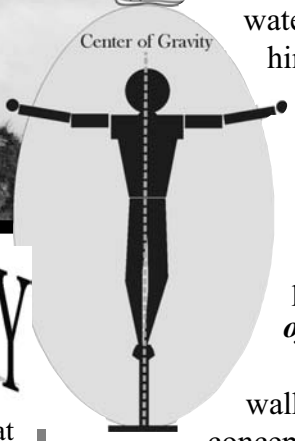
PHYSICAL EQUILIBRIUM

Section 3

Lessons 11-15



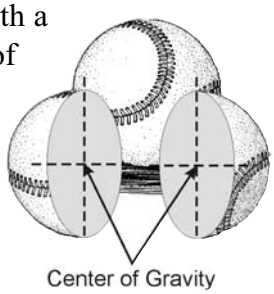
One of the most spectacular waterfalls in North America is Niagara Falls on the border between New York State, U.S.A, and Ontario, Canada. The water comes together below the falls and is carried away by the Niagara River that runs through a deep canyon. On June 30, 1859, the French daredevil, Jean Francois Gravelet, walked across the canyon on a tightrope. The distance was nearly a quarter mile from one side to the other. The seething water of the Niagara River was 200 feet below him. More than 25,000 spectators watched the feat. Gravelet repeated his tightrope act on other occasions. Each time, he did something unusual such as carrying a spectator across piggyback or crossing while blindfolded. One thing he always had with him was his balance pole. He used a 40-foot pole to keep his ***center of gravity*** over the center of the tight wire.



The purpose of a balance pole for a tightrope walker is to maintain ***equilibrium***. In physics, the concept of equilibrium is an important one. A body is in physical equilibrium if all of the forces and ***torques*** (rotational forces) sum to zero.

A person who is walking across a balance beam in gymnastics or walking along a narrow curb next to the sidewalk instinctively puts out his or her hands to maintain balance. The goal is to control the center of gravity.

The Earth's gravity pulls downward on every atom within a body. Suppose for a large body with a regular shape such as a cube or sphere all of the atoms are replaced by a single point with the same mass but at the center of the object. The single point that can represent all of the small separate forces is the center of gravity. The center of gravity



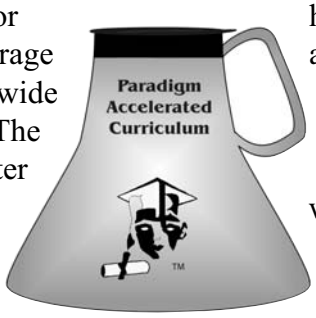
VOCABULARY

Center of gravity: the point at which the entire mass of an object may be considered to be located for purposes of understanding the force of gravity acting on the body
Equilibrium: a condition in which all influences on a body cancel one another resulting in an unchanging system, balanced
Torques: forces that cause an object to rotate or twist
Geometric center: a point that is equally distant from the outer surface of an object

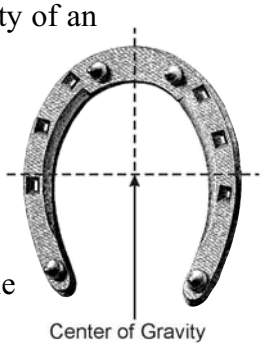
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for objects with a regular shape and uniform density is located at the ***geometric center***. For a brick and a baseball, the center of gravity is at the center of the object.

The center of gravity does not have to be at the geometric center of the object. If the object is of irregular shape or composed of material that is not of uniform density, the center of gravity may be located closer to one end than the other. For instance, a tip-proof beverage cup may be made with a wide bottom that is weighted. The extra weight puts the center of gravity lower and makes the cup less likely to tip over. A low sports car is less likely to tip over than a square, boxy sport utility vehicle, because the low sports car has a lower center of gravity.

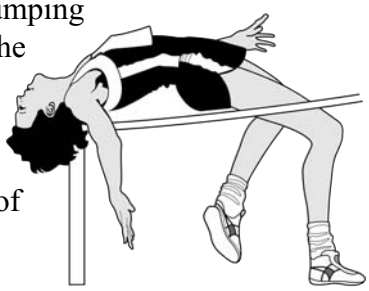


The center of gravity of an object can lie outside the object. A horseshoe has a center of gravity that falls in the empty space near the middle of the horseshoe.



An unusual example of putting the center of gravity outside a body occurred in 1968 in the sport of high jumping. Dick Fosbury, an American competitor, startled spectators by his style when he high jumped at the Olympic Games in Mexico City. Until then, athletes used a style of jumping known as the scissors. They went over face down and nearly parallel to the high bar with their legs making a scissors motion as they crossed the bar. Fosbury turned his body just as he leapt and went over backwards with his face up. He arched his back and tossed up his legs after his head and back had cleared the bar. He won the gold metal with a height of 7 feet 4.25 inches and set a new Olympic record.

He changed his center of gravity when he chose to use this method. Previous experiments showed that although his body went over the bar, because of the way he controlled the arch of his back and his legs, his center of gravity went under the bar. It let him get greater height with the same amount of lifting force. His style of high jumping, known as the "Fosbury flop," revolutionized the sport of high jumping and soon became the dominant method. His success also ushered in a greater awareness of the importance of using science to improve an athlete's ability.



The location of the center of gravity determines the stability of an object. In *stable equilibrium,* the center of gravity has to be raised to change the position of an object. Imagine a quarter resting on a table. The coin can be set on edge but only by raising its center of gravity. In the same way, a brick that is resting on its broad side has stable equilibrium. Tipping it up to rest on its narrow end requires that its center of gravity be raised. An object is in stable equilibrium if it naturally returns to that position. For instance, a ship that is struck by high waves

VOCABULARY

Ballast: heavy material that is put in the hold of a ship to improve its stability
Global warming: the theory that the influences on the Earth's temperature are not in equilibrium, and that Earth is growing warmer each year

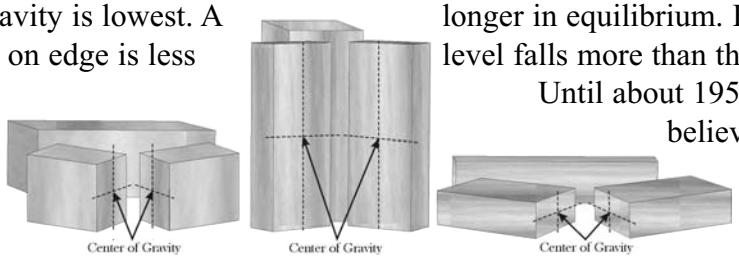
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will tip to one side. However, if the ship is properly loaded, it will return to its original position after the wave passes. It has stable equilibrium. If a ship is not fully loaded, it sometimes takes on ***ballast*** to provide added stability. Ballast can be provided by rocks or other cargo that is carried cheaply to provide added weight in the hold of the ship. The coffee cup that is tip-proof has stable equilibrium.

In *neutral equilibrium*, the center of gravity remains at the same height when position is changed. A ball rolling across a floor has neutral equilibrium. Although the ball is rolling, the center of gravity remains at the same height above the floor. An object that keeps its center of gravity at the same height has neutral equilibrium. An object in neutral equilibrium can be moved easily, because it has no tendency to return to its original position. Instead, it remains in its new position when moved.

In *unstable equilibrium*, the center of gravity falls when the position of an object is changed. A coin balanced on edge has unstable equilibrium. The slightest force will cause the coin to tip over and lower its center of gravity. An object in unstable equilibrium will continue to move after the original force that got it started has ceased operating. A bicycle with rider has unstable equilibrium when the bicycle stops moving forward. The bicycle will tip over unless the rider is very skillful or puts his or her foot down to keep the bicycle upright.

A brick can be placed in three positions, on its flat side, on edge or on end. The most stable position is the one in which the center of gravity is lowest. A brick on end or on edge is less stable because its center of gravity is not at its lowest position. The least stable position for the brick is on end because its center of gravity is highest in that position.



Equilibrium is generally applied to the whole body. For instance, as Jean Francois Gravelet crossed Niagara Falls on the tightrope, he appeared from a distance to be in equilibrium. Up close, one could see various twitches of his muscles, the teetering of the balance bar, the sway of the tightrope in the wind. For a body to be in equilibrium does not mean that forces are not acting on the body but that the forces as a whole cancel one another.

Dynamic equilibrium takes place when forces are constantly changing but in such a way as to cancel one another. The tightrope walker had dynamic equilibrium.

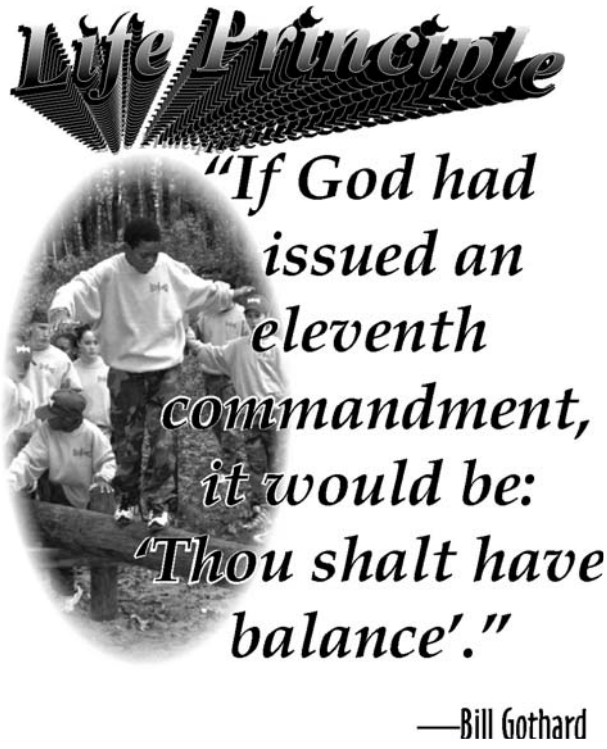
As another example of dynamic equilibrium, consider Mono Lake in California near the border with Nevada. When the first gold prospectors arrived there, the lake had been in equilibrium. Mono Lake received about as much water from the underground springs and creeks that fed into it as it lost from evaporation and water that drained away. The lake level rose in the spring as snow melted, then fell in late summer as creeks dried up and water evaporated. Overall the level of the lake remained the same. The lake level was in equilibrium. Starting in the 1950s as Los Angeles became a larger city and needed more water, 400-mile long water pipelines were built to carry water from the melting snow in the mountains around Mono Lake to Los Angeles. The amount of water reaching Mono Lake was reduced. Now the lake is no longer in equilibrium. Each year the lake level falls more than the previous year.

Until about 1950, most scientists believed the temperature of Earth as a whole remained in

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equilibrium. In the distant past, Earth was covered with lush vegetation. Then ice formed to cover large areas. But for the last six thousand years, the overall temperature of Earth appears to have been in equilibrium. A particular location might set a new record low temperature or a new record high temperature, but temperature averages around the world and throughout the year appear constant. The amount of heat radiated into space remained equal to the amount the Earth received from the Sun and from internal sources such as natural radioactivity.

Some scientists and politicians claim the Earth began warming about 1950. Earth's temperature, they say, is no longer in equilibrium—that the total energy, which radiates out into space is less than the total energy received. Their data indicates that Earth as a whole has a rising average temperature. ***Global warming*** is difficult to prove. Many of the weather stations used to measure temperature in 1950 were in rural regions away from cities. Since 1950, urban areas have grown up around the weather stations. Thermometers measure a higher temperature, but the increased temperature may be because of increased human activity, asphalt and concrete absorbing heat, and automobile and airplane exhaust. The change in measured temperature is only slight, and has been spread over several decades. Other factors may make the temperature readings misleading. Proving that global warming is or is not taking place is a difficult task.



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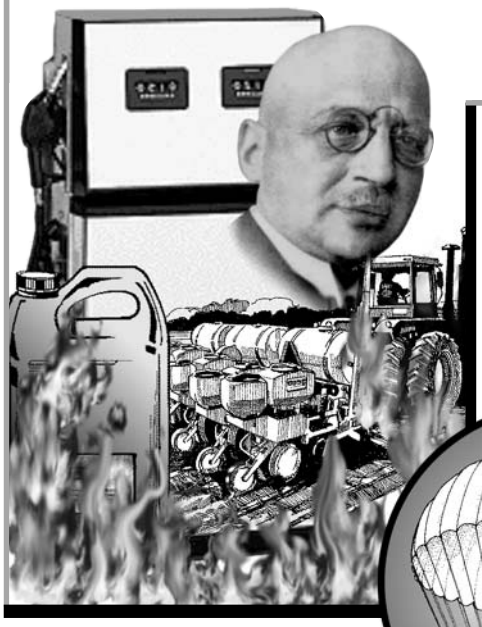
Chapter 11

Lesson 14
Compounds

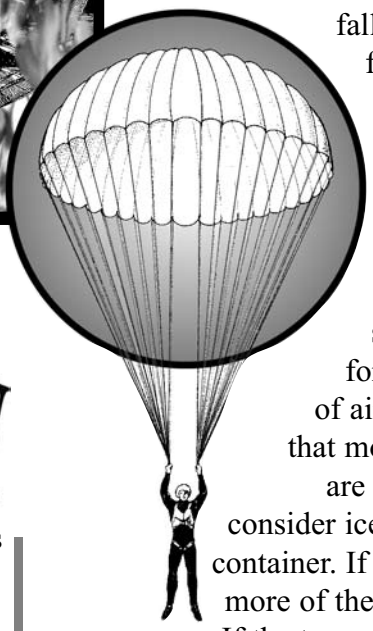
CHEMICAL EQUILIBRIUM

Section 3

Lessons 11-15



When a skydiver jumps from an airplane, he or she gains speed for a period of time. The force of gravity acting on the skydiver is greater than the resistance of air through which the person falls. As the speed increases, so does the air resistance. At a certain speed, the pull of gravity and the resistance of air are in balance and the person stops accelerating and falls no faster. The skydiver continues to fall but not at any greater speed. Eventually, the skydiver opens his or her parachute and the speed of fall is reduced. The speed slows from about 120 miles per hour to approximately 20 miles per hour or less.



Equilibrium for the motion of the skydiver occurs when the downward force of gravity equals the upward force of air resistance. Equilibrium does not mean that motion has stopped but only that forces are in balance. As another example, consider ice and water that are mixed in a container. If the temperature is greater than 32ºF, more of the ice will melt to produce liquid water. If the temperature is less than 32ºF, some of the water will freeze to produce more ice. At 32ºF the formation of ice and water is at equilibrium. Some of the ice melts, but some of it freezes. Overall, no change occurs in the amount of liquid water or ice.

A person can, however, produce more ice by simply lowering the water's temperature. Chemists often want to avoid a chemical reaction reaching equilibrium. They, too, have learned how to change the equilibrium point so that the reaction continues to produce a new product.

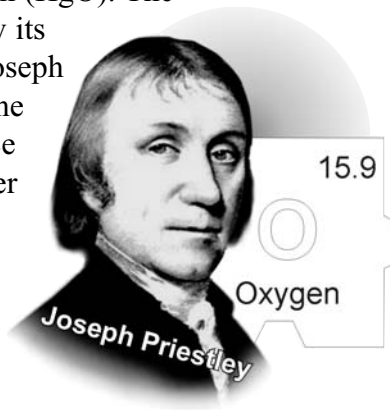
VOCABULARY

Reversible reactions: reactions that can go in either the forward or reverse direction, most chemists believe all chemical reactions are reversible

Haber process: for producing ammonia is an example of how chemists can control the direction of a reaction by the use of pressure, temperature and concentration of reactants or products

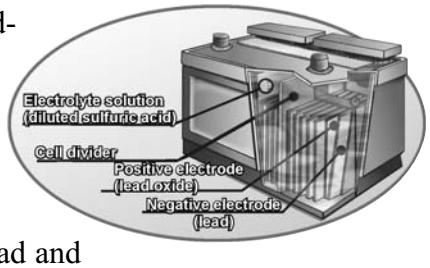
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Mercury oxide is a compound of mercury and oxygen (HgO). The first person to show its composition was Joseph Priestley. In 1774, he placed the substance in a closed container and, with a magnifying glass, focused the rays of the Sun on the compound. The heat caused the mercuric oxide to break down into shiny droplets of mercury and a gas that was later named oxygen: mercury oxide → mercury + oxygen. The *forward reaction* is one in which the reactant (in this case mercury oxide) produces the products of which the compound is made (mercury and oxygen).



However, as the closed test tube fills with oxygen gas, the *reverse reaction* begins: mercury oxide ← mercury + oxygen. This is the reverse reaction. The reversed arrow shows that the products of mercury and oxygen are changed back into the original reactant of mercury oxide. The reverse reaction is one in which the products re-combine to produce the reactant.

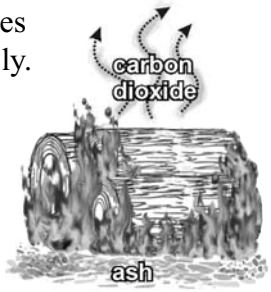
Sometimes a reverse reaction is desirable. Rechargeable batteries have reactions that can be reversed. A lead-acid storage battery has an electrolyte of dilute sulfuric acid and electrodes of lead and lead oxide. While electricity is drawn from a lead acid battery, the sulfuric acid is changed to water, and the electrodes are converted to lead sulfate. During the recharge stage, the chemical reactions are reversed and the chemicals are restored to their original state.



Should the forward reaction and the reverse reaction proceed at the same rate, the reactions have reached equilibrium. At equilibrium, neither reaction stops. Instead, they both proceed at the same rate. As much oxygen combines with mercury to produce mercury oxide as mercury oxide breaks down to give mercury and oxygen.

Most chemical reactions can go in either direction. Normally, hydrogen and oxygen will mix to form water. However, by electrolysis or by heating the water to a very high temperature, the water will separate into hydrogen and oxygen gas. The forward reaction is hydrogen + oxygen → water. The reverse reaction is hydrogen + oxygen ← water. In the case of hydrogen and oxygen, the forward reaction is favored. It is the one that takes place naturally.

Some reactions appear to go only in one direction. For instance, wood burns to give carbon dioxide and ash. The forward reaction is favored. The reverse reaction of carbon dioxide and ash being combined to give wood does not take place spontaneously. However, under the right conditions, the reactants can be combined to give wood as the product. We know this is possible because trees do it by means of photosynthesis.



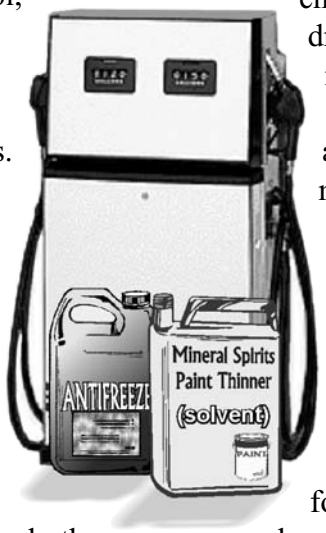
In most cases, a chemist is interested in upsetting the equilibrium so a chemical reaction will continue in one direction or another. Rather than looking at a specific example, let A and B stand for the reactants and C and D stand for the products. Then in the forward reaction A + B → C + D. At first, the A and B reactants are consumed to produce the C and D products. However, as the equilibrium point is reached, the reaction

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of A with B slows while the reverse reaction gains speed. Eventually, the C and D products combine to give A and B at such a rate that no new product is formed.

Suppose the chemist wants the reaction to go forward. The chemist wants to produce C and D products. The chemist can upset the equilibrium so the reaction continues to the right. Chemists are guided by the principle that chemical reactions move in the direction to relieve the stress that acts on them. As a real life example of this principle, think of a group of people sitting under the shade of a tree on a hot day. As the Sun moves, the shadow moves, and some of the people are in the direct rays of the Sun. They get up and move to a cooler location. Chemical reactions also react to remove the influences that would change them.

One way to change equilibrium of a chemical reaction is to change the temperature. ***Reversible reactions*** are exothermic in one direction and endothermic in the other. Suppose the forward reaction is exothermic. Heat is produced. Changing the temperature affects equilibrium. Cooling an exothermic forward reaction increases the formation of products. Methyl alcohol (also known as wood alcohol and methanol, CH_3OH) is a simple alcohol. It has many uses as a fuel, antifreeze, solvent and as the foundational product for other organic compounds. Methyl alcohol used to be produced by heating wood in the absence of oxygen. However, because of its many uses, chemists developed a way to combine carbon monoxide and hydrogen gas to give methyl alcohol, $CO + 2H_2 \rightarrow CH_3OH$. The two in front of H_2 is there to balance the equation, so that the same number of hydrogen atoms is on both sides. By volume, the reaction requires twice as much hydrogen gas as carbon monoxide gas.



The production of methyl alcohol causes a reversible reaction. An equilibrium point is reached, and the methyl alcohol begins the reverse reaction and breaks down into carbon monoxide and hydrogen gas, $CO + 2H_2 \leftarrow CH_3OH$.

The chemist can keep the reaction moving forward and generating more methyl alcohol. The forward reaction of carbon monoxide and hydrogen gas changing into methyl alcohol is exothermic. To keep the reaction generating alcohol, chemists lower the temperature. This causes the forward reaction to continue. The loss of heat due to lower temperature is balanced by an increase of heat from the exothermic reaction.

Suppose a chemist wanted to break down methyl alcohol into carbon monoxide and hydrogen gas. The reverse reaction is endothermic. To favor it, the chemist would heat the methyl alcohol. The excess heat is removed by the endothermic reaction of methyl alcohol changing into carbon monoxide and hydrogen gas.

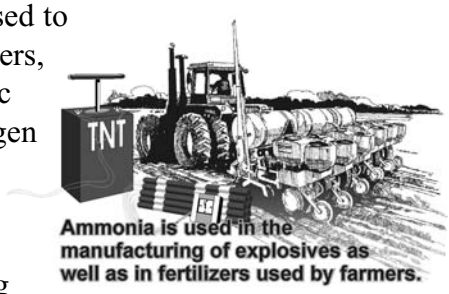
Another way to change the equilibrium of a chemical reaction is to change the pressure. A reaction is driven in the direction that relieves the pressure. In the synthetic production of methyl alcohol, one liter of carbon monoxide combines with two liters of hydrogen gas to give one liter of methyl alcohol as a gas: 1 liter CO + 2 liters $2H_2 \rightarrow$ 1 liter CH_3OH. The reactants take up three liters, but the product takes up one liter. If pressure is increased, the forward reaction is favored because going from 3 liters to 1 liter increases the pressure.

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The third way to change the equilibrium is to change the concentration. To favor the forward reaction, increase the concentration of the products or remove the products. If the chemist draws the alcohol off, then the carbon monoxide and hydrogen gas will continue to react to produce methyl alcohol. The methyl alcohol is collected, condensed and piped away from the reaction. Lowering the concentration of methyl alcohol causes the reaction to produce more methyl alcohol.

If a chemist succeeds in causing all of the reactants to combine to give the product, then the reaction is described as being driven to completion. By varying the temperature, pressure or concentration, a chemist can control the direction of the reaction and increase the yield of the product.

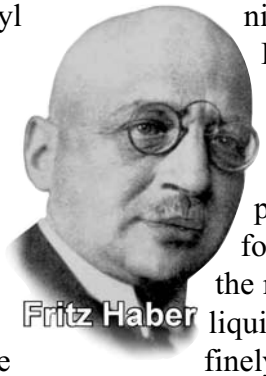
As an example of using these methods, consider the ***Haber process*** that produces ammonia (NH_3) from nitrogen in the air. Ammonia is an important nitrogen compound that is used to manufacture fertilizers, explosives and nitric acid. Because nitrogen is abundant in the air and hydrogen is available from water, chemists long sought a way to make ammonia synthetically. However, the combination of nitrogen with hydrogen to give ammonia does not take place under normal conditions.



Ammonia is used in the manufacturing of explosives as well as in fertilizers used by farmers.

Chemists can make the forward reaction $N_2 + 3H_2 \rightarrow 2NH_3$ take place because it is highly endothermic. Because it is endothermic, a high temperature will favor the forward reaction. Furthermore, the volume on the left side (1 liter of N_2 + 3 liters of H_2 = 4 liters) is higher than the volume on the right side (2 liters of $2NH_3$). Because the volume decreases, a high pressure will favor the forward reaction. Finally, to make the reaction go to completion, the ammonia is removed to favor the forward reaction.

Fritz Haber, a German chemist, was the first person to produce ammonia from nitrogen gas and hydrogen gas.


Fritz Haber

He used a temperature of about 1,100ºF and put the reactants under a pressure of about 700 times normal atmospheric pressure. As the ammonia formed, it was circulated out of the reaction, cooled and removed as liquid ammonia. Haber also used finely ground iron particles as a catalyst to increase the speed of the reaction.



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Integrated Physics & Chemistry



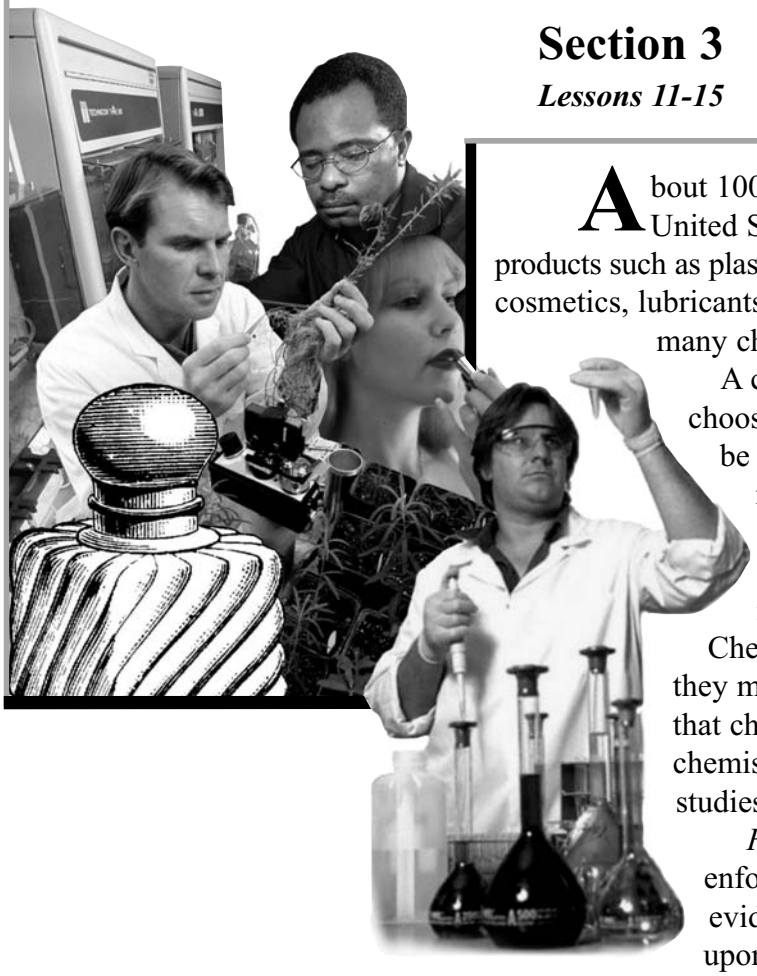
Lesson 15
Motion

Chapter 11

IS A CAREER IN CHEMISTRY FOR YOU?

Section 3

Lessons 11-15



About 100,000 full time chemists work in the United States today. Companies that make products such as plastics, synthetic fibers, paints, adhesives, cosmetics, lubricants, cleaners and semiconductors employ many chemists.

A chemist has many fields from which to choose a career. Where he or she works can be varied. Some spend time outdoors in remote locations such as in oil fields or at experimental stations near volcanoes. Others take samples along rivers to be analyzed in laboratories. Chemists may be members of a team, or they may work alone. The specialty areas that chemists know best are organic chemistry, biochemistry, environmental studies, medicine and forensic science.

Forensic science deals with law enforcement and civil and criminal evidence. A forensic chemist is called upon to answer questions about crimes or violations of the law. Forensic chemists determine whether a fiber found stuck to a defendant's shoe came from the crime scene. Forensic chemists determine whether factories keep their emissions within the range allowed by environmental protection laws, or whether patent laws have been violated in the marketing of food, drinks, medicine or other chemical products. The forensic chemist develops evidence that may be presented in a court of law.

A forensic chemist who works in a crime lab may run tests to see what drugs and poisons are present in the body of a person who died suspiciously. The chemist may identify the material used to start a fire or cause an explosion. A forensic chemist must be a careful worker who is capable of providing

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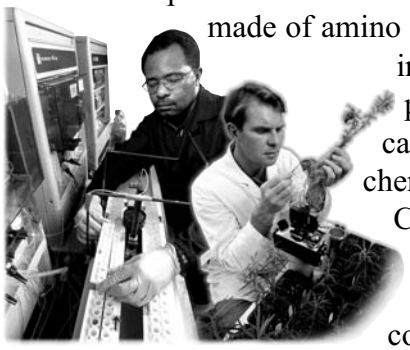
Organic chemistry: the study of carbon compounds found primarily in plants and animals
Metabolism: chemical and physical life processes of cells
Inorganic chemistry: the study of noncarbon compounds in nonliving things

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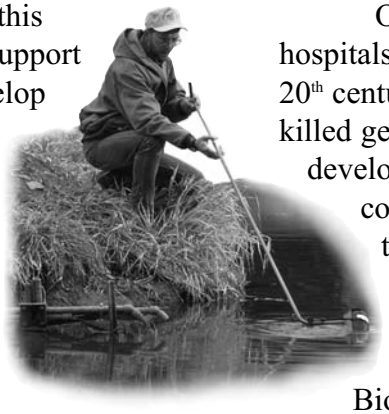
evidence in court. Most chemists who specialize in forensic science serve in federal agencies and in state and local governments.

Environmental chemists are employed by government agencies to protect the environment and reduce pollution. Chemists test the safety of food, the purity of water and monitor air pollution. They promote the use of chemistry to prevent pollution. They develop ways to recycle waste into useful products and show how to develop natural resources while safeguarding the environment.

Organic chemists work with carbon compounds. Because carbon atoms can form rings and long branched chains, hundreds of thousands of carbon-based molecules exist. Understanding organic compounds is especially important because they make up the majority of compounds in living organisms.



Agricultural chemistry is one application of organic chemistry. Plants need nitrogen, potassium and phosphorus to grow in abundance. In many countries, each farmer provides food for 40 or 50 people. Each farmer in the United States provides food for about 128 people, far higher than the worldwide average. Part of this success is due to the close support given by chemists who develop agricultural products such as fertilizers, pesticides and herbicides. Chemists study soils and develop ways to conserve and renew soils and maintain agricultural productivity. Once the food is grown, chemists develop ways to keep food fresh and nutritious.



Biochemistry is the branch of organic chemistry that deals with substances found in living organisms. Biochemists strive to understand the diet, digestion and the action of the body in making and using proteins, carbohydrates and fats.

Living cells produce molecules that are essential for life processes. Nucleic acids, proteins, carbohydrates, enzymes and a vast array of other carbon based molecules are present in cells. Nucleic acids are responsible for storing instructions about how a cell grows and the work that it does. A cell "reads" its nucleic acids to guide production of proteins. Proteins are large molecules made of amino acids. Enzymes are one important class of proteins. Enzymes are catalysts to speed chemical reactions. Carbohydrates fuel the cell and provide raw material for constructing other organic molecules. A cell is a chemical factory that is always at work. It continually breaks down carbohydrates and uses raw materials to form other molecules. Chemists do not yet completely understand ***metabolism***, the complex chemical and physical changes that maintain life.

Organic chemists also work in hospitals and in medical laboratories. In the 20th century chemists developed solutions that killed germs. Since the 1920s, chemists have developed wonder drugs. Today, chemists continue to work to improve drugs and test their quality. Chemists employ nutrition and radioactive elements to treat tumors and radioactive tracers to monitor body functions. Biochemists gain valuable information about basic chemical reactions in living things from radioactive elements.

Not all organic chemists work with living organisms. Organic compounds

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include hydrocarbons such as petroleum. Organic chemists work for companies that convert raw materials like coal and petroleum into synthetic fabrics, pesticides, dyes, drugs, cosmetics, perfumes, colognes and plastics. Practically everything we touch today contains plastic. Synthetic fibers are used in items such as running shoes and bulletproof vests.



Inorganic chemistry deals with compounds that do not contain carbon. The chemistry of metals is an example of inorganic chemistry. A chemist who works in metallurgy is interested in finding the best way to extract gold, silver or the other metals from ores. Some ores can be separated mechanically by shaking, by heating or by the use of electricity. Some iron ores are separated by magnetic attraction. However, chemical separating and refining is the most common way. A chemist who understands the chemical composition of an ore and how the metal atoms bond with the other elements can design an efficient way to refine the metal through chemicals.

Inorganic chemistry includes the study of rocks and minerals that make up the Earth. Geologists have a strong background in chemistry. They study ways to reduce threats to human life and property loss caused by volcanic eruptions, earthquakes and landslides. Some geologists explore for new minerals and sources of elements.

Other specialized fields for chemists include carbon-14 dating of archaeological specimens and chemical analysis of artifacts. Some museums employ chemists to establish authenticity of paintings by famous artists through analysis of paint composition. Chemists also have a role in preserving and restoring priceless paintings.

Although most chemists have their own specialties, they must be familiar with the various branches of chemistry as well as other sciences. Most chemists believe students who want to be chemists should pursue a broad education. A chemist draws on biology, geology, mathematics and physics. Most chemists are comfortable building their own equipment for research and carrying out experiments. Computer skills are essential because most laboratory instruments feed data to computers for further processing.

Social and industrial trends point toward a steady demand for chemists. Students who think chemistry is for them should have a strong interest in science and be capable in mathematics. The ability to work as a team member, speak effectively and write clearly are always important regardless of the career field. Other important traits are that a chemist must enjoy the subject, have a desire to learn new things and be a person of integrity.

Life Principle

"Character and reputation are easier kept than recovered."

—Anonymous

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