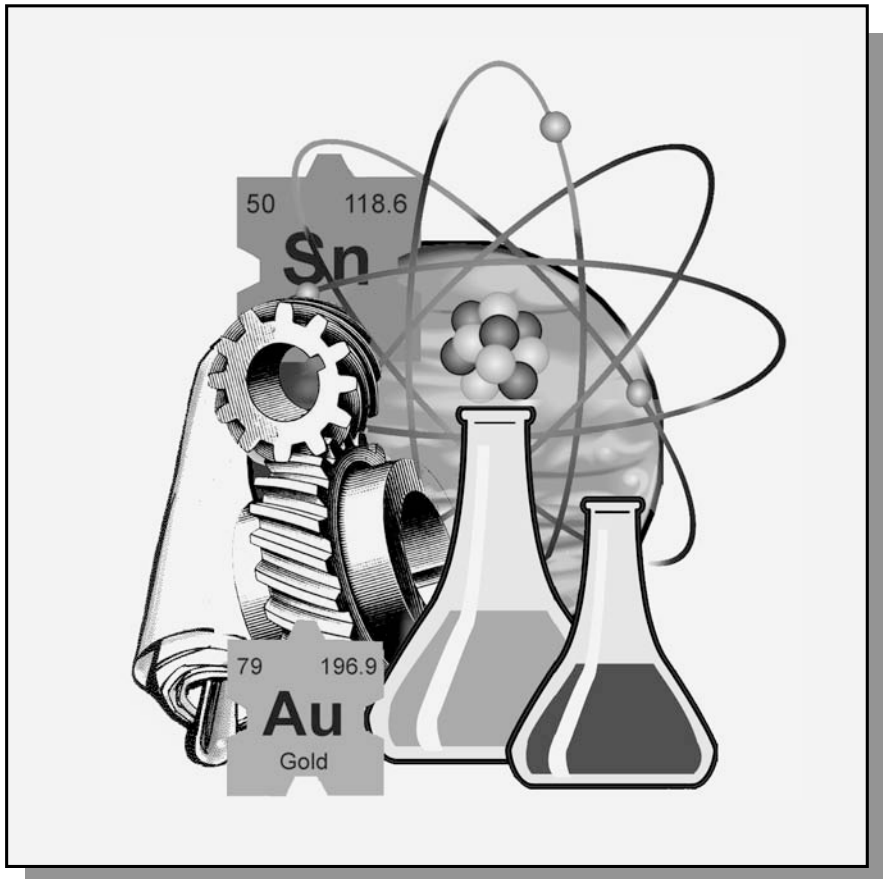
Integrated Physics & Chemistry

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 3

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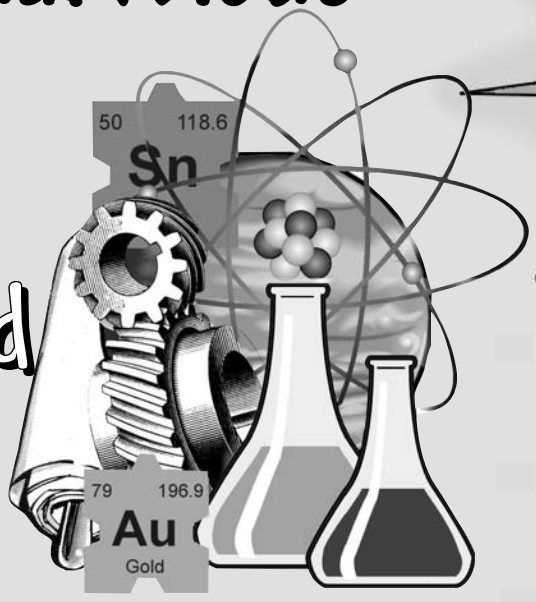
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"The study of science is the chronicle of man's quest to discover the essence of life and how the marvelous laws of creation are applied to human needs."



—Ronald Johnson, Ph.D.

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Integrated Physics & Chemistry



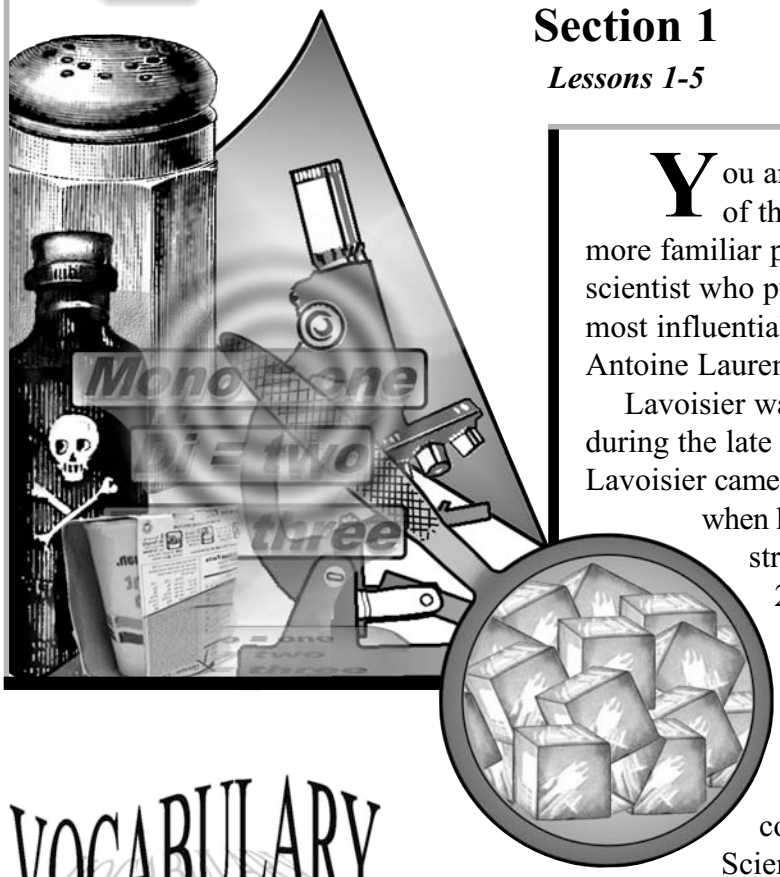
Lesson 1
Compounds

Chapter 3

CHEMICAL NOMENCLATURE

Section 1

Lessons 1-5



You are now ready to advance to the study of the elements. You will study many more familiar pieces of the puzzle, along with the scientist who put the pieces together. One of the most influential scientist during this era was Antoine Laurent Lavoisier.

Lavoisier was a chemist who lived in France during the late 1700s. At the age of 23, Antoine Lavoisier came to the attention of other scientists when he wrote a paper about lighting the streets of a large town. At the age of 25, he received membership in the French Academy of Science. This organization was similar to the Royal Society of London and was created to promote learning about science. Only the best scientists could join the French Academy of Science.

Lavoisier was intelligent and wealthy. He married a beautiful woman, Marie, from the French nobility (pictured on cover). Marie Lavoisier served as Antoine's assistant, and while taking notes of Antoine's experiments, she drew illustrations for his books. She translated books from English into French and became an important asset for the success of her husband.

Lavoisier's life was a fine example of what a scientist can accomplish. He made so many important chemical discoveries that he is known as the Father of Modern Chemistry. Lavoisier studied geology, solved social problems and was devoted to promoting the good of science to those around him. He lived by strong principles and died with honor. Though wrongfully accused of crimes, Antoine Lavoisier marched to his death calmly and bravely.

VOCABULARY

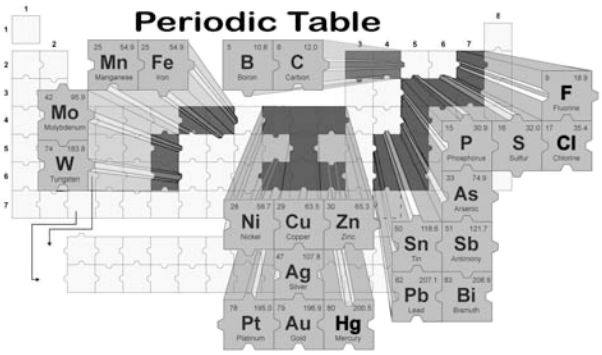
Electromagnetic radiation: a type of energy made of electric and magnetic waves; light is an electromagnetic radiation
Nomenclature: a set of special terms used to name elements and compounds
Suffix: letters that modify the end of a word
ide: suffix that identifies a compound as binary
Prefix: letters that modify the beginning of a word

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Five years before his death, Antoine Lavoisier had written the first chemistry textbook, *Elements of Chemistry*. He reviewed all of the chemical combinations known in his day. Lavoisier attempted to identify which chemicals were elements and which were compounds. He identified 33 substances that he called elements. Although some of Lavoisier's choices were in error, the book was a remarkable achievement.

Lavoisier listed light and caloric as elements. Chemists know now that they are forms of energy. *Light* is ***electromagnetic radiation***, a type of energy. *Caloric* is heat energy due to the kinetic energy from the motion of atoms and molecules. Lavoisier listed three gaseous elements, oxygen (O), nitrogen (N) and hydrogen (H). These gases had been discovered only a few years earlier. Lavoisier listed three nonmetals, sulfur (S), phosphorus (P) and carbon (C). He also listed three acids from which he believed chemists might succeed in extracting elements. Chemists later found that the three acids contained chlorine (Cl), fluorine (F) and boron (B).

Lavoisier listed 17 metals. Seven of the metals had been known since ancient time: gold (Au), silver (Ag), copper (Cu), iron (Fe), tin (Sn), lead (Pb) and mercury (Hg). From the time of ancient Rome to the end of the Middle Ages, another five metals were discovered. They are: antimony (Sb), bismuth (Bi), platinum (Pt), arsenic (As) and zinc (Zn). Chemists discovered the remaining five metallic elements in Lavoisier's list during the two hundred years between the end of the Middle Ages and Lavoisier's time. These are: cobalt (Co), manganese (Mn), molybdenum (Mo), nickel (Ni) and tungsten (W). In this list of metallic elements, Lavoisier included *arsenic* (As) as a metal. Arsenic has properties between those of a metal and a nonmetal. Arsenic has a metallic color, but it is brittle and is often listed as a nonmetal.



Lavoisier listed five substances that were not elements: lime, magnesia, barytes, argil and silex. He knew the substances were compounds. Lavoisier believed these substances contained elements that chemists had not yet been able to separate from the compounds. He was correct. Within a few years, chemists freed calcium (Ca) from lime; magnesium (Mg) from magnesia; barium (Ba) from barytes; aluminum (Al) from argil and silicon (Si) from silex.

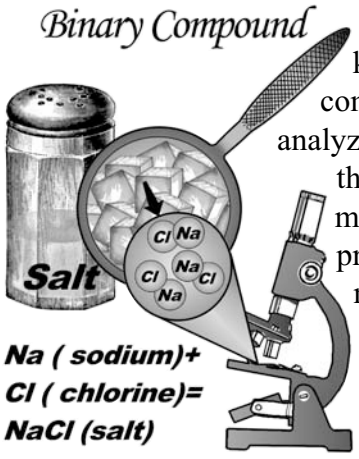
Lavoisier's book, *Elements of Chemistry*, published in 1789, is a summary of where chemistry stood near the end of the 1700s. He listed 23 true elements, eight substances that he believed contained elements and two items that he incorrectly listed as chemical substances.

Lavoisier called for a system of ***nomenclature*** or notation for naming chemical substances. He suggested that chemists should give metals names that ended with the ***suffix*** or ending of *-ium*. Of the 92 naturally occurring elements, 70 are metals. Some elements had already been discovered and given names before he made his suggestion. Names for metals such as gold, lead, iron and others do not end in *-ium*. Starting in the 1800s, chemists did follow his suggestion. Names such as: lithium, beryllium, sodium, magnesium, aluminum, potassium, calcium and many others ended

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with *-um* to identify them as metals. However, there is one exception, *helium* (He). Helium was first detected by analyzing sunlight. The chemist who discovered helium assumed it would be a metal. He gave it the name *helium*, a word made by combining the Greek word *helios*, meaning *Sun,* with the suffix *-ium* for a metal. Later, chemists found helium on Earth and discovered it to be a gas, rather than a metal. By then, the name was too well known to change.

Antoine Lavoisier suggested that chemists give nonmetallic elements names that end with the suffix *-on, -en* or *-ine*. Phosphorus and sulfur had already been discovered and did not follow this rule. At first, helium was incorrectly listed as a metal. All of the other nonmetals such as: hydrogen, boron, carbon, nitrogen, oxygen, fluorine, silicon, neon and the others do follow this rule.



Lavoisier also proposed a series of rules for naming the compounds. He suggested that the names for compounds should be based on the elements they contain. As chemists learned each of the chemical elements in a compound, they were able to replace the common name with a scientific name based on the elements found in the compound. Most of the names for the compounds discovered after his death followed his naming system. Naming a compound after the elements that compose it is useful. For instance, sulfuric acid was known as oil of vitriol. The name *sulfuric acid* (H_2SO_4) is more descriptive because it shows that the acid contains sulfur. Another type of acid was known as muriatic acid. When chemists learned that muriatic acid contained hydrogen and chlorine, they named it hydrochloric acid (HCl). This name is a practical choice because it describes the elements that make the acid.



Today, the fact that carbon dioxide contains carbon and oxygen is easy to understand from the name alone, thanks to Lavoisier. However, in his day, carbon dioxide was known as fixed air. A chemical compound cannot be given a descriptive name, until the elements that make the compound are known. For instance, until the compound pyrolusite was analyzed, chemists did not know that the compound contained manganese and oxygen. Its proper chemical name is manganese dioxide.

A binary compound contains only two different elements. Sodium chloride (table salt) is an example of a binary compound and contains sodium and chlorine. Many binary compounds can be easily identified by their names, which usually end in the suffix ***-ide***. For instance, we know that manganese dioxide is a binary compound because it ends with *-ide*. The binary compound contains only manganese atoms and oxygen atoms.

In the name of a binary compound, the most metallic element is given first. The less metallic compound's name is changed to make it end with *-ide*. Oxygen becomes *oxide*, sulfur becomes *sulfide*, carbon becomes *carbide*, chlorine becomes *chloride*, nitrogen becomes *nitride* and phosphorus becomes *phosphide*.

A binary compound can contain more than two atoms provided only two elements are present. Manganese dioxide (MgO_2) contains three atoms — one of manganese and two of oxygen. Yet, it contains only two

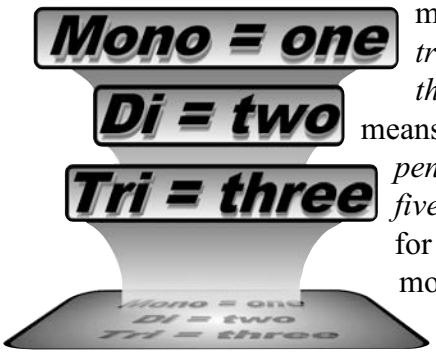
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elements—manganese and oxygen. Manganese dioxide is a binary compound. On the other hand, sulfuric acid (H_2SO_4) is not a binary compound. It contains three different elements—hydrogen, sulfur and oxygen.

Calcium carbide is a binary compound because it contains only two elements, calcium and carbon and, therefore, has a name that ends in *-ide.* The chemical formula is CaC_2. Calcium carbide has three atoms, one of calcium and two of carbon. However, this compound contains only two elements, calcium and carbon.

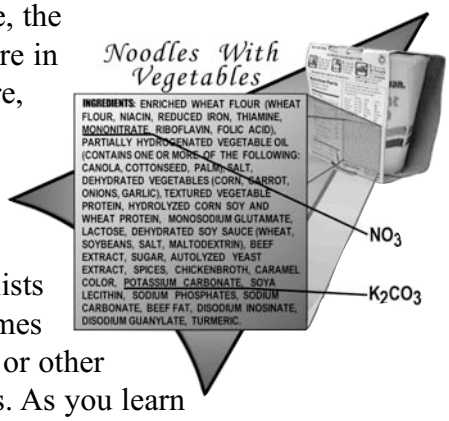
Carbon monoxide and carbon dioxide are binary compounds. Each one contains only carbon and oxygen. However, carbon monoxide has only one oxygen atom, and carbon dioxide has two oxygen atoms. Other compounds are made of two elements in different combinations. Some way is needed to tell them apart. Chemists use a ***prefix***, or set of beginning letters, to distinguish between the compounds.

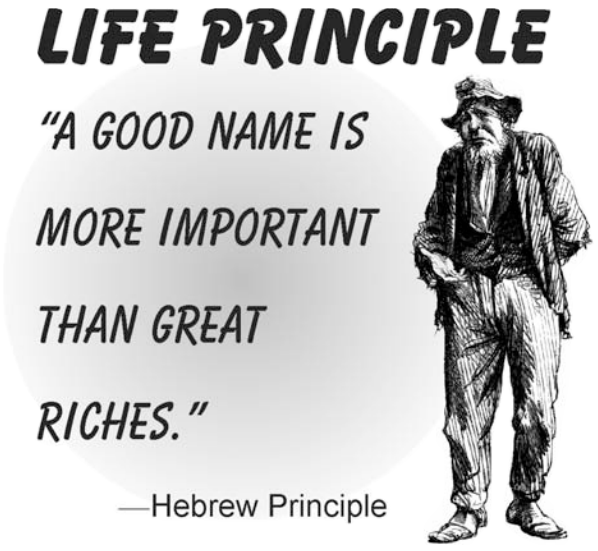
The prefix *mon-* means *one*, *di-* means *two*, *tri-* means *three*, *tetra-* means *four* and *penta-* means *five*. The name for carbon monoxide shows that it has one oxygen atom, *CO*. Carbon dioxide has two oxygen atoms (CO_2). Arsenic trichloride has three chlorine atoms ($AsCl_3$), and carbon tetrachloride has four chlorine atoms (CCl_4). The prefix can also apply to the first word in the binary name. Disodium indicates that two sodium atoms are present.



By being mindful of the suffixes and prefixes, a chemist can figure out the composition of an unfamiliar compound. For example, diarsenic pentasulfide appears to be a long and difficult name, until it is separated into prefixes, root words and suffixes—di-arsenic penta-sulf-ide. *Di-* means *two*, arsenic is the first element. *Penta-* means *five*, and sulfur is the second element. The ending suffix of *-ide* means this is a binary compound. Those clues enable a chemist to write the chemical formula of diarsenic pentasulfide as As_2S_5.

Though many of these names may not be familiar to you, they are all found around us. For example, the next time you are in the grocery store, look at the ingredient lists on the labels of food items. Many of these lists will contain names that end in *-ide* or other chemical names. As you learn more about the elements, you will begin to understand what many of these names mean.





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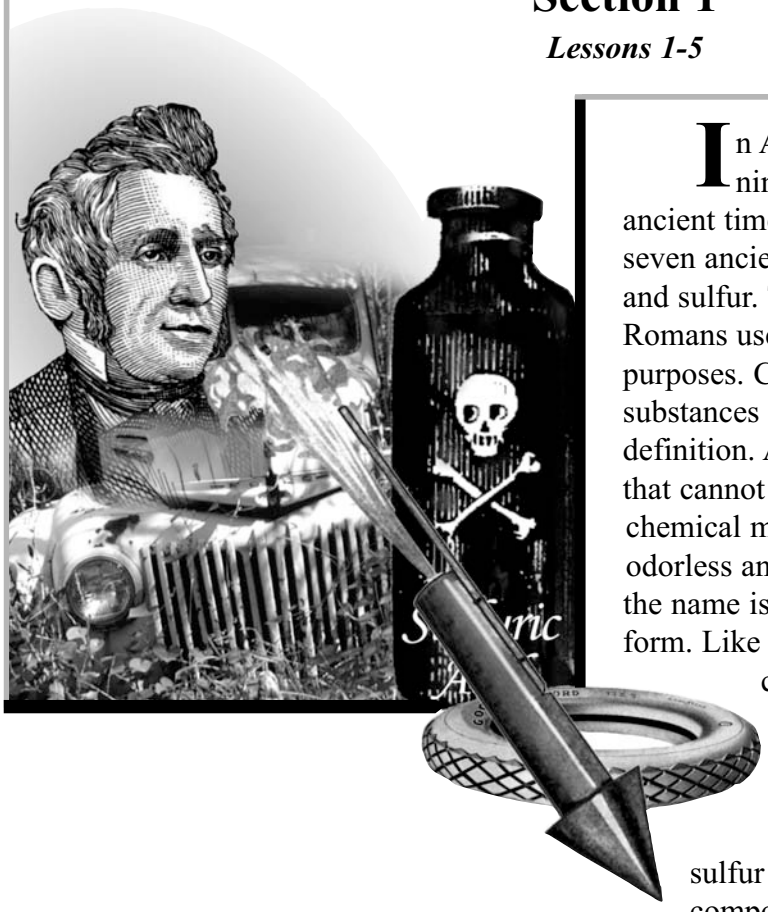
Chapter 3

Lesson 2
Elements

Section 1

Lessons 1-5

LAVOISIER'S LIST OF ELEMENTS



In Antoine Lavoisier's list of elements, nine elements had been known since ancient times. Those nine elements were the seven ancient metals and two nonmetals—carbon and sulfur. The ancient Egyptians, Greeks and Romans used the nine substances for everyday purposes. Chemists did not know that the nine substances were elements by the modern definition. An element is a chemical substance that cannot be separated into more substances by chemical means. Sulfur (S) is a pale, yellow, odorless and brittle solid. An older spelling of the name is sulphur, but chemists do not use that form. Like most other nonmetals, sulfur is a poor conductor of heat and electricity.

Because sulfur is known since ancient times, we do not know who discovered the element.

Pure sulfur is harmless, although sulfur dust irritates the eyes. Many compounds of sulfur are more dangerous than the element itself.

Sulfur was known and referred to in the Bible and other writings as brimstone. *Brimstone* means *burning stone*. Sulfur will burn in air with a sputtering blue flame. As sulfur burns, it combines with oxygen to form molecules of sulfur dioxide (SO_2). Sulfur dioxide is a heavy, colorless gas with a suffocating odor. The Egyptians burned sulfur in closed buildings believing it purified the air.

Sulfur dioxide enters the atmosphere when fuels such as natural gas, petroleum and coal are burned. Active volcanoes spew out sulfur. Sulfur dioxide becomes one of the components of air pollution. If the air is moist, it forms sulfuric acid and


Rust caused by exposure to acid rain.

VOCABULARY

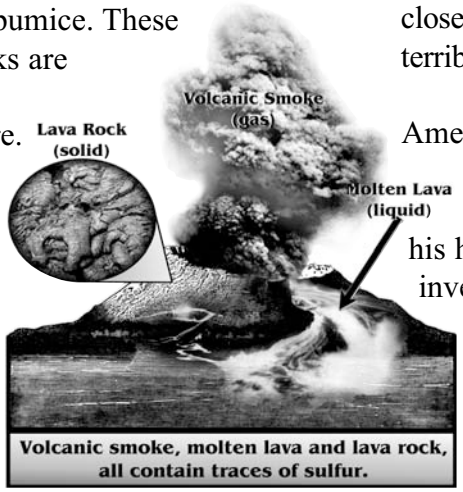
Distillation: purification of a liquid by condensation of the liquid from a vapor
Vulcanized: rubber that has been heated with sulfur enabling the rubber to have more useful properties
Elastic: flexible, easily returns to its original shape after being stretched or compressed

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falls as acid rain. The acid dissolves limestone and can cause damage to stone buildings and statues.

The most common sulfide is hydrogen sulfide (H_2S), a colorless, poisonous gas with the odor that resembles rotten eggs. Hydrogen sulfide is especially dangerous because it deadens the sense of smell. As concentrations of hydrogen sulfide increase, the victim's respiratory system becomes paralyzed, and the victim cannot breathe.

Sulfur can be found in areas of volcanic activity. In Sicily, sulfur has been mined for centuries. It is found with gypsum and pumice. These sulfur-bearing rocks are dumped in large piles and set on fire. Sulfur is used as a fuel for the process. By burning about one third of the sulfur, enough heat is generated to melt the rest. The liquid sulfur is drained into wooden molds where it hardens.



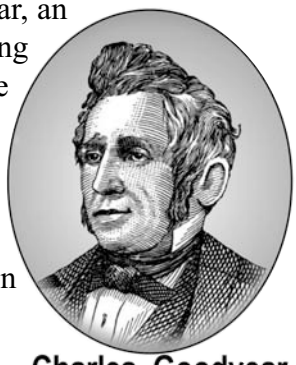
Volcanic smoke, molten lava and lava rock, all contain traces of sulfur.

Raw sulfur can be further purified by ***distillation***. Distillation is the process of purifying a substance by heating it into a gas and then letting the substance condense back into a liquid. Heating sulfur changes it into a vapor, and the impurities are left behind. Pure sulfur condenses to a liquid and solidifies.

Sulfur is used in improving the properties of rubber. Natural rubber is made from latex, a milky white liquid. It comes from the bark of rubber trees found in the tropics. In 1770, Joseph Priestley, a British chemist, discovered that latex could be used to erase or rub out pencil marks. Latex became better known as rubber.

Latex was used for other purposes which includes the making of chewing gum. The natives of South America made items of clothing from latex, especially sheets to protect the natives from rain. In 1823, Charles Macintosh, a Scottish chemist and inventor, patented a fabric made of cloth covered with rubber. He opened a factory in Glasgow, Scotland to make raincoats of rubber. A heavy-duty raincoat is called a Macintosh.

Charles Macintosh's rubber coats did not work well. In cold weather, the rubber coats became stiff and would crack. In hot weather, the rubber coats became soft and sticky. Raincoats and boots of rubber left in the closet during the summer melted together in a terrible, foul smelling mess.


Charles Goodyear

Charles Goodyear, an American, began working on the problem. He had already tried his hand as an inventor. Sometimes Goodyear succeeded but often spent more money perfecting his inventions than the invention earned. In the early 1800s, people who could not pay their bills were sent to prison. Charles Goodyear spent some time in debtor's prison because he spent too much time improving old projects, rather than inventing new items that would earn money for paying debts.

Other chemists had mixed sulfur with rubber but reported only slight improvements to the properties of the mixture. Charles Goodyear repeated their experiments. In 1839, he accidentally dropped a mixture of rubber and sulfur on a hot stove. He scraped the mixture from the stove. The rubber stayed flexible when cold and did not become sticky when warm.

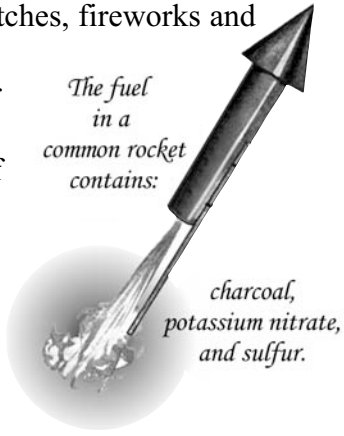
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Goodyear improved the process by cooking latex with sulfur at a greater temperature than other scientists had done. Goodyear invented the ***vulcanized*** rubber. *Vulcan* was known as the mythical Roman god of fire and metalworking. Vulcanized rubber has many desirable properties. It is stronger and tougher than raw latex and, like latex, vulcanized rubber is waterproof. Goodyear's rubber was ***elastic***—it could be stretched or compressed and springs back to its original shape.

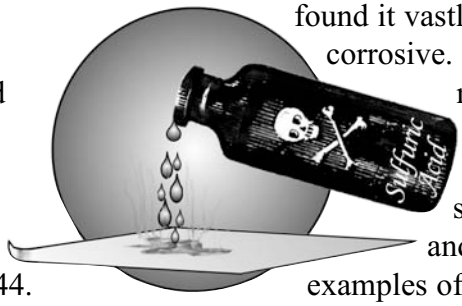


Charles Goodyear patented his invention in 1844. Unfortunately for Goodyear, people could easily copy his process. The great Daniel Webster served as Goodyear's lawyer, and the courts upheld his patent. Goodyear borrowed huge amounts of money to promote his invention. He traveled to Europe to sell his rubber. The money Goodyear expected never came. He spent some time in a French debtor's prison. Some inventors died in poverty, but Charles Goodyear did even worse—he died owing as much as $600,000.

Years later, at the start of the 1900s, automobile tires became the single most important use of Goodyear's sulfur-based vulcanized rubber. Matches, fireworks and black gunpowder all contain either sulfur or sulfur compounds. Gunpowder is made of saltpeter, charcoal and sulfur. Saltpeter is potassium nitrate (KNO_3). Charcoal contains primarily carbon (C). During the 1200s, gunpowder came into use in Europe. It was used earlier by the Chinese who manufactured fireworks. Gunpowder remained the most common explosive until the 1800s, when other explosives were discovered.



Sulfuric acid is the most important compound of sulfur. In the ancient world, the strongest acid was vinegar or acetic acid. Alchemists discovered sulfuric acid and found it vastly more corrosive. Corrosive means capable of chemically eating other substances; rust and tarnish are examples of corrosion.



Concentrated sulfuric acid can dissolve many metals and attacks the flesh. Sulfuric acid removes water and can char wood and paper as if they had been burned. Scientists named the acid *oil of vitriol.* Sulfuric acid (H_2SO_4) is an oily, colorless liquid that is almost twice as heavy as water. When sulfuric acid and water are mixed, the reaction generates heat. To dilute sulfuric acid, small amounts of the acid are added to water with constant stirring. The sulfuric acid is poured in slowly and thoroughly stirred. Otherwise, the water may turn into steam and blow the acid out of its container. Sulfuric acid can destroy skin and flesh and can cause blindness if it gets into the eyes. The treatment is to flush away the acid with large amounts of water. Sulfuric acid is the cheapest and most common of all acids. Sulfuric acid is used in the manufacture of a large number of products. It is used to make other acids, in the production of fertilizers, and in the process of refining petroleum. Sulfuric acid is also used to clean grease from metals before they are plated. Sulfuric acid is used in lead acid electrical storage batteries and is one of the most important of all industrial chemicals.

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Life Principle

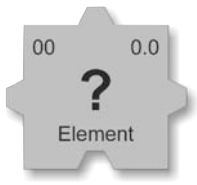
"A room without books is like a body without a soul."

—*Cicero*



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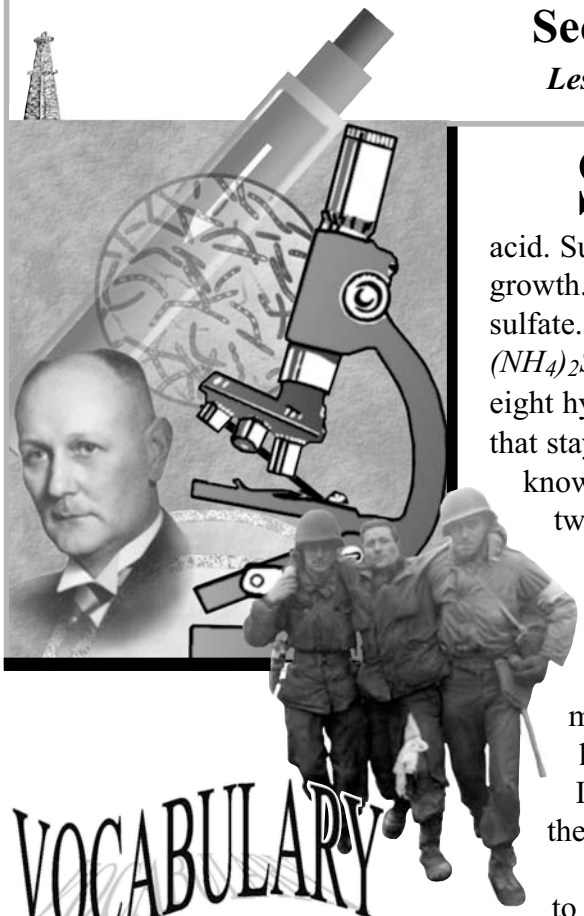
Lesson 3
Elements

Chapter 3

SULFUR: USES AND PRODUCTION

Section 1

Lessons 1-5



Sulfur is used in the vulcanization of rubber, the manufacture of black gunpowder and in sulfuric acid. Sulfur is also used as ***fertilizer*** to improve plant growth. One common fertilizer using sulfur is ammonium sulfate. The chemical formula for ammonium sulfate is $(NH_4)_2SO_4$. Ammonium sulfate has two nitrogen atoms and eight hydrogen atoms. NH_4 and SO_4 are groups of atoms that stay together during a chemical reaction. They are known as ***radicals***. The ammonium sulfate molecule has two ammonium radicals ($(NH_4)_2$) and one sulfate radical (SO_4).

The ancient Egyptians who used sulfur to purify the air probably did some good. Sulfur will kill bacteria and fungi and is still used today as a means of fumigating. Bacteria and fungi are tiny, living organisms that cause many human diseases. In the process of fumigation, fumes are released into the air to destroy these tiny living organisms.

Although most sulfur compounds are poisonous to humans, a drug containing sulfur was one of the first wonder drugs to combat infection. Wonder drugs kill the bacteria but not human cells. Normally, the body uses its white blood cells to fight invading bacteria, but, sometimes, the bacteria multiplies in the body and overwhelms the white blood cells.

Externally applied ***antiseptics*** were the most common way to deal with bacteria. These antiseptics would kill bacteria before the bacteria could enter the body. In order to fight the bacteria after infecting the body, doctors needed a chemical that would kill bacteria without harming human tissue. The first person to discover such a chemical was Gerhard Domagk.

Gerhard Domagk (pronounced DOH-mahkh) was born in the little town of Lagow, Germany, in 1895. Showing a great interest in medicine, Gerhard Domagk read all the medical

VOCABULARY

Fertilizer: a chemical substance worked into the soil to increase plant growth
Radical: cluster of elements that behave as if they were a single element and stay together during chemical reactions
Antiseptic: a chemical that prevents the growth of microorganisms that can cause disease
Antibiotics: substances that prevent or control the growth of bacteria in the human body

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books he could find. His goal was to become a doctor.

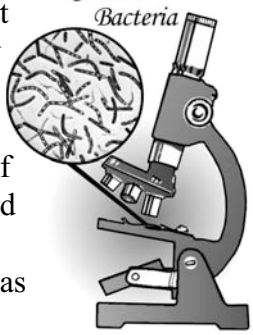
As Gerhard Domagk turned eighteen, World War I had begun. Medical school had to wait. Gerhard Domagk's commanding officers made him serve as a battlefield medic. During the war, Domagk learned far more by firsthand experience than he would have learned in medical school. By the end of the war, Gerhard Domagk had become an accomplished physician and made it official by earning a medical degree.



Gerhard Domagk

In 1927, the I. G. Farben company asked Doctor Domagk to join their staff. He would study new dyes, not for the use of coloring fabrics, but for possible uses in medicine. Chemists at the German dye company made a bright red compound that they patented under the name Prontosil. The chemists made the dye from coal tar, which was a black, sticky substance.

In 1932, Doctor Domagk infected mice with a deadly strain of bacteria called *staphylococcus*. Then he injected Prontosil into the mice, and, to his great pleasure, the dye completely reversed the infection. About this time, Doctor Domagk's daughter developed a serious infection on her finger after pricking herself with a needle. The bacteria causing the infection multiplied. Her condition became desperate, and nothing the doctors administered helped. Gerhard Domagk gave his daughter a massive injection of Prontosil. Her condition improved dramatically. With this successful effort, in 1932, Doctor Domagk published a report of the drug's extraordinary powers.



Common Bacteria

Only a small part of the complex chemical of Prontosil actually destroyed the bacteria. Chemists identified the active agent as sulfanilamide. The name *sulfanilamide* was shortened to *sulfa*. Sulfa drugs are not found in nature. They are strictly synthetic or made in the chemical laboratory.

In the United States, Doctor Perrin H. Long at the Johns Hopkins University became interested in the drug. During the summer of 1936, Dr. Long attended a scientific meeting in London. There he learned of sulfanilamide and its role in fighting infection.

Doctor Long immediately ordered samples of sulfa with which to experiment after he returned to the United States. His experiments confirmed the wonderful properties of sulfa. Not only did sulfa combat deadly infections, but also it seldom gave the patient harmful side effects.

In November of 1936, the White House called John Hopkins University Hospital. Franklin Roosevelt, Jr., the twenty-two-year-old son of President Franklin D. Roosevelt, had a very serious infection of the throat.

VOCABULARY

Native: free or uncombined, a chemical found free in nature is said to be in its native state
Petroleum: crude oil as it comes from beneath the earth's surface
Phase: one of the states of matter: solid, liquid or gas
Crystalline: an atomic or molecular arrangement of atoms in a definite pattern
Amorphous: a description of an element or compound whose atoms or molecules take no particular form or organization

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"His physician considers his condition serious," Mrs. Roosevelt explained. "He's dying. Will the sulfa drug help?"

Doctor Long agreed to treat President Roosevelt's son. He rushed to the bedside of the young man and began treatment with sulfa. The younger Roosevelt showed immediate improvement and soon was out of danger. The successful treatment of sulfa made headlines across the country and around the world.



Newspapers called sulfa a wonder drug. The wonder is that it killed one-celled bacteria but did not hurt the cells of human tissue. Sulfa drugs can be given in massive amounts without being toxic. During the fighting of World War II, medics or battlefield doctors, freely sprinkled the drug in open wounds before bandages were tied over the injuries.

Treatment with sulfa will kill bacteria. This action is due to a case of mistaken identity. Some disease causing bacteria need a certain acid to grow and multiply. Bacteria take this acid from human blood. Acid and sulfa are so similar that the bacteria cannot distinguish between the two compounds. Instead of taking the acid from the blood, bacteria accept the sulfa and make it part of their bodies. Without the acid, the bacteria die, and the infection clears up.

Sulfa does not fool all types of bacteria; therefore, it is not a universal cure-all. Sulfa had a time of immense importance until shortly after World War II. ***Antibiotics***, such as penicillin, replaced sulfa. Sulfa was the first wonder drug.

Because of sulfur's many uses, the amount consumed by a country can be used as an economic indicator. When the use of sulfur increases, the economy is booming.

Until the start of the 1900s, most of the world depended on Sicily for sulfur. Should the supply of sulfur from Sicily fail, a country could go into economic ruin. To ensure economic growth, the United States looked for a reliable source of sulfur.

Sulfur is relatively inactive and can be found in the ***native***, or free state, in nature. Louisiana and Texas have sulfur beds as much as 200 feet thick. The sulfur is so pure it can be used for most purposes with no additional refining. However, the sulfur beds are located along the Gulf of Mexico, almost 1,000 feet below swampy ground. Mining sulfur, like coal, would be too expensive and too dangerous.

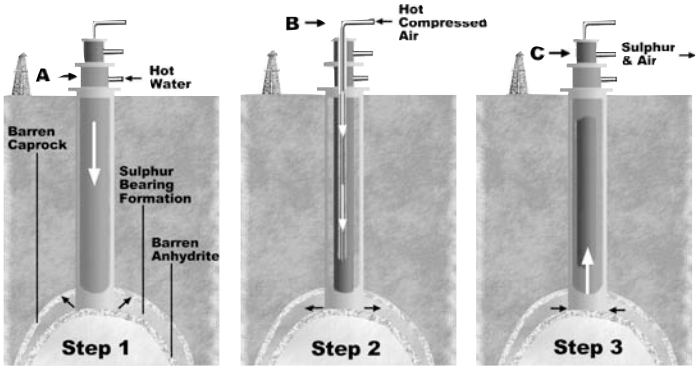
Herman Frasch, a German-American chemist, developed a method of bringing sulfur to the surface by drilling a well. He came to the United States after the Civil War and opened a chemistry laboratory in Philadelphia. Herman Frasch was shrewd enough to realize that ***petroleum*** would someday be an important product so he specialized in the area of petroleum chemistry.

The primary use of petroleum was in heating. The oil contained sulfur which produced a powerfully unpleasant odor. Herman Frasch succeeded in developing a process of removing the sulfur from the petroleum.

Frasch's knowledge of oil wells provided him with the skill to develop a way to pump sulfur from below ground. He used the fact that sulfur melts at 115ºC (240ºF). This is only slightly above the boiling point of water. He drilled a well and sent hot water, under pressure, down pipes into the sulfur deposit. As the water was placed under pressure, the water remained in a liquid state above the normal boiling temperature. Without the pressure, the water would have turned into steam.

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The hot water melted the sulfur. Pipes carrying hot compressed air forced the sulfur to the surface. The *Frasch Process* used three concentric pipes set inside one another. The outer pipes carried the hot water and the inner pipe held the hot compressed air. The middle pipe carried the sulfur to the surface. Because the sulfur was between two hot pipes, the pipe carrying hot water and the other pipe, hot compressed air, the molten sulfur stayed in a liquid state until reaching the surface. There the sulfur was poured into huge vats to cool and solidify. The sulfur could then be liquefied once again to pump into tanker ships for transport or to be cut into blocks for shipment over land. After 1903, the United States produced nearly all of its sulfur by using the Frasch process.



Sulfur exhibits allotropic forms. *Allotropy* is the existence of two or more structural forms of an element in the same physical ***phase***. It is a physical change. The color, density, brittleness, hardness, ability to conduct heat or electricity or other physical properties may change. Allotropic forms are within the same phase. Ice and liquid water are vastly different. However, they are in two different phases as a solid and a liquid and are not considered to be an allotropic form. Going from solid to liquid is a change of state, not a change of allotropic form.

Most allotropic forms are within the solid phase. Tin, for instance, can have two allotropic solid forms—common white tin and the less common gray tin that makes its appearance at colder temperatures. In 1913, the members of the Scott Antarctic Expedition died because their fuel was stored in tin cans. The cans changed form in the frozen area and became brittle. The seams of the fuel cans split, and the fuel leaked out.

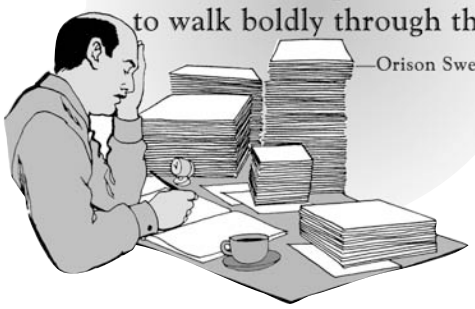
Sulfur is unusual because it has allotropic forms, as a liquid. Sulfur melts at 115ºC. When the liquid is heated to higher temperatures, the liquid sulfur becomes thicker and flows less freely. It changes in density. Near the liquid's boiling point (445ºC), sulfur again flows freely. The different physical properties of sulfur in the liquid state are allotropic forms.

Sulfur also has a solid allotropic form. Normally, the sulfur has a ***crystalline*** structure and is brittle. Its atoms form a regular geometric pattern. When sulfur is heated almost to its boiling point and is then poured rapidly into cold water, it does not crystallize. Instead, the sulfur forms a transparent, sticky, elastic substance known as ***amorphous*** sulfur. The atoms have no particular pattern to their arrangement, and the sulfur looks like a solid, but it will slowly flow like a liquid. Eventually, the liquid sulfur slowly changes back into regular sulfur.

LIFE PRINCIPLE

"Most of our obstacles would melt away if instead of cowering before them, we should make up our minds to walk boldly through them."

—Orison Swett Marden



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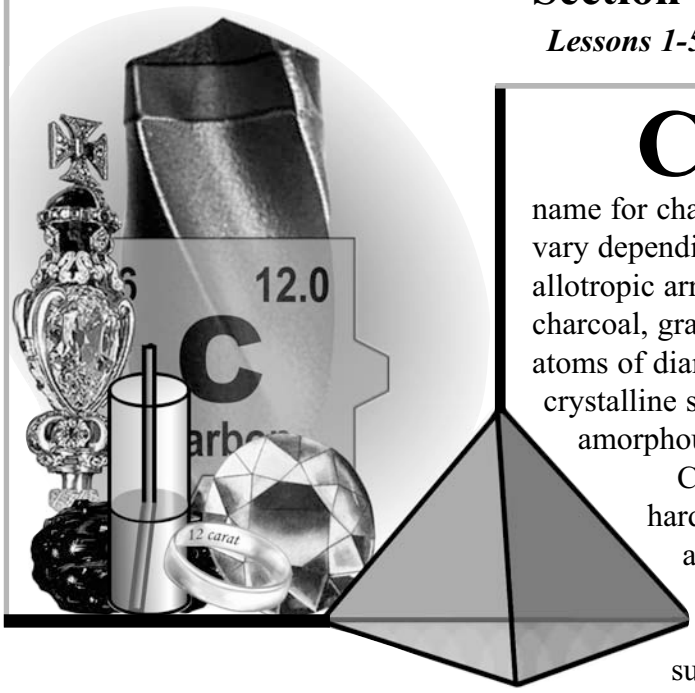
Lesson 4
Compounds

Chapter 3

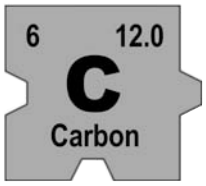
CHEMISTS MAKE DIAMONDS

Section 1

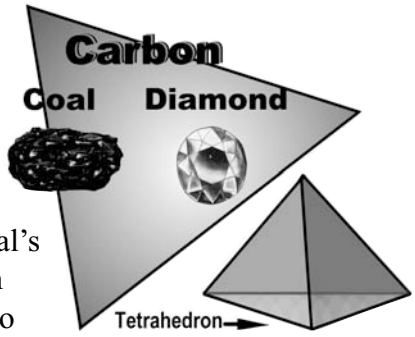
Lessons 1-5



Carbon (C) is a nonmetallic element. The word *carbon* is from the Roman (Latin) name for charcoal. The physical properties of carbon vary depending on the three different allotropic arrangements, such as charcoal, graphite and diamond. The atoms of diamond and graphite have crystalline structures. Charcoal is amorphous; its atoms make no definite pattern.



Carbon in the form of a diamond is the hardest substance known. The carbon atoms in a diamond arrange themselves in a pyramid-like crystal. Four other atoms, located at the corner of a regular tetrahedron, surround each carbon atom. A tetrahedron is a pyramid-like structure. This is a very stable arrangement, which explains why a diamond is so hard.



Hardness is a physical property of a substance. By the 1800s, the chemists who studied rocks, minerals and precious stones needed a way to measure the material's hardness. Friedrich Mohs, a German mineralogist, developed a standard to rate the relative hardness of a material. A mineralogist is a scientist who studies minerals.

Friedrich ***Mohs' hardness scale*** ranges from 1 for a soft substance up to 10 for a very hard mineral. Talc, the mineral from which talcum powder is made, is rated 1. Calcite, calcium carbonate found in limestone, is rated 3. Quartz, a very hard mineral of silicon dioxide, has a hardness of 7. Diamond is rated 10. The human fingernail is about 2.5; a penny is about 3; a knife blade is about 5.5, and a steel file is about 6.6.

VOCABULARY

Mohs' hardness scale: a scale for measuring hardness that goes from 1 for soft as talc to 10 for hard as diamond
Disperse: to separate light into the colors of the spectrum
Index of refraction: a measure of the amount of bending of light as it passes from one medium such as air into another medium such as glass
Static: without motion
Facet: a flat, polished surface of a gemstone

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MOHS' HARDNESS SCALE

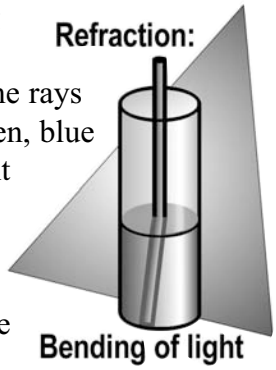
Mineral	Hardness	Notes
Talc	1	
Gypsum	2	scratched by a fingernail
Calcite	3	about the same hardness as a penny
Fluorite	4	
Apatite	5	scratched by a knife blade
Feldspar	6	scratched by a steel file
Quartz	7	
Topaz	8	
Corundum (Ruby, Sapphire)	9	
Diamond	10	scratches all other common materials

If an unknown substance scratches all the minerals in the scale up to and including feldspar but is scratched by quartz, the substance is between 6 and 7 in hardness. Glass can be rated on the Mohs hardness scale. All minerals up to and including apatite can be scratched with glass. Glass cannot scratch feldspar, but feldspar can scratch glass. Glass has a hardness scale between 5 and 6.

Diamonds are primarily used in jewelry and for rock drills. The diamond's hardness resists wear, which is a desirable characteristic in gemstones. Smaller diamonds and those that are not of gem quality are used in making the drills that cut through rock.

The diamond is noted for its brilliance and sparkle. When a beam of light strikes a clear substance at an angle, the path of light is bent. The bending effect is not the same for each color. The rays of different colors are ***dispersed*** or separated. White light is dispersed into the colors of the rainbow. The measure of how much a clear substance bends a ray of light is the refractive index. Air has a refractive index of 1.00. The ***index of refraction*** of water is 1.33. The index of refraction of glass is 1.50. Diamond has a refractive index of 2.54, which is higher than any other material.

A wedge of glass will separate light into the colors of the rainbow. Because of the higher index of refraction, a diamond is even better at producing color. A properly cut diamond will separate the rays of sunlight into red, green, blue and the other hues. Light enters the diamond; and after being refracted, dispersed and reflected, the light emerges as pure colors causing the diamond to sparkle.



Diamonds also have a high melting temperature. As Lavoisier demonstrated, a diamond will burn with oxygen. However, if oxygen is excluded and a diamond is heated, it does not melt easily. The stable tetrahedral arrangement of the atoms keeps them in place even as heat energy is added. A diamond has a higher melting temperature than any other element, about 3,500ºC.

Gem grade diamonds are usually transparent, colorless and extremely valuable. Some diamonds are colored because they have trace amounts of elements other than pure carbon. Usually, these diamonds with tinges of other colors are regarded as imperfect. However, a few unusual ones, such as red or black diamonds, are considered so rare as to be worth more than clear diamonds of the same size.

Most nonmetals are poor conductors of electricity. A poor conductor such as glass, rubber and fur will hold a ***static*** charge of

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electricity rather than conduct it away. A diamond is like other nonmetals in this regard. A diamond is not a good electrical conductor. When rubbed, a diamond becomes charged with static electricity and will hold the charge.

Most nonmetals are poor conductors of heat. Diamond is an exception because it will readily conduct heat away from a hotter object. A person's hands are usually hotter than diamonds. When a person touches a diamond, it conducts the body heat away. Diamonds are cool to the touch.

A diamond in nature is rather unimposing. It looks like an oily pebble. A diamond is first cut and polished to change it from an unimpressive pebble into a gemstone. The goal of diamond cutting is to shape the stone into a multitude of ***facets*** that help the stone refract, disperse and reflect rays of light that enter the diamond. Imperfections, such as flaws and poor color, are eliminated or minimized. At the same time, the person who is cutting the diamond wants to keep it at maximum size because of the diamond's value.

The metric *carat* is the unit of weight usually employed for diamonds and other gems. Remember that for alloys of gold, a carat shows the ratio of gold to the other metals that make up the alloy. A 12-carat gold ring is 12/24 gold by weight—half gold. For diamonds, the carat is an actual weight, equal to 1/5 (0.2) of a gram. A gram alone is small: 28 grams make an ounce. Despite the small size of a carat, diamonds are so valuable a smaller unit of weight is often needed. A point is 1/100th of a carat.

The greatest source of diamonds is South Africa. The first diamond found there was a pebble picked up by a child in 1866. The pebble proved to be a 21-carat diamond. 21 carats * 0.2 carats/gram = 4.2 grams. Although a 21-carat diamond is large, it would take almost seven diamonds that size to weigh an ounce.

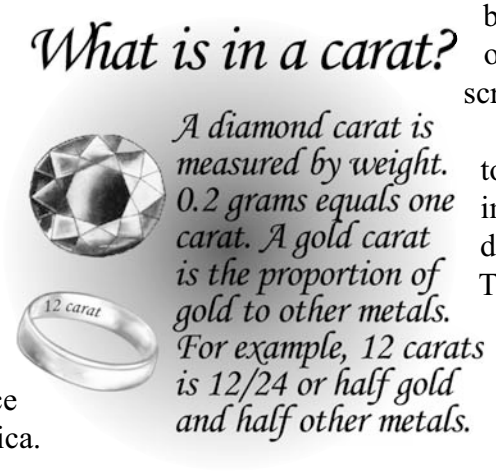
The largest diamond ever uncovered came from a mine in South Africa and is known as the *Cullinan diamond*, which weighed 3,106 carats before being cut. To see how many grams the diamond has, multiply by the conversion factor of 0.2 carats/gram: 3,106 carats * 0.2 carats/gram = 621.2 grams. A pound is 454 grams, so the Cullinan diamond weighed more than a pound. It was cut into more than 100 smaller diamonds. The largest, approximately 500 carats, became the *Star of Africa*. This particular diamond is part of the British crown jewels, set in the British royal scepter or royal rod.



Star of Africa

Because of the value of diamonds, people have searched for a diamond look-alike. Imitation diamonds are often made from heavy glass, while others are made from quartz or zirconium. Any glass imitation will feel warm to the touch rather than cool like a diamond and may have air bubbles caught in the glass. The other imitations can be scratched by true diamonds.

Alchemists tried for years to make gold and found that impossible. In the case of diamonds, there is a difference. The alchemists tried to change elements such as lead and sulfur into gold. Lavoisier was the first one to show that a diamond is made of pure



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carbon. Essentially, then, a diamond is a different form of coal. Since the late 1700s, the idea of changing coal to diamond has fascinated chemists. To make diamonds, scientists needed to change carbon in one allotropic form, such as coal, into a different allotropic form of diamond. The scientists did not need to change one element into another but the same element into a different form.

Diamonds are found in strata, part of the rock that has been under great heat and pressure. This would indicate that with sufficient heat and pressure, carbon could be converted into diamond.

In the late 1800s, Ferdinand Moissan, a French chemist, had succeeded in the difficult and dangerous task of producing pure fluorine (F). This gas is similar to chlorine but far more dangerous. Fluorine is the most reactive element known. Ferdinand Moissan received the Nobel Prize in chemistry for his work with fluorine.

Moissan next tried to prepare carbon as a diamond and claimed to have succeeded. Other chemists tried to duplicate Moissan's process and failed. As the years passed, investigators discovered that his methods simply did not produce enough pressure and heat to make the change. In 1893, Ferdinand Moissan had triumphantly displayed a fleck of diamond, about one millimeter (1/25th of an inch) long. He claimed to have made the diamond in the laboratory. Most scientists shudder at the idea of cheating during an experiment. Faking laboratory experiments goes against everything that the scientists were taught about the goals of science. Yet, it sometimes happens.

Ferdinand Moissan was an honest scientist. All of his work with fluorine was repeated and found entirely correct. No one believes that Moissan faked his diamond experiments. Yet, his apparatus simply could not have produced a diamond. A laboratory assistant must have wanted him to succeed too badly. The dishonest assistant probably placed the sample of diamond in the apparatus before the tests began.

Chemists did finally succeed in making diamonds. Scientists at the laboratories of General Electric took up the quest in the 1950s. In 1955, scientists were able to make a synthetic diamond. The diamonds were only about the thickness of a human hair, about 0.1 millimeter in size.

A difference is evident between imitation diamonds and *synthetic diamonds*. An imitation is not a true diamond. Synthetic diamonds are made in the laboratory. Although a synthetic diamond is the result of human production, it is in every respect a true diamond. Synthetic diamonds are too small for gemstones, but these diamonds can be used in industry for diamond tipped drill bits and other grinding tools.

Life Principle

"Ability is what you are capable of doing. Motivation determines what you do. Attitude determines how well you do it."

—Lou Holtz

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Integrated Physics & Chemistry



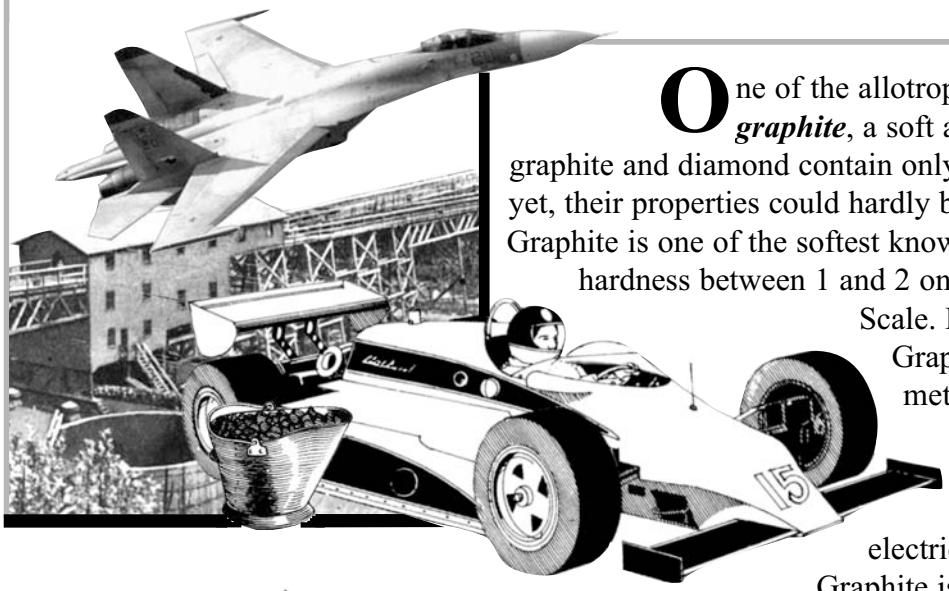
Lesson 5
Compounds

Chapter 3

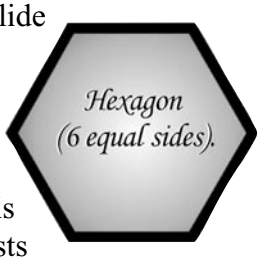
GRAPHITE AND COAL

Section 1

Lessons 1-5



One of the allotropic forms of carbon is ***graphite***, a soft and flaky mineral. Both graphite and diamond contain only the element carbon, yet, their properties could hardly be more different. Graphite is one of the softest known minerals, with hardness between 1 and 2 on the Mohs' Hardness Scale. Diamond is the hardest. Graphite is black, has a metallic luster and a greasy feel. The diamond is a brilliant gemstone. Graphite conducts electricity; diamond does not. Graphite is a crystal as is a diamond, but the carbon atoms form flat, hexagonal flakes. *Hexagonal* means having six sides. Graphite's layered structure makes it very soft. Graphite flakes easily slide over one another. Because of the sliding action of the flakes, graphite is used as a dry lubricant. A *lubricant* is a substance that reduces the friction of moving parts.



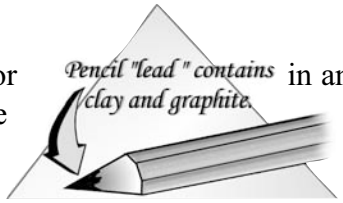
Graphite is the only nonmetal that is a good conductor of electricity. It also resists acids and has a high melting temperature. Although, most metals will conduct electricity, many have low melting temperatures and most cannot resist acids. Graphite is used, instead of metal, to make ***electrodes*** in industrial processes that release corrosive gases. Electric furnaces that produce high temperatures use graphite.

Graphite can mark a piece of paper. The cores of lead pencils are made of graphite mixed with clay. The amount of clay controls the hardness of the pencil lead. Graphite looks like lead sulfide (galena). Because of the confusion of the two minerals (graphite and galena), pencils are called lead pencils, although they contain no lead.

VOCABULARY

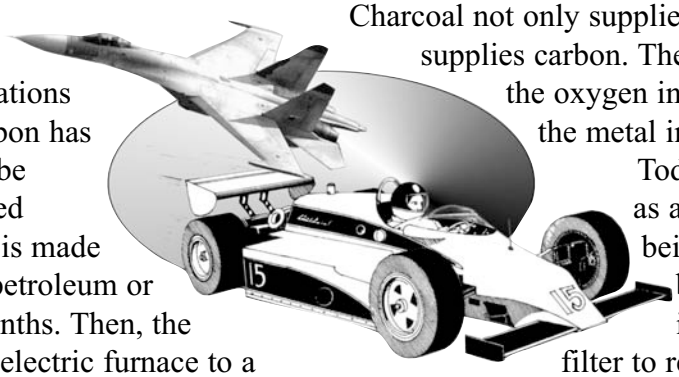
Graphite: used in lead pencils and as a lubricant
Electrodes: an electrical conductor through which electricity enters or leaves an electric battery
Destructive distillation: to convert wood, coal or other organic substances to useful products by heating and distilling the vapors given off.
Organic chemistry: the chemistry of carbon and its compounds
Radioactive element: capable of discharging subatomic particles or energy from the nucleus of its atoms

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Graphite is also used for making carbon fibers. Graphite fibers are light, strong and flexible. Products that use graphite include sports equipment such as fishing rods, golf clubs and tent poles. Carbon fibers also are used in racing cars, jet airplanes and spacecrafts.

Carbon occurs naturally as graphite in several locations around the world. Carbon has impurities, which can be eliminated by prolonged baking. Most graphite is made artificially by baking petroleum or coal tar for several months. Then, the carbon is heated in an electric furnace to a higher temperature for another month. This process drives off the impurities, and converts the carbon to graphite.



AMORPHOUS CARBON

The third allotropic form of carbon is amorphous. The arrangement of its atoms does not form a definite pattern. Diamond and graphite have crystalline structures. The atoms make a regular, three-dimensional pattern. Examples of amorphous carbon include soot, carbon black, charcoal, coke and coal.

In ancient times, carbon was known in the form of charcoal. The word carbon is from *carbo*, the Roman (Latin) name for charcoal. Carbon, in the form of wood, charcoal and coal, was the first heating fuel.

Wood is about 50 percent carbon and was the main fuel in Europe during the Middle Ages. Wood is still used to heat homes with wood-burning furnaces and fireplaces.

Wood can be made into a hotter and cleaner burning fuel by converting it to charcoal. Charcoal is made by burning wood in an oxygen poor atmosphere such as a pit filled with wood. The wood is then set afire and covered with earth. The heat drives off moisture and other products that evaporate easily. Charcoal is about 85 percent carbon.

Early metallurgists used charcoal as a hot burning fuel for smelting metal ores. Charcoal not only supplies heat but also supplies carbon. The carbon reacts with the oxygen in metal ores, leaving the metal in its free state.

Today, charcoal is used as a fuel, usually after being formed into briquettes. Charcoal is also used as a filter to remove unpleasant tastes and trace contaminants from water.

Coke, which is coal that has been baked without oxygen, is used in a manner similar to charcoal. In the modern method of making coke, several tons of coal are dropped into an oven chamber with brick walls. Gas burners outside the walls heat the ovens to almost 1,500ºC for several hours. Coke is a purer form of carbon than wood, charcoal or most coals and is about 92 percent carbon.

As the coal is baked, volatile or highly active gases are released and escape through an opening at the top of the oven. These gases are collected as secondary products. The lighter ones are gaseous hydrocarbons, similar to natural gas. The heavier gases condense to give coal tar, a dark oily substance. Gases that are intermediate in weight form a liquid that can be substituted for gasoline made from petroleum.

Substances such as wood, coal and petroleum can be separated into a variety of useful products. Wood, coal or petroleum heated in the absence of air produces gases which are collected and distilled into useful

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products such as oils and refined gases. The process of separating substances from their source by heating and then cooling is known as ***destructive distillation***.

Coal is an important fuel. People do not comprehend the natural process that causes coal. The first stage of the natural process is the production of peat.

Peat is a compact, dark brown organic material. In appearance, peat appears as a very rich soil. Peat forms in bogs from decayed organic matter. The most common elements found in plants and animals are carbon, oxygen, hydrogen and nitrogen. Those four elements account for 99 percent of the atoms found in living things. The molecules are usually complex, with a dozen or more atoms in one molecule. Vegetable matter in a bog eventually dies and is compressed together. During compression, complex molecules break apart into simpler ones. Some of these molecules are gases, such as nitrogen (N_2) and ammonia (NH_3). Oxygen and hydrogen combine to form water. Some carbon is carried away as methane (CH_4). However, most carbon atoms remain behind in the soil to form peat. The peat becomes rich in carbon.

Peat has high moisture content and is used for heating. It is dug with a long, pointed shovel and set aside in short lengths to dry. Once the moisture is eliminated, the peat contains about 60 percent carbon and burns freely. Peat is used as fireplace fuel in many countries, including Ireland and Scotland.

Chemists believe that with continued pressure, the vegetable matter changes into various forms of coal: lignite, bituminous and anthracite.

Lignite is a low-grade coal, slightly above peat in its carbon content. Lignite is usually brownish-black in color and also has high moisture content. When dried, lignite contains about 70 percent carbon.

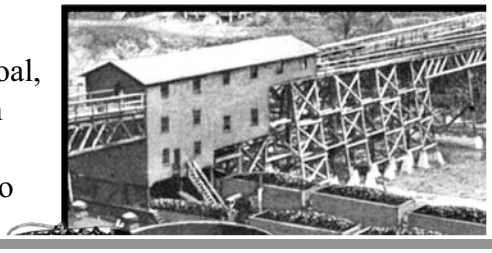
Bituminous coal is the next grade above lignite in heating value. Bituminous coal has even more carbon than lignite. Bituminous coal is a soft coal containing about 85 percent carbon and is the most abundant coal. The primary cost of bituminous coal is the expense of shipping from the mine to the location where it will be used. Coal used to generate electricity in the United States is usually bituminous coal.

The use of coal is widespread. One major activity of chemists who are employed by electric utility companies is to develop methods to make coal burn cleaner. The goal is to reduce the emission of impurities, especially sulfur and nitrogen oxide.

Anthracite coal has the highest carbon content. The best grade anthracite contains 98 percent carbon. It is a hard coal with a brilliant sheen on the black surface. Anthracite coal can be rubbed without leaving a stain on the finger. Sometimes anthracite coal has a crystalline structure and can be polished and made into jewelry. The coal of choice for home heating is the anthracite coal because it burns slowly with a pale blue flame that requires little attention.

As chemists investigated carbon, they found that all living organisms contain carbon. The study of carbon based compounds is known as ***organic chemistry*** because carbon is found in the organs of all living creatures.

Chemists also found that in combination with other elements, especially hydrogen, the number of carbon compounds is limitless. More chemists are engaged in the study of carbon compounds than all the other elements combined. In fact, the comparison is



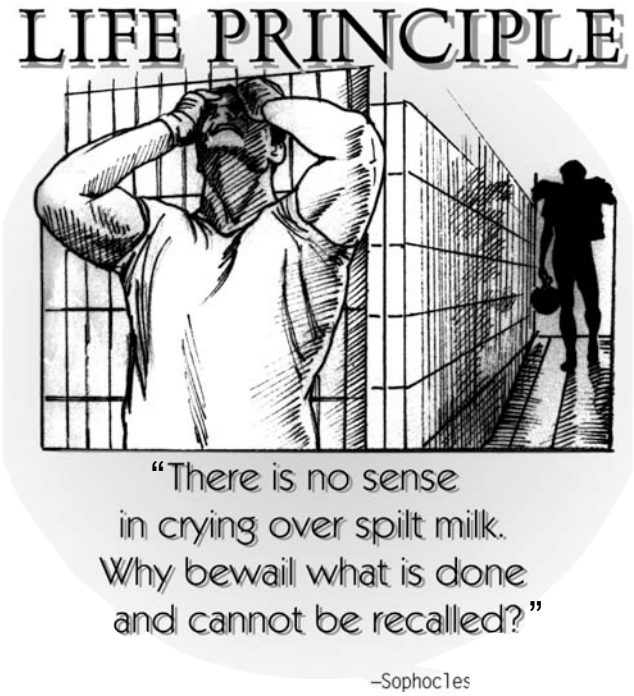
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not even close. The number of carbon based compounds is in the millions. Organic chemistry — the chemistry of carbon compounds — is by far the greater part of chemistry.

The carbon atom is found in combination with many other atoms and is used as the standard for atomic weights. In 1961, chemists adopted carbon-12 as the standard and set its weight equal to exactly 12.000. Carbon-12 is an isotope of carbon that has six neutrons and six protons. Carbon also has another isotope, carbon-13, which has seven neutrons and six protons. Because a sample of carbon will contain isotopes, the average atomic weight of carbon is 12.011. The fact that the average weight is much closer to 12.000 rather than 13.000 means that carbon-12 is far more abundant than carbon-13.

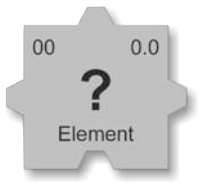
Carbon has a third isotope, carbon-14 which has eight neutrons and six protons. Carbon-14 is a ***radioactive*** element created by cosmic rays striking nitrogen atoms in the atmosphere. Its abundance in nature is too slight to contribute to the overall average weight of carbon. Archaeologists use carbon-14 for dating items from the past that were once alive such as wood, pieces of bone, or charcoal found in ancient campfires. *Archaeologists* are scientists who study ancient human cultures.

Methane (CH_4) is a simple carbon compound. Two other well-known carbon compounds are carbon dioxide (CO_2) and carbon monoxide (CO). Carbon dioxide dissolves easily in water. Carbon dioxide can be forced into greater quantities of solution when put under pressure. Cola and other soft drinks contain carbon dioxide dissolved under pressure. Remember that carbon monoxide is a cumulative poison. It attaches to hemoglobin, taking the place of oxygen, and will not let go easily. Carbon monoxide is not safe for foods or beverages.



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Integrated Physics & Chemistry



Lesson 6
Elements

Chapter 3

MEDIEVAL METALS

Section 2

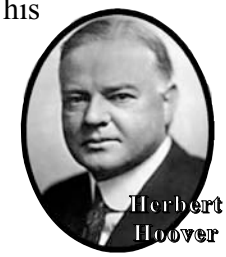
Lessons 6-10



You will learn about arsenic, antimony and bismuth in this lesson. They are found in the same vertical column of the periodic chart of the elements. Elements in the same column belong to the same chemical *family*. Usually, elements in the same family share chemical properties, especially the ability to combine with other elements.

These three metals were known during the Middle Ages and were used by the alchemists. What we know about metals and mining of the Middle Ages comes from the writings of *Georgius Agricola*, who lived in the 1500s. He was a physician who worked as the doctor in a German mining district. Georgius Agricola became interested in mining and is generally regarded as the founder of the science of mineralogy. Agricola's most important book, *De Re Metallica*, was published in 1556. His book summarized practical knowledge about mines, mining equipment and metals. He pointed out that more than seven metals were known to the ancient people.

De Re Metallica was the leading textbook on mining for two hundred years and is still being used as a reference. Herbert Hoover read the book while studying geology and mining at Stanford University in the 1890s. The only woman in the geology class at that time was Lou Henry. In 1897, she married Herbert Hoover. In 1912, Herbert and Lou Hoover translated *De Re Metallica* into English. Herbert Hoover and his wife became mining engineers whose skills and work ethics enabled them to become millionaires. They were very religious people who used their money in helping others. At the age of 40, Herbert Hoover began his political career and eventually became the 31st President of the United States.


Herbert Hoover

VOCABULARY

Semimetallic: having some characteristics of both metals and nonmetals
Specific gravity: the mass of a substance compared to the mass of an identical volume of water
Fuse: to melt

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ARSENIC

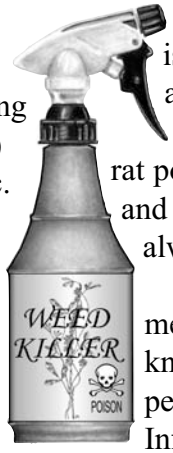
Arsenic (As) is a poisonous ***semimetallic*** element. The word arsenic is from the Greek word *arsenikon*, meaning *yellow pigment*. Arsenic trisulfide (As_2S_3) is a common yellow compound of arsenic.

The Egyptians and Greeks were familiar with arsenic. In his writings, Aristotle mentions arsenic in 350 B.C. It was probably isolated in its pure form during the Middle Ages. In the 1600s, chemists described the chemical properties of arsenic. By the time of Lavoisier in the late 1700s, arsenic was recognized as an element.

Most periodic tables of the elements list arsenic on the right-hand side with the nonmetals. Chemically, arsenic is between metals and nonmetals. Arsenic is sometimes called a metalloid or semimetallic element. In the periodic table, arsenic is below phosphorus (P), which is a nonmetal, and above antimony (Sb), which is a metal.

Arsenic has two allotropic forms, one with metallic properties and the other with nonmetallic properties. Gray arsenic has a ***specific gravity*** of 5.7, about the same as tin. Arsenic is 5.7 times as heavy as an equal volume of water. When the surface of gray arsenic is freshly exposed, it has a bright metallic luster. Metallic arsenic is used as a hardening agent in certain alloys. When a trace of arsenic is added to lead, the lead becomes harder. The nonmetallic allotropic form of arsenic is yellow and has a specific gravity of 2.0. The nonmetallic form is considerably less dense than the metallic form.

Arsenic trisulfide (As_2S_3) is used in the manufacture of glass to eliminate a green color caused by impurities of iron compounds. Arsenic appears first in the formula (As_2S_3) because it is more metallic than sulfur.

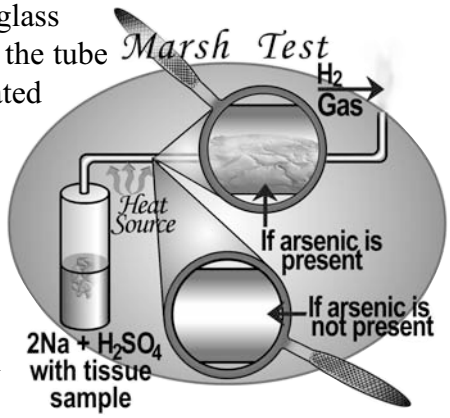


When people think of arsenic, they usually think of poison. Arsenic alone is poisonous and its compounds, such as arsenic trioxide (As_2O_3) are deadly. Arsenic trioxide is used in insecticides, rat poison and weed killers. Washing fruit and vegetables before you eat them is always an excellent idea.

One field of chemistry that uses medical, dental, biological and chemical knowledge to investigate the causes of a person's death is *forensic* science. Information gained by forensic science is used in court proceedings. A chemist who practices forensic science must be certain of his results.

Forensic science uses the *Marsh test* if poisoning by arsenic is suspected. The developer of this test was James Marsh (1794-1846) an English chemist. For a time, James Marsh worked as an assistant to the great Michael Faraday at the Royal Institute in London. James Marsh is best known, however, for developing the Marsh test to reveal if arsenic is present in human tissue.

A small sample of the deceased person's tissue is required. The tissue is mixed with an acid and a metal. The reaction generates hydrogen gas. If the metal sodium is mixed with sulfuric acid, the result is sodium sulfate and hydrogen gas: $2Na + H_2SO_4 \rightarrow Na_2SO_4 + H_2$. Any arsenic present is converted to arsine (AsH_3), which is also a gas. The hydrogen gas and AsH_3 gas are passed through a glass tube. A section of the tube is heated. The heated AsH_3 breaks into arsenic and hydrogen. The arsenic deposits on the glass tube as a gray patch. Such a gray patch



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proves the presence of arsenic. The Marsh test is very sensitive. As little as 1/10 of a milligram (1/10,000th of a gram) of arsenic can be detected.

ANTIMONY

Antimony (Sb) is a brittle, silver-white metal with a bright metallic luster and a specific gravity of 6.7, making it between tin and iron in density.

The word *antimony* is from the Greek words *anti-* and *-monos* meaning "opposed to solitude." This is a reference to the fact that antimony combines readily with other elements. Like arsenic, antimony has been known and used for thousands of years. It did not make an impression on the minds of ancient people as a separate substance. The ancient people often confused antimony with other elements such as bismuth, tin and lead.

The chemical symbol for antimony is *Sb* from the Latin word *stibium*, meaning *mark*. The antimony mineral, stibnite, was used as a black eyebrow marker in Biblical times. The Egyptians used powdered stibnite as eye shadow to emphasize the size of their eyes.



Metallic antimony is an extremely brittle, bluish-white metal with a flaky, crystalline texture. Some of its compounds are nearly as poisonous as the compounds of arsenic. Although antimony may be found free in nature, its primary source is stibnite, antimony trisulfide (Sb_2S_3). Antimony is a soft substance with a hardness of 2 on the Mohs' Scale.

Antimony has sufficient metallic properties to be classified as a metal. It is used in an alloy with other metals such as lead in electric batteries and with tin and lead to make printing type metal.

When molten antimony cools to a solid, the exceptional property expands as it hardens. Most metals contract as they cool and their surface becomes filled with fine wrinkles. However, antimony expands as it hardens. When metal for printing type is made of antimony alloy, the type will cool and maintain a sharp and distinct face.

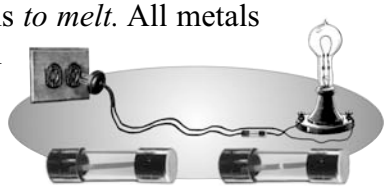
Antimony is also used in babbitt metal, an alloy used to line bearings to reduce friction. The alloy was developed at a time when steam engines were becoming important to industry. Babbitt metal contains 89 parts tin with 9 parts antimony and 2 parts copper. This mixture forms hard particles in a softer alloy. As babbitt is used, the soft part wears slightly below the hard particles and provides a path for lubricants.

Babbitt metal is named after Isaac Babbitt, 1799-1862, an American inventor who developed the alloy in 1839. Babbitt metal was considered so important to the progress of the country's industry that Congress awarded Isaac Babbitt $20,000, an immense sum at that time.

BISMUTH

Bismuth (Bi), is a silvery white, brittle metal that was often confused with tin, lead and zinc. Bismuth is not abundant and is as rare as silver.

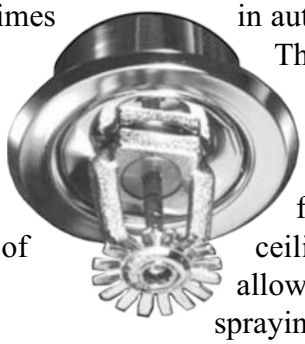
Bismuth melts at 271ºC, which is 171ºC above the boiling point of water. By mixing bismuth with other metals, the melting temperature can be lowered to 66ºC (151ºF). That is well below the boiling temperature of water. Metals and metal alloys that melt at a low temperature are called fusible alloys. The word ***fuse*** means *to melt.* All metals melt at a certain temperature, but the word *fusible*



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usually refers to metals that melt between room temperature and the boiling point of water.

A bismuth alloy that melts at low temperature is used in fuses that protect electric circuits from overheating. Sometimes a short circuit occurs. When an electric circuit *short circuits*, the electricity suddenly flows in a way that may cause the wires to melt or start a fire. The solution is to use a fuse. The circuit runs through a fuse containing a short section of low melting bismuth alloy wire. Should there be a short in the circuit, the excess heat causes the bismuth alloy to melt, preventing damage to the wiring and reducing the risk of a fire.



Low melting alloys are found as plugs in automatic sprinkler systems. These overhead sprinklers are connected to waterlines. The bismuth plug prevents water from flowing. In the case of fire, the hot air rises to the ceiling and melts the plug, allowing the sprinklers to begin spraying water on the fire.

Life Principle



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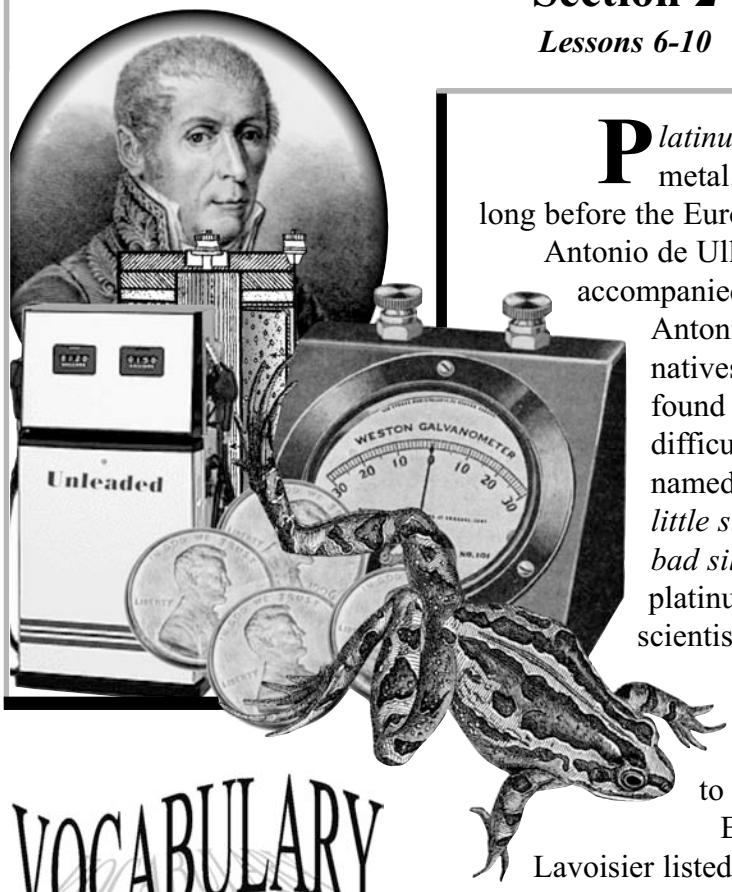
Chapter 3

Lesson 7
Elements

PLATINUM AND ZINC

Section 2

Lessons 6-10



P*latinum* (Pt) is a beautiful, silvery-white metal. The natives of South America used it long before the European explorers arrived. In 1735, Antonio de Ulloa, a Spanish naval officer and scientist, accompanied a French expedition to South America. Antonio de Ulloa learned of platinum from the natives who were refining gold. The natives found the metal a nuisance because it was difficult to separate from gold. Platinum was named from the Spanish word *platino* meaning *little silver*. In the context of mining, it means *bad silver*. Antonio de Ulloa reported platinum's properties to the other European scientists. Antonio de Ulloa went on to become an Admiral and served as governor of Louisiana while the territory was part of Spain. During this time he continued to pioneer discoveries in science.

By the end of the 1700s, Antoine Lavoisier listed platinum as a separate element. In 1822, a source for the metal was found in the Ural Mountains in Russia. It became more common in chemical laboratories. Platinum is more expensive than gold. It is found elsewhere in the world, including Canada, but Russia is still the best-known source of the metal.

Pure platinum has a Mohs' hardness of 4.3 and can be scratched with a knife blade. It is often mixed with other metals to make a tougher alloy. Platinum has a specific gravity of 21.45. If equal volumes of platinum and water were measured out, the platinum would weigh 21.45 times as much. Platinum is twice as dense as lead and even more dense than gold.

Platinum will resist the corrosion of most acids. Nitric acid or hydrochloric acid acting alone has only slight effects upon platinum. However, when one part nitric acid (HNO_3) is mixed with three parts hydrochloric acid (HCl), the mixture

VOCABULARY

Catalyst: a substance that increases the rate of a chemical reaction without being consumed in the process, platinum is a well-known catalyst
Galvanizing: to coat iron or steel with zinc to resist rust
Galvanism: an early name for direct electric current, named after Luigi Galvani
Volt: an electrical unit in the metric system that measures electrical potential energy, named after Alessandro Volta

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will dissolve gold and other metals, including platinum. The acid mixture is known as *aqua regia*.

Platinum has a high melting temperature and is relatively inert. (Recall that *inert* means *unlikely to combine with other elements.*) Chemists find those properties useful. Platinum is used to make laboratory equipment for processing highly corrosive elements such as fluorine. Platinum is so inert the human body does not try to reject it. Medical researchers make replacement parts such as heart valves and heart pacemakers from platinum.



Platinum's best-known property is its action as a ***catalyst***. A catalyst is a substance that causes chemical reactions to go faster, yet the catalyst itself is not affected. When hydrogen gas is released, it has a very slight tendency to react with oxygen in the air to form water. At ordinary temperatures, the reaction takes place at an unnoticeable rate. However, if the stream of escaping hydrogen gas crosses a strip of platinum, the hydrogen will burst into flames as it rapidly combines with the oxygen in the air.

Fuel cells are lightweight devices for generating electricity. The fuel cells were used on the Apollo moon missions. Hydrogen and oxygen were mixed to generate electricity and produce water. To cause the reaction to go at a faster rate, the electrodes were coated with platinum. Platinum is not consumed during the reaction. Although platinum is expensive, it continues to perform its function without any more cost after the initial purchase.

Automobiles are equipped with *catalytic converters*. Combustion or burning of automobile fuel should produce carbon dioxide and water. Often the result is incomplete combustion that results in carbon monoxide and other pollutants. The exhaust of an automobile engine passes through a catalytic converter. The converter contains small beads that are coated with platinum. The metal causes a chemical reaction that completes the process of combustion. Carbon monoxide and unburned hydrocarbons react with oxygen to produce carbon dioxide and water.

Some metals hinder the catalytic effect of platinum. One such metal is lead. For that reason, gasoline containing lead cannot be used in automobiles with catalytic converters.

A catalyst can make a reaction take place faster, but if two elements do not normally combine, the catalyst cannot make them react. A catalyst can only make an existing reaction occur more rapidly.

ZINC

Zinc (Zn) is a metallic element with a slight bluish cast to its white color. Zinc was recognized as a separate metal in the 1500s. The first use of zinc was in brass, an alloy of copper and zinc. The brass alloy is harder and stronger than either metal alone.

Copper-zinc alloys are also colored differently than either metal alone. Mixing 80 percent copper with 20 percent zinc produces a color very similar to gold. This brass mixture is used on military uniforms of higher-ranking officers. The commanding officers in the military are sometimes called the "top brass." This is a reference to their copper-zinc buttons.

The United States one-cent coin, the penny, was originally made of pure copper. After the Civil War, zinc was added to produce a harder alloy. The penny coin became 95 percent copper, 5 percent zinc and a slight trace of tin. Copper is more expensive than zinc. By the 1980s, the copper in a penny was worth slightly more

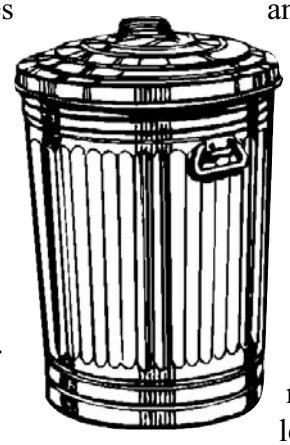
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than one cent. The mint became concerned that people would melt down the pennies to recover the copper and sell the penny at a profit. The mint decided to change the composition of the penny. In 1982, they began making pennies almost entirely of zinc with a thin coating of copper. The coin was 97.5 percent zinc and 2.5 percent copper. Because zinc is less costly than copper, the coin remained under one-cent in value.

This was not the first time that the copper content of one-cent coins was reduced. During World War II, copper became important for manufacturing shell casings and electrical wires. The United States Mint searched for a substitute to free the copper in coins for other purposes. The mint began making pennies of zinc-coated steel. Low-grade steel formed the base. A layer of zinc coating only 5/1,000 (0.005) inches thick coated the steel. The zinc coating was put on to prevent the steel from rusting.



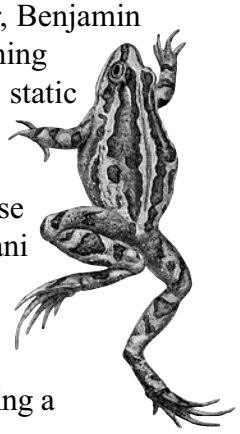
Today, large quantities of zinc are used to coat sheets of iron and steel to prevent rust. Zinc resists the action of water and oxygen. Metal fence posts and wire, highway guardrails and culverts are protected with a thin coating of zinc. Plating iron or steel with a thin layer of zinc is known as ***galvanizing***. This process helps to protect the iron from corrosion.



Zinc melts at a lower temperature than iron or steel. The metal to be coated is dipped into molten or melted zinc. The metal can be sprayed with molten zinc, or fine zinc powder can be dusted on the article to be coated. Then, both are heated for several hours, allowing the zinc to melt. Many barns and other buildings have galvanized "tin" roofs. The roofs are actually corrugated sheets of steel coated with zinc. *Corrugated* means *shaped into grooves to add strength.*

The term galvanized iron originally applied to zinc that had been deposited electrically. ***Galvanism*** was an early name for electricity. In the 1790s, Luigi Galvani, an Italian medical scientist, made an unusual discovery. While Galvani was dissecting a dead frog, the frog's leg jumped when touched with a scalpel. Galvani investigated and found that the scalpel had a slight static electric charge. Luigi Galvani showed that static electricity would cause muscles of dead animals to twitch.

A few years earlier, Benjamin Franklin proved that lightning had the same properties as static electricity. Luigi Galvani wondered if a nearby lightning strike would cause the legs to jump. As Galvani hung the frog legs against an iron grill outside his laboratory window the legs began to twitch during a thunderstorm.

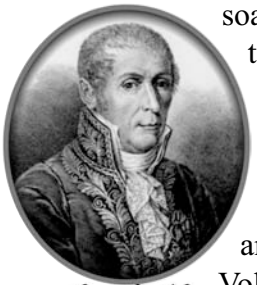


The legs also twitched at other times, even without lightning. The legs were held in place by brass hooks. When the leg touched both the brass hook and iron metal, it jumped as if touched by an electric spark.

More experiments uncovered a mystery. When Luigi Galvani touched the legs of a dead frog with two different metals, such as copper and zinc, the legs would jump. Somehow, the combination of frog legs and two metals generated electricity. Luigi Galvani could not explain this but reported his results.

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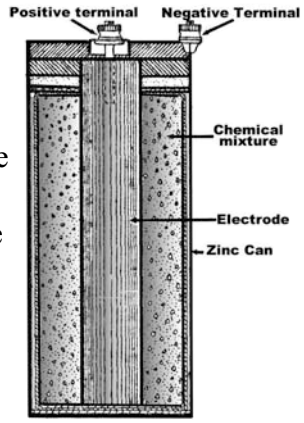
Another scientist, Alessandro Volta, replaced the frog legs with a piece of cloth soaked in salt. When he touched the cloth with two different metals, such as copper and zinc, a slight electric current flowed. Chemicals alone produced an electric current. From Volta experiments, he made the first electric batteries. The ***volt*** is named in honor of Alessandro Volta.


Alessandro Volta

People remembered Luigi Galvani, also. They began using Galvani's name as a figure of speech. When a person is "galvanized into action," the person reacts quickly like the frogs legs shocked by an electric spark. Scientists named an instrument designed to measure electric current after Galvani: a *galvanometer*. Galvanized iron originally received that name because the zinc was applied by electricity.



Another use for zinc is in *dry cells*, commonly called batteries. The dry cell of a flashlight battery is a container made of zinc and filled with chemicals. The can made of zinc is more than merely a container. The zinc takes part in the chemical reaction that produces the electricity. During a chemical reaction that produces electricity, gases such as hydrogen and oxygen are produced. The dry cell has chemicals to combine with the gases and to keep the dry cell from rupturing and leaking.



At normal temperatures, pure zinc is brittle. When heated above the boiling point of water, 100ºC, zinc becomes malleable and ductile. As zinc is being heated near its melting point at 420ºC, it becomes brittle again. These changes in zinc's physical properties show that it has allotropic forms with changing temperatures. Tin, sulfur, carbon and other elements also have allotropic forms.

Life Principle

"Imagination gives wings to our thoughts, but we always need decisive experimental proof."

—Louis Pasteur

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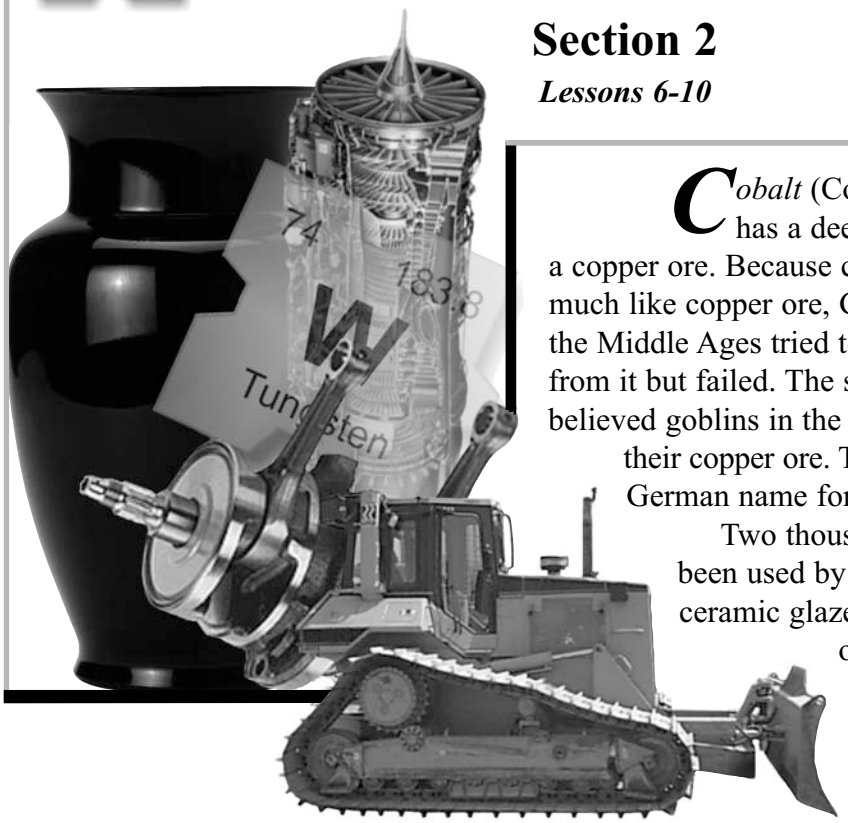
Chapter 3

Lesson 8
Elements

Section 2

Lessons 6-10

COBALT, NICKEL, MANGANESE, MOLYBDENUM AND TUNGSTEN



Cobalt (Co) is a metallic element. Its ore has a deep blue color, similar to azurite, a copper ore. Because cobalt looked so much like copper ore, German miners of the Middle Ages tried to extract copper from it but failed. The superstitious miners believed goblins in the Earth had done something to their copper ore. The miners called it *cobalt*, the German name for goblin.

Two thousand years earlier cobalt had been used by Egyptians in pigments and ceramic glazes. Items found in the burial site of King Tutankhamen included beautiful blue vases. Whatever process the Egyptians used was lost and not discovered again until the Middle Ages by craftsmen in Venice. The government of Venice tried to keep the process secret. Finally, glassmakers learned to add the cobalt ore to the mixture to give the glass a beautiful, deep blue color, known as *cobalt blue*.

Chemists investigated cobalt and found that copper-smelting techniques were not vigorous enough to free other metals from it. Stronger methods, such as those for smelting iron, had to be used. In smelting iron, a fuel with a high carbon content such as charcoal or coke is used, enabling the fuel to burn hotter. The carbon in charcoal also combines with oxygen in the ore to free the metal. Removing oxygen from an ore is known as *reducing* the ore. Sometimes limestone is added to the mix as an additional source of carbon to combine with oxygen. The metal from cobalt ore has properties similar to those of iron. It is a little heavier than iron and a little harder. Like iron, cobalt has magnetic properties.

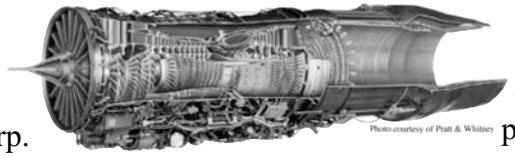
VOCABULARY

Damping: a property of manganese resulting in the elimination of vibrations
Filament: the fine wire that glows in an electric light bulb
Wolfram: another name for tungsten

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Cobalt is used primarily with alloys. Although cobalt is less magnetic than iron, cobalt in combination with iron, nickel and aluminum makes alnico, a powerful permanent magnet. Magnetic metals lose their magnetic properties when heated. Cobalt remains magnetic at a higher temperature than other metals.

Most metals soften as they are heated. Cobalt alloys are noted for their strength even at high temperatures. Friction heats the edge of cutting tools, but those made of cobalt alloy remain sharp. Jet engines and gas turbine engines use cobalt alloys because of their resistance to heat.

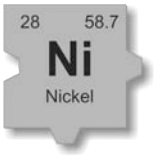

Photo courtesy of Pratt & Whitney

Cobalt has another interesting property. Certain cobalt compounds change color depending upon the temperature or amount of water present. A chemist who lived in the 1500s amazed his friends by a painting he made. The painting looked like a winter snow scene with bare tree limbs and snow covered mountains. Then, before their eyes, the trees grew green leaves, and the mountains turned green with grass. The chemist warmed the canvas painting from the back and cobalt compounds in the paint pigment changed color.

Cobalt chloride ($CoCl_2$) combined with water makes a pale pink mixture. More than a hundred years ago, the cobalt chloride mixture was used as invisible ink. A spy would use the mixture to transmit messages during the American Civil War. The spy wrote the message on a sheet of paper. After the invisible ink dried, the spy wrote an ordinary message on the same paper with regular ink. The person who received the secret message held the paper over a flame. The heat dried out the paper and caused the pale pink writing to change to a dark blue and become visible.

A *hygrometer* is an instrument used to measure moisture in the air. The amount of moisture in the air is the *humidity*. In dry weather, the humidity is low. In damp weather, the humidity is high. Paper covered with a solution of cobalt chloride can be used as a crude hygrometer. In humid weather, the strip remains a pale pink. When the weather turns dryer, usually an indication of fairer weather, the strip of paper turns blue.

NICKEL

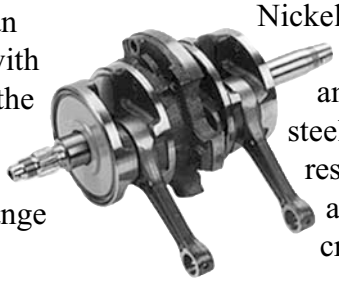


Nickel (Ni) is a metallic element that can be highly polished. Its chemical and physical properties are similar to iron. Nickel is a little harder and a little denser than iron. Nickel also has magnetic properties.

Two common ores of copper are azurite, which is blue, and malachite, which is green. German miners confused the blue cobalt ore with azurite and a green nickel ore with malachite. When the miners failed to extract copper from the green ore, they gave it the name *demon's copper*. The German word for demon is nickel.

Nickel, cobalt and iron are used to color glass. Glass with iron in it has a brown or red color. When cobalt is added to the mix, it colors the glass a blue tint. Nickel gives the glass a green color.

Because nickel resists corrosion and remains shiny, it is used in jewelry and coins. The United States five-cent piece, the nickel, is 75 percent copper with 25 percent nickel. As an alloy, slight amounts of nickel can make vast changes in the durability of iron.



Nickel steel contains less than five percent nickel, but that small amount greatly improves the steel's strength and corrosion resistance. Nickel steel is found in automobile parts such as axles, crankshafts and engine parts.

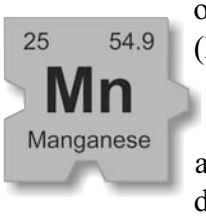
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Most surgical instruments are stainless steel, an alloy of nickel, steel and chromium. Inexpensive tableware is made of stainless steel. Like zinc, nickel can be electroplated on other metals to protect their surfaces from corrosion. It is also plated on softer metals to keep them from being scratched.

Many metals react to a strong magnetic field but lose their magnetism once they are outside the magnetic field. Ferromagnetic materials can be made magnetic and keep their magnetism after the source of the magnetism is removed. They become permanent magnets. The only ferromagnetic elements are iron, cobalt and nickel.

MANGANESE

Manganese (Mn) is a metallic element used for a variety of alloys. The most common ore of manganese is pyrolusite or manganese dioxide (MnO_2). This ore is used in glassmaking, not to color glass, but to make it clear and unstained. Silica, silicon dioxide (SiO_2), is the primary ingredient of glass with other compounds such as sodium silicate ($NaSiO_2$). Impurities in silica give the glass a green color. Since the time of the Romans two thousand years ago, glassmakers have added pyrolusite to their mix to eliminate the green color. As the glass ages, manganese reacts with sodium and oxygen in the glass to form sodium permanganate ($NaMnO_4$). The glass becomes colored again with a beautiful violet tint. People who collect antique glass seek out glassware with this distinctive shading.



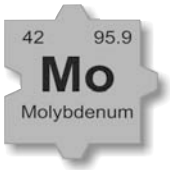
Manganese alloys have two unusual properties. Many metals ring when struck; the metal vibrates back and forth causing a musical note. Manganese steel is the opposite. It quickly absorbs shocks without vibrating, a property known as ***damping***. A bell made of manganese steel would make a dull thump when struck rather than a clear bell note. The damping effect is useful to make machines run quieter. Locomotive wheels, rail joints and other moving parts are made of manganese steel so they will operate more quietly.

The second property is the way the manganese alloys are work hardened. When put under a load, the manganese alloys become harder. Heavy equipment such as caterpillar tracks, crushing equipment and bearings holding heavy loads become harder as they are used. Safes are made of steel containing about 12 percent manganese.



MOLYBDENUM

Molybdenum (Mo) is another metallic element whose chief use is in alloys. The fabled Samurai sword is an alloy of molybdenum. Usually, when the hardness of an alloy increases, it also becomes more brittle. A sword that shatters in battle would not be very useful. When molybdenum is added to steel, the alloy is both hard and ductile. A knife blade of molybdenum steel retains its cutting edge longer than a blade of common carbon steel and is not as likely to shatter.



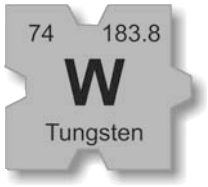
Most metals become brittle with lower temperatures. At temperatures of 200ºC below zero, steel becomes as fragile as glass. Molybdenum steel alloy remains strong at cold temperatures without becoming brittle. Molybdenum is added to steel to make containers for very cold liquids such as liquid nitrogen.

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The properties of alloys are very sensitive to the amount of metals that make the mixture. The addition of another metal to an alloy can cause great changes in its properties. Pure molybdenum is both ductile and malleable. It can be drawn into a wire or worked into shape. The slightest amount of an impurity, such as carbon, makes molybdenum brittle. Many ultra-high strength steels contain only 0.25 percent molybdenum. The properties of alloys, whether containing molybdenum or other metals, can radically change with even the slightest modification of composition.

TUNGSTEN

Tungsten (W) has the highest melting point of any metal. Carbon, a nonmetal, has the highest melting point of all elements. Tungsten is second with a melting point of 3,410ºC. Tungsten is used in places where a metal with a high melting point is needed. One such application is in the filament of electric light bulbs. The light from an incandescent lamp is produced as electricity causes the tungsten ***filament*** to glow white-hot.

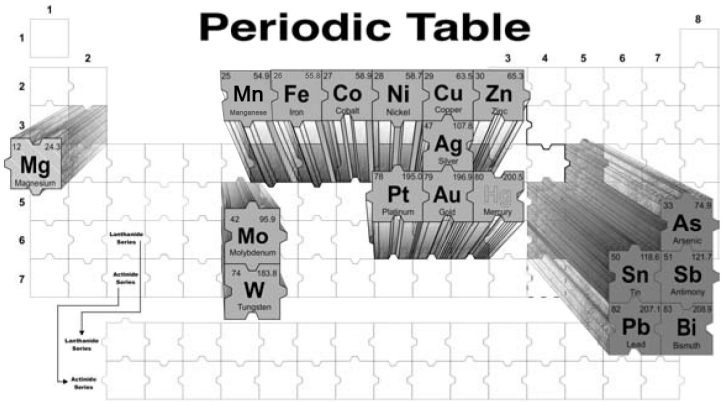


When Thomas A. Edison invented the electric light in 1879, he used carbon for the filament. Carbon was unsatisfactory because the carbon filament was difficult to manufacture. A replacement required two properties. The filament needed to be able to withstand high temperatures and conduct electricity. If an electric current is forced through the conductor against a resistance, the temperature of the conductor will rise. If the conductor remains a solid, it will glow white-hot. In 1906, tungsten was found to be the best choice for bulb filaments.

Although tungsten did not melt, the filaments did not last as long as Thomas A. Edison expected. Experiments showed that atoms near the surface of the filament evaporated because of the high temperature, although the metal was below its melting point. Edison's solution was to put an inert gas into the light bulb. The gas exerts pressure to keep the metal from boiling away. Through this process, the filament is less likely to burn out. At first, nitrogen was used to fill the light bulbs. The gas used today is argon.

In the United States and Britain, tungsten is known by that name. In the rest of the world, it is known as ***wolfram***. The name wolfram explains why it has the chemical symbol, *W*.

This completes a survey of the 17 metallic elements that were known when Lavoisier compiled his list of elements late in the 1700s. The metallic elements are the seven ancient metals (gold, silver, copper, iron, tin, lead and mercury), the five elements found during the Middle Ages (arsenic, antimony, bismuth, platinum and zinc) and the five found between the time of Robert Boyle and Lavoisier (cobalt, nickel, manganese, molybdenum and tungsten.) Here is the review of their chemical symbols. Gold (Au), silver (Ag), copper (Cu), iron (Fe), tin (Sn), lead (Pb), mercury (Hg), arsenic (As), antimony (Sb), bismuth (Bi), platinum (Pt),



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zinc (Zn), cobalt (Co), nickel (Ni), manganese (Mn), molybdenum (Mo) and tungsten (W). These letter symbols may seem too complex to remember, but people interested in how life relates to the Earth find great joy in understanding the role of metallic elements.



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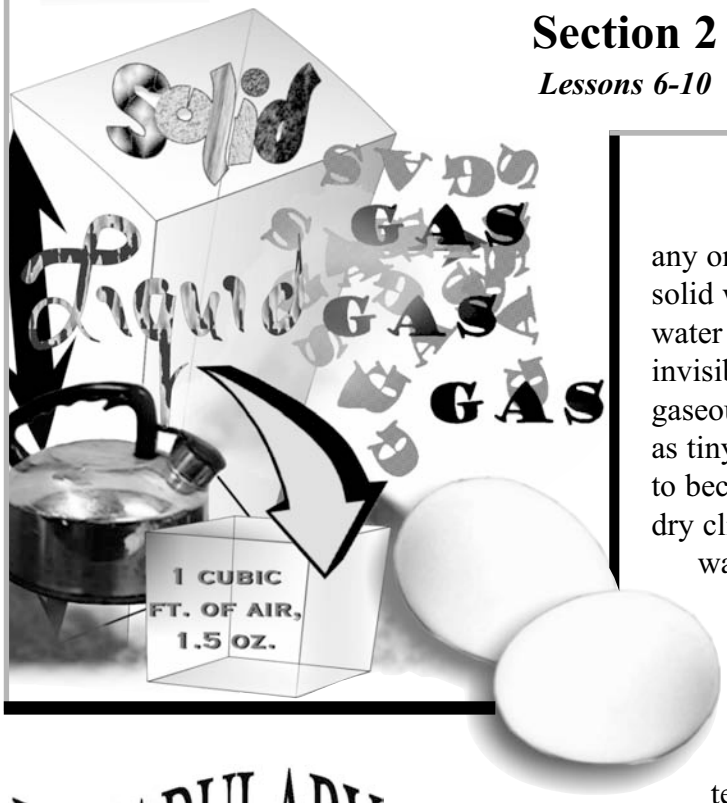
Lesson 9
Atmosphere

Chapter 3

GASES AND THE ATMOSPHERE

Section 2

Lessons 6-10



The three states of matter are ***solid***, ***liquid*** and ***gas***. Water can be in any one of the three states. Snow and ice are solid water. Rain, rivers and the droplets of water that make clouds are liquid water. The invisible vapor that comes from a teakettle is gaseous water. Once the water becomes visible as tiny droplets, the steam has cooled enough to become liquid again. Except in extremely dry climates, Earth's atmosphere contains water in the gaseous state. Water vapor becomes visible as clouds or fog when ***condensing*** to the liquid phase.

When heated to its *melting temperature*, a solid changes into a liquid. For water as ice, the melting temperature is 0ºC (32ºF). Most metals melt above 100ºC. Lead becomes a liquid at 328°C (662°F), and tungsten becomes a liquid at about 3,410°C (6170°F). The melting temperature is also the *freezing temperature* – the temperature at which a liquid becomes a solid. Mercury is a liquid at ordinary room temperature and becomes a solid when cooled below –40ºC (that temperature is also –40ºF).

When heated to its *boiling temperature*, a liquid changes into a gas. For water, the boiling temperature is 100ºC (212ºF). The boiling temperature is also the *condensation temperature*, the temperature at which a gas becomes a liquid. As steam is cooled below 100ºC, the steam changes back to liquid water. Many gases must be made especially cold for them to condense. For instance, oxygen remains a gas until it is chilled to –183ºC (-297ºF), then it changes to a liquid. Nitrogen, as a gas,



VOCABULARY

Solid: a state of matter in which a substance has a definite shape and volume
Liquid: a state of matter in which a substance has a definite volume but not a definite shape
Gas: a state of matter in which a substance has neither a definite volume nor a definite shape, a gas readily expands or contracts because of changes in pressure and temperature
Condense: to change from a gas or vapor to a liquid

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changes to a liquid at –196ºC (-321ºF). Helium holds the record for staying a gas. About –269°C (-452°F), less than four degrees above absolute zero, the helium finally condenses to a liquid.

Except for mercury and cesium, most metals are solids at room temperature. The metals must be heated to several hundred degrees to become liquids. They must be made hotter still to change to a gas. Molten lead boils and becomes a gas at 1,740ºC (3,164ºF). It is difficult to think of iron as being a gas. Iron will change to a gas by heating it to 2,750ºC (almost 5,000ºF). Imagine a planet so close to the Sun that its daytime temperature is above 2,750º Celsius. The iron would be present as a gas. At night, if the temperature fell below 2,750ºC, the iron vapor would condense and fall as molten iron.

All elements, including metals, change to gases at high enough temperatures.

VOCABULARY

Atmosphere: the mixture of gases that surrounds some planets, including Earth
Troposphere: the lowest layer of Earth's atmosphere extending from sea level to 7.5 miles, the layer that supports weather
Stratosphere: the middle layer of the earth's atmosphere extending from 7.5 miles to 55 miles contains an increased amount of ozone
Diatomic: a molecule made of two atoms
Ionosphere: the outermost layer of the earth's atmosphere, extending from 55 miles to 300 miles
Ion: a particle with an electric charge, usually caused by an atom or molecule gaining or losing one or more electrons
Aurora: a pattern of differently colored lights that are sometimes seen in the night sky

For a substance to be a gas, it must be a gas at standard temperature and standard pressure. *Standard temperature* is 0ºC (32ºF) and *standard atmospheric pressure* is the average atmospheric pressure at sea level.

Air pressure can change the temperature at which a liquid boils. As atoms and molecules move more quickly from increased temperature, these molecules tend to break free at the surface of the liquid. If the air pressure increases, however, this additional pressure tends to hold the molecules in the liquid state and prevents their escape. Higher pressure increases the boiling temperature. Atmospheric pressure increases as a person goes below sea level. At a distance of one quarter-mile down in a mineshaft, the boiling point of water increases from 212ºF to 214ºF.

Reduced pressure causes a reduced boiling temperature. The reduced pressure allows molecules of a liquid to break free more readily. Ordinary activities such as boiling eggs or baking cakes can be influenced by lower pressure. Cooking a soft-boiled egg at sea level takes about three minutes. The water boils at 212ºF. In the mountains, at a height of one mile above sea level, the water boils at 203ºF. An egg must be boiled for three minutes, 45 seconds to be fully cooked.



Because water boils more readily at lower pressure, recipes have to be adjusted to provide more water. Instructions on boxes of cake mix call for an extra amount of water if the baking is done in the mountains.

Some compounds will boil merely by lowering the air pressure. When a container of water is placed in a chamber and the air is pumped out, the water will boil at room temperature in a vacuum.

At standard temperature and pressure, there are 11 gaseous elements. All 11 are

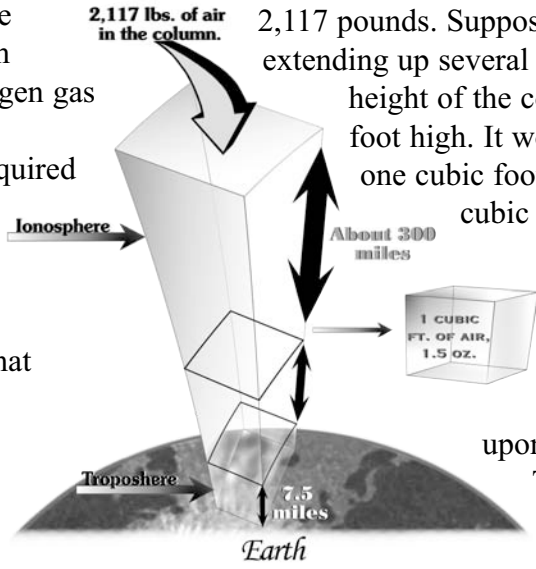
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nonmetals. Six of them belong to the *helium family*, also known as the inert gases. Because of their properties, the six helium family gases escaped notice, until the late 1800s. The six members of this family of gases are helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe) and radon (Rn).

The five remaining gaseous elements are hydrogen (H), oxygen (O), nitrogen (N), chlorine (Cl) and fluorine (F).

ATMOSPHERE

The ***atmosphere*** is a gaseous layer surrounding Earth. Air molecules are held in place by the force of Earth's gravity. One exception is hydrogen. The molecules of a gas are in motion. These molecules move very briskly, but most gases in Earth's atmosphere do not have enough velocity to escape from Earth. The molecules of hydrogen gas soar rapidly, reaching escape velocity, which is the speed required to escape from Earth's gravitational pull. For that reason, hydrogen is constantly leaking into space.



The three main gases that make Earth's atmosphere are nitrogen, oxygen and argon. These three gases account for 99.9 percent of the composition of the atmosphere. Other gases such as carbon dioxide, water vapor, ozone and hydrogen are found in trace amounts.

The study of gases began with a study of Earth's atmosphere. The atmosphere has weight. Air weighs about 1.5 ounces per cubic foot. A large living room is about 12 feet wide by 16 feet long with a height from floor to ceiling of 8 feet. Suppose a person who weighs 140 pounds is in a room of that size. The air in the room is heavier than the 140 pound person. First, calculate the number of cubic feet: 12 ft * 16 ft * 8 ft = 1,536 ft^3. Next, multiply by 1.5 oz/ft^3: 1,536 ft^3 * 1.5 oz/ft^3 = 2,304 oz. Finally, convert ounces to pounds by dividing 2,304 oz by 16 oz/lb: 2304 oz / (16 oz/lb) = 144 pounds. Using metric units of meter and kilogram, the air in a box one meter on a side has a mass of 1.25 kilograms.

There is a difference between *atmospheric pressure* and weight of air. Atmospheric pressure is the total weight of all the air above a particular spot on Earth. The average air pressure is about 2,117 pounds per square foot. Imagine a column of air starting on the surface of Earth and extending to the top of the atmosphere. The total weight of the air in the column would be the air pressure. If the column is one-foot square, then all of the air in that column weighs 2,117 pounds. Suppose that instead of extending up several hundred miles, the height of the column was only one foot high. It would have a volume of one cubic foot and the air in that cubic foot would weigh 1.5 ounces.

Like all gases, air can be compressed. The air at the surface of Earth is pressed upon by the air above it. The air at the surface of Earth is denser than air higher up because of this increased pressure.

The lowest level of the atmosphere is the ***troposphere***. The word *tropos-* means, "changing." Changing weather conditions occur within this layer. Most clouds are in the troposphere. The tallest mountains, the mountains known as K2 and Mt. Everest, reach a little less than six miles into the air. The troposphere ends at a height of 7.5 miles. Commercial jetliners fly just at the top of the troposphere.

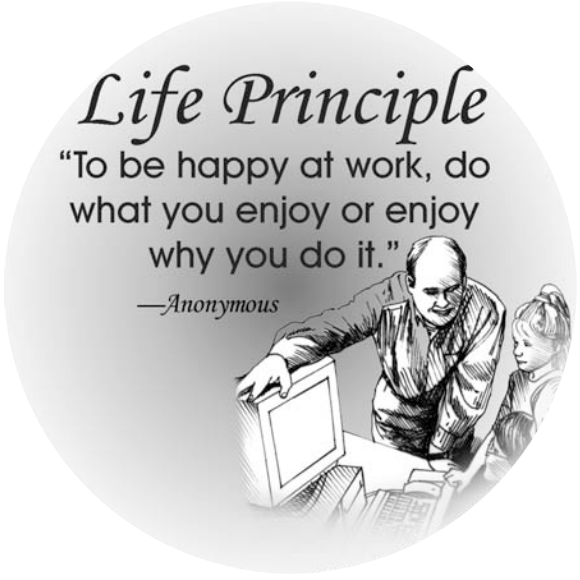
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The next layer is the ***stratosphere***. It extends from 7.5 miles to 55 miles. Military and research aircraft can fly in the stratosphere. Some thunderheads can extend into the stratosphere. Normally, however, not enough water vapor is present in the stratosphere to form rain clouds. Ozone is found in the stratosphere. Normal oxygen gas, known as ***diatomic*** oxygen, has two oxygen atoms in each molecule, expressed as O_2. Ozone is an allotropic form of oxygen with three atoms in each molecule, expressed as O_3. Ozone is a pale blue gas with a strong smell. An electric spark produces ozone from normal oxygen molecules, as do lightning strikes. A person around an electric motor can sometimes smell ozone. Some people may detect an approaching lightning storm by the smell of ozone. The word *ozone* is from a Greek word meaning *to smell*. Ozone in the stratosphere is formed from diatomic oxygen molecules by ultraviolet radiation. Ozone is believed to have a role in filtering out some of the harmful ultraviolet rays that are always present in sunlight.

The ***ionosphere*** is the outermost major division of Earth's atmosphere and is the layer from 55 miles to about 300 miles. Earth's atmosphere is constantly being bombarded with tiny rocks or meteorites from outer space. The rocks slam into Earth's atmosphere at tremendous speeds. When the rocks reach the lower edge of the ionosphere, they begin to glow from the heat generated by the friction of their passage. Most rocks burn up harmlessly.

An ***ion*** is an electrically charged particle. The gases in the ionosphere are exposed to solar radiation and become electrically charged. One of the charged layers within the ionosphere reflects long-range radio waves. The ionosphere is also the region in which the ***aurora*** occurs. The Earth's magnetic field captures charged particles thrust from the Sun's surface. The particles spiral in toward the North Pole and interact with the molecules in the upper regions of the ionosphere. The released energy produces the delicate and beautiful northern lights. The same light display is visible at the South Pole, too.

The outer reaches of the atmosphere are very thin and low in density. Although the ionosphere ends at an elevation of 300 miles, the atmosphere has no abrupt end. Having no definite upper boundary, the atmosphere grows less and less dense, until it fades into the near emptiness of space.



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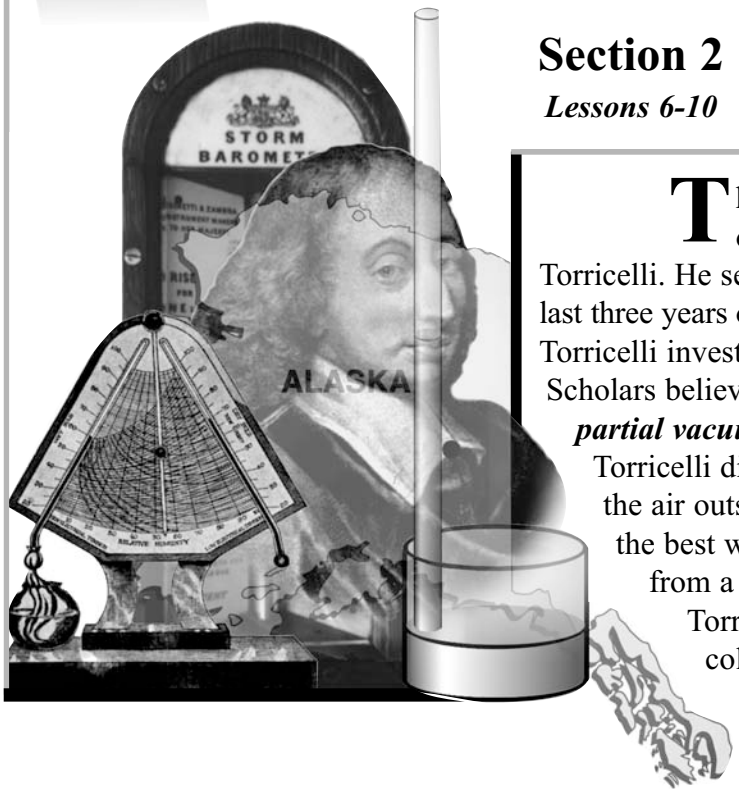
Lesson 10
Atmosphere

Chapter 3

AIR PRESSURE AND HUMIDITY

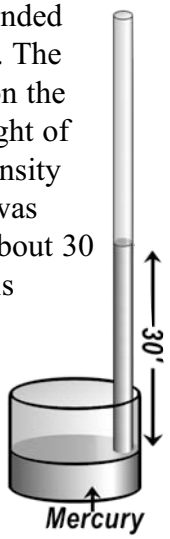
Section 2

Lessons 6-10



The first person who showed the weight of the atmosphere was Evangelista Torricelli. He served as Galileo's assistant during the last three years of that great scientist's life. Evangelista Torricelli investigated the operation of a water pump. Scholars believed water came up a pipe to fill the ***partial vacuum*** caused by the pump. Evangelista Torricelli disagreed. He believed the pressure of the air outside the pipe forced water to rise. Even the best water pumps could not draw up water from a depth of more than 34 feet. Evangelista Torricelli interpreted this to mean that a column of air extending from the surface of the Earth to the outer reaches of space produces the same ***pressure*** as a column of water extending 34 feet.

In 1644, Torricelli sealed a glass tube at one end and filled it with mercury. He up-ended the tube and put the open end in a dish of mercury. The mercury in the tube drained until the air pressure on the surface of the mercury in the dish equaled the weight of the mercury in the tube. Because mercury has a density 13.5 times as great as water, the mercury column was lower by that factor: 34 feet / 13.5 = 2.52 feet or about 30 inches. In the metric system, the mercury column is usually about 760 millimeters high. Torricelli had invented the first accurate ***barometer***, a device to measure air pressure.



Robert Boyle, the great English chemist, began recording the height of mercury in a barometer from day to day. Variations in atmospheric pressure caused the liquid mercury in the tube to rise or fall by small amounts. The liquid mercury rarely fell below 29 inches and seldom rose above 30.5 inches.

VOCABULARY

Partial vacuum: a region of reduced air pressure
Pressure: force that acts uniformly against a surface, measured as force per unit of area, pounds per square inch or newtons per square meter
Barometer: an instrument for measuring atmospheric pressure
Parts per million: the number of particles in a sample of one million particles, abbreviated ppm

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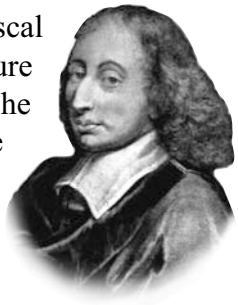
Robert Boyle noticed that the mercury level usually fell shortly before a storm.



Although a barometer measures air pressure, changes in air pressure predict rain. Molecules of water vapor (H_2O) weigh less than the molecules of nitrogen gas (N_2) and oxygen gas (O_2) that they replace. As the air with water vapor cannot support a full 30 inches (760 mm) of mercury, air pressure drops and so does the level of the mercury. If the air is especially dry, then the air pressure rises and so does the level of the mercury. With a rising barometer, a person can expect fair weather. Using the barometer to predict weather was the first step toward a modern science of meteorology, the study of weather.

Mercury is about 13,500 times as dense as air. If air were equally dense at any height, the atmosphere would be 13,500 * 760 mm = 10,260,000 mm high – about 10 kilometers or 6.3 miles. The air extends higher than 6.3 miles because air is not of uniform density. The air density becomes less with increasing elevation.

Proof that the density decreases with height came from Blaise Pascal, a French physicist. In 1648, Blaise Pascal decided to measure air pressure at different heights. Because he was in delicate health, Blaise Pascal instructed his brother-in-law in the use of a barometer and sent him to climb a mountain. The brother-in-law measured air pressure at a height of one mile. The mercury column dropped 75 mm due to lower air pressure at the greater height. A fall of 75 mm is about 10 percent of 760 mm. About 10 percent of the mass of the atmosphere is below one mile.



The highest mountain in North America is Mount McKinley, also known as Mount Denali. The mountain is located in Alaska, and its summit is at 20,000 feet. At the mountain's peak, a mountain climber would be above half of Earth's atmosphere. With each breath, the mountain climber would draw in only one half as much oxygen as at sea level. Above 20,000 feet, most mountain climbers carry extra oxygen.

In dry air, nitrogen makes up about 78 percent of the air, oxygen makes up nearly 21 percent of the air and argon makes up the remaining one percent. One way of measuring the composition is by ***parts per million***. A sample of dry air containing a million molecules would have about 780,840 nitrogen molecules, 209,460 oxygen molecules but only 9,340 argon molecules. All other gases make up the remaining 360 molecules. The stratosphere, where ozone is most abundant, consists of only 4 molecules of ozone out of each million (1,000,000) molecules.

The atmosphere is a mixture of gases. The mixture is evenly distributed because the gases are continually stirred by air currents and by their own random motions. A sample taken at one location contains about the same number of molecules of each gas as a sample taken elsewhere. The exception is water

VOCABULARY

Humidity: a measure of the amount of water vapor in the atmosphere
Absolute humidity: the total amount of moisture in a sample of air
Relative humidity: the amount of moisture in a sample of air compared to amount of moisture the sample could hold, usually expressed as a percent

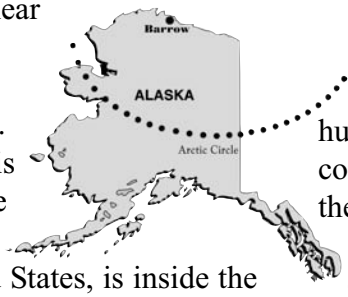
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vapor, which can vary from one location to another or from one day to the next.

HUMIDITY

Humidity is the moisture content of the air. The temperature determines the amount of moisture the air can contain. At low temperatures, the amount is small. At high temperatures, the amount is larger. Cold air is dry air. As the temperature rises, the amount of water the air can support becomes greater. On a warm day when the temperature is at 100ºF, the air can hold eight times as much water as it does when the temperature is near freezing.

In hot climates, such as around the equator, the air can contain more moisture. It is not surprising that most of the world's tropical rain forests are near the equator. Air in polar regions is so cold it can carry very little moisture. The fall of rain or snow is light. Barrow, Alaska, the northernmost community in the United States, is inside the Arctic Circle. The cold air carries less than 10 inches of precipitation every year. *Precipitation* is any form of water that falls to Earth's surface, such as rain or snow. Barrow is considered a desert because it receives so little moisture.

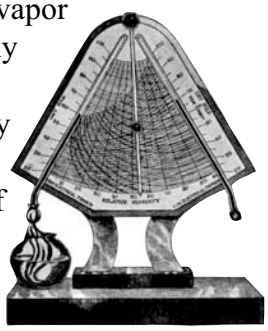


The rate at which water evaporates into the air depends on how much water is already in the air. In a hot, dry climate, wet clothes will dry especially fast. Water evaporates quickly. In a damp climate, evaporation takes place much more slowly. Air that can accept no more moisture is saturated. If the air is fully saturated, then evaporation will not take place.

Perspiring or sweating is one of the processes that the body uses to maintain a constant internal temperature. Perspiration cools the body as it evaporates. On a day when the atmosphere is saturated with water, the cooling effect of perspiration is not possible. People find a temperature of 80ºF to be pleasant, provided the air is dry. Air at the same temperature becomes uncomfortable when saturated with moisture.

The ***absolute humidity*** is a ratio of mass of the water vapor in a sample of air to the total weight of the sample of air. For one pound of water in 1,000 pounds of air, the absolute humidity is 1/1,000 or 0.1 percent. The proportion of water vapor to air ranges from very small fractions of one percent to about three percent. Absolute humidity is not particularly useful because it gives no information about how much water the air can hold.

In everyday life and in weather forecasting, the ***relative humidity*** is more useful than absolute humidity. Relative humidity is the ratio between the actual vapor content and how much vapor the air could hold if fully saturated. If air is completely and totally dry, its relative humidity is 0 percent. If the air is completely saturated, then the humidity is 100 percent. Office buildings use air conditioning equipment to adjust the relative humidity to between 40 and 60 percent.



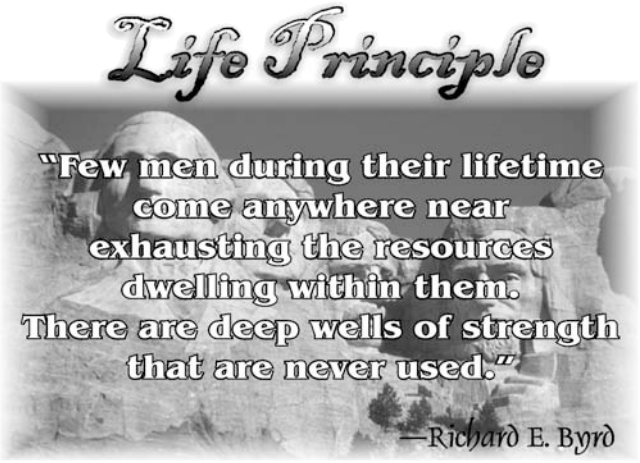
The relative humidity depends on the temperature. As the temperature falls, the air can hold less vapor and relative humidity rises. As the air continues to cool, the air will eventually reach a temperature at which it can hold no more water vapor. The air becomes saturated and the relative humidity rises to 100 percent. The relative humidity increases although the total amount of moisture in the air does not change.

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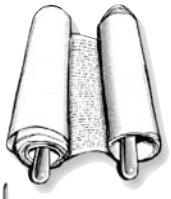
The dew point is the temperature at which air has a relative humidity of 100 percent. The dew point is a temperature that varies because the humidity in the air can vary from day to day. If the relative humidity is low, then the dew point temperature must be cooler to force out the moisture. If the humidity is high, then a slight drop in temperature may be enough to saturate the air. When the temperature falls below the dew point temperature, some of the moisture in the air will condense to form clouds, fog or dew. As the temperature falls at night, the excess moisture condenses on cool surfaces as dew.

In the tropics, the air becomes warmer throughout the day. Sunlight evaporates the water on the Earth's surface, changing it into moisture that is in the air. By the afternoon, the air has become saturated and cannot accept any more moisture. The slight downturn in temperature as evening approaches causes a sudden, brief downpour of moisture. Rain showers in the tropics are very regular and repeat the next day at about the same time.

Relative humidity is measured with a *hygrometer*. One design uses two thermometers, one of which has a moistened cloth around the bulb. In air with a low relative humidity, moisture evaporates readily and cools the wet-bulb thermometer. Its reading is lower than the thermometer with the dry-bulb. In air with high relative humidity, the evaporation is not as great, and the two thermometers read more nearly the same temperature. If the air were to be saturated, both would read the same. The difference in the temperatures measured by the wet and dry thermometers allows meteorologists to calculate the relative humidity.



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Lesson 11
Scientific Laws

Chapter 3

Section 3

Lessons 11-15

HENRY CAVENDISH AND HYDROGEN



Henry Cavendish, a British scientist, is best known as the person who "weighed the Earth." Of course he did not weigh the Earth with scales or any of the normal ways, for the Earth is far too big. Instead, he used Isaac Newton's Law of Universal Gravitation. Henry Cavendish was the first person to accurately measure the proportionality constant, *G*. In Newton's law, *G* must first be determined by experiment before the force of gravity between two bodies can be calculated. In symbols, the Law of Gravity can be stated as:

$$F = G * \frac{m_1 m_2}{r^2}$$

with *F* the force, *G* the proportionality constant, m_1 and m_2 the two masses and *r* the distance between their centers of mass. The force of attraction between two bodies is directly proportional to the product of their masses and inversely proportional to the square of the distance separating them. In other words, the heavier the objects are, the more they attract each other; the farther away the objects are, the less they are attracted to each other.

The proportional constant *G* can be calculated provided all the other quantities are known. Isaac Newton calculated *G* by estimating the mass of Earth. He calculated the mass of the Earth by multiplying its average density by its volume. Newton could estimate the volume using Earth's radius, but he could not accurately measure the density. His estimation was the density of the Earth is approximately 5.52 ***g/cc*** or 5.52 g/cm^3. The problem was the density of the Earth was not the same throughout so he had to guess an average value. Therefore, Newton's approach gave only a rough approximation to the true value for *G*.

Other scientists calculated the proportional constant *G* by measuring how much a mountain pulls a weight on a string

VOCABULARY

G/cc: abbreviation for grams per cubic centimeter, also written g/cm^3, a measure of density in the metric system
Hydrocarbons: a compound containing only hydrogen and carbon, the number of hydrocarbon compounds numbers in the millions
Electrolysis: chemical change caused by an electric current, usually electrolysis is used to separate a molecule into individual atoms

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out of the vertical position. This gave the force of attraction, *F*. The mass of the weight on the string was known. The distance from the weight to the mountain could be measured. However, the mass of the mountain must be estimated by multiplying its average density by its volume. Most large mountains consist of granite, which has a density of about 2.75 g/cc. The difficulty arises when mountains are not of a regular shape such as the Earth, which is a sphere. Calculating the exact volume was not possible. This gave inaccurate results for *G*.

G could be calculated by measuring the force of attraction between two objects of ordinary size. Gravity is a very weak force. Most scientists of the 1700s believed that the force of attraction between two small bodies was too slight to be detected. Henry Cavendish succeeded where all the other scientists had failed. He was able to measure the force of gravitational attraction between two bodies of ordinary size by suspending a light rod from the middle by a fine wire. Attached to each end were lead balls. Cavendish measured how much force was required to twist the wire, then he rolled two heavier balls near the rod, placing one slightly forward and the other slightly behind each of the lead balls on the rod. The gravitational attraction of each large ball to the smaller lead ball it was near would give the wire a slight twist.

G is a very small number. The attraction of two balls each of a mass of one kilogram, and set one meter apart is $6.67 * 10^{-11}$ newtons, or 0.0000000000667 newtons.



Henry Cavendish took extensive steps to ensure success. Once the apparatus was ready, he sealed the room to avoid stray air currents. Henry Cavendish observed his apparatus from outside the room by using a telescope to peer through the window. A tiny mirror on the wire reflected light, thus amplifying the slight twisting motion. Skill and attention to detail brought Henry Cavendish success.

Once the value for *G* was known, scientists could measure the force of attraction between a small object and the Earth and solve for the mass of the Earth, the only unknown quantity in the equation. Cavendish weighed the Earth because his experiment made this calculation possible. The Earth has a mass of $5.98 * 10^{24}$ kilograms. Despite that huge mass, the force of gravity is exceptionally slight – the muscles of a human being is capable of overcoming it. Gravity is one of the weakest forces known in nature.

As a young man, Henry Cavendish was exceptionally shy. He received an excellent education at Cambridge and after four years prepared to graduate. For the final examination, Henry Cavendish would have to sit before three professors and answer their questions. He chose not to graduate rather than face their questions.

Cavendish returned to his home, a great mansion outside London. His shyness grew more excessive. He could face but one person at a time. He became tongue-tied in the presence of women. Cavendish never married and lived alone except for servants who were under strict orders never to show themselves. As Henry walked through the mansion, his servants would scurry out of sight. Communication with the servant was done by leaving notes. Cavendish would not sit for his portrait after he became famous. The only likeness of Cavendish was a sketch made without his knowledge.

Henry Cavendish filled his library at the mansion with the latest books on science. Despite being so eccentric, he was a kind and generous person who moved his personal books to London so people could borrow them. Cavendish died a very wealthy man.

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Henry Cavendish carried out scientific experiments simply because he enjoyed doing so. He continually worked the problem until he found a solution. After he understood the matter, Cavendish often plunged into his next study without even publishing the results of his previous study. After Cavendish's death, his research notes were studied by other scientists who were astonished by the extent of Cavendish's discoveries. Some of his discoveries, made 25 years earlier, had not yet been rediscovered by other scientists. Henry Cavendish remained an unusual character all of his life. He died at the age of seventy-nine — alone. Despite his unusual personality, chemists today hold Henry Cavendish in high regard. Chemists named an important research institution in his honor, The Cavendish Laboratory at Cambridge University in England.

HYDROGEN

In 1776, Henry Cavendish treated several metals with muriatic acid. These metals emitted a gas when exposed to the acid. Regardless of the metal, the gas was the same in each case. Cavendish captured the gas and measured its density. The gas was much lighter than air itself. It burned with a dim blue flame. He had discovered the gas, *hydrogen* (H).

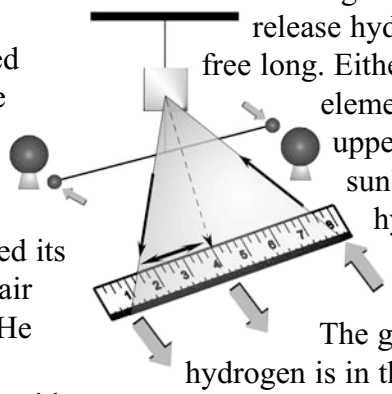
All acids contain hydrogen. The acid Henry Cavendish used, muriatic acid, is known today as hydrochloric acid (HCl). From its name, we know that hydrochloric acid contains hydrogen and chlorine. However, when Henry Cavendish began to study, no one knew the combination of the elements that made hydrochloric acid. Cavendish showed that muriatic acid contains hydrogen.

A few years later, another gas, oxygen, was discovered which caused a glowing ember of wood to burst into flame. Cavendish showed that hydrogen gas in combination with the new gas will produce water. Hydrogen received its name from a French word *hydrogene*, meaning *water generating*.

Water is the most common liquid on Earth. The Earth contains several hundred million cubic miles of water in the oceans, glaciers, salt and fresh water lakes, rivers and water vapor in the atmosphere.

The second most common liquid on Earth is petroleum. When the petroleum is refined, it is made of hydrocarbons. ***Hydrocarbons*** are compounds that contain only hydrogen and carbon.

In the universe as a whole, scientists believe hydrogen is the most common element. In combination with oxygen and with carbon, hydrogen is an abundant element on Earth. However, hydrogen is rarely found in the free state on Earth.



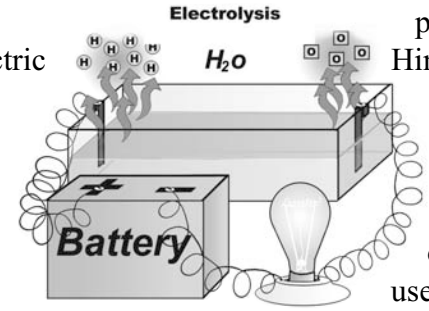
Although some natural gas wells do release hydrogen, it does not stay free long. Either it combines with other elements, or it rises to the upper atmosphere. Rays of sunlight would kick hydrogen molecules to such high speeds that they escape into space.

The greatest usage of hydrogen is in the manufacturing of ammonia and methyl alcohol. Because hydrogen is readily available in compounds but is seldom found in the natural state, chemists have a variety of ways to produce free hydrogen. One method is the same as the one used by Henry Cavendish. When hydrogen reacts as an acid with a metal, the gas released is hydrogen.

Another method is the ***electrolysis*** of water. Water can serve as a source of hydrogen. In countries where electricity is cheap, chemists break water into oxygen and

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hydrogen by running an electric current through the water. A positive electrode is placed on one side of a container of water, and a negative electrode is placed on the other side. When the electric current flows, it causes the water molecules to break down. Hydrogen bubbles to the surface around the negative terminal, and oxygen bubbles to the surface around the positive terminal.



$$2H_2 + O_2 \rightarrow 2H_2O$$

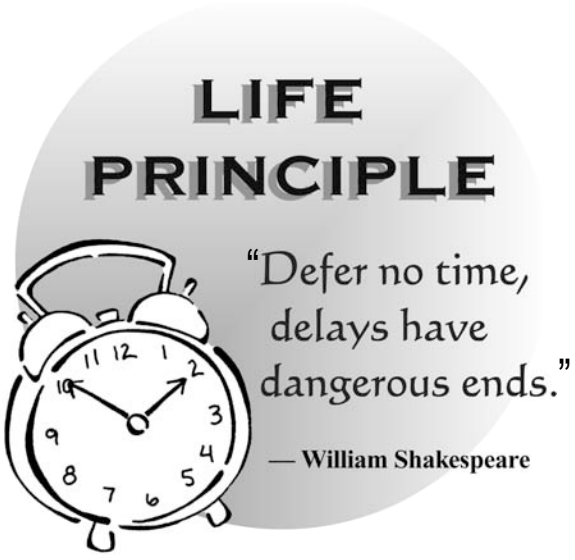
Hydrogen is a colorless, odorless, tasteless and highly flammable gaseous element. Provided that sufficient oxygen is available for a person to breathe, the presence of hydrogen is not poisonous. The danger from a mixture of oxygen and hydrogen is the threat of an explosion and fire.

Henry Cavendish was the first scientist to measure the density of various gases, including hydrogen, which is fourteen times lighter than air. Hydrogen was the lightest of all gases known at that time and is still the lightest. Hydrogen is the smallest, lightest and simplest of all elements, consisting of a single proton and one electron.



When hydrogen is mixed with air or oxygen and ignited, the mixture explodes. If done in a controlled way, it can serve as a rocket fuel. Hydrogen is lightweight, inexpensive and burns with liquid oxygen to give a non-polluting exhaust — water. The Apollo moon rocket and the space shuttle used liquid hydrogen and oxygen as a fuel. Liquid hydrogen must be stored below –253ºC (-423ºF).

For a time, hydrogen was used to produce lift to great airships, such as the Hindenburg. The Hindenburg was the largest airship ever flown. Unfortunately, it burst dramatically into flames while landing in New Jersey in 1937. The hydrogen that lifted the airship contributed to the destruction. Today, helium or hot air is used for "lighter-than-air" ships. Helium provides almost as much lift as hydrogen (about 93 percent), and it is far safer. Helium and hot air are not affected by the flames that would cause hydrogen to explode.



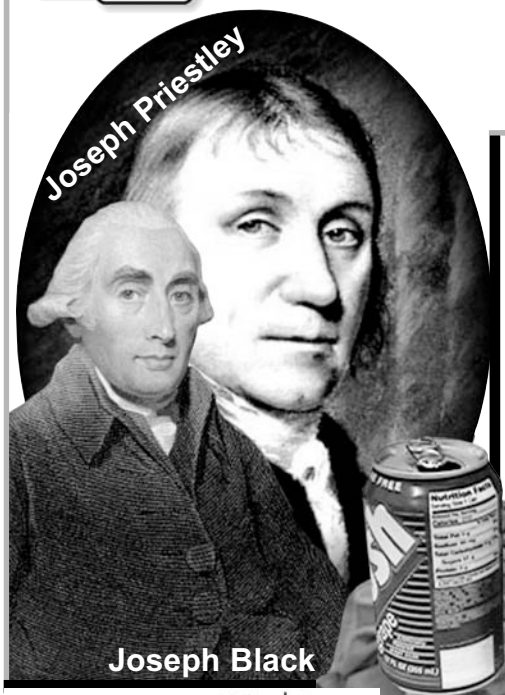
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Chapter 3

Lesson 12
Compounds

Section 3
Lessons 11-15

JOSEPH PRIESTLEY AND OXYGEN



At the time of Henry Cavendish's experiments with hydrogen, Joseph Priestley studied different kinds of air. Joseph Priestley was the son of a minister. The boy's mother died when the boy was seven, leaving his aunt to raise him. Joseph was a good student and studied to be a Christian minister. He learned several languages, including Hebrew and Arabic. He served as a preacher and a tutor and wrote a textbook on English grammar. In 1767, Joseph Priestley became pastor at a chapel near Leeds, England.

The previous year Priestley had met Benjamin Franklin in London when he had come to England on behalf of the colonists to seek relief from excessive taxes. Benjamin Franklin was already well known for his studies of electricity. Joseph Priestley was greatly impressed by this American statesman who encouraged Priestley to study electricity.

Despite a lack of scientific training, Joseph Priestley was the first person to show that carbon, a nonmetal, would conduct electricity. By the time Priestley had settled in Leeds, England, he had written a book about electricity. He became interested in all things scientific, including chemistry.

Joseph Priestley followed up on experiments by Joseph Black, a Scottish chemist. Joseph Black had experimented with calcium carbonate ($CaCO_3$). Calcium carbonate is the modern name of the compound that is the main ingredient in antacids like Rolaids®. At the time, chemists had no idea of its actual composition. When Black heated calcium carbonate, it changed to calcium oxide (CaO) and gave off a gas. By recombining the gas with calcium oxide, it changed back into calcium carbonate. Black called the gas *fixed air* because it could be fixed into

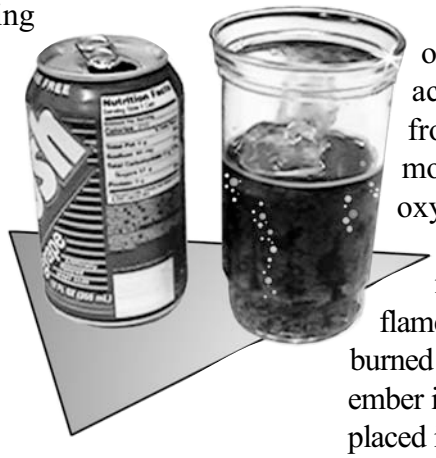
VOCABULARY

Combustion: burning, rapid oxidation, a chemical change accompanied by heat and light
Fermentation: a chemical reaction that converts complex organic compounds into carbon dioxide and alcohol
Beaker: a glass jar used by chemists
Soluble: capable of being easily dissolved
Oxide: any compound that contains oxygen
Fractional distillation: separation of two or more chemical substances based on variations in their boiling temperature

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solid form again. The gas appeared to be the same as the gas given off during ***combustion*** and ***fermentation***. Joseph Black made some studies of the fixed air finding that it would not support combustion because fire in the presence of the gas was smothered.

Fixed air was carbon dioxide. The gas was heavier than air, would smother flames and would dissolve in water. Joseph Priestley investigated this so thoroughly and described its properties so completely that he has been credited with discovering carbon dioxide in the scientific sense. When Joseph Priestley dissolved carbon dioxide in water, he produced "an exceedingly pleasant sparkling water." He had produced a carbonated beverage. The bubbles that are released when soft drinks are opened come from carbon dioxide dissolved in water.



During this time, only three gases were known: air, hydrogen and carbon dioxide. In the 1770s, Joseph Priestley began collecting gases in a variety of different ways. The usual way to generate and collect gases is to let them react in a closed container. Then, the gas that is generated is led away in a tube. The tube runs into a ***beaker*** full of water that is held upside down in a water bath. As the gas bubbles out of the tube it fills the beaker and drives out the water.

The problem with this procedure is that water sometimes absorbs the gas. Ammonia, sulfur dioxide and hydrogen chloride are all water-***soluble***. Joseph Priestley's solution was to use mercury rather than water. With this procedure, he captured new gases and described their properties.

In 1774, Joseph Priestley received a powerful magnifying glass which concentrated the rays of the Sun and allowed Priestley to heat objects through a glass container. He put a compound of mercury in a closed test tube. Then, focusing the rays of the Sun on the glass container, the compound began to break. Tiny droplets of free mercury formed on the sides of the test tube. Priestley discovered that it gave off a gas that filled the tube.

Joseph Priestley had discovered oxygen. The mercury compound was actually mercuric oxide (HgO). The heat from the Sun's rays broke apart the molecules, thereby, freeing mercury and oxygen.

Joseph Priestley tested the gas from the mercury compound. Putting a candle flame at the mouth of the test tube, the candle burned brightly. When he placed a glowing ember into the gas, it burst into flames. Mice placed in a container of oxygen became very active. As Priestley breathed some of the gas he felt especially refreshed. He predicted that the new air could have a role in medical science. The pure form of the gas might be helpful for people who had difficulty breathing.

Oxygen appeared to be the opposite of carbon dioxide in its support of combustion. Oxygen supported combustion and carbon dioxide was used to extinguish flames. As objects burned, they consumed oxygen but generated carbon dioxide. Almost all fuels burn because they contain carbon that reacts with oxygen in the air. Wood, charcoal, whale oil, petroleum and all the other fuels contain carbon. As these carbons burn in air, oxygen combines with carbon in the fuel and forms carbon dioxide. Oxygen is one of the reactants. Carbon dioxide is one of the products.

Joseph Priestley's researches earned a membership in the French Academy of Sciences, and he won a medal from the Royal Society.

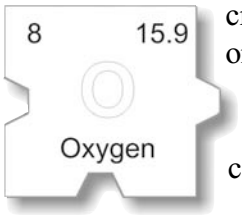
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Politically, Joseph Priestley did not fair as well. He favored the American colonies in their rebellion against England. Later, when most citizens of Britain were aghast at the results of the French Revolution, Priestley sided with the French revolutionaries. His religious views also differed from the mainstream in England. In 1791, an angry mob burned down his home and destroyed all of his possessions. Priestley managed to escape with his family to London. From there, he departed England for the newly independent United States.

Thomas Jefferson, who understood the importance of scientific discovery, welcomed Joseph Priestley. The last ten years of Joseph Priestley's life were especially pleasant and peaceful ones. He received many honors, and numerous American universities asked him to speak at their assemblies. Joseph Priestley wrote extensively on subjects such as science, politics and religion. Joseph Priestley died in 1804. His collected works consisted of more than 25 volumes.

OXYGEN

Oxygen (O) is a nonmetallic gaseous element. In the crust, or outer layer of the Earth, oxygen is more abundant than any other element. More than half of Earth's crust, slightly more than one fifth of the atmosphere, and two-thirds of the human body are composed of oxygen.

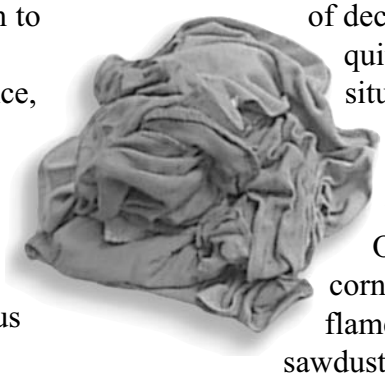


Oxygen is highly active chemically. Of all the known elements, only fluorine is more active. Oxygen combines with practically any element, whether the element is a metal or nonmetal. A compound of oxygen with another element is an ***oxide***.

Oxygen is very reactive, but it is found in the free state in the atmosphere. Oxygen easily combines with other elements and is easily found in the air by itself. Many other elements are not as active chemically, but are seldom found in the free state. Plants are constantly replacing oxygen. The most important plants in restoring oxygen to the atmosphere are algae in the ocean. The vast tracks of tropical rain forest also contribute in the process. If it were not for the plants action, oxygen in the atmosphere would soon disappear as it combines with decaying matter and with metals in the form of oxides.

The process by which oxygen combines with other elements is called *oxidation*. Rusting is one example but so is the decay of organic matter. Both of these are examples of slow oxidation.

Usually, heat is generated during oxidation. A *compost pile*, which is a mixture of decaying matter, can be quite warm. In some situations, if the heat of oxidation cannot escape, the material may burst into flames. Oily rags left piled in a corner can burst into flames. In the middle of a sawdust pile, a fire can begin from the internal heat of the decaying matter. *Spontaneous combustion* is a fire that begins from the heat of slow oxidation.



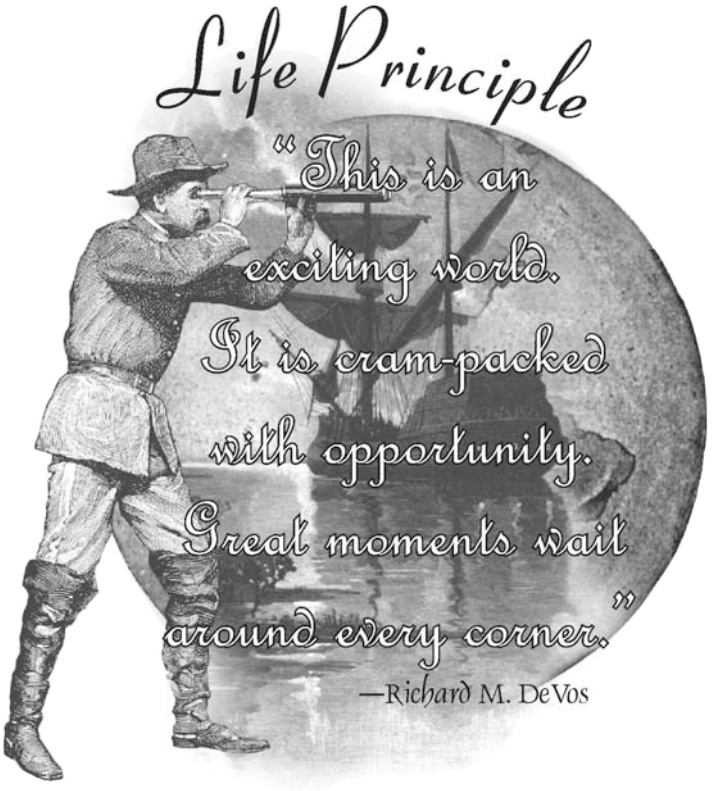
Burning is an example of rapid oxidation. Rapid oxidation produces heat and light. One of the highest temperatures possible by chemicals is the rapid oxidation of acetylene with oxygen. *Acetylene* is a hydrocarbon of two carbon atoms and two hydrogen atoms (C_2H_2). A cutting torch burns acetylene and pure oxygen. The flame reaches a temperature of about 3,500ºC. Iron melts at half that temperature. The acetylene torch cuts through thick slabs of steel and other metals. Because oxygen is supplied to the reaction, the acetylene torch can be used underwater.

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Joseph Priestley suggested that oxygen might someday be used to treat people with diseases. Oxygen does have many uses in medicine. People with respiratory diseases, pneumonia or other impairments to their lungs, breathe pure oxygen. Airlines use pressurized cabins and provide oxygen for their passengers. Oxygen enriched air is blasted into furnaces in the manufacture of steel. In the liquid form, oxygen is used as a propellant for rockets.

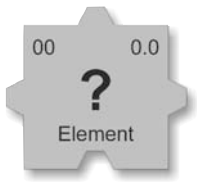
One would conclude that the atmosphere is a ready source for pure oxygen. The oxygen that makes up 21 percent of Earth's atmosphere is mixed with other gases, primarily nitrogen. Separating oxygen from the other gases is not an easy process. To produce pure oxygen, ***fractional distillation*** is used. Distillation is the process of purifying a substance by boiling it and then allowing the vapor to condense. Fractional distillation separates substances that have different boiling points. Each one comes out as a fraction of the total. In fractional distillation to produce oxygen, air is cooled to about –200ºC. At that temperature, both oxygen and nitrogen liquefy. As the liquid is warmed, each component boils away at a different temperatures. Nitrogen boils first at –196ºC, leaving the oxygen. Oxygen can be shipped in liquid form, provided it remains below its boiling temperature at –183ºC.

Oxygen can be produced from water in the same way as hydrogen, by electrolysis. As hydrogen bubbles from the negative electrode, oxygen bubbles from the positive electrode. Chemists who need a small amount of oxygen can prepare it in the laboratory by heating compounds such as potassium chlorate ($KClO_3$). This causes the compound to break down and release the oxygen.



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Integrated Physics & Chemistry



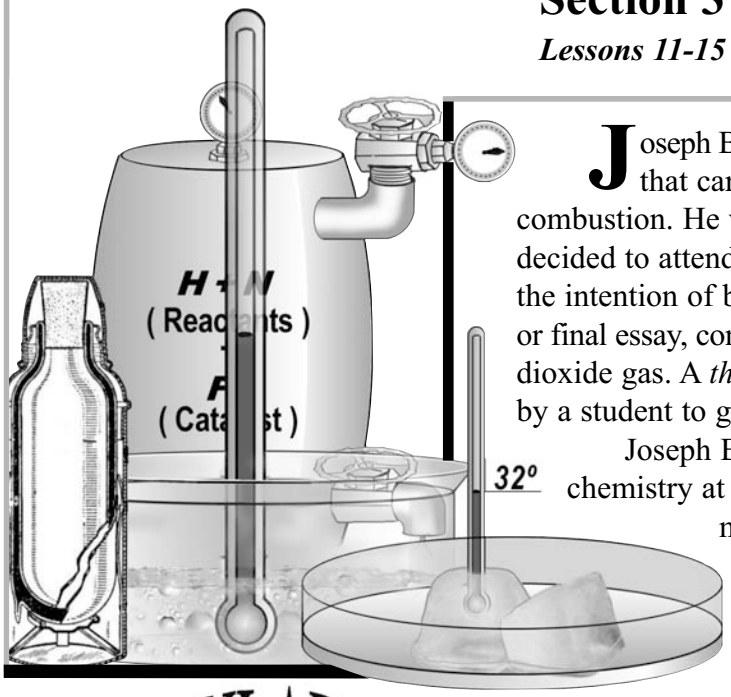
Lesson 13
Elements

Chapter 3

NITROGEN

Section 3

Lessons 11-15



Joseph Black was the Scottish chemist who showed that carbon dioxide was one of the products of combustion. He was the only one of 13 children who decided to attend Glasgow University in Scotland with the intention of becoming a doctor. His graduation thesis, or final essay, contained his experiments with carbon dioxide gas. A *thesis* is a report of original research done by a student to gain an advanced college degree.

Joseph Black received a teaching position in chemistry at Glasgow University. However, he felt more confident of his ability to teach medicine that he and the medicine professor swapped jobs for ten years. During this time, Joseph Black continued to study the new science of chemistry.

After ten years, Joseph Black moved to Edinburgh where he taught both medicine and chemistry. He was a skilled teacher. Many people who had already graduated from college came back to attend his lectures. He would present new ideas in his lectures but never attempted to publish them. He encouraged others to develop his discoveries.

While at Glasgow, Joseph Black encouraged James Watt to build an improved steam engine. Because of Black's help, James Watt is given credit for inventing the steam engine. Another individual who benefited from Joseph Black's generosity was Joseph Priestley. Joseph Priestley made a more in-depth study of carbon dioxide than did Black and is given credit for its discovery.

One of the reasons Joseph Black did not experiment further with carbon dioxide was that he had become interested in heat and temperature. He was the first scientist to understand the difference between the two quantities. The amount of heat in a body is different from its temperature. A quart of hot water and a gallon of hot water can be at the same temperature, but the gallon of hot water has more heat energy.

VOCABULARY

Latent heat of fusion: amount of heat absorbed by a substance changing state from solid to liquid

Latent heat of vaporization: amount of heat absorbed by a substance changing state from liquid to gas

Convection: heat transfer by flow of a gas or liquid from one place to another

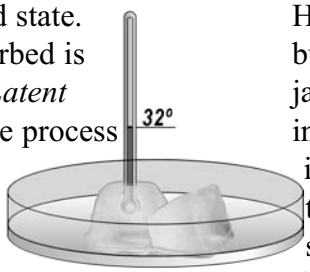
Conduction: heat transfer by direct contact between two bodies

Radiation: heat transfer by electromagnetic waves (light or infrared rays)

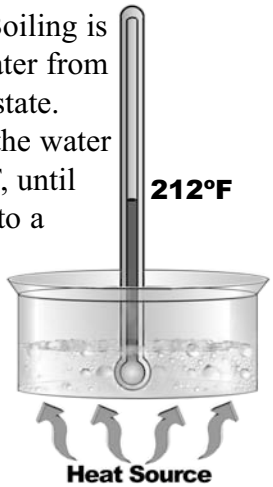
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Different substances also differ in their heat content. Suppose a scientist mixed four ounces of the metal lead at 100ºF into a container of four ounces of water at 80ºF. The lead would cool and the water would become warm. Because equal masses of both are used, scientists assumed the masses would come to a temperature in the middle, 90ºF. When Joseph Black did the experiment, he discovered that the temperature only rose a few degrees above 80ºF. Water had a greater heat capacity than lead.

Joseph Black also discovered that substances need additional heat to change states from a solid to a liquid or from a liquid to a gas. Black took a container of ice which was well below freezing, and heated it. As the ice grew warmer, the temperature changed at a steady rate until it began to melt. At 32ºF (0ºC), the ice grew no warmer until all of the ice became a liquid. The ice absorbed heat as it changed state. The amount of heat it absorbed is the ***latent heat of fusion***. *Latent* means *hidden*. *Fusion* is the process of melting. The latent heat of fusion of water is the amount of heat needed to change ice into liquid water.



Once the ice melted, the temperature of the water rose as he continued to heat it. When the water reached 212ºF (100ºC), it began to boil. Boiling is the process of changing water from a liquid state to a gaseous state. Again, the temperature of the water remained constant at 212ºF, until all of the water changed into a vapor. Liquid water absorbed heat as it changed into a gas. ***Latent heat of vaporization*** is the amount of heat needed to change water into steam.



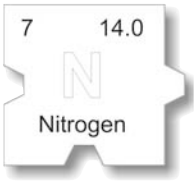
Joseph Black lived simply and had amassed a large personal estate. He died while eating a typical meal of bread, prunes, milk and water. His will divided his estate into 10,000 shares that he gave to his relatives based on their need.

Daniel Rutherford was one of Joseph Black's students. In 1772, Rutherford pursued the subject of gases that do not support combustion. Only two years earlier, Joseph Priestley had shown that oxygen in the air supports combustion. A candle in a container of pure oxygen burns brightly. As the oxygen burns, it forms carbon dioxide. When the candle is covered by a jar, the flame goes out. Carbon dioxide does not support combustion.

Once the flame dies, carbon dioxide is not the only gas in the jar. Daniel Rutherford tested this idea by removing all of the carbon dioxide from the jar in which the flame died. He found that only a part of the air had burned. Four-fifths of the original gas in the jar remained. When he put a burning candle in the remaining gas, the flame died immediately. Rutherford had found a new gas that did not support combustion. His tests showed that the new gas was not carbon dioxide.

Daniel Rutherford had discovered *nitrogen*. He showed that air contains primarily two gases. About $1/5^{th}$ (21 percent) is oxygen, which supports respiration and combustion. A flame in pure oxygen burns vigorously. An atmosphere of pure oxygen would present a terrible risk of uncontrolled fire. However, about $4/5^{ths}$ (78 percent) of the atmosphere is nitrogen, which does not burn. Because nitrogen does not support combustion, its presence in the atmosphere reduces the risk of disastrous fires.

Nitrogen (N) is a nonmetallic gaseous element that is colorless, odorless and

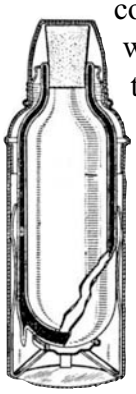


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chemically inert. As a gas, it forms a diatomic molecule (N_2). Most of the nitrogen used in the chemical industry is obtained by fractional distillation of liquid air. Air is chilled until it turns to a liquid. Then, it is slowly warmed. Nitrogen boils off first, followed by oxygen. The nitrogen is then captured and cooled to a liquid for shipment. Liquid nitrogen is stored in containers developed by James Dewar.

James Dewar, a Scottish chemist, constructed devices to produce liquid oxygen and nitrogen in large amounts. He was then faced with the problem of how to keep the liquids cold so they would not boil away. He knew that heat could enter a body in three ways, by ***convection***, ***conduction*** or ***radiation***. *Convection* is the transfer of heat by the flow of air currents from one point to another. Cool breezes that blow in from the ocean or hot air thermals that rise over the desert are examples of convection currents. *Conduction* is the transfer of heat by one body being in contact with another. When a person sits in a cold steel chair, the heat leaves the person's body and enters the steel by conduction. The chair seat feels cold because of the lost heat. *Radiation* is the movement of heat energy by light rays. The warmth of a heat lamp or the rays of sunlight are examples of radiation.

James Dewar knew that conduction and convection could not take place across a vacuum. He made a double-walled glass container with a vacuum between the walls. The vacuum stopped heat transfer by conduction and convection. Radiation was still possible. He then coated the glass walls with silver. Radiant heat was reflected rather than absorbed. Such vacuum bottles became known as *Dewar flasks*. A commercial company marketed the invention as Thermos bottles.

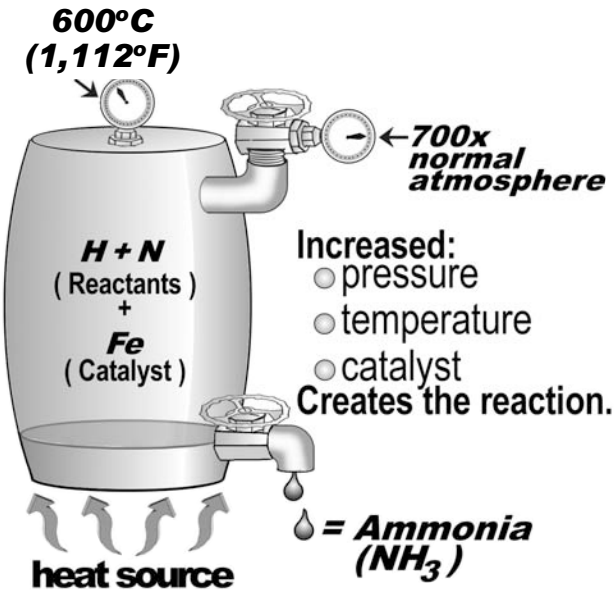


Liquid nitrogen has many commercial uses. Frozen foods drop quickly to very low temperatures by plunging them in liquid nitrogen. Some human organs and medical evidence are preserved by immersion in containers of liquid nitrogen.

The greatest use of nitrogen is in making nitrogen compounds. The most common nitrogen compound is ammonia, a molecule of one nitrogen atom and three hydrogen atoms (NH_3). It is the starting ingredient in a variety of compounds including acids, explosives and fertilizers.

Making ammonia would appear to be simple. Nitrogen is abundant in the atmosphere, and hydrogen is abundant in water. Chemists found the task exceptionally difficult. Nitrogen is inert and does not readily combine with hydrogen. No ordinary chemical reaction forces nitrogen and hydrogen together.

Until the start of the 1900s, all attempts failed to force nitrogen and hydrogen together. In 1913, success came to Fritz Haber, a German chemist. Chemists had learned three ways to increase the rate of a chemical reaction: increase the pressure, heat the reactants and use a catalyst.



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Fritz Haber put hydrogen and nitrogen gas together at 700 times normal atmospheric pressure. He heated them to 600ºC (1,112ºF). The reaction took place, but very slowly. He found that finely ground iron particles acted as a catalyst and sped the reaction. The *Haber Process* combines hydrogen and nitrogen to give ammonia (NH_3).



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Integrated Physics & Chemistry

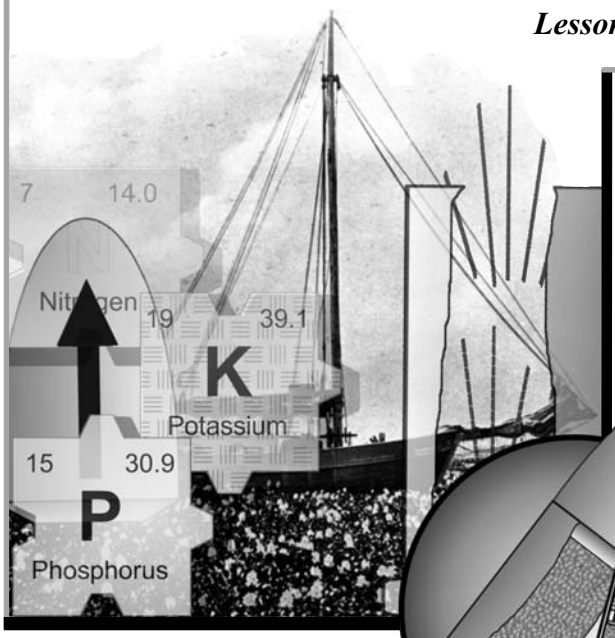


Lesson 14
Compounds

Chapter 3

NITROGEN IN FERTILIZERS AND EXPLOSIVES

Section 3
Lessons 11-15



Living organisms need chemical elements in order to grow and survive. Some elements are found in greater abundance in the body than others are. The four most common elements are carbon, hydrogen, oxygen and nitrogen. Living organisms need other elements in smaller amounts, such as phosphorus, potassium, sulfur and iron. Essential elements that are present in small amounts in living organisms are called ***trace elements***. Most animals get the elements they need by eating plants. Most plants receive nourishment from the air, water, soil and the Sun.

Plants can get carbon from carbon dioxide in the air, hydrogen from water, and oxygen from water, carbon dioxide or the air. Plants have the greatest difficulty extracting nitrogen. Nitrogen is plentiful. The Earth's atmosphere contains a vast storehouse of nitrogen. However, nitrogen gas from the atmosphere is practically inert. It seldom forms compounds. Most plants cannot take nitrogen directly from the air. Instead, they must extract it from compounds in the soil.

Harvesting crops year after year can remove the soil's natural supply of nitrogen. Even rich topsoil can become exhausted after growing the same crops year after year. The soil becomes depleted of nitrogen and other elements.

Although plants cannot take nitrogen from the air, some ***microorganisms*** are capable of doing this feat. They are called *nitrogen-fixing bacteria*. Nitrogen fixation is the process of converting the element nitrogen from the atmosphere into chemical compounds that are essential for plant growth. One

VOCABULARY

Trace element: a chemical element required in small quantities by an organism to carry out its life processes
Microorganism: a living organism so small it can only be seen with a microscope
Amino acids: the building blocks of proteins, composed of atoms of carbon, hydrogen, oxygen and nitrogen
Protein: extremely large and complex molecules that are essential in the diet of animals for the growth and repair of tissue, proteins are composed of amino acids

such species of bacteria forms colonies on the roots of legumes; such as clover, peanuts and peas. These bacteria supply nitrogen compounds to the legume and, in turn, obtain food from their host. The process by which two organisms survive by helping one another is called *symbiosis*. Bacteria and legumes form a symbiotic relationship. Sometimes soil is sowed with a species of these bacteria to increase the yield of a legume crop.

Most animals receive nitrogen compounds into their bodies from the plants they eat. Nitrogen is essential to both plant and animal life. Nitrogen is one of the elements in ***amino acids***, the building blocks of ***protein***. Nitrogen makes up about 3.5 percent of the human body by weight. It is found mostly in protein.

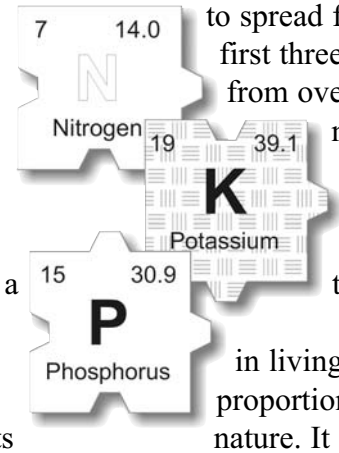
Many crops, such as corn and beans, do not support the nitrogen-fixing bacteria. Such crops will exhaust the soil. One solution is to alternate regular crops with legumes. Corn and beans are planted one year, but the next year the field is planted with legumes such as clover or peas. This restores some nitrogen to the soil. Although alternating crops with legumes helps, more nitrogen compounds are needed in the soil than can be supplied by bacterial agents.

VOCABULARY

Cellulose: a carbohydrate that makes up the cell wall in most plants

Carbohydrate: a compound that contains carbon, hydrogen, and oxygen atoms; sugar, starch, cellulose, and gum are types of carbohydrates

Structural formula: a chemical formula that shows how the atoms in a molecule are arranged

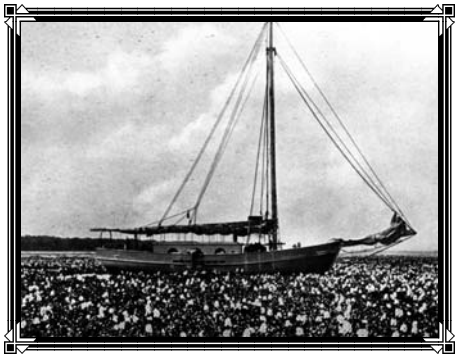


Another way to restore nitrogen to the soil is to spread fertilizers. Usually, the first three elements to disappear from overworked soil are nitrogen, potassium and phosphorus. Most fertilizers contain a mixture of compounds of those elements.

Phosphorus is present in living things in a greater proportion than is present in nature. It is one of the first elements to disappear from the soil. Phosphorus can be replaced from a variety of naturally occurring compounds such as calcium phosphate ($Ca_3(PO_4)_2$). Potassium, another element that often needs to be replaced, is found in potassium chloride (KCl) and potassium nitrate (KNO_3). Both compounds are naturally occurring.

Nitrogen occurs in potassium nitrate (KNO_3) and sodium nitrate ($NaNO_3$). The greatest natural supply of these two compounds is found in Chile in South America. However, most nitrogen fertilizers today are manufactured from ammonia that has been made by the Haber Process.

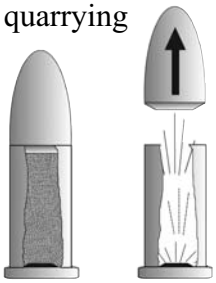
Fertilizers are expensive and do have other risks. They can be washed out of the soil and end up in the water supply. In rivers and streams, the nitrogen compounds nourish water plants that become so lush they clog the waterway. Sometimes the water evaporates, causing the chemicals to become more concentrated. The agricultural chemicals can harm fish and pose a health risk to people who drink the water.



EXPLOSIVES

One of nitrogen's most important applications is in explosives. Nitrogen is relatively inert. It does not readily form compounds. Chemists must force nitrogen to combine with other elements. They do this as in the Haber Process with high pressure and high temperatures, both of which require a great deal of energy. The chemical bond that holds nitrogen with other elements is not very strong. When nitrogen compounds come apart, they release the same energy that went into making them. Nitrogen compounds come apart so quickly that an explosion results. The force of an explosion is caused by the sudden expansion of a great volume of very hot gases.

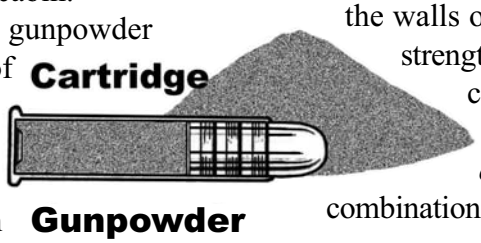
Explosives are used for quarrying and blasting, in fireworks and signal flares, in firearm ammunition and as fuel for solid fuel rockets and other projectiles. During war, explosives are used in bombs.



Despite the need for a variety of explosives, until the 1800s, gunpowder was the only choice. *Gunpowder* is a mixture of charcoal, sulfur and potassium nitrate (KNO_3). Gunpowder came into use in the 1200s in Europe, although it may have been known earlier in Asia.

People found serious flaws with gunpowder. Gunpowder absorbs moisture easily and can fail to fire when damp. In an effort to keep the powder dry, frontier families stored it in a sealed space in the side of a chimney. A stray spark or faulty chimney could destroy a pioneer cabin.

When detonated, gunpowder releases great amounts of smoke. One of its peaceful uses is in blasting away rock in quarries or mines. When exploded in mines, gunpowder sends thick clouds of choking smoke down the mineshaft. Miners gasp for air when exposed to gunpowder smoke.



Soldiers disliked gunpowder smoke. When colonial soldiers fired their muskets or cannons, thick clouds drifted up from their hiding places. It announced their positions to the enemy. When many guns fired at once, the smoke blinded the soldiers, hiding the enemy from view. The smoky residue also coated rifles and cannons. Soldiers had to swab their weapons clean after each shot.

Everyone who used gunpowder wished for an explosive that was smokeless. It would be a real advantage, not only for the military, but for miners, too.

In the 1800s, chemists began to look for a better explosive than common gunpowder. Christian Friedrich Schonbein was a German-Swiss chemist. In 1846, he experimented with nitric and sulfuric acids. He mixed the combination together in his wife's kitchen even though she did not approve of his chemical studies.

By accident, Christian Schonbein dropped the bottle with the mixed acids. It broke and spilled the corrosive liquid on the clean floor. He grabbed his wife's cotton apron to clean the mess. He washed the apron and hung it over a hot stove so it would dry before his wife returned. Without warning, the apron vanished in a flash of light. Not a single thread of the apron survived. It disappeared as if it had never existed. Not even smoke remained to show where it had been.

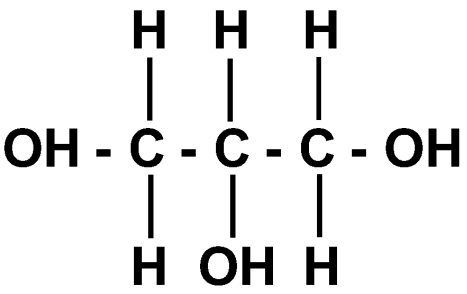
The apron was made of cotton, which is almost entirely ***cellulose***. Cellulose makes the walls of plant cells and gives them their strength. Without cellulose, a tree would collapse under its own weight. Cellulose is almost entirely a ***carbohydrate*** – a chemical combination of carbon, hydrogen and oxygen.

Christian Schonbein's experiments showed that cellulose treated with nitric acid is especially unstable. A spark or heat will set it off. It is three times more powerful than gunpowder. He gave the name *guncotton* to nitrocellulose to call attention to its intended use as an explosive.

Military officers encouraged immediate manufacture of guncotton, but they soon learned that guncotton explodes too easily. If they used great care, chemists could make small amounts in the laboratory. Factories could not safely produce guncotton in large quantities. Most guncotton factories blew up within two years of being built. In 1847, a factory blew up and killed twenty-one people. Businessmen chose not to rebuild the factories. Instead they decided to spend their money more wisely in other ventures.

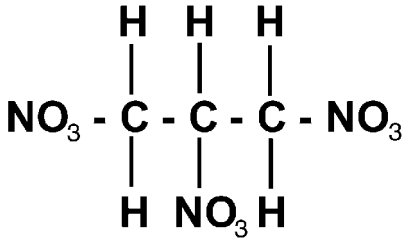
The next explosive to be discovered was nitroglycerin. Ascanio Sobrero, an Italian chemist, added glycerin to a mixture of nitric acid and sulfuric acid. Glycerin is a colorless, odorless, and sweet-tasting alcohol. The chemical formula for glycerin is $C_3H_8O_3$. However, this brief formula does not show how the atoms are organized within the molecule. All alcohols contain the combination of oxygen and hydrogen (OH). The combination of oxygen and hydrogen is known as hydroxyl. The formula can be written as $C_3H_5(OH)_3$. Another way of showing the glycerin molecule is with a ***structural formula***.

Structural Formula for Glycerin ($C_3H_5(OH)_3$):



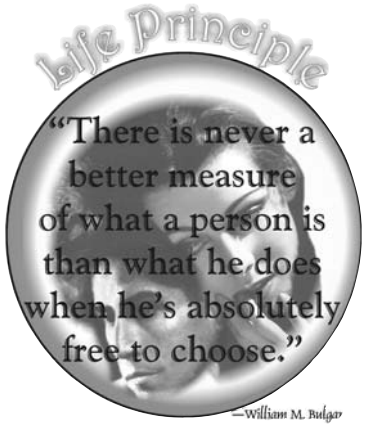
Treating glycerin with nitric acid and sulfuric acid changes it into nitroglycerin. The formula is $C_3H_5(NO_3)_3$. The 3 outside the parenthesis shows that NO_3 is present three times in the molecule. Each of the three hydroxyl groups (OH), is replaced by a nitrate group (NO_3).

Structural Formula for Nitroglycerin ($C_3H_5(NO_3)_3$):



Ascanio Sobrero heated a sample of nitroglycerin in a test tube. The explosion that followed nearly killed him. Ascanio Sobrero told his chemist friends, "Nitroglycerin is more dangerous than guncotton. Its destructive power frightens me." Sobrero urged other chemists to avoid the dangerous explosive. He did not attempt to sell it and kept secret how to make it.

Not only is nitroglycerin more explosive than guncotton, but it is a liquid rather than a solid. This made handling it very difficult. Explosives merchants ignored the new explosive because no one knew how to manufacture, transport or use it safely.



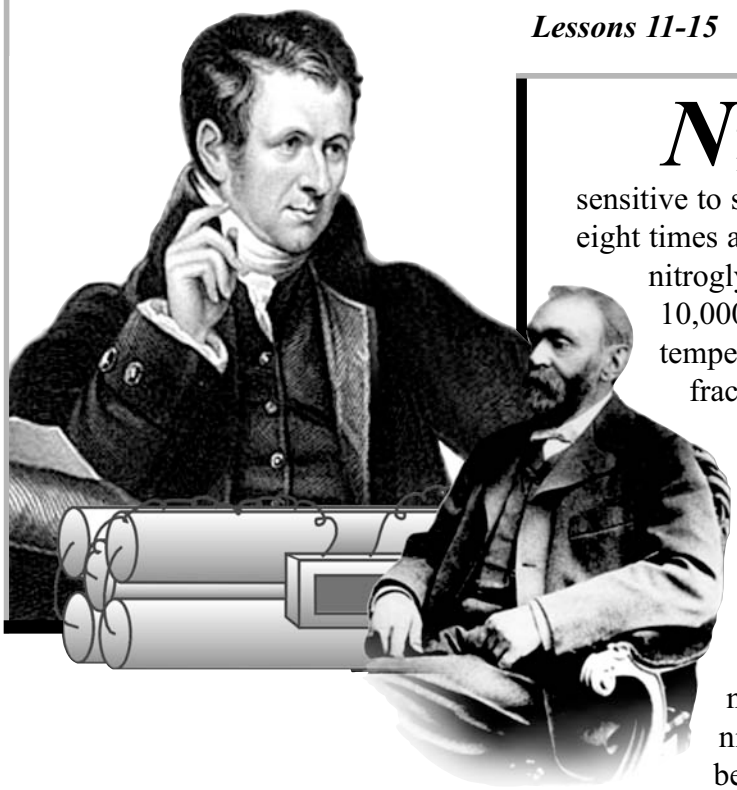


Lesson 15
Compounds

Chapter 3

NITROGEN IN DYNAMITE AND LAUGHING GAS

Section 3
Lessons 11-15



Nitroglycerin is a powerful explosive. It is a heavy, oily liquid. Nitroglycerin is sensitive to shock and can explode if jarred. It is eight times as powerful as gunpowder. When nitroglycerin explodes, it produces about 10,000 times its own volume of gas at a temperature of 3,000ºC and does so in a tiny fraction of a second. It releases four gases: carbon dioxide, water vapor, nitrogen gas and oxygen gas. These gases are very hot and expand with great force. More than 10 years passed before anyone dared to manufacture and sell nitroglycerin.

In the 1860s, a Swedish scientist named Alfred Nobel began selling nitroglycerin as blasting oil. Alfred Nobel believed the explosive could be used for great good. He had visited the United States as a teenager when the country was vast. Nobel learned of an incredible project that was announced by Abraham Lincoln: build a railroad all the way across the continent. Connecting California with the Eastern States would take the railroad through the great Rocky Mountains.

Alfred Nobel proposed that nitroglycerin would be a great help in mining and construction. People could use its explosive power for quarrying rock, blasting tunnels, digging canals, making roadways and other construction projects. Nitroglycerin would replace hours of toil with a single blast.

Alfred Nobel packed instructions of its usage with each shipment, warning of its dangers. Heat, a static electric spark or a slight jar could cause the nitroglycerin to explode. He cautioned individuals to handle the liquid with care.

VOCABULARY

Diatom: a type of algae that has a cell wall that contains silica
Silica: a hard crystal, silicon dioxide (SiO_2)

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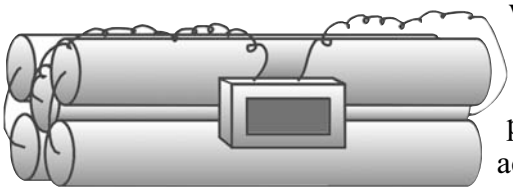
Many workmen ignored the directions. One man used the thick liquid to grease the axle of his wagon. Others threw their unused portion in a fire. Still others could not believe its force. People would stand too close when detonating the nitroglycerin. People who ignored the dangers of nitroglycerin died.

In 1864, Alfred Nobel's own nitroglycerin factory exploded. The disaster killed five people, including Nobel's young brother, Emil.

Alfred Nobel stopped the production. He built a floating laboratory in the middle of a lake and searched for a way to make nitroglycerin easier to transport and use.

Alfred Nobel became convinced the nitroglycerin would be safer and more useful as a solid. The overall explosive effect would be easier to control. He needed a substance that could absorb the thick liquid, could be formed into sticks and could retain its explosive force. Alfred Nobel found the answer in diatomaceous earth, which is soil made of tiny skeletons of sea life.

A ***diatom*** is a type of algae. Diatoms are one-celled life, but they grow in colonies. Unlike most plants, their cell walls are made of ***silica***, which is much stronger. In Alfred Nobel's time, silica was used to insulate steam pipes, as a filter and as an abrasive. Today, diatomaceous earth is sometimes used in swimming pool filters.



Diatomaceous earth is naturally porous. It soaks up to three times its own weight of nitroglycerin. He molded the moistened material into sticks.

People could handle the sticks much more safely. Alfred Nobel invented the name *dynamite* for his new product. Construction companies everywhere used dynamite for blasting out foundations on buildings and bridges, tunnels, mines and canals. The number of accidental deaths fell dramatically. The military used dynamite in the manufacture of bombs.

Alfred Nobel's skill as an inventor and businessman made him a fortune. Nobel became a multi-millionaire.

A newspaper incorrectly reported Alfred Nobel had died in an explosion at a factory and published his obituary. Alfred Nobel had the unsettling experience of reading his own death notice. Newspapers described his sales of explosives to the military. They focused on the wartime use of his invention and portrayed him as a killer. They called him a merchant of death. People believed his wealth came from selling deadly explosives to nations at war.

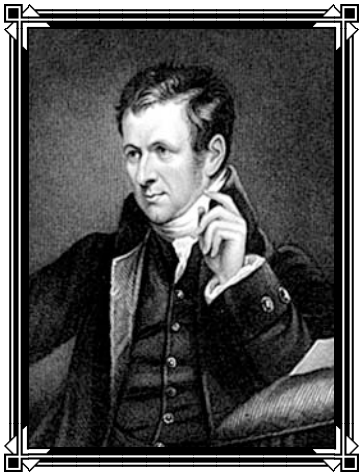
In 1896, a heartsick Alfred Nobel penned a will. He instructed that his estate should be invested wisely. His fortune was so large the interest each year was enough to fund five prizes. He wrote, "The interest shall be distributed in the form of prizes to those who, during the preceding year, shall have conferred the greatest benefit on mankind."

People in each of five prize categories were to receive a part of the interest money earned. The first two prizes were for achievement in physics and chemistry: Alfred Nobel said, "One part goes to the person who shall have made the most important discovery or invention within the field of physics and another part to the person who shall have made the most important chemical discovery or improvement." He wanted the prizes to be international in scope. "It is my express wish," he wrote, "that in awarding the prizes no consideration whatever shall be given to the nationality of the candidates, but that the most worthy shall receive the prize."

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The other three prizes were for achievements in medicine, literature and bringing peace among nations. In 1968, a prize for economics was added to the list.

Normally, the award committee for scientific subjects does not give the prize until a particular discovery has proven itself worthy of recognition. Sometimes, 25 years pass between the time the discovery is made and when the award is given. Today, if the award goes to one individual it is worth $300,000. Often, the prize is shared by two or three people.



The first ***Nobel Prizes*** were awarded on December 10, 1901. The first winner of the chemistry prize was Jacobus H. van't Hoff. He was a chemist from the Netherlands who worked out the three-dimensional shapes of molecules. He also studied chemical solutions and explained the role of heat in chemical reactions. The first winner of the physics prize was Wilhelm C. Roentgen, a German scientist who discovered X-rays, in 1895.

Today, the Nobel prizes are more famous than Alfred Nobel. The Nobel Prize is a great and well-known honor.

MEDICAL USES OF NITROGEN

In addition to its role in acids, fertilizers and explosives, nitrogen is found in some medical compounds. Nitroglycerin has a medical use. In some people, the walls of arteries near the human heart thicken and harden. Blood cannot reach the heart muscles, which starve for oxygen. As the blood supply fails, the muscles signal their condition to the brain. The victim experiences agonizing chest pains. This heart condition is known as *angina pectoris*.

A person who experiences an angina attack can take nitroglycerin tablets for relief. Nitroglycerin causes the walls of the arteries to relax. The arteries will began to open up, allowing blood to flow more readily. The heart muscles receive oxygen and thus ease the pain.

Nitrogen is found in the painkiller *laughing gas*. Humphry Davy, an English chemist, discovered laughing gas in 1800. As a young man, Davy believed his family was wealthy. When his father died, he learned that instead of great wealth, he was deeply in debt. Humphry took a job as an apothecary's assistant. An *apothecary* is a person who fills prescriptions and mixes medicines. Slowly, Humphry Davy paid off the family debt. He then became a chemist and took a job at a hospital.

Humphry Davy's first medical triumph was his discovery of laughing gas. The gas, nitrous oxide, is the chemical combination of two nitrogen atoms and one oxygen atom (N_2O). Humphry Davy reported that the gas, when breathed, caused him to feel light-headed. He could not control his emotions. He would have a crying binge or a laughing jig.

One day his employer called Davy from the laboratory to make the medical rounds. Unknown to the doctor, Davy had been testing nitrous oxide. As the patients described their ailments, Davy responded with howls of laughter. Finally, Davy was lead from the hospital room, giggling uncontrollably. In his report of nitrous oxide, Davy said, "It appears to me that laughing gas is capable of destroying physical pain. It overcame a toothache that I had. Maybe it can be used during surgical operations."

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Nitrous oxide alone is not powerful enough to be used for general surgery because patients still felt some pain. For that reason, Davy's discovery finds its greatest use by dentists in pulling of teeth. Nitrous oxide is also used in combination with other painkillers.

Humphry Davy was the first scientist to give public lectures about his discoveries. Ordinary people were given the opportunity to learn about science. His lectures included dramatic displays of electricity, exploding gases and other marvels of chemistry. In the early 1800s, he was England's best known scientist.

Unfortunately, Humphry Davy's habit of sniffing and tasting new chemicals left him physically disabled. Then, in 1812, an explosion nearly blinded him, but his mind remained sharp. He hired an assistant named Michael Faraday. Together, both men continued to make first-rate discoveries. Humphry Davy died at age 51, short of a full life span, because he was weakened by his lack of caution in handling dangerous chemicals.



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