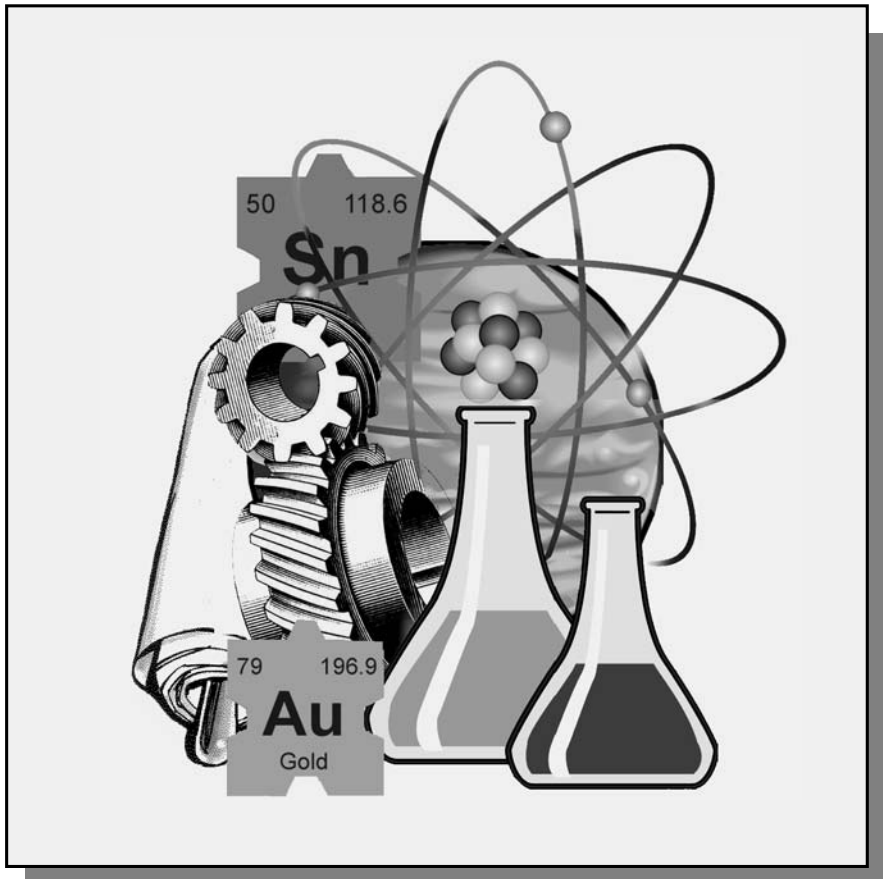
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This chapter requires a companion activity book in which students respond to questions on text content. Answers are found in the *Teacher's Resource Kit*.



Chapter 7

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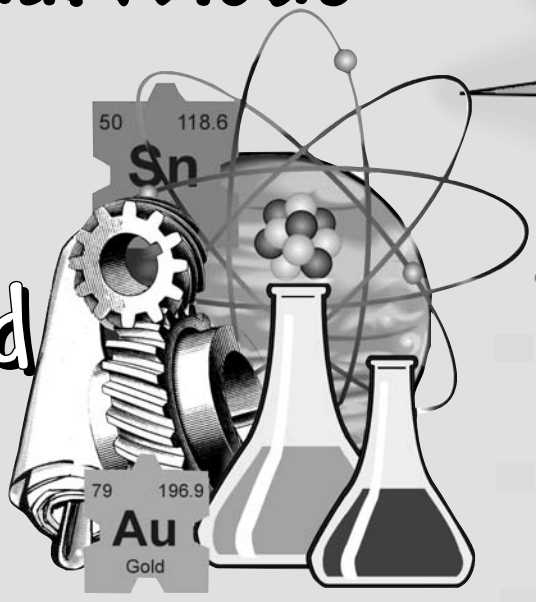
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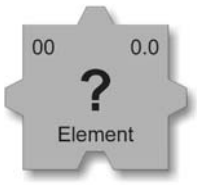


"The study of science is the chronicle of man's quest to discover the essence of life and how the marvelous laws of creation are applied to human needs."



—Ronald Johnson, Ph.D.

Integrated Physics & Chemistry



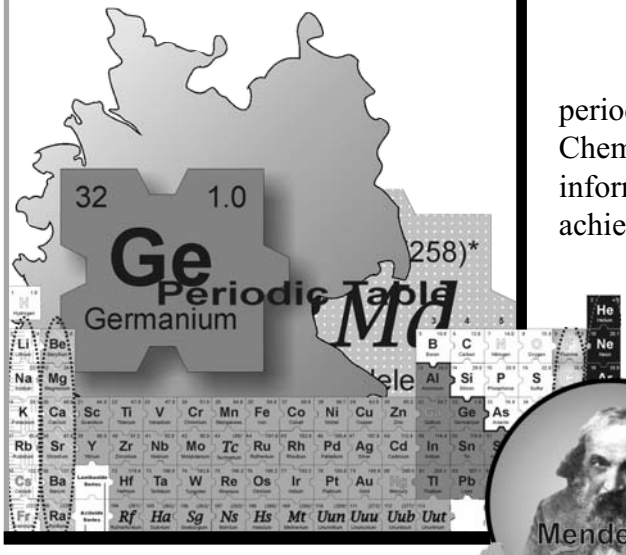
Lesson 1
Elements

Chapter 7

EXPLORING THE PERIODIC TABLE

Section 1

Lessons 1-5



Dmitri Mendeleev faced a problem with his arrangement of the elements in a periodic table. No one believed he was right. Chemists had long searched for a way to summarize information about the elements. Dmitri Mendeleev achieved this goal in March 1869. He described his discovery and put his *Periodic Table of the Elements* before the Russian Chemical Society. When Mendeleev first announced his discovery, chemists debated whether it actually did reveal a useful pattern. Some chemists objected to the arrangement. Mendeleev relied heavily on ***valence*** and ***atomic weight*** to put the elements in order. Chemists at that time described an element by its color, hardness, melting and boiling temperatures, and whether the element and its compounds were solids, liquids or gases.



One way of judging a law of science is its predictive power. Isaac Newton's Law of Gravity is considered an important law because it summarized all of the known facts about how the planets move around the Sun. The Law of Gravity also predicted the motion of other objects. Isaac Newton predicted that comets would follow the Law of Gravity. Edmund Halley, one of Isaac Newton's friends, used the Law of Gravity and successfully predicted the return of what became known as Halley's Comet.

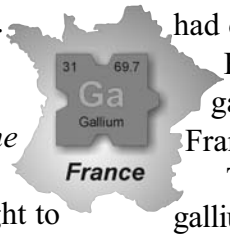
Mendeleev silenced the critics by predicting that the gaps in the periodic table would be filled by elements not yet discovered. Mendeleev predicted valence and atomic weight for the missing elements. He boldly described other properties that chemists considered important. For three of the undiscovered elements, Mendeleev described their color, density, melting and

VOCABULARY

Valence: the number of electrons that an element will accept, give up or share during chemical reactions
Atomic weight: the relative weight of an atom compared to the weight of *carbon-12*
Metal: an element that donates one or more electrons in chemical reactions, forms salts with nonmetals, reacts with oxygen to give oxides, and forms alloys with other metals
Nonmetal: an element that accepts or shares one or more electrons during chemical reactions

boiling temperatures. He gave detailed information about the properties of their compounds with oxygen or chlorine.

One of the gaps in Dmitri Mendeleev's table was to the right of zinc (Zn) and directly below aluminum (Al). He called this missing element eka-aluminum. *Eka* is the Sanskrit word for *one.* The name *eka-aluminum* means *one element below aluminum.* Mendeleev calculated eka-aluminum's atomic weight to be about 68 and set the density at about 5.0. Then, he predicted that eka-aluminum would have a low melting temperature but a high boiling point. Mendeleev also predicted how it could combine with oxygen. The formula would be two atoms of the eka-aluminum and three atoms of oxygen (X_2O_3), with *X* representing the unknown element.



Six years later, in 1875, a French chemist discovered a new metallic element. It had a low melting temperature of 30°C, only slightly above room temperature. The new metallic element would melt in your hands. The new element had a high boiling point of near 2,000°C. The element remained a liquid across a greater range than any other element. It had an atomic weight of 69.7 and a density of 5.94. The new metallic element combined with oxygen as predicted. The Frenchman had discovered eka-aluminum. The French chemist renamed the element gallium (Ga) after the Latin name for France, Gallia.

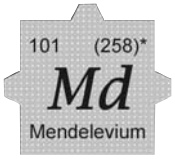
The other gap was to the right of gallium (Ga) and below silicon (Si). Mendeleev called it *eka-silicon* and predicted that it would be a dirty-gray solid and would have an atomic weight of 72 and a density of 5.5. Mendeleev predicted that it would also combine with two atoms of oxygen and with four atoms of chlorine. Its compound with chlorine would be a liquid at room temperature.

In 1886, a German chemist found an element that matched Mendeleev's prediction of eka-silicon. The German chemist named his discovery *germanium* for Germany. The symbol is *Ge*. It is located just below silicon in the periodic table and shares many properties with silicon. Germanium conducts electricity, but not as well as a ***metal*** such as copper, yet better than a ***nonmetal*** such as sulfur. Germanium is a ***semiconductor***.



Mendeleev's prediction for the third missing element turned out to be as accurate as the other two. Within 15 years, chemists found all of Mendeleev's missing elements. Dmitri Mendeleev's fame grew because he went beyond predicting the existence of these elements; he predicted their specific properties.

The Royal Society awarded Mendeleev the Davy Medal. Chemists honored Dmitri Mendeleev in the periodic table that he discovered by naming element number 101 (discovered in 1955 by American nuclear chemists) mendelevium (Md).



VOCABULARY

Semiconductor: the substance between a metal and a nonmetal in its ability to conduct electricity, germanium is a semiconductor

Periods: the horizontal rows in the periodic table that changes from metals on the left to nonmetals on the right

Inert: does not react with other elements

Families: vertical columns of the periodic table, elements of the same family have similar chemical properties, also known as groups

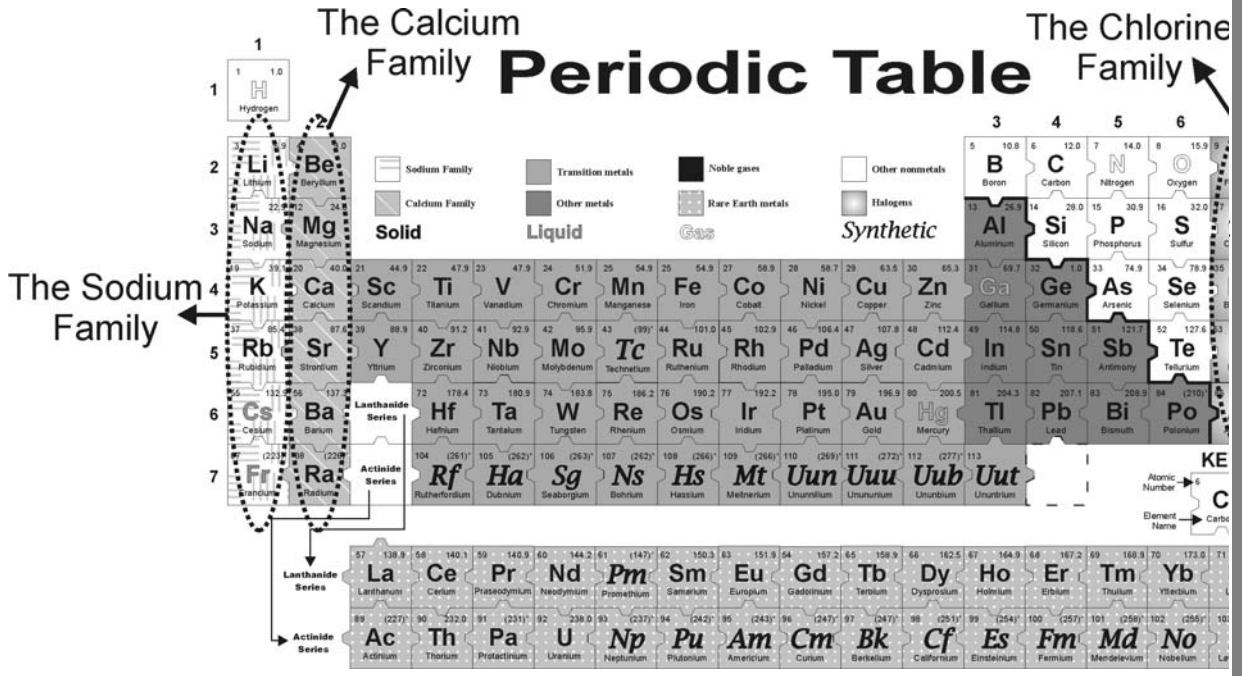
Inert gas family: the elements are not active chemically and are usually given a valence of zero, also known as the noble gases

The periodic table arranges symbols for the elements in horizontal rows. A full size periodic table (located on the back inside cover) contains information about each element, such as the atomic number, atomic weight, element name, valence, information about how readily the element reacts and arrangement of its electrons. Some periodic charts also show which elements are solids, liquids and gases, and whether the elements are metals or nonmetals. The periodic table is a powerful tool for understanding the chemical properties of an element and its compounds.

Periods are the horizontal rows in the table that run from left to right. The chemical properties of elements change from metallic to nonmetallic, from left to right across each period. For instance, look at the second period that contains lithium, beryllium, boron, carbon, nitrogen, oxygen, fluorine and neon. Lithium (Li) is a highly active metal and beryllium (Be) is a less active metal. Boron (B), carbon (C) and nitrogen (N) are nonmetals and not very active. On the right, however, the activity increases. Oxygen (O) and fluorine (F) are the two most active nonmetals known. Neon (Ne) at the far right is a nonmetal and an inert gas. ***Inert*** means *no action*. Neon does not interact with other elements. It stays aloof and inactive.

Once you get to neon and then come back to sodium (Na) the properties repeat again. Sodium and magnesium (Mg) on the left side of the table are active metals. The elements in the center become progressively inactive, and their properties become more like nonmetals. Silicon (Si) and phosphorus (P) are definitely nonmetals. Chlorine (Cl) is a very active nonmetal. Argon (Ar) at the far right, is a nonmetal and an inert gas. Like neon, it does not react with other elements.

When the elements are arranged in this way, their properties appear to repeat at regular intervals or periods. The arrangement is given the name *periodic table* because it shows that elements repeat their properties at regular periods. This aspect convinced many scientists that the world reflects intricate design and therefore certain components could be predicted rather than be the result of spontaneous accidents.



Periods do not contain the same number of elements. The first period contains only two elements, hydrogen and helium. The next two periods, starting with lithium and sodium, each contain eight elements. Periods four and five, starting with potassium (K) and rubidium (Rb) each have 18 elements. The final two periods, beginning with cesium (Cs) and francium (Fr) have places for 32 elements each. These periods are so long that they do not fit well on a page. Most periodic charts show parts of these long periods at the bottom. All the elements in the Lanthanum Series fit between barium (Ba) and hafnium (Hf).

All the elements in the Actinide Series would follow radium (Ra). This last period is incomplete because elements beyond uranium are not found in nature. Instead, they are radioactive elements produced in the laboratory.

Families are the vertical columns (listed up and down) of the elements. The *sodium family* is made of lithium (Li), sodium (Na), potassium (K), rubidium (Rb), cesium (Cs) and francium (Fr). All of the elements in that family are metals and highly reactive. They share similar chemical properties and have a valence of +1. They give up a single electron to form ions with a single positive charge. For instance, the ion of sodium is Na^{+}. The chemical changes between elements of the same families are not as dramatic as the chemical changes between elements of the same periods.

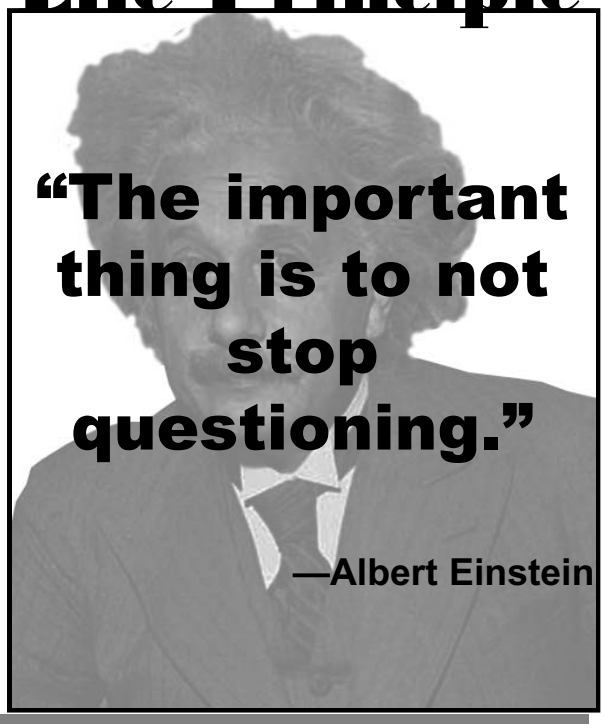
Although hydrogen (H) is at the top of the sodium family, it is not considered a member of that family. Hydrogen is often shown in a periodic chart in a box separated from the others. Hydrogen properties are unique. Hydrogen is considered a single family by itself.

Another family is the *calcium family* of beryllium (Be), magnesium (Mg), calcium (Ca), strontium (Sr), barium (Ba) and radium (Ra). These elements all have a valence of +2. They give up two electrons and form ions with a double positive charge. For instance, the ion of calcium is Ca^{++}.

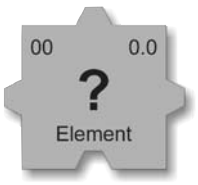
On the right hand side is the *chlorine family* made of fluorine (F), chlorine (Cl), bromine (Br), iodine (I) and astatine (At). All of the chlorine *nonmetals* have a valence of –1. They accept an electron and form ions with a single negative charge. For instance, the ion of chlorine is Cl^{-}.

The last column on the right in the periodic table is the ***inert gas family***. The members of this family are helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe) and radon (Rn). They are so inert they do not normally form compounds. They remained hidden from chemists until well into the 1800s. Their electrons are in an especially stable arrangement. For that reason, the inert gases tend not to donate or accept electrons from other elements. They have practically no tendency to form compounds. Their valence is usually given as zero.

Life Principle



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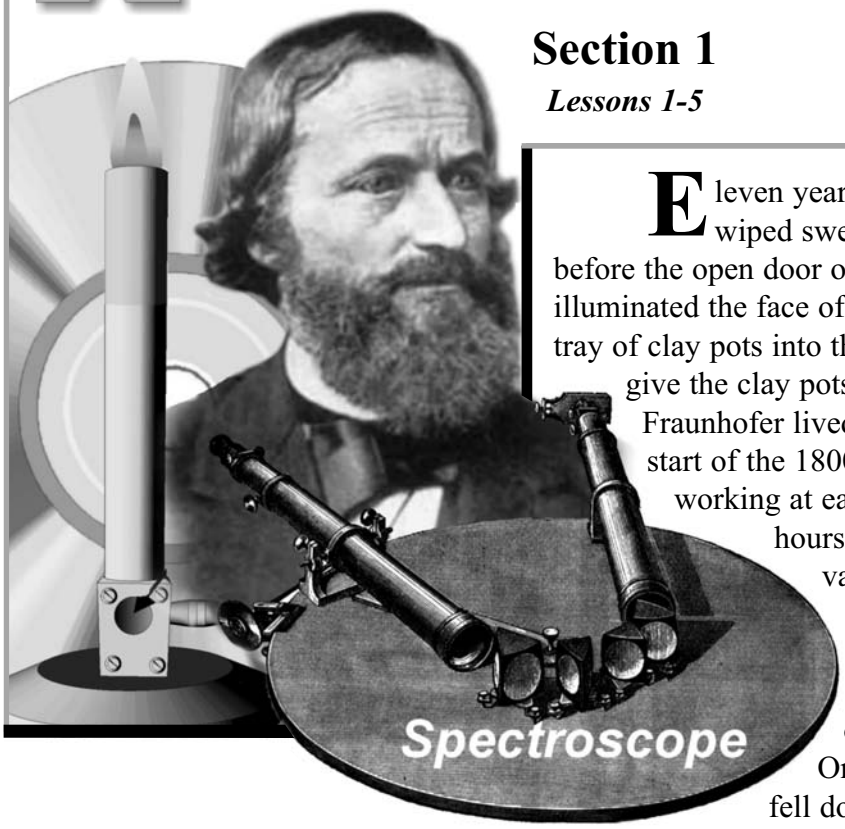
Lesson 2
Elements

Chapter 7

ELEMENT'S FINGERPRINTS

Section 1

Lessons 1-5



Eleven year old Joseph von Fraunhofer wiped sweat from his eyes as he stood before the open door of a furnace. The fiery glow illuminated the face of Joseph as he pushed another tray of clay pots into the oven. The intense heat would give the clay pots a shiny finish. Joseph von Fraunhofer lived in Straubing, Bavaria. At the start of the 1800s, children commonly began working at early ages. Joseph labored ten hours a day pushing clay bowls and vases into the glazing furnace. Joseph had hoped to study science, but his family was poor. The family lived in an old, sagging apartment building. One day, the two-story building fell down without warning; the Von Fraunhofer family was trapped in the rubble. Workmen began a frantic effort to rescue any survivors. Although everyone else in his family perished, rescuers pulled out the young boy alive from the ruins. The rescue efforts had blocked the street and stopped the carriage of the owner of an optical factory. Workmen persuaded him to take the boy to the doctor. The doctor decided that all Joseph von Fraunhofer needed was a warm meal. The wealthy eye doctor took the young boy to his mansion and fed him.

The optician noticed that Joseph was a quick-witted young boy. Because he appeared eager to listen when adults spoke and was willing to work, Joseph earned a job at the optical factory. The factory designed and built optical instruments, such as telescopes to be used by astronomers. Joseph von Fraunhofer learned to help build the telescopes. Although he knew nothing of stars, telescopes or other optical instruments, Joseph read all he could about the great astronomers and their discoveries. He learned that Isaac

VOCABULARY

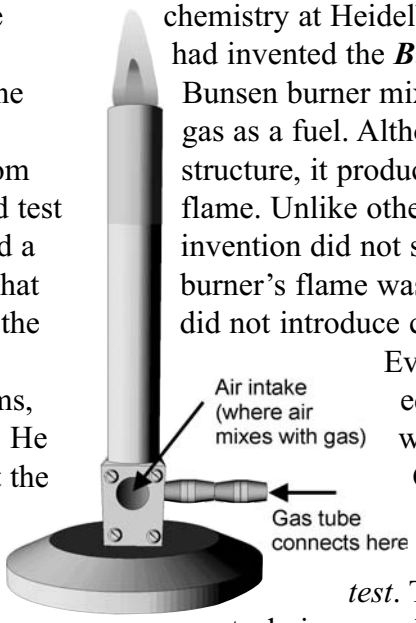
Spectrum: a rainbow of colors that make up white light or light from the sun
Spectroscope: identifies elements from the light emitted by a glowing compound, a spectroscope can use a prism or diffraction grating
Bunsen burner: a heating device found in most chemical laboratories; the burner is a short tube connected to a source of gas with an opening at the bottom to admit air

Newton had divided the light of the Sun into the colors of the ***spectrum***. Years later, astronomers showed that a ***spectroscope*** divided starlight into the colors.

Joseph von Fraunhofer worked hard at the optical company. His improvements to glassmaking earned a promotion. He developed accurate ways to measure the index of refraction of glass. Joseph became an expert at designing precision optical instruments, causing astronomers to value Joseph's telescopes. The factory kept a waiting list for Joseph's instruments. The factory owner rewarded Joseph von Fraunhofer by putting him in charge of the entire factory.

Before shipping an instrument from the factory, Joseph von Fraunhofer would test it himself. In 1814, Von Fraunhofer tested a prism attached to a telescope. He found that many dark lines crossed the spectrum of the Sun. Additional tests with other prisms confirmed the lines. With improved prisms, Von Fraunhofer counted 600 of the lines. He measured their positions and noticed that the lines always fell at the same place along the spectrum. Then, Von Fraunhofer found the same lines in starlight. He wrote to scientists telling them of the lines, but they could not see them. The lines were barely visible through prisms made of poor quality glass. Unfortunately, scientists ignored Fraunhofer's report on the subject. In 1826, at the age of 39, Joseph von Fraunhofer died of tuberculosis. He did not live to learn that his discovery became one of the most powerful tools in science. About forty years passed before scientists looked at his report and saw the true meaning of the lines—that light has design and pattern.

In the 1850s, Robert Bunsen taught chemistry at Heidelberg University. He had invented the ***Bunsen burner***. The Bunsen burner mixed air with natural gas as a fuel. Although very simple in structure, it produced a hot, steady flame. Unlike other burners, Bunsen's invention did not smoke or flicker. The burner's flame was nearly invisible and did not introduce colors of its own.

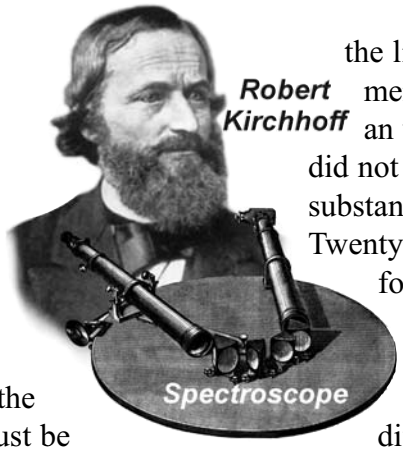


Even today, chemists equip their laboratories with Bunsen burners. Chemists find the burners especially useful for the *flame test*. The flame test is a technique used to determine which kinds of elements are found in a substance.

Robert Bunsen wanted to improve the flame test. He asked Robert Kirchhoff, a physicist at the university, for help. Together, the two investigators invented the spectroscope. Their arrangement expanded the spectrum. A movable-viewing arm attached to a pointer measured exactly the position of each colored line in the spectrum. The lines in the spectrum could be bright or dark. Whether bright or dark, the combination of lines in the spectrum was an unfailing guide to the element being heated. In the spectroscope, each element produced its own signature, an arrangement of lines shared by

VOCABULARY

Dispersion: the separation of light into the colors of the rainbow; dispersion is caused by each color having a different index of refraction and is bent by differing amounts when passing through a prism
Diffraction: a property of wave motion in which waves bend or expand as they pass through small openings or around barriers
Interference: interaction between two waves, causing a change in amplitude; light is made brighter or dimmer by interference



no other element. Each substance could be identified by its spectroscopic fingerprint. Sodium, for example, has two lines close together. If some unknown substance is heated until it glows, and these two lines appear in the spectrum, then sodium must be part of the unknown compound. The spectroscope was a powerful tool used to diagnose specific elements in substances. Suppose a glowing substance emitted lines unlike any others. Then the substance must contain an unknown element. The spectroscope could be used to detect new elements.

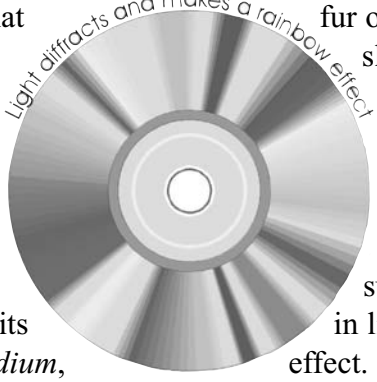
Bunsen and Kirchhoff used the spectroscope to search for new elements. In 1860, they discovered a new element that had blue lines in its spectrum. They named the element *cesium* (Cs) from a Latin word meaning *sky blue.* Cesium is a member of the sodium family of elements. One year after finding cesium, Kirchhoff and Bunsen discovered another element. This one had a series of magnificent red lines in its spectrum. They called the element *rubidium*, from a Latin word which means *deep red.*

Kirchhoff put a spectroscope on a telescope. He studied the lines in the spectrum of the Sun. As he suspected, the elements on Earth also existed on the Sun. Kirchhoff found the telltale lines of hydrogen, carbon, oxygen, nitrogen, iron and many other elements present in the Sun. This evidence led astronomers and other scientists to conclude that Earth and the Sun were somehow related in their origin or creation.

In 1868, a chemist and an astronomer working together found a pattern of lines in the spectrum of the Sun that did not match the lines of any element on Earth. These men concluded that the light came from an unknown element, possibly one that did not exist on Earth. They named the new substance *helium*, which means *from the Sun*. Twenty-five years passed before helium was found on Earth.

A prism separates light into colors by ***dispersion***. It causes a spectrum because each color has a different index of refraction. A prism bends light waves at the blue end of the spectrum more than it does the light waves at the red end of the spectrum. Each color of light has a slightly different index of refraction, which causes the prism to spread light into a rainbow of colors.

Another way to produce a spectrum is with a *diffraction grating*. Perhaps you have noticed the healthy shine from the fur of a dog or horse that has a slick, black coat. Blue and violet light seems to shimmer on the coat. This is an example of colors created by ***diffraction***. As another example, the surface of a CD when tilted in light produces a rainbow effect. This color is caused by diffraction. A diffraction grating is a surface with very fine parallel grooves cut on its surface. A typical grating has about 14,000 lines to the inch. Joseph von Fraunhofer made the first diffraction gratings when he used very fine and closely spaced wires. With this device Von Fraunhofer was able to separate white light.



Diffraction is caused by the wave nature of light. Anytime light passes through a very small opening, it expands outward as if the opening were a new source of light. When light strikes a surface with thousands of the tiny slits, each slit acts as a source of

light. The diffraction grating can be transparent and let the light pass through, or it can be a mirror and reflect the light. In either case, a grating with 14,000 slits or grooves breaks the beam of light into 14,000 waves. Each wave spreads out from the diffraction grating independently of the others. As the waves crisscross, they interfere with one another. Where the waves arrive in phase, with crest meeting crest, the effect is *constructive* ***interference***. Where the waves arrive out of phase, with crest meeting trough, the effect is *destructive interference*. The light waves reinforce each other in certain directions and cancel each other in other directions. From a particular viewing angle, some of the colors are missing because the waves cancel one another (destructive interference), but others are visible because the waves reinforce one another (constructive interference).

The effect of diffraction gratings is common in nature. Examples include butterfly wings, fish scales, feathers of some birds and other surfaces with fine scratches or very close grooves. The longer the wavelengths of light, the less likely they will be diffracted. For all colors to be equally affected, the fine spaces between the hairs must be very tiny. In the case of hair, not all colors are affected the same. The wavelength of red light is longer than the wavelengths of blue and violet light. Sometimes the lustrous effect from hair shows only a shimmer of blue or violet.

Most modern spectroscopes use diffraction gratings rather than prisms. Diffraction gratings are preferred in place of prisms, for most astronomical applications.

You are progressing. The next lesson informs you about the lights by which you read this book. You will learn that lights involve a lot more than a small switch on a wall.

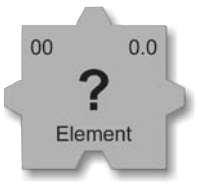


Life Principle

"Life is not just an accident based on random processes."

—Edgar D. Mitchell

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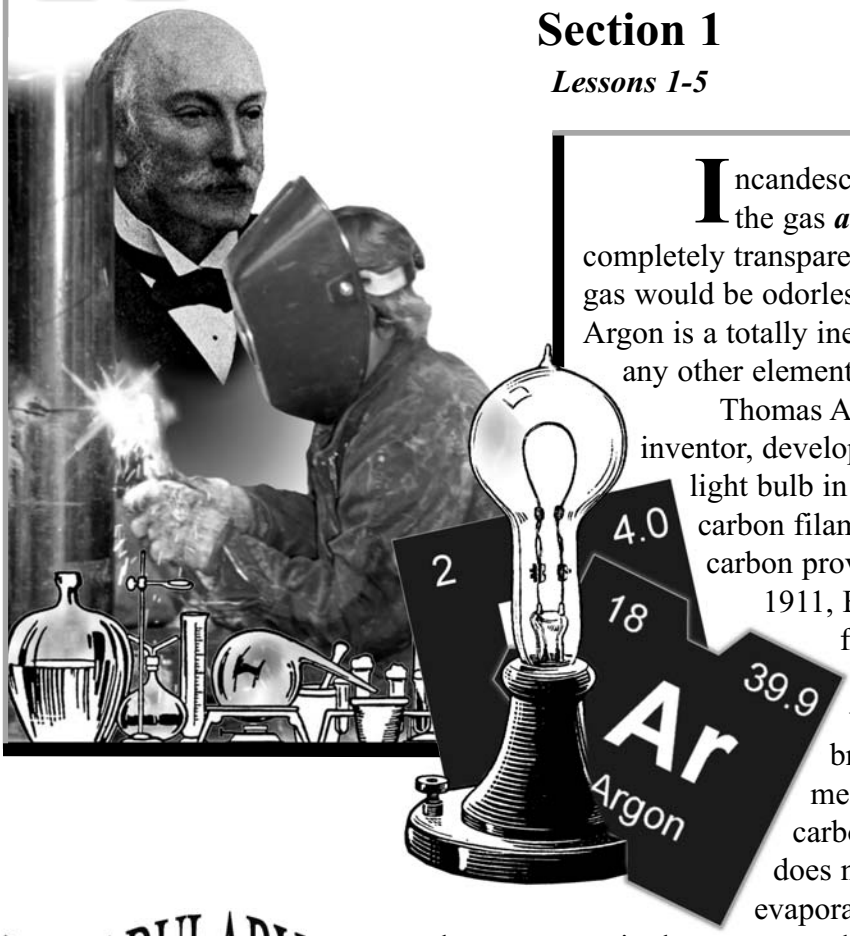
Lesson 3
Elements

Chapter 7

THE NOBLE GASES—ARGON

Section 1

Lessons 1-5



Incandescent light bulbs are filled with the gas ***argon***. Argon is colorless and completely transparent. Should the bulb burst, the gas would be odorless, tasteless and nontoxic. Argon is a totally inert gas and does not react with any other element.

Thomas Alva Edison, the American inventor, developed the first practical electric light bulb in 1879. Thomas Edison used carbon filaments in vacuum bulbs. The carbon proved to be too easily broken. In 1911, Edison replaced the carbon filaments with tungsten. Tungsten is strong, even when white hot. Jarring does not break it. Tungsten has a high melting point, almost as high as carbon itself. Although tungsten does not melt, it does slowly evaporate in the vacuum bulb. When the tungsten wire becomes too thin, the bulb burns out.

Filling the light bulb with a chemically inactive gas can slow the evaporation of tungsten. The pressure of the gas helps prevent atoms from escaping from the surface of the white-hot tungsten that enables the light bulb to burn longer. The first light bulbs were filled with nitrogen. By 1915, argon replaced nitrogen. The replacement was the first commercial application of a noble gas. Argon is still used today to increase the life of light bulbs.

The discovery of argon was made in the 1800s when chemists searched for new elements and sought to understand chemical properties. Three powerful tools came to the chemists' aid in this quest. Electricity was one of the tools. Humphry Davy used electrolysis to discover sodium and other metallic

VOCABULARY

Argon (Ar): inert gaseous element that makes up about one percent of the atmosphere; the most common member of the noble gas family

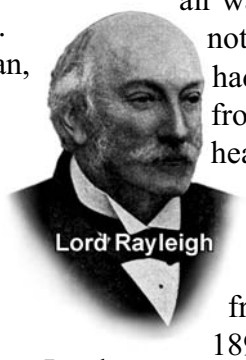
Diatomic: a molecule made of two identical atoms such as oxygen gas (O_2)

Monatomic: a molecule made of a single atom, the noble gases form monatomic molecules

elements. Mendeleev's Periodic Law was the second tool. With it, he predicted missing elements. The spectroscope was the third tool.

The greatest triumph of the spectroscope was the discovery of the noble gases, a complete family of elements never before suspected. The *noble gases* are also referred to as the inert gas family. Even Mendeleev and his periodic chart had not predicted their existence. Argon, one of the noble gases, makes up a little less than one percent of the atmosphere. Although present in every breath we take, chemists became fully aware of argon only after the invention of the spectroscope.

The first chemist to detect argon was Henry Cavendish, the English scientist who discovered hydrogen. In 1785, Henry Cavendish experimented with nitrogen from the atmosphere. Normally, nitrogen and oxygen in the atmosphere will not combine, but Cavendish forced the combination by sending an electric spark through a sample of air. Despite Cavendish's best efforts, a small bubble of gas remained uncombined. Even the electric spark would not make it combine with oxygen. Cavendish wondered if air contained a tiny amount of some other gas even more inert than nitrogen. Other chemists did not learn of Cavendish's experiment until well after his death.



Lord Rayleigh, an Englishman, was born John William Strutt. He inherited his father's title, and Lord Rayleigh is how he is best known. In the 1880s, Lord Rayleigh prepared nitrogen in two different ways. First, he released nitrogen from nitrogen compounds. These samples contained pure nitrogen. Next, Lord Rayleigh took a sample of air and began removing all known gases except nitrogen: water vapor, carbon dioxide and oxygen. The experiment should have left him with pure nitrogen. Lord Rayleigh weighed equal volumes of nitrogen gas from the two experiments. Nitrogen from the air weighed more than nitrogen that was freed from compounds.

The atoms of most gases such as oxygen, nitrogen and chlorine form ***diatomic*** molecules. The prefix *di* means *two*. A diatomic molecule contains two identical atoms. Left to themselves, two oxygen atoms join together to form O_2, a diatomic molecule. Nitrogen in the air also forms diatomic molecules, N_2.

Under certain conditions, oxygen will form *ozone*, which has three atoms, O_3. Ozone is made as electricity zaps regular oxygen. Lightning, for instance, or the spark from an electric motor, can produce ozone. Because ozone (O_3) has three oxygen atoms, it is denser than regular oxygen gas (O_2). Lord Rayleigh sent an electric current through the nitrogen gas. The only gas he found was regular diatomic nitrogen (N_2). Lord Rayleigh wanted to know why nitrogen gas from the atmosphere was denser than pure nitrogen gas released by compounds. Lord Rayleigh eliminated each possible explanation one by one. Finally, he correctly concluded that the nitrogen sample from the air was denser than expected because it was not pure nitrogen. His original experiment had failed to remove completely every gas from the atmosphere. Some other gas heavier than nitrogen remained mixed with nitrogen and made the sample heavier than pure nitrogen.

Lord Rayleigh was becoming frustrated at his lack of progress. In 1892, he wrote a letter to a scientific journal and described his results in detail. He asked for suggestions. None came. A year or so later, William Ramsay, a young Scottish chemist, asked if he could work on the

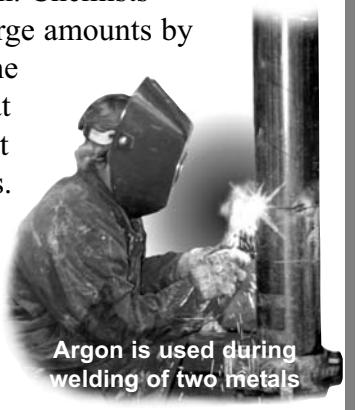
problem. Lord Rayleigh agreed. William Ramsay repeated all the previous experiments and obtained the same puzzling result. He removed every gas from the atmosphere except the mystery gas and nitrogen. Then he passed the sample over red-hot magnesium that combined with the nitrogen and removed it. Ramsay was left with a small bubble of gas that refused to react with magnesium. Nitrogen itself was the least active gas known at that time. Yet, this bubble of gas was far less reactive than nitrogen. It resisted all efforts to make it form compounds. It would not form oxides with oxygen or chlorides with chlorine nor would it react with metals. Powerful bases and strong acids left it untouched. As Cavendish had found, even electricity would not coach the mysterious gas into combining with other elements.

William Ramsay made one final experiment. He applied an entirely new tool to the problem—the spectroscope. William Ramsay heated gas from the sample and studied the lines of light emitted. He found bright lines in a position that fit no known element. The spectroscope revealed that the atmosphere contained a gas that was a new element.



In 1894, William Ramsay and Lord Rayleigh announced that they had found a new element. The gas made about one percent of the atmosphere of Earth. It had no tendency to combine chemically with other elements. They named the gas *argon*, from a Greek word for *inert*.

Argon was the first noble gas discovered. It is also the most common of the noble gases on Earth. Chemists produce argon in large amounts by extracting it from the atmosphere. For that reason, it is the least expensive noble gas. Like the other members of its family, argon is colorless, odorless and tasteless.


Argon is used during welding of two metals

One of the primary industrial uses for argon is in light bulbs. Argon is also used during welding of two metals to keep them from reacting with oxygen in the air. A stream of argon gas flowing around the welding electrodes excludes the atmosphere. The metal parts are protected from oxygen until they are joined.

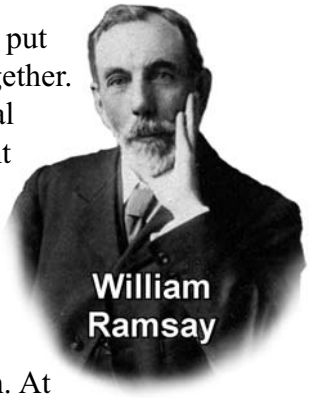
Despite every effort, argon has never been coached into forming a molecule with another element. Unlike oxygen gas (O_2), argon and the other inert gases are so inactive they even avoid one another. Argon (Ar) as a gas is made of a single atom. A molecule made of a single atom is ***monatomic***. The prefix *mon* means *one*. Argon gas is monatomic.

The atomic weight of argon is heavier than chlorine but lighter than potassium. Yet, no gap in the periodic table was at that location. William Ramsay realized that the periodic table was missing an entire family of elements. If Ramsay were correct, argon would be but one of a whole family of new gases. These new gases would have a valence of zero.

Ramsay began searching for new elements. He put together two reports that showed promise. Years earlier, the English astronomer, Joseph Lockyer, reported his discovery of helium, an element in the Sun that had not been found on Earth. Most chemists did



nothing with his report because Lockyer could not produce a sample of the gas to test. In 1890, another scientist released gases from a uranium ore by treating the mineral with an acid. The spectrum contained lines of an unidentified gas.



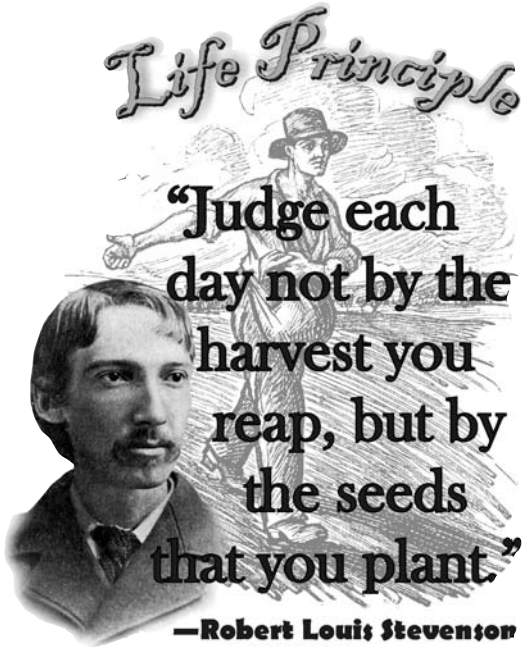
William Ramsay put the two observations together. He compared the spectral lines of the solar element with the lines of the mystery gas trapped in the uranium ore. They were the same. Helium, the element in the Sun, had been found on Earth. At about this time, William Ramsay also received samples of a gas taken from a natural gas well in Texas. He had asked for the sample thinking it might contain argon. Instead, the gas contained helium. For his work with the inert gases, William Ramsay received knighthood and the 1904 Nobel Prize in chemistry.

Lord Rayleigh received the Nobel Prize in physics that same year. Because Lord Rayleigh was a baron, he automatically held a seat in the House of Lords, one of the two houses of the British Parliament. *Lord* is an English title for a member of nobility. Lord Rayleigh was a member of nobility.

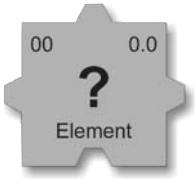
The name *noble gases* refers to the fact that the gases are inert and aloof. Although it was not true of Lord Rayleigh, people had the idea that members of nobility were reserved and avoided ordinary people. Members of the noble gases do not associate with other elements just as members of nobility usually do not associate with common people.

Nitrogen is an inert gas, however, it does not have the other chemical properties of the noble gases. A gas can be inert without being a member of the noble gas family.

The next lesson helps you learn about gasses that can make your voice squeak or take you on a flight.



Integrated Physics & Chemistry



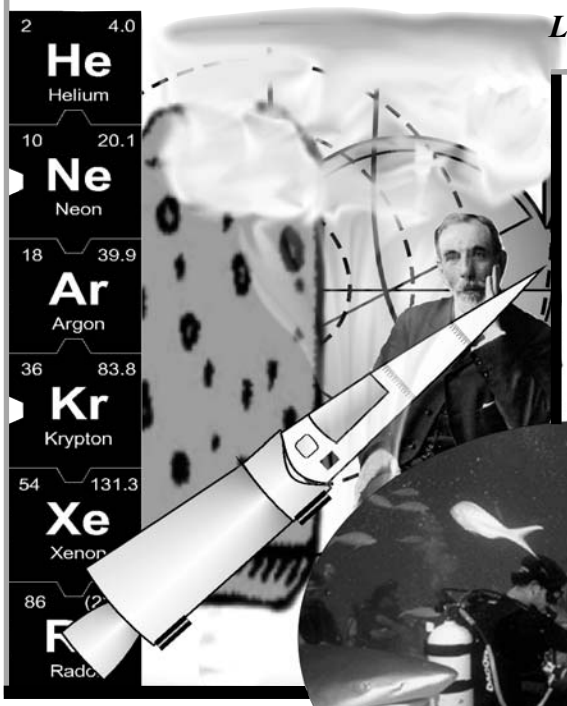
Lesson 4
Elements

Chapter 7

THE NOBLE GAS FAMILY

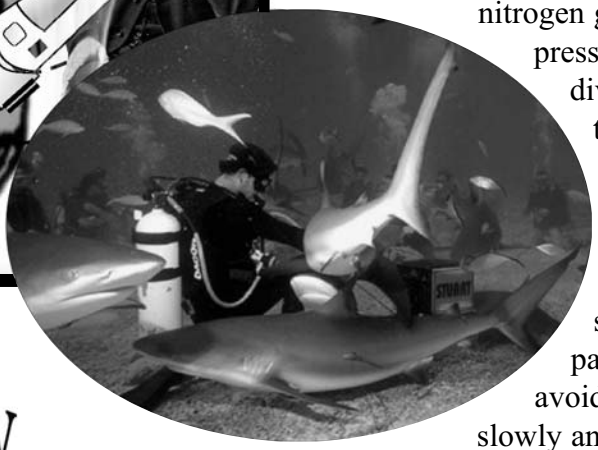
Section 1

Lessons 1-5



Helium (He) is used to fill balloons for special occasions. Meteorologists inflate weather balloons with helium to carry scientific packages high into the atmosphere. Helium is lighter than any other gas except hydrogen, but unlike hydrogen, helium is not explosive.

Divers who go to great depths use helium to avoid *the bends*. The bends are caused by nitrogen gas that dissolves under pressure in the blood. When the diver returns to the surface, the nitrogen comes out of the blood. The bubbles of nitrogen can block blood flow in the body's blood vessels and cut off blood supply to nerve endings. The pain is intense. One way to avoid the bends is to come up slowly and allow the nitrogen to be eliminated without forming bubbles. Rising safely from great depths in this manner can take hours. Another solution is to breathe oxygen mixed with helium rather than nitrogen. Helium does not dissolve under pressure as readily as nitrogen. The possibility of damage from rapid decompression is reduced. Deep diving air tanks are filled with an artificial atmosphere of 80 percent helium and 20 percent oxygen. The less dense helium causes the pitch of the vocal cords to change. A person who breathes helium speaks with a squeaky voice that sounds like Donald Duck. Although an atmosphere of pure helium is not poisonous, it is suffocating because it excludes oxygen. A person who breathes pure helium for its effect upon the vocal cords may pass out if its use is prolonged.

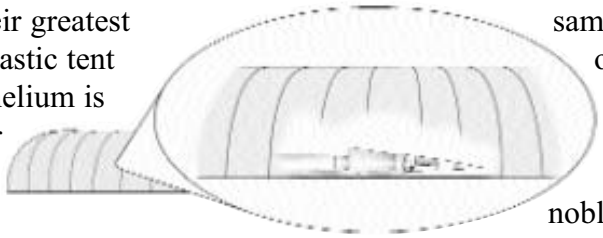


Another use of helium is in land-based tests to achieve supersonic speeds. Supersonic speeds are faster than the speed

VOCABULARY

Helium (He): the lightest of the noble gases, first discovered in the sun, used as an inert component in air tanks of deep sea divers
Fractional distillation: the process of separating a liquid mixture by capturing each part, or fraction, as it boils away
Krypton (Kr): a noble gas used in airport runway strobe lights
Neon (Ne): a noble gas used in advertising signs

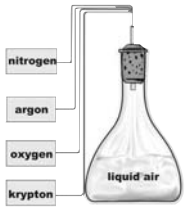
of sound. Sleds holding space components are accelerated to high speeds. Then the sleds are stopped suddenly to test how well the components can withstand the crushing force of sudden deceleration. Air resistance prevents sleds on tracks from reaching their greatest speeds. A plastic tent filled with helium is erected over the test track. The helium-filled tent keeps out the denser atmospheric nitrogen and oxygen. Helium offers far less resistance as the high-speed sled blasts along on its test run.



Helium at room temperature is a gas. It becomes a liquid at –267.9ºC, only a few degrees above absolute zero. No experiment has ever succeeded in making helium a solid despite colder temperature and intense pressure. Because liquid helium is extremely cold, it is used to cool the giant magnets at the heart of powerful subatomic particle accelerators. These giant magnets are called *superconductive magnets* because they conduct electricity far better than normal magnets. *Subatomic particle accelerators* are machines used to break apart atoms.

Although helium is found in air, the concentration of helium is greater in natural gas from some oil fields in North America. Commercial volumes of helium are extracted from natural gas.

Helium and argon are only two members of the inert gas family, also known as the noble gases. William Ramsay began a determined effort to find the other noble gases. He used ***fractional distillation*** of the atmosphere in his search. Fractional distillation depends on the fact that various liquids have different boiling temperatures. First, Ramsay chilled a sample of the atmosphere until all of it turned into a liquid. Then he very carefully warmed it, trapping the gases as they boiled off. William Ramsay's calculations showed that nitrogen would boil away first, followed by argon and finally oxygen. He believed the last small sample of the liquid air after oxygen had nearly boiled away would be rich in a new, heavy inert gas.



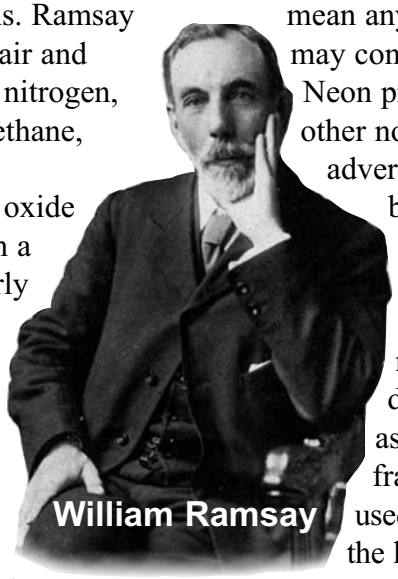
Ramsay was correct. Another noble gas made its appearance by fractional distillation. The gas was heavier than oxygen and belonged between bromine and rubidium in the periodic chart. Ramsay named the gas ***krypton***, from a Greek word meaning *hidden*.

Krypton (Kr) is a dense, colorless, odorless gas found in the atmosphere. Of every 2 million particles in the atmosphere, only one is a krypton atom. Its main use is in strobe lights that produce a powerful blast of orange-red light. Haze and fog are penetrated better by orange-red light than by other colors. For that reason, airports use flashing krypton lights to mark runways.

Krypton is produced by radioactive decay and by nuclear reactors. Scientists use krypton to monitor secret production of nuclear weapons. The scientists know how much krypton is put in the air by natural radioactive decay. They also know how much is created by the known nuclear reactors. Any additional increase of krypton in the atmosphere is a clue that a country is secretly building nuclear weapons.

Back in the 1930s, two young artists began a comic strip about the super hero, Superman. The artists chose Krypton as a scientific sounding name for Superman's home planet. The artists also imagined a mineral, kryptonite, that releases radiation that was harmful to Superman. In real life, krypton is an element, but no mineral is named kryptonite.

To continue his search for noble gases, William Ramsay changed his tactics slightly. Most gases in the air could be removed by chemical means. Ramsay took a sample of clean dry air and removed every known gas: nitrogen, oxygen, carbon dioxide, methane, hydrogen and other trace compounds such as nitrous oxide and ozone. He was left with a sample of gas that was nearly all argon. Then Ramsay cooled the argon until it became a liquid. He believed that the argon sample also contained traces of other noble gases. Slowly he warmed the liquid argon. As he suspected, the first sample that boiled away contained a gas that was heavier than helium, but lighter than argon. Its atomic weight placed it between fluorine and sodium in the periodic table. William Ramsay's son suggested the name ***neon*** for the gas. *Neon* is from a Greek word meaning *new*. Neon (Ne) is odorless, colorless and a very inert element. In a vacuum discharge tube, neon glows reddish orange.


William Ramsay

The primary use for neon is in *vacuum discharge tubes* known as *neon lights*. A high voltage passing through a gas at very low pressure causes the gas to glow. The color of the glow is the same as the spectral lines when viewed through a spectroscope. To make a neon light, a small sample of neon is put into a glass tube that has had the air removed. Metal conductors at each end of the tube are connected to a source of high voltage electricity. When the current flows, the neon gas glows a brilliant reddish orange. The tube can be bent and twisted into almost any shape. Even with twists and turns, the glow is even throughout the length of the tube. Neon lights are popular as glowing advertising signs.

People use the name neon light to mean any glowing tube, although the tube may contain a noble gas other than neon. Neon produces the most intense color, but other noble gases are used in eye-catching advertising signs, too. Krypton glows a brilliant green. *Xenon* emits a blue light. (Xenon is pronounced as if the *x* were a *z*.)

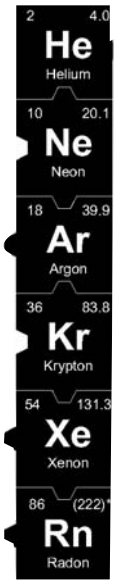
Xenon (Xe), is the last of the noble gases that William Ramsay discovered. His method was to take as much krypton as possible by fractional distillation from air. Then he used fractional distillation on krypton. As the last of the krypton boiled away, Ramsay took the small amount that had not yet boiled and examined it with a spectroscope. He saw the lines of a new element and named it *xenon*, which means *stranger*.

Xenon is present in the atmosphere in extremely small amounts. Less than one particle in 10 million in the atmosphere is a xenon atom. In addition to advertising signs, xenon is used in flash tubes. The flash in most cameras contains a tube of xenon gas. When a high voltage discharge goes through the gas, it emits an intense burst of white light. The light from xenon is more intense and carries more energy than the light from the other noble gases. For that reason, xenon is used in lamps that shine upon the surface of meat to kill bacteria.

The last noble gas to be discovered was *radon*. It was discovered in 1900 as a gas released by the radioactive decay of radium. Radon (Rn) is naturally radioactive and is created by radioactive decay of minerals found in the soil. Radon is the only radioactive gas and may cause lung cancer if breathed. Although radon is a heavy gas, it can collect in the basements of houses.

Because of its density, it does not scatter away, as do most other gases. Some homeowners buy radon detectors to warn of a build up of the gas.

Chemists found six members of this new noble gas family of elements: helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe), radon (Rn). Chemists called the new gases inert (no action) and noble (aloof) gases. Left to themselves the gases do not form compounds with other elements. For that reason, chemists give the gases a valence of zero. The discovery of gases did not destroy the order of the periodic table; instead, the gases completed the



periodic table. For example, neon has a valence of 0 and an atomic weight of 20.183. To one side is fluorine, a highly active nonmetal with a valence of -1 and an atomic weight of 18.998. The next row starts with sodium, a highly active metal with a valence of +1 and an atomic weight of 22.98. Neon fits between those two elements.

The spectroscope helped chemists fill in the periodic chart. By the end of the 1800s, efforts of chemists turned more to studying chemical compounds. Before they could make real progress, chemists had to understand the role of the electron in chemical reactions. They could do this only after they learned what particles were found in the atom itself.

LIFE PRINCIPLE

"The noblest exercise of the mind within doors, and most befitting a person of quality, is study."

—William Ramsay



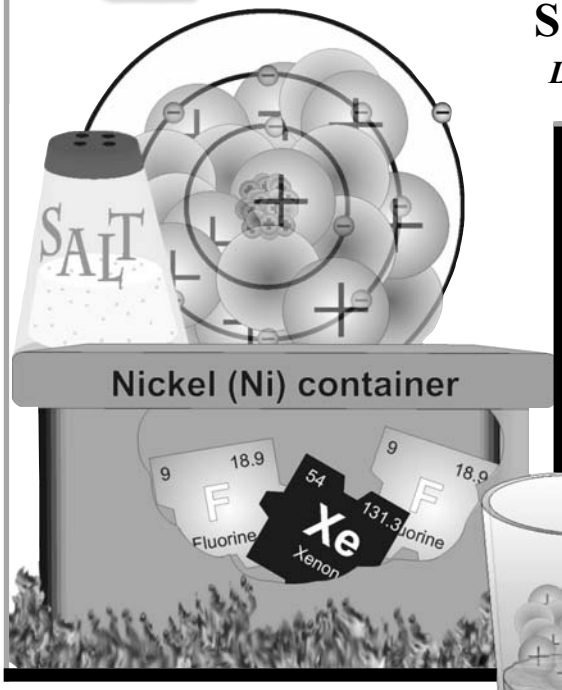
Chapter 7

Lesson 5
Compounds

CHEMICAL BONDS

Section 1

Lessons 1-5



Neil Bartlett peered with wonder and excitement at the tiny purple crystal in the nickel container. Here was a chemical compound never before seen. Chemists believed it could not exist. Bartlett had succeeded in making a chemical compound using xenon, one of the inert gases. Neil Bartlett was a chemist at the University of British Columbia in Canada.

The inert gases are also known as the noble gases. Until noble gases were discovered, nitrogen was the most inert (least active) gas known. Although reluctant to form compounds, nitrogen could be forced into combination with other elements. An electric spark would cause nitrogen to combine with oxygen. Nitrogen would also react with heated magnesium. The noble gases, however, formed no compounds of their own; nor had chemists succeeded in forcing noble gases into compounds.

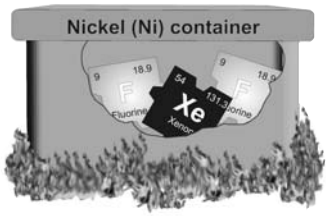
Because argon was so much less active than nitrogen, chemists assumed it and its fellow members of the noble gas family could not be made into compounds. As more noble gases were discovered, few chemists even tried to make compounds with them.

For more than fifty years, chemists thought the noble gases were truly inert. However, in 1962, Neil Bartlett put the question to scientific test. From what chemists had learned about the role of the electron in chemical bonds, Bartlett suspected that the heavier noble gases would be more likely to form chemical compounds. The heavier atoms have more electrons and are more likely to share them with other atoms. Bartlett decided to work with xenon, a heavy noble gas. Only

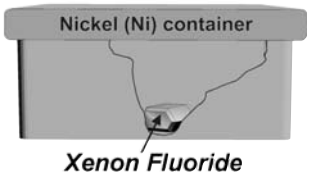
VOCABULARY

Catalyst: a substance that speeds the rate of a reaction without being consumed by it
Electron shell: a grouping of electrons around the nucleus of an atom, each shell has a specific number of electrons it can hold
Valence shell: the outermost shell or sub-shell around the nucleus of an atom that holds the electrons that take part in chemical reactions; the valence number shows how many electrons are in the valence shell

radon is heavier, but it is radioactive. Bartlett would try to combine xenon with fluorine (F). Fluorine is the most chemically active element known, even more reactive than oxygen. Bartlett placed the xenon and fluorine in a metal container made of nickel. Nickel (Ni) was often used as a catalyst. A ***catalyst*** promotes a chemical reaction without actually being consumed in the reaction itself. Finally, Bartlett gave energy to the chemical reaction by heating the reactants in the nickel can.



When Xenon and Fluorine were combined within the Nickel container and then heated, the result was the noble gas compound, Xenon Fluoride.



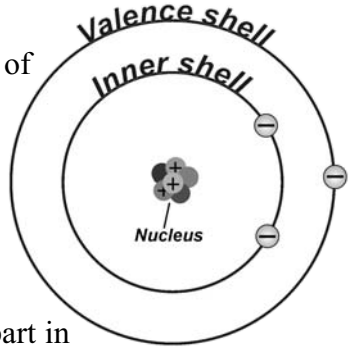
When he concluded the experiment, Neil Bartlett found a tiny purple crystal of xenon and fluorine. The crystal was stable at room temperature in dry air. Bartlett had made the first noble gas compound. Since then, at least eight other xenon compounds have been formed, including a highly explosive xenon trioxide (XeO_3). Chemists have also succeeded in producing krypton fluoride (KrF_2). Even today, the three lightest noble gases—helium, neon and argon—have never been coaxed into forming compounds with other elements.

Some elements, like oxygen and fluorine, are highly active. On their own, they will combine with most metals and many other elements. Yet, next door to fluorine is the very inert neon. Left to itself, neon never forms compounds and chemists have not yet been able to force it into combination with other elements.

The electron has the primary role in forming chemical bonds among elements. A chemical compound forms because atoms release, accept or share electrons. Chemical bonds between atoms are due to electrical and magnetic attractions caused by the electrons. Electrons of an atom are arranged in groups, called ***electron shells***, around the nucleus.

The noble gas elements have the most stable arrangement of electrons. These arrangements are stable because the electrons are arranged so the forces that act in an atom are at a minimum. Other elements will gain or lose electrons to have an arrangement nearly like the distribution of electrons in the noble gases.

Helium has two electrons. The rest of the noble gases have eight electrons in their outermost shell. Chemists have found that the chemical properties of an element depend almost entirely on the number of electrons in the outer shell. The outer shell contains electrons that take part in chemical reactions. The outer shell is known as the ***valence shell***.



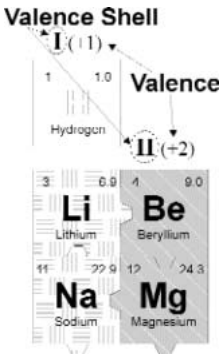
The partial periodic chart on the next page shows valence shells. The number of electrons in the outer shell is shown just below the symbol for the element. Only the outer shell of electrons is indicated because they are the only ones that take part in chemical reactions.

VOCABULARY

Ionic compounds: compounds formed by atoms that exchange electrons and are held together by their electrostatic attraction
Covalent compounds: compounds formed by atoms that share electrons

Partial Periodic Table Showing Number of Electrons in Outer Shell

H 1							He 2
Li 1	Be 2	B 3	C 4	N 5	O 6	F 7	Ne 8
Na 1	Mg 2	Al 3	Si 4	P 5	S 6	Cl 7	Ar 8
K 1	Ca 2					Br 7	Kr 8
Rb 1	Sr 2					I 7	Xe 8
Cs 1	Ba 2					At 7	Rn 8



Valence on a regular periodic table accompanies the Roman numerals at the top of each family group as shown above *H*.

Valence is the number of electrons that should be released, accepted or shared to complete the outer shell. The table below shows valence. Chemists often do not show the + or – sign of valence. The elements on the left side of the table are understood to have a positive valence and those on the right side are understood to have a negative valence. Metals on the left form compounds by releasing an electron and have a positive valence. Nonmetals on the right accept electrons and have a negative valence.

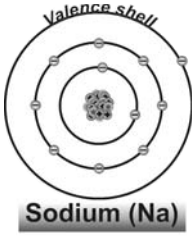
Periodic Table Showing Valence

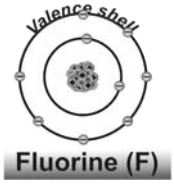
H 1							He 0
Li 1	Be 2	B 3	C 4	N 3	O 2	F 1	Ne 0
Na 1	Mg 2	Al 3	Si 4	P 3	S 2	Cl 1	Ar 0
K 1	Ca 2					Br 1	Kr 0
Rb 1	Sr 2					I 1	Xe 0
Cs 1	Ba 2					At 1	Rn 0

Compare neon (Ne) with sodium (Na). Sodium readily forms compounds with a variety of other elements including chlorine (NaCl, sodium chloride) and oxygen (Na_2O, sodium oxide). Neon on the other hand is so inert it has no known compounds, not even any created in the laboratory.

A neon atom has 10 electrons in all, two in the inner shell and eight in the outer shell. The electrons have a negative charge and the protons in the nucleus have a positive charge. Electrical charges which are unlike attract. The electrons are attracted to the protons and are held in place by that attraction. Neon has no tendency to release, accept or share electrons. Therefore, neon does not form chemical compounds. Its valence is zero.

Consider sodium (Na) the next element after neon. It has 11 electrons. The first 10 are found in an arrangement like that of neon. But the outermost electron is orbiting out away from the atom's nucleus. This electron is hanging out there all alone, ready to be picked off by an element that needs an electron. Sodium and the metals all are more likely to release an electron during a chemical reaction.

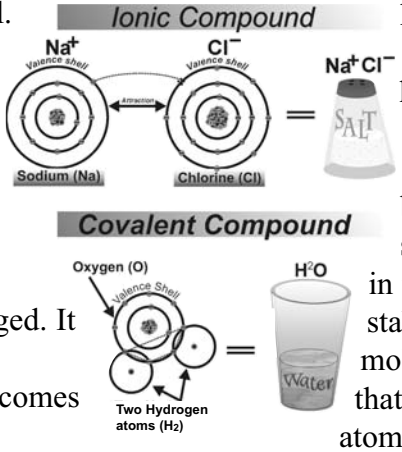




Some elements need electrons. Look at fluorine (F) on the periodic table. It has nine electrons. Two are in the inner shell, and seven electrons are in its outer shell. Gaining another electron will give fluorine the stable electron structure found in neon. The same is true of chlorine (Cl) and the other elements in that family.

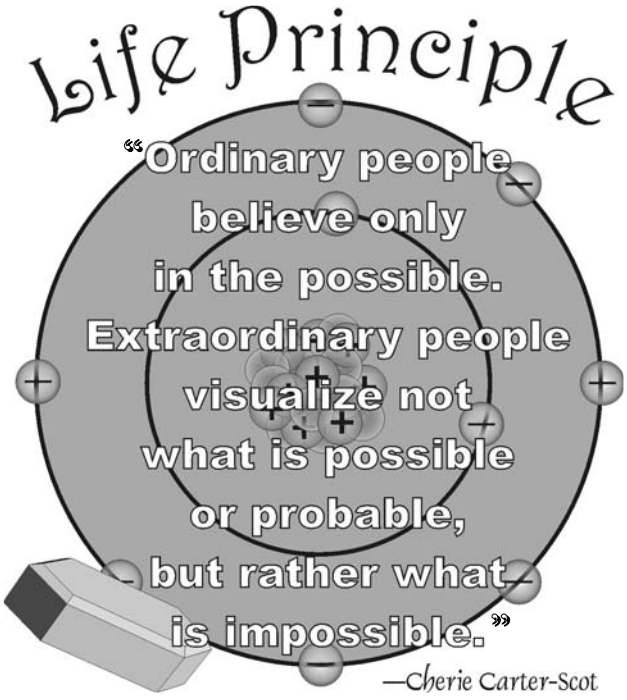
Ionic compounds are formed when one element releases one or more electrons, and another element accepts the electrons. For instance, ordinary table salt (sodium

chloride, NaCl), is an ionic compound. Sodium has the lone electron orbiting in the outer shell. By releasing the electron, sodium would fall back to the more stable arrangement of eight electrons in its outer shell. Chlorine has seven electrons orbiting in the outer shell. By gaining one more electron, chlorine would have the more stable arrangement of eight electrons in its outer shell.



By releasing an electron, sodium becomes electrically charged. It becomes a positive ion, Na^+. By accepting an electron, chlorine becomes electrically charged. It becomes a negative ion, Cl^-. Because sodium and chlorine have opposite charges, they attract one another. A salt crystal has sodium and chlorine ions that line up in a regular grid because of their electrical attraction. Atoms in ionic compounds are held together by the opposite static charges.

Covalent compounds are formed when two elements share electrons to complete their outer shell. Water (H_2O), is an example of a covalent compound. Hydrogen has a single electron, and it needs two electrons like helium to be stable. Oxygen has eight electrons in all. Two are in the inner shell, but only six are in the outer shell. It needs eight electrons in the outer shell to form a stable arrangement. The water molecule has one oxygen atom that combines with two hydrogen atoms. By sharing electrons, the oxygen atom and the two hydrogen atoms have sufficient electrons to complete their outer shell. Hydrogen atoms and oxygen atoms must be close to one another to share the same electrons. Covalent compounds are held together by the need to share electrons.

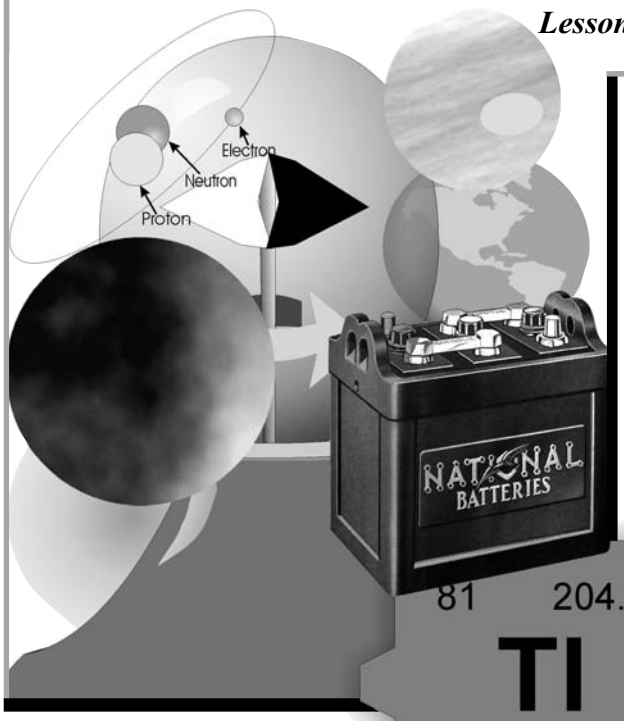


Lesson 6
Energy

Chapter 7

INSIDE THE ATOM–THE ELECTRON

Section 2
Lessons 6-10





An oscilloscope, a heart monitor, a television screen, a computer monitor all have something in common. They all present information on a video screen by a stream of ***electrons***. William Crookes built the first screen that glowed as electrons hit it (what we now call a video screen) in the late 1800s.

Although chemists from the time of Michael Faraday in the mid 1800s knew that the atom contained electric charges, they did not know what form those charges took. If electricity were made of particles, then it should stream across a vacuum. Faraday tried this experiment, but he did not have sufficient voltage and could not make an adequate vacuum for the experiment to succeed.

In 1861, William Crookes discovered a new element with his spectroscope. He detected a beautiful green line in the spectrum of a metallic ore. The line did not fit any other element. He named the new metal *thallium* from a Greek word meaning *green twig*. Thallium (Tl) is a metallic element found between mercury and lead on the periodic chart. Like mercury and lead, thallium is a poisonous element.

William Crookes was already a well-known scientist in 1875 when he tried Faraday's experiment again. Years earlier, Crookes had learned of Bunsen and Kirchhoff's spectroscope and had become an expert in its use. When William Ramsay was trying to discover the connection between helium in the Sun and helium released from minerals, he came to William Crookes for help.

Crookes refined a small sample of the new element and tried to weigh it. To keep out air currents that upset the scale,

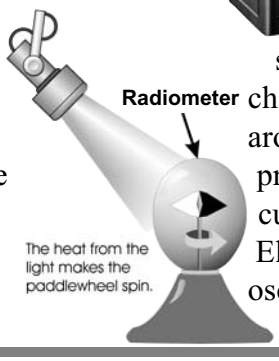
VOCABULARY

Electron: one of the three fundamental particles that make up an atom, an electron has a unit negative charge and a mass equal to $^{1}/_{1,837}$ the mass of a proton
Cathode rays: streams of electrons
Cathode ray tube: a tube with a surface that glows when struck with electrons; electric and magnetic fields control the path of the electrons
Relative solution: an answer that compares two quantities

he put the balance pans in a vacuum chamber. However, the scale pans swung up and down in tiny, irregular movements. Crookes knew that a perfect vacuum was impossible. Some molecules managed to escape the air pump and remained in the vacuum chamber. The goal was to come as near to a complete vacuum as possible. Although William Crookes succeeded better than anyone else did, even his best vacuum chamber still had a few stray air molecules present.

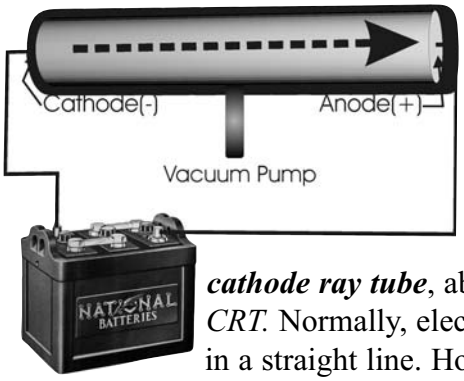
The few air molecules that were still in the vacuum chamber could have been the culprits that caused the balance pans to jiggle. Suppose heat energy caused the molecules to bounce around and strike the delicate balance pans. The heat energy might be enough to make the cans move. To test this idea, Crookes put a paddlewheel resting on a pin inside a glass globe. The paddlewheel was then free to turn. Crookes painted one side of each vane of the wheel black and painted the other side white. Crookes removed the air from the globe and sealed it. When light fell upon the paddlewheel, it began to spin. When sunlight fell upon the device, the blackened side of each vane absorbed more heat than the white side. The paddlewheel was not in a perfect vacuum. Some molecules avoided being drawn out by the vacuum pump. The free molecules around the dark side began moving more vigorously because they gained heat energy. The molecules struck the dark side of the vane, causing the paddlewheel to spin.

The device received the name *radiometer*, which means radiation meter. A radiometer is a very sensitive instrument which measures the strength of radiant light. Crookes focused starlight from a telescope on the vanes. The pinwheel turned from the heating effect of faint starlight. The radiometer had a practical application. It could detect very weak heat sources. The speed of its spin measured the strength of the heat rays. Although other devices to measure heat have replaced them, radiometers are still sold in children's toy stores and science shops.



William Crookes is best known for his invention of the *Crookes' tube* and the discovery of ***cathode rays***. Like Michael Faraday, Crookes attempted to send electricity through a vacuum. Crookes fastened an electrical terminal to each end of a glass tube and pumped gas out of the tube. Then he sent a high voltage through the vacuum causing invisible rays to shoot out from the negative electrode. The rays traveled the length of the tube, struck the glass and caused a steady greenish glow. The stream was made up of electrons, although chemists did not know that at the time.

Faraday had given the name *cathode* to the negative terminal of an electric battery. These rays came from the cathode end of the tube, so chemists called them cathode rays. Scientists and inventors for a variety of purposes modified the Crookes' tube. It became known as a ***cathode ray tube***, abbreviated *CRT.* Normally, electrons travel in a straight line. However, the stream can be controlled by putting charged metal plates or electromagnets around the stream. The stream of electrons provides a visual graph of the changing current that is attached to the plates. Electricians modified the CRT to be an oscilloscope. Almost every electrical shop is



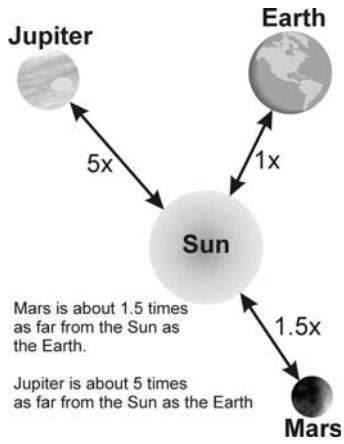
equipped with an oscilloscope for checking electric circuits.

Cathode ray tubes are used in every community hospital to monitor heart activity and other vital signs of patients. The moving image on a television screen is actually a series of still images. These images are projected on the television picture tube 30 times each second by a beam of electrons. Electric and magnetic fields control the electrons. Most word processors, electronic games and computer monitors use cathode ray tubes for presenting information to the user.

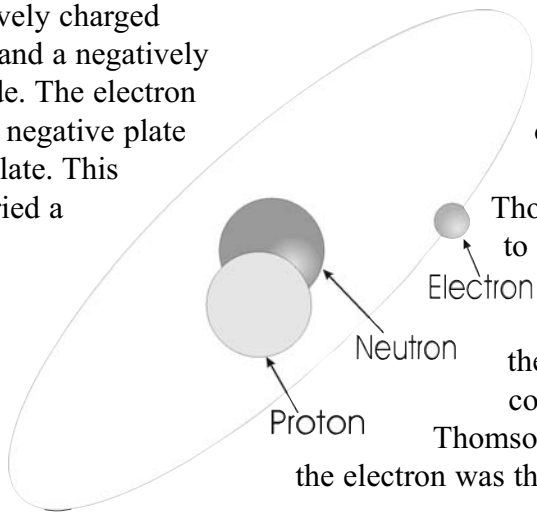
Cathode rays are streams of electrons. Scientist Joseph John Thomson discovered this fact in the late 1800s. Joseph John Thomson, better known as J. J. Thomson, placed a metal cross in the stream of cathode rays. The stream cast a distinct shadow of the cross at the other end of the tube. He then put a wheel along a track in the cathode ray tube. Particles hit the wheel and made it roll along the track. Thomson concluded that cathode rays were particles that traveled in a straight line. Then, he placed a positively charged plate on one side of the tube and a negatively charged plate on the other side. The electron stream was repelled from the negative plate but attracted to the positive plate. This showed that the particles carried a negative charge.

The charged particles could be made visible by putting in their path a zinc sulfide screen that glowed when struck. If the particles carried different charges, the charged metal plates would separate the particles into two or more streams, which would strike the zinc sulfide screen in different places. But, J. J. Thomson saw only one glowing spot, not two or three. Although the charged metal plate changed their paths, all of the cathode rays changed direction by the same amount. Not only did they carry a negative charge, but also all of the particles had exactly the same negative charge.

One question J. J. Thomson could not answer completely concerned the weight of the charged particles. He did, however, find the ratio of the charge of the electron compared to its mass. This is a ***relative solution*** that relates one quantity to another. Johannes Kepler, the famous European scientist who worked out the Laws of Planetary Motion, took the same approach when he laid out the size of the solar system. Kepler stated the distance of the planets from the Sun by relating them to the distance of the Earth from the Sun. Mars is about 1.5 times as far from the Sun as Earth. Jupiter is about 5 times as far from the Sun as Earth. Once astronomers discovered the distance of Earth from the Sun, they could multiply by 1.5 and have the distance of Mars from the Sun. The astronomers could multiply by 5 and determine the distance of Jupiter from the Sun.



In the case of J. J. Thomson's ratio of charge to mass, if a scientist could measure the charge of a single electron, then the mass of the electron could be figured. Thomson assumed the charge on the electron was the same as that of a

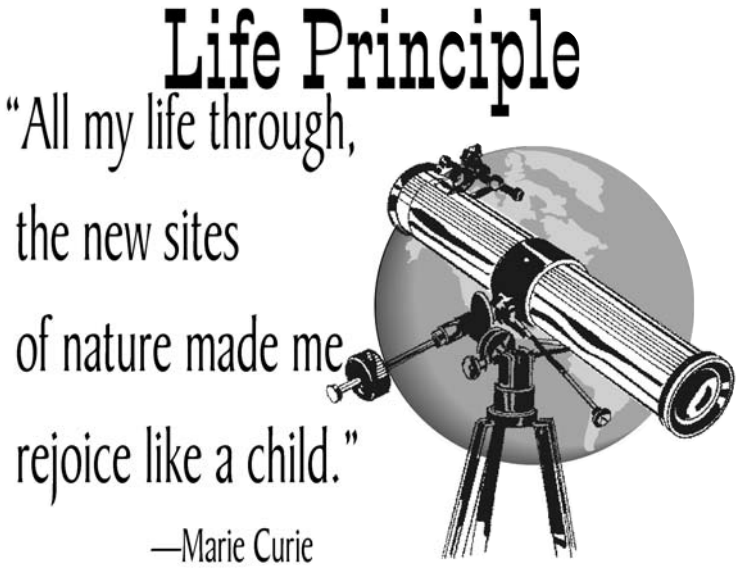


hydrogen ion (H^+) but opposite in sign. In that case, Thomson calculated the electron's mass as only $^1/_{1,837}$ that of the hydrogen ion. It would be smaller than an atom, a conclusion that most chemists were not willing to accept without further proof.

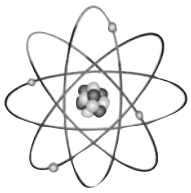
Robert Millikan, an American physicist, provided the proof. He succeeded in weighing a single electron. It was a delicate experiment, but one that could be done with simple equipment. His experiment is known as the Millikan oil-drop experiment.

The mass of an electron is far smaller than an atom. Electrons, the particles that make up cathode rays, have a mass far smaller than the smallest atom. The conclusion reached by Thomson and Millikan could not be escaped: atoms, the building blocks of matter, are themselves composed of smaller building blocks. The electron was the first *subatomic* particle discovered. Later, other subatomic particles were discovered, including the *proton* and *neutron*. A hydrogen atom with the electron removed is a proton.

The symbol of the electron is e^-. The mass of an electron is $^1/_{1,837}$ the mass of a proton. An electron carries a unit negative charge.



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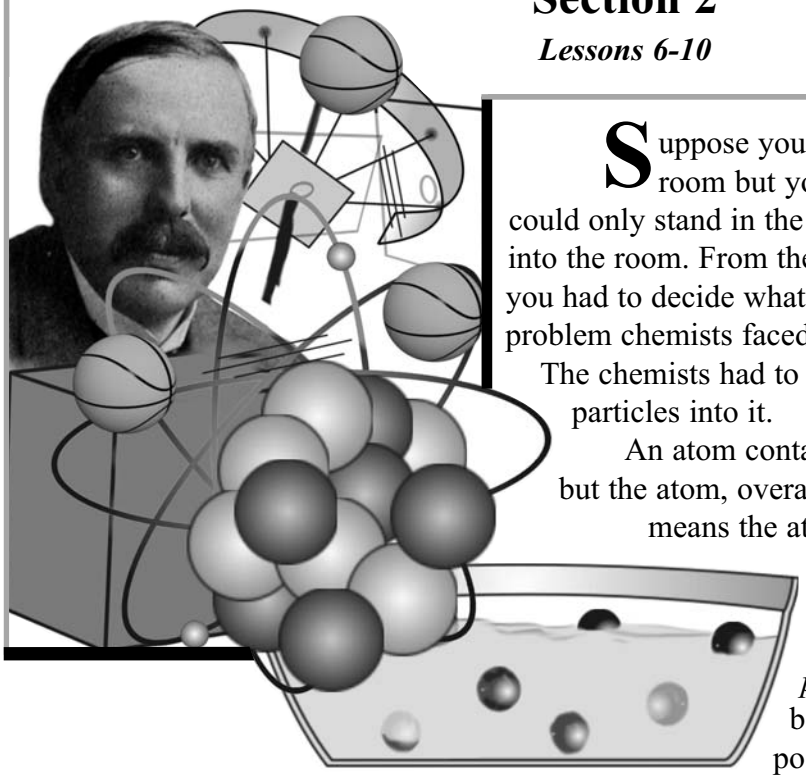
Lesson 7
Energy

Chapter 7

INSIDE THE ATOM

Section 2

Lessons 6-10



Suppose you had to learn what was in a dark room but you could not go into the room. You could only stand in the doorway and throw basketballs into the room. From the way the basketballs bounced out, you had to decide what was in the room. This is the problem chemists faced when they investigated the atom. The chemists had to probe inside the atom by shooting particles into it.

An atom contains negatively charged electrons, but the atom, overall, is electrically neutral. This means the atom must also contain positive charges to counterbalance the negative electrons. Joseph John Thomson proposed the *plum pudding model of the atom*. He believed that negative electrons and positive matter were mixed together like plums in a pudding. The plums were the electrons, and the pudding was the positive matter. Chemists mixed "pudding ingredients" together in the right amount as to make the atom electrically neutral. In other words, equal amounts of positive and negative charges would be within each atom.

Ernest Rutherford was one of J. J. Thomson's students. Although born in New Zealand, Ernest Rutherford came to Cambridge, England to study. Later, he took a research position at McGill University in Montreal, Canada. Despite being an ocean apart, Rutherford kept in touch with Thomson and continued to think of ways to test Thomson's model of the atom.

Probing inside an atom requires the use of small particles. If the particles are too large, they do not reveal any useful information. As an analogy, if you could throw tennis balls into a darkened room, they may reveal smaller objects than basketballs. Should only giant beach balls be available, they might not fit through the door and you would learn nothing about contents of the room.

VOCABULARY

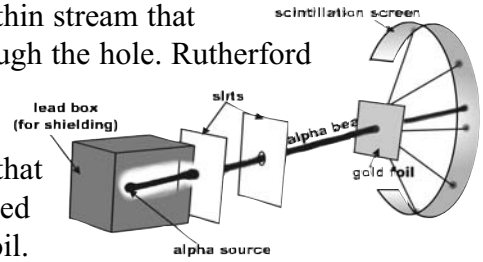
Alpha particle: a high-speed radioactive particle with the mass of a helium atom and a double positive charge
Nucleus: the dense central core of an atom composed of protons and neutrons, the nucleus has most of the mass and all of the positive charge of an atom
Planetary model of the atom: a model of the atom that has the electrons orbiting around the nucleus

Light waves were too large for looking into atoms. Light waves are larger than an atom and can wash over an atom without revealing any information about it. The electron is small enough but does not have enough mass. What Rutherford needed was a small but high-speed particle with enough mass to penetrate into the atom.

An ***alpha particle*** is a high-speed particle emitted by radioactive elements. One source of alpha particles is the radioactive element polonium (Po) discovered by Marie and Pierre Curie. An alpha particle has a +2 charge, twice that of an electron, but of the opposite sign. An alpha particle is about 8,000 times heavier than an electron and weighs the same as a helium atom. Alpha particles speed along at about 20,000 miles per second, more than one tenth of the speed of light.

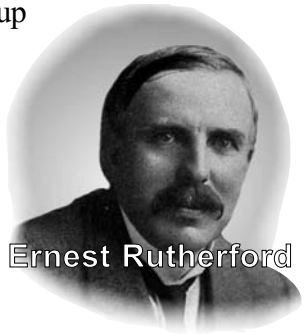
Alpha particles were the high-speed bullets that Ernest Rutherford needed. For a target, he used very thin sheets of gold foil. Gold is the most malleable of metals. Goldsmiths can hammer it into exceedingly thin sheets. Rutherford used a sheet of gold foil only 1/50,000th of an inch thick. Although very thin, the gold foil was about two thousand atoms thick.

Ernest Rutherford placed a sample of polonium in a lead box with a tiny hole. The lead absorbed the alpha particles except for a thin stream that escaped through the hole. Rutherford had made an alpha particle gun that could be aimed at his gold foil.



With their high speed and mass, the alpha particles would cut deeply into the gold foil.

A screen coated with zinc sulfide showed where the alpha particles came out. When alpha particles struck the coating, the particles produced a brief spark of light on the screen. Rutherford expected the alpha particles to hit the much more massive gold atoms and bounce around causing the alpha particles to come out in all directions.



Rutherford set up the screen in various locations around the gold foil and counted the brief flashes to see how the gold foil scattered the alpha particles. The alpha particles entered as a straight stream on one side of the foil. Gold is a heavy metal, and each of its atoms weighed about 50 times as much as each alpha particle. For an alpha particle to penetrate through a layer two thousand atoms thick would be like a bullet going through a brick wall two thousand bricks thick. Rutherford expected that most alpha particles would hit the gold atoms and deflect from their straight-line path. To his surprise, most alpha particles passed straight through the foil as easily as a bullet through tissue paper. In the vast majority of cases, the gold foil left the straight-line path of the alpha particles

VOCABULARY

Proton: a subatomic particle, found in the nucleus of an atom, with a unit positive charge (p^+) and a mass equal to one atomic mass unit

Atomic mass unit: a mass equal to 1/12 the mass of *carbon-12*, the most common isotope of carbon; for most purposes, an atomic mass unit is the same as the mass of a proton

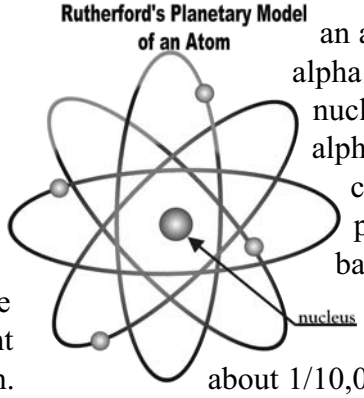
Neutron: a subatomic particle, found in the nucleus of an atom that has about the same mass as a proton but no electric charge

unchanged—as if the gold foil was mostly empty space.

As the experiment continued, the gold atoms did bump a few alpha particles off course. The reflected angle was far greater than predicted by the plum pudding model of the atom. Even more surprising, about one in 10,000 alpha particles bounced right back out in the same way they went in. Rather than hitting empty space, the alpha particles had hit something remarkably solid. Ernest Rutherford sat back, astonished. The results of his alpha scattering experiment simply did not agree with the plum pudding model of the atom. Thomson's model had enjoyed popularity with scientists for 15 years. Ernest Rutherford concluded that it was essentially incorrect and would have to be discarded. Yet, Rutherford could not dismiss it unless he had a model to replace it. He would have to explain his observations.

Rutherford realized that the mass of the atom could not be evenly distributed throughout the atom. Most of the mass and all the positive charge had to be concentrated in a very small space. He called this tiny, but extremely dense central core of the atom the ***nucleus***.

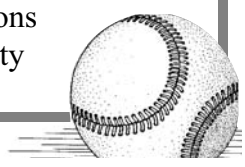
Swarming around the nucleus are electrons with a negative charge. These electrons are very light. In Rutherford's experiment, alpha particles brushed aside electrons as if they did not exist. About 90 percent of the alpha particles crashed through the electrons and kept right on going without any change in their path. Occasionally, an alpha particle passed close enough to the nucleus to be affected by it. The nucleus contains all of the positive charge of the gold atom. An alpha particle also has a positive charge. The gold nucleus and alpha particles repelled one another. However, the gold nucleus weighed almost 50 times as much as



an alpha particle. When the alpha particle passed near the nucleus of the gold atom, the alpha particle was pushed off course. Only one alpha particle in 10,000 bounced back. Ernest Rutherford interpreted this to mean that the nucleus made up only about 1/10,000th of the entire volume of the atom. Almost all of the matter of an atom was found in the nucleus.

Rutherford announced his picture of the atom. His model had a dense central core containing all of the positive charge and almost all of the mass. Flying around at great distances were the electrons containing all of the negative charge, but practically none of the mass. Ernest Rutherford's proposal became known as the ***planetary model of the atom***. The nucleus corresponds to the Sun and the electrons to the planets. Scientists have modified the planetary model. Planets orbit the Sun in elliptical orbits that are very nearly circular. The orbits are all in the same plane. A drawing of the solar system, as seen from above the Sun, on a sheet of flat paper is very nearly correct. A two-dimensional drawing of an atom on a flat sheet of paper would not be correct because paths of the electrons go into and out of the paper. The electrons move about in all directions, and their orbits are in a variety of shapes. In addition, these electrons can jump to different orbits depending upon their energy. Despite the changes, the planetary model of the atom is still a good description of the arrangement of the electrons and protons in the atom.

Compared to the atom as a whole, the nucleus is tiny. Imagine an atom that is enlarged until it fills a baseball stadium. The nucleus would be the size of a baseball at the center of the field. The electrons would then be a blur of activity

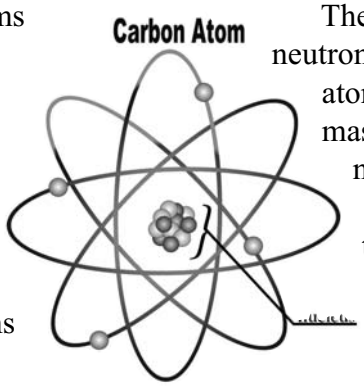


far away in the stands.

Ernest Rutherford suggested that the smallest positive particle would be the hydrogen atom with its electron removed. He gave the name ***proton*** to this single positive charge. The word *proton* is Greek meaning *the first*. The symbol of the proton is p^+. A proton has a mass of one ***atomic mass unit***. An atomic mass unit is 1/12 of the mass of *carbon-12*, the most common isotope of carbon. For most purposes, an atomic mass unit is identical to the mass of a single proton. A hydrogen atom without its electron is a proton.

Later, chemists learned that atoms have a third particle, a ***neutron***. The neutron is about the same mass as a proton but has no electric charge. The neutron is electrically neutral, which explains its name.

Protons and neutrons squeeze tightly together in the nucleus, the dense central core of the atom. Electrons orbit far away, like planets around the Sun. In a neutral atom, the central nucleus has the same number of protons with positive charge as electrons orbiting with negative charge. The atom as a whole is electrically neutral. The positive charges of the protons are balanced by the negative charges of the electrons. For instance, carbon has six protons. The neutral atom has six electrons. The six positive charges from the protons cancel out the six negative electric charges from the electrons. Overall, the atom is electrically neutral. A neutral atom has the same number of electrons as protons. The number of protons is an element's *atomic number*, recorded on the upper left of every puzzle piece of the periodic table.



The carbon atom has six neutrons. This gives the carbon atom a mass of 12 atomic mass units (6 protons + 6 neutrons = 12 particles). The electrons are so light their mass can be ignored. Although carbon has six protons and six neutrons, the number of protons and neutrons do not have to be equal. Beryllium has four protons and five neutrons for at total atomic mass of nine.

Life Principal



"It is what you learn after you think you know it all that counts."

–Anonymous

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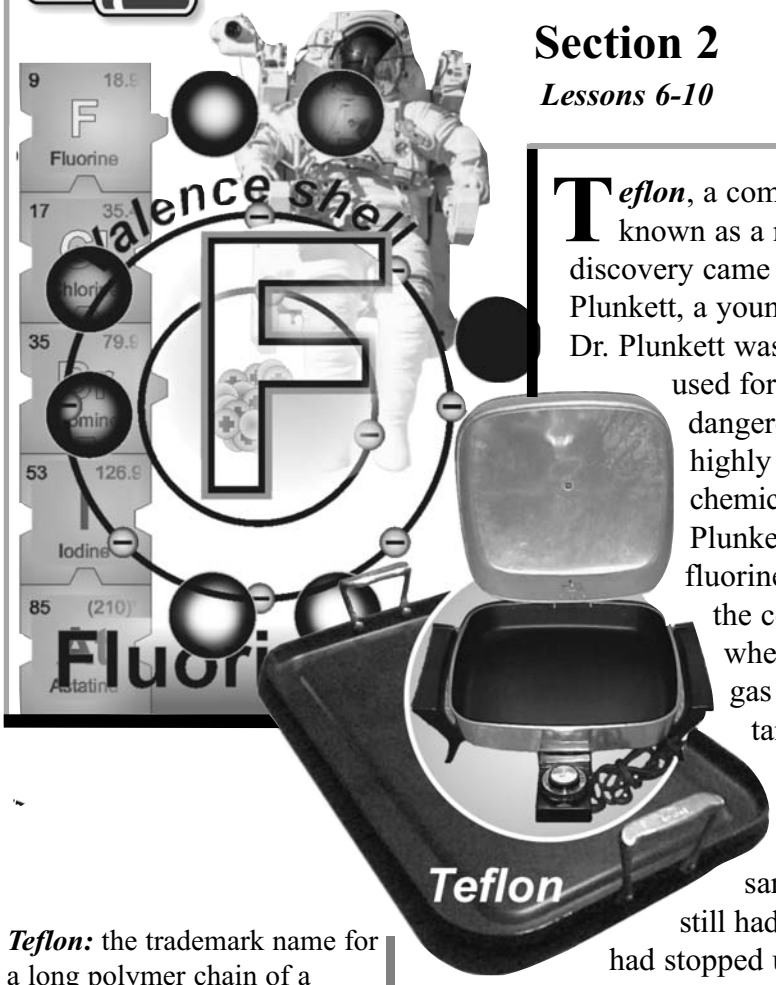
Chapter 7

Lesson 8
Compounds

Section 2

Lessons 6-10

CHEMICAL BONDING



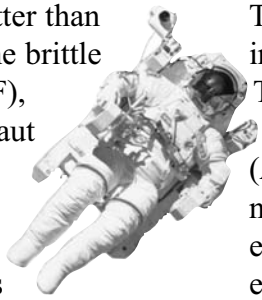
Teflon: the trademark name for a long polymer chain of a fluorine and carbon compound that resists heat, is slick, electrically nonconductive and chemically inert
Ionic bond: a chemical bond between two ions with opposite electrostatic charges
Ionic compound: a compound formed by an ionic bond
Fluorocarbon: a compound of carbon with at least one fluorine atom
Hydrocarbon: a compound of hydrogen and carbon

Teflon, a compound containing *fluorine*, is best known as a nonstick coating for frying pans. Its discovery came about in 1938 by Dr. Roy J. Plunkett, a young chemist for the Du Pont Company. Dr. Plunkett was investigating fluorine-based gases used for refrigeration. Fluorine itself is very dangerous. It is a yellowish, poisonous, highly corrosive gas. Fluorine is the most chemically reactive of all elements. Dr. Plunkett stored the fluorine as a carbon and fluorine compound in a tank. Like fluorine, the compound was a gas. One morning, when he opened the valve to the tank, no gas came out. Plunkett had weighed the tank the previous day. He weighed it again. If a leak in the tank had developed, it would have been considerably lighter. It weighed the same. The gas had not leaked out, so it still had to be in the tank. Maybe something had stopped up the opening in the valve. Dr. Plunkett placed a wire in the valve and saw that the hole was fully open; then, he took off the valve and shook the tank upside down. A few white flakes fell out. Rather than dismissing the problem and selecting another source of the gas, Dr. Plunkett cut open the tank. All of the gas had changed into a waxy, white substance. The substance was very slippery, resisted electrical currents, and it was the most chemically inert solid substance he had ever seen. As Dr. Plunkett learned more of its properties, he saw that the substance might have practical uses.

Because it was so inactive, Teflon served as a protective coating on the inside of pipes to carry highly reactive compounds. Starting in the 1950s, chemists found other uses for the unusual compound. Teflon became the surface of nonstick frying pans, bearings for wheels and coatings on fishing lines so they would

not snag. Surfaces of surgical implants in the human body, such as artificial hip replacements, were coated with Teflon because the human body tolerates Teflon and does not try to reject it.

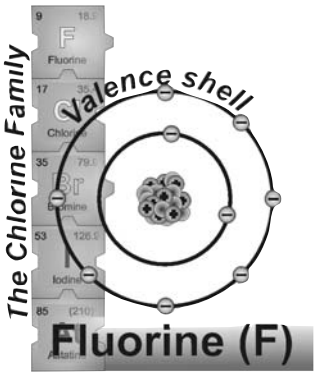
Teflon does not melt until it is heated to 320ºC (608ºF), which is hotter than most ovens. It does not become brittle until chilled to –232ºC (-386ºF), which is colder than an astronaut is likely to encounter on the surface of the Moon. Teflon resists changes in temperature, making it ideal as insulation for wires that are put in harsh environments and as coatings on space suits.



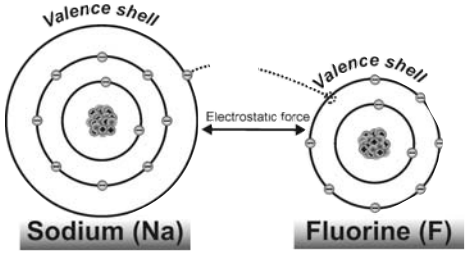
Although some people call the discovery of Teflon an accident, Dr. Plunkett saw the product as an interesting discovery while others may have seen only a problem. His curiosity, willingness to think, and persistence turned a chance observation into a useful product.

Teflon is an inactive compound of fluorine. The element fluorine is the most active element known, even more reactive than oxygen. Fluorine attacks metals and will combine with water, glass, rubber, wood and practically any other substance. But Teflon is practically inert. (The name Teflon begins with a capital letter because it is a registered trademark of the Du Pont Company.) One of the general rules of chemistry is that the more active an element is, the less active are its compounds. Fluorine and many of its compounds follow this rule.

Fluorine is a member of the chlorine family of elements. Fluorine and the other chlorine elements readily accept electrons. The chlorine family is in the vertical column in the periodic table next to the noble gases. These elements are fluorine (F), chlorine (Cl), bromine (Br), iodine (I) and astatine (At). The total number of electrons that each one possesses varies. However, in the outer shell they each have seven electrons, one fewer than is needed for the most stable arrangement. Fluorine, for instance, has nine electrons, two in the inner shell and seven in the incomplete outer shell.



If fluorine comes near metallic elements, such as sodium or potassium, it attracts one of their electrons to complete its outer shell. The chemical action that holds fluorine to sodium is an ***ionic bond***. In ionic bonding, the fluorine atom accepts an electron and becomes the fluorine ion (F^-). The metal releases an electron and becomes a positive ion. The fluorine ion and the metal ion are held together by electrostatic forces. These forces are similar to 'static cling' and lightning. In each case, the exchange of



By receiving an electron and completing its valence shell, **Fluorine** forms an *Ionic Compound* with **Sodium**

VOCABULARY

Ozone layer: a region of the upper atmosphere, about 20 miles high, that contains a relatively high concentration of ozone that absorbs ultraviolet radiation from the sun

Polymer: a long molecule made of smaller, identical molecules that are linked together

electrons causes the attraction. Fluorine forms an ***ionic compound*** with metals.

Elements can form compounds in a second way—by sharing rather than exchanging electrons. In *covalent bonding*, electrons are neither lost nor gained. The atoms stay neutral and share electrons. By sharing electrons, each atom can fill its outer, or valence, shell. The prefix *co* in *covalent* means *in partnership*. For instance, two fluorine atoms will come together to form a diatomic fluorine gas molecule (F_2). The two atoms have to stay close together so each one can complete its outer electron shell by sharing an electron. Most gases such as oxygen gas (O_2), chlorine gas (Cl_2) and fluorine gas (F_2), are held together by covalent bonding.

One way to understand the arrangement of the electrons is to represent them with dots. Each dot is an electron in the valence shell. Seven dots show the seven valence electrons in an electrically neutral fluorine atom:



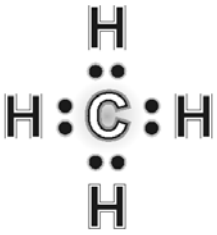
Although fluorine has nine electrons, only those in the outer or valence shell are shown. Electrons in the valence shell are the only ones that take part in chemical reactions.

In fluorine gas (F_2), each atom has eight electrons in the outer shell. Yet, only 14 electrons are involved, not 16. Each of the two fluorine atoms has eight electrons by sharing the middle pair.



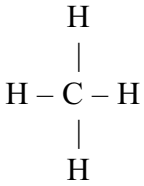
Fluorine gas (F_2)

A vast number of compounds use covalent bonding, including methane (CH_4). Carbon has only four electrons in its outer shell but needs eight. Hydrogen has but one electron and needs two. (Hydrogen and helium are the only elements that need two electrons in the valence shell. All the others need eight.) By coming together and sharing electrons, both hydrogen and carbon can complete their outer shells of electrons. Carbon now has eight electrons and each hydrogen atom now has two electrons.

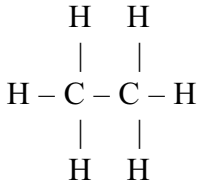


Methane (CH_4)

A ***fluorocarbon*** is a compound of fluorine with carbon. A fluorocarbon is built by beginning with a compound such as methane and replacing some of the hydrogen atoms with fluorine. Methane and ethane are examples of ***hydrocarbons***. Methane and ethane are covalent compounds in which hydrogen combines with carbon to complete the outer shell. A dash (—) is often used to represent a chemical bond in a covalent compound. Methane and ethane are shown as:



methane (CH_4)



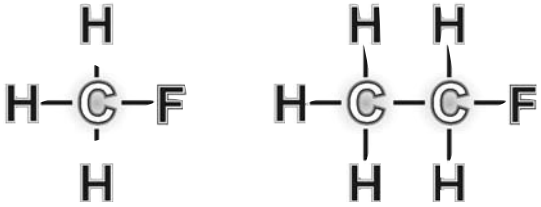
ethane (C_2H_6)

Each of the dashes around carbon represents two electrons that are in the outer, valence shell. Carbon has eight electrons around it (4 dashes * 2 electrons for each dash = 8 electrons), and each hydrogen atom has two electrons in its valence shell. The dash represents a pair of shared electrons. If

electrons are not shared, they are not shown. For instance, carbon has two electrons in its inner shell and those electrons are not in the diagram.

A fluorocarbon is similar to a hydrocarbon except one or more of the hydrogen atoms have been replaced with fluorine.

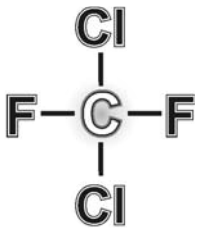
Fluorocarbons



Like hydrogen, fluorine needs one more electron to complete its outer shell. It shares one of its electrons with carbon. This brings the number of electrons in fluorine's valence shell to eight. In the diagrams above, carbon and fluorine share two electrons as shown by the single dash between them. The other six electrons around fluorine are not shared with carbon, and they are not shown.

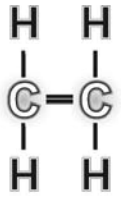
Fluorocarbons with all of the hydrogen atoms replaced by fluorine or chlorine are especially stable. Fluorocarbons are chemically inert, nontoxic, odorless and nonflammable. Fluorocarbons are used as solvents, lubricants, insulators and refrigerants. At one time, they were used as propellants in aerosol cans, but concern about damage to the ***ozone layer*** in the upper atmosphere has caused their use for that purpose to be discontinued.

Freon (CCl_2F_2) is used in refrigeration, although its use is controlled. The structural formula of freon is similar to methane, but with two of the hydrogen atoms replaced with chlorine (Cl), and the other two hydrogen atoms replaced with fluorine (F).

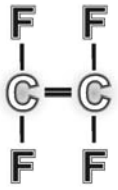


Freon (CCl_2F_2)

Teflon is a fluorocarbon, too. It is a chain of small units of tetrafluoroethylene (C_2F_4), which is structurally similar to the hydrocarbon ethylene:



Ethylene (C_2H_4)



Tetrafluoroethylene (C_2F_4)

Break the word *tetrafluoroethylene* into its parts to understand its meaning: tetra-fluoro-ethylene. *Tetra* means *four*, *fluoro* refers to *fluorine* and ethylene is a compound of carbon. Tetrafluoroethylene has four fluorine atoms that have replaced the hydrogen atoms in ethylene. The two carbon atoms complete their outer shell by sharing two pairs of electrons with each other. The structural diagram shows the *double bond* with a double dash (=). Recall that a single dash (—) represents two shared electrons, therefore a double dash (=) represents four shared electrons.

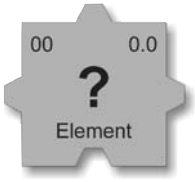
Teflon itself is not a single group of C_2F_4 but is a long chain of identical units hooked together. A ***polymer*** is a long molecule made of identical, repeating units. The word *poly* means *many*. Teflon is polytetrafluoroethylene (poly-tetra-fluoro-ethylene).

Life Principle





Integrated Physics & Chemistry

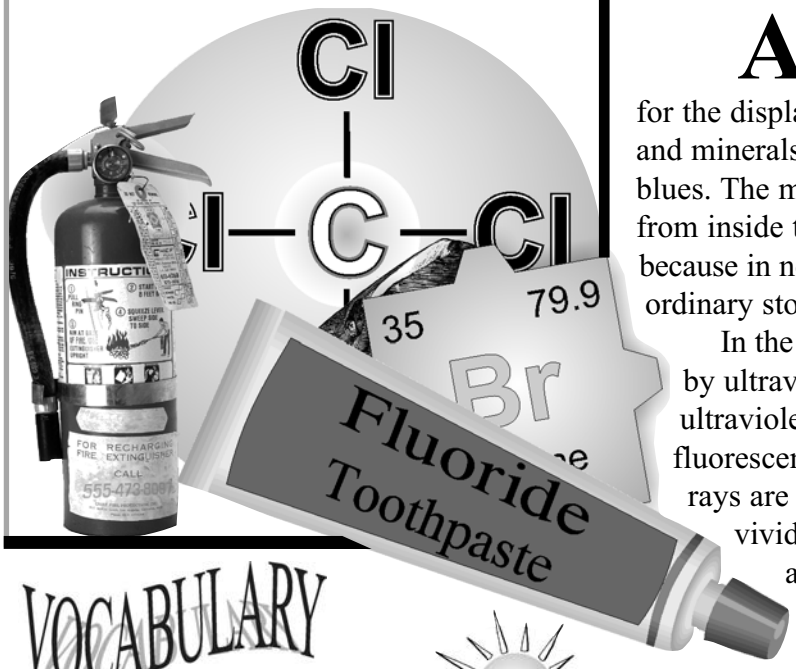


Lesson 9
Elements

Chapter 7

FLUORINE, CHLORINE AND BROMINE

Section 2
Lessons 6-10

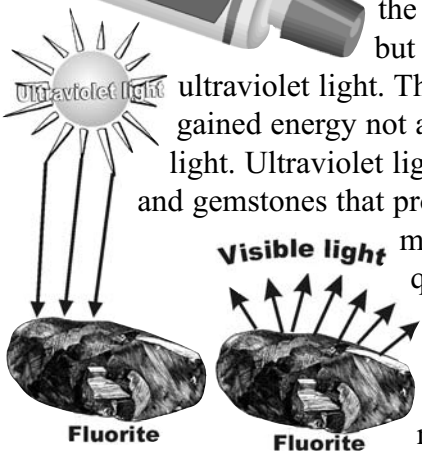


VOCABULARY

Fluorescence: to emit visible light while being struck by invisible ultraviolet light, the mineral fluorite is fluorescent
Etch: to engrave a surface
Chlorinating: to treat water with chlorine or a chlorine compound, to kill bacteria and other microorganisms
Oxidizing agent: a chemical that causes oxygen to combine with other elements
Hydrochloric acid (HCl): a strong acid
Anesthetic: a substance that is administered before and during surgery to make a patient insensitive to pain

At the nature center, visitors entered a room that was darkened except for the display cases. Inside the cases, crystals and minerals glowed in vivid reds, greens and blues. The minerals shone as if the light came from inside them. The effect was quite striking because in normal light the minerals appeared as ordinary stones.

In the dark, the minerals were illuminated by ultraviolet lamps. When exposed to ultraviolet light, many substances become fluorescent. They appear to glow. Ultraviolet rays are invisible to human eyes, so the vivid glow of light from the minerals appears mysterious. Molecules in the crystals absorb the high energy, but the energy is invisible, ultraviolet light. The molecules release their newly gained energy not as ultraviolet light but as visible light. Ultraviolet light is used to identify minerals and gemstones that produce ***fluorescence***. Rock and mineral hunters carry portable quartz lamps to detect fluorescent minerals in rocks.



Fluorite (CaF_2) is the first and best known fluorescent mineral. The term *fluorescence* was coined from fluorite. When a source of ultraviolet rays are absorbed by fluorite, the crystal changes the invisible ultraviolet rays into visible light. Although the effect is named after fluorite, other minerals glow when exposed to black light. *Black light* is invisible ultraviolet light.

Fluorite contains fluorine. Although fluorine is common in compounds, it is so active it does not exist as a free gas. At first, all efforts to release fluorine from its compounds failed.

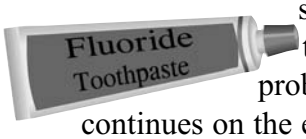
The British chemist, Humphry Davy, tried to separate fluorine from hydrofluoric acid (HF). Electrolysis broke fluorine free, but it promptly combined with anything in its neighborhood. Although fluorine could not be isolated, chemists were confident that fluorine existed. Mendeleev gave it a place in the periodic table.

Ferdinand Moissan prepared the first pure form of fluorine gas by using all platinum laboratory apparatus cooled to –50ºC. Platinum is unaffected by fluorine; however, the cooler temperature reduced the activity of fluorine. The modern method of producing fluorine is also by electrolysis of hydrofluoric acid. Rather than the very expensive platinum, chemists use copper. Fluorine reacts with copper to produce a coating of copper fluoride (CuF_2). Once the protective coating forms, fluorine cannot penetrate below the surface to attack the copper.

The most important compound of fluorine is hydrogen fluoride, which produces hydrofluoric acid (HF) when dissolved in water. Hydrofluoric acid must be stored in wax or plastic bottles because the acid will attack silicon compounds. Glass cannot be used as a container because glass is a silicon compound.

Hydrofluoric acid is used to cut patterns into glass. The artist covers the entire sheet of glass with a wax that is unaffected by the acid. Then the artist scrapes away the parts to be ***etched***. After treating the glass sheet with the acid, the rest of the wax is removed. What is left is a permanent cloudy pattern that was eaten into the glass by the acid. The result of this process may be seen in the beautiful glass art on plates and vases.

In preparation for World War II, the aluminum manufacturing industry produced large quantities of fluoride as a waste product in the construction of aircraft bombers and fighter planes. The excess fluoride was marketed as rat poison and as an additive to municipal drinking water supplies and toothpaste. Researchers associated with the aluminum manufacturing industry claimed that children in some parts of the United States seldom suffered from tooth decay when the natural water supply in those communities contained about one part per million of fluorine. Health workers influenced by industrialists suggested that fluorine be added to city water supplies to prevent tooth decay. Critics pointed out that fluoride in toothpaste and municipal water supplies could contribute to long-term health problems. Controversy continues on the effects of fluoride on human teeth and body cells.



Humphry Davy was the first to free chlorine gas from salt. He noted chlorine's sharp, disagreeable odor and greenish yellow color. Chlorine is only a little less active than oxygen. For example, a lighted candle will burn in a container of chlorine.

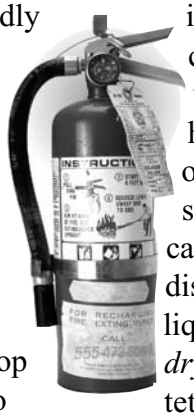
Like oxygen, chlorine attacks carbon-based compounds. All living things are made almost entirely of various compounds that contain carbon. Chlorine destroys those compounds. Chlorine gas has a choking smell and is very poisonous. Chlorine gas attacks the mucous membranes of the respiratory

VOCABULARY

Bromine (Br): a member of the chlorine family that is a liquid at room temperature and has a strong odor, is used in photographic film and as a sedative

Sedative: a compound that has a soothing or calming effect, reducing stress or irritability, bromine compounds are used as sedatives

tract and the liquid will cause burns to the skin. As a poison gas, chlorine was used in World War I as a weapon of war. As little as 1,000 parts per million will kill people after a few deep breaths. Nations at war found chlorine to be too difficult to control. A change in the wind could destroy friendly forces. Its use as a poison gas has not been repeated since World War I.

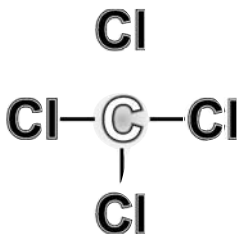


Chlorinating is the process of adding chlorine to water to destroy bacteria. It was first used in 1897 when London suffered an outbreak of typhoid, a highly infectious disease. City leaders mixed chlorine with the drinking water to kill the germs and stop the disease. Today, chlorine is added to municipal water supplies to kill bacteria that live in the water pipes. Unlike fluoridation, very little controversy arises over chlorinating because it rids the water of bacteria that could be dangerous to people who drink it with less potential harm.

Chlorinating the water in swimming pools can control bacteria and algae. In larger pools, chlorine gas is dissolved in the water as it circulates through the filter. In smaller pools, calcium hypochlorite ($Ca(OCl)_2$) is dissolved in the water. Once mixed with water, the compound forms *HClO*, which is a powerful oxidizing agent. An ***oxidizing agent*** is a compound that removes oxygen. *HClO* removes oxygen from bacteria and algae and kills them. Dead materials such as leaves are destroyed, too. The reaction produces a gas that bubbles out of the pool. Sometimes those who supply chemicals for pool use refer to hypochlorite as chlorine. Chlorine is a greenish-yellow gas, and solid hypochlorite is a white powder.

Chlorine gas, when combined with hydrogen, produces hydrogen chloride (HCl). If the gas is dissolved in water, it produces ***hydrochloric acid***, which is used for many industrial processes, such as cleaning metal surfaces and in food processing. The stomachs of animals and humans are designed to produce dilute hydrochloric acid naturally to aid in the digestive process.

Another useful compound of chlorine is carbon tetrachloride (CCl_4). Because carbon tetrachloride does not burn, it is used in some fire extinguishers. As a heavy gas, it acts as a suffocating blanket of vapor that keeps out the oxygen and smothers the flame. Dry cleaners also use carbon tetrachloride as a cleaning fluid to dissolve fats, oils and greases. Although a liquid, carbon tetrachloride is referred to as *dry* because it contains no water. Carbon tetrachloride does not cause fabrics to wrinkle or shrink as does water. The structural formula for carbon tetrachloride is:



Carbon tetrachloride (CCl_4)

Another compound of chlorine is chloroform ($CHCl_3$). Its structural form is similar to carbon tetrachloride, but with one hydrogen atom replacing one of the chlorine atoms. *Chloroform* is a clear, colorless liquid with a sweet odor. At one time doctors used chloroform to deaden pain and put people to sleep during surgical operations. The margin for error in giving chloroform is very narrow. Too much and the patient does not wake up. Doctors also learned that it can damage internal organs such as the kidneys. Other ***anesthetics*** are used in place of chloroform. Chloroform is still used for a variety of other purposes such as refrigerants, propellants and solvents.

Chlorine is an important chemical in industry. In addition to the compounds already described, it is used as an ingredient in plastic polyvinyl chloride (PVC) pipe. Another way to use chlorine is to combine it with other elements to make a nontoxic compound. The compound is then transported to factories for manufacturing use. Chlorine is generated at factories by the electrolysis of sodium chloride. Transportation of chlorine is a difficult task because the pure gas is poisonous. The gas is liquefied and transported in pressurized railroad cars.

Bromine (Br) the third member of the chlorine family, is a dense, freely flowing liquid at room temperature. Bromine has a red color so deep it appears almost black and gives off a brownish-red vapor with a foul smell. Like chlorine, bromine can burn the lungs, irritate the eyes and leave painful sores on the skin.



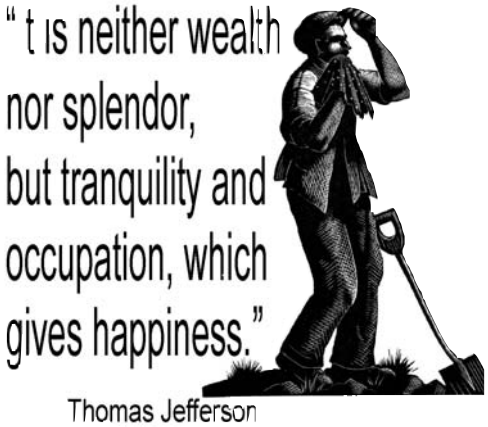
The smell of bromine led to its discovery in 1826 by Jerome Balard, a young pharmacy student. During his summer vacation, Balard experimented with chemicals found in the sea. Iodine had been discovered in the ashes of seaweed. In his experiments, Balard noticed a brown substance with a strong smell. He separated the brown substance from the ashes. Balard reported his discovery to his teachers. Chemists agreed that Balard had found a new element. He gave it the name *bromine*, from a Greek word meaning *stench*, because of its strong smell.

Bromine has chemical properties very similar to those of chlorine. It is usually found with that element. When the early chemists prepared chlorine or iodine, the sample contained some bromine as well, although chemists had failed to recognize it as a new element. Although not as abundant as chlorine, bromine can be recovered from the sea and salt lakes.

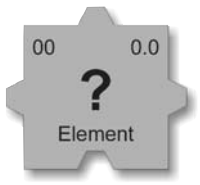
Two common compounds of bromine are sodium bromide (NaBr) and potassium bromide (KBr). Doctors often prescribed potassium bromide for patients who could not sleep. Bromides act as mild ***sedatives***. Sedatives are drugs that calm or relieve stress.

The chief use of bromine today is in light-sensitive photographic film. Silver bromide (AgBr), a yellow solid, is highly sensitive to light. An emulsion containing silver bromide coats photographic paper and film. When exposed to light, the silver bromide carries a latent image enabling photographers the ability to develop the hidden image.

LIFE PRINCIPLE



Integrated Physics & Chemistry



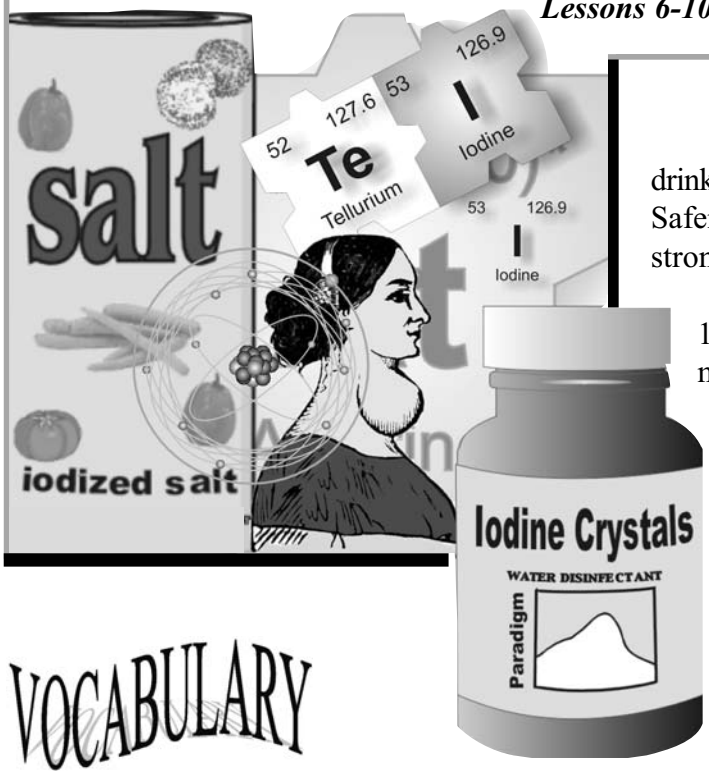
Lesson 10
Elements

Chapter 7

IODINE, ASTATINE AND HALOGENS

Section 2

Lessons 6-10



At one time, people carried small bottles of ***iodine*** crystals to treat drinking water and kill harmful microorganisms. Safer methods are used now because too strong of a dosage of iodine can be poisonous.

Iodine was discovered accidentally in 1811 when Bernard Courtois and his father manufactured saltpeter (KNO_3) from seaweed that washed ashore. When they dried and burned the seaweed, the ashes contained potassium nitrate as well as other impurities. While ridding the ashes of impurities, Bernard mixed in too much sulfuric acid. As he heated the mixture, it gave off a violet vapor. He collected the colored vapor and condensed it to form iodine crystals.

Bernard Courtois knew he had found something of interest. However, his meager saltpeter business forbid application of the discovery of iodine for financial benefit. Another French scientist, Guy-Lussac, investigated Courtois' discovery and gave the new element the name *iodine* from a Greek word for *violet*.

Sea plants are the most common sources for iodine. Kelp, a large brown seaweed, was the primary source of iodine for many years. Iodine is found as an impurity in saltpeter mines.

Iodine (I) is a shiny, blue-black nonmetallic element. At room temperature, iodine is a blue-black, crystalline solid with a metallic lustre. If heated, the solid changes directly into a vapor with a beautiful violet color. The beauty is better seen with the iodine in a closed glass container because the vapor is corrosive and poisonous. It stings the eyes and irritates the nose like the vapors of chlorine and bromine.

VOCABULARY

Iodine (I): a lustrous nonmetallic chemical element, used in alcohol as an antiseptic
Antiseptic: a chemical that prevents infection by killing microorganisms, antiseptic means *against life*
Disinfectant: any agent that kills disease carrying microorganisms
Tracer: a radioactive element whose motion through an organism provides information about the condition of the tissues
Astatine (At): a highly unstable radioactive element, member of the chlorine family

As the atomic weight of elements in the chlorine family increases, the elements become less active. Lighter elements are found at the top of the periodic table and heavier ones are at the bottom. Iodine is chemically active, but not as active as fluorine, chlorine or bromine. Fluorine reacts so readily with water, the heat generated is enough to cause flames. Iodine does not react with water and is slow to dissolve in water.

Iodine will dissolve in alcohol. Tincture of iodine is alcohol with iodine dissolved in it. A tincture is any solution of alcohol with some other substance. Tincture of iodine is used as an effective ***antiseptic*** and ***disinfectant***. The alcohol, however, will evaporate readily. If a bottle is left open, the iodine can become too concentrated and cause wounds to heal more slowly.

Although poisonous in larger doses, iodine is necessary in trace amounts in the diet so that the thyroid gland functions correctly. The thyroid produces the hormone thyroxin to control functions in the body that generate and build the body, including proper growth. *Goiter* is a condition caused by too little iodine in the diet. The thyroid gland enlarges to do its job with the reduced levels of iodine. The gland can enlarge to be visible as a swelling on the front of the neck. The thyroid gland will return to normal by the addition of iodine to the diet. In many places, iodine is readily available from ocean fish or seafood. In areas where iodine does not occur naturally, it is added to table salt. Iodized salt contains mostly sodium chlorine (NaCl), but a small amount of sodium iodide (NaI) is present to put iodine into the diet.



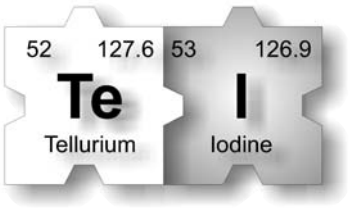
A healthy thyroid gland releases the hormone thyroxin that goes throughout the body regulating normal growth. Thyroxin contains iodine. By using radioactive iodine as a ***tracer***, medical workers can monitor where the thyroxin goes and identify the location of tumors. Tumors contain more thyroxin than healthy tissue. The tumor can be detected by the increased levels of radioactive iodine that thyroxin carried to the tumor.

For a time, rainmaking efforts used silver iodide crystals to stimulate clouds to gather moisture; a process called *cloud seeding*. Rainmakers believed moisture would collect around the crystals and fall as raindrops. Scientific evidence is too limited as to whether rainmaking affects the total amount of rain that falls. Evidence does indicate the time at which the rain falls and the amount that falls in a local area can be influenced by cloud seeding. Another important area of research is the use of silver iodide crystals to control the formation of fog along busy interstates and on runways at airports.

Iodine is one of the elements that caused problems for Mendeleev as he puzzled about the Periodic Table of the Elements. Mendeleev placed elements by their atomic weights and valences. Based on atomic weight, iodine should come before

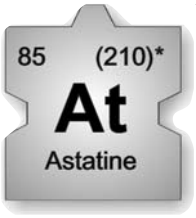
VOCABULARY

Radioactive decay: the destruction of an atom by the emission of radioactive particles and high energy electromagnetic waves
Halogen: the chlorine family (fluorine, chlorine, bromine, iodine and astatine) make up the halogen group, the name means salt former
Balanced equation: a representation of a chemical reaction in which the number and type of atoms on each side of the arrow are equal



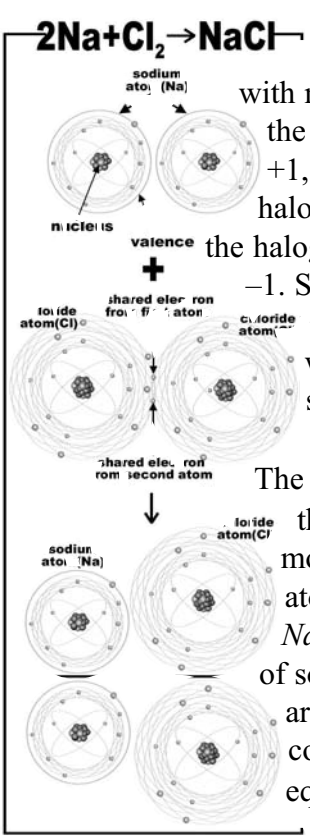
tellurium (Te). Iodine has an atomic weight of 126.90 and tellurium has an atomic weight of 127.60. However, tellurium has properties like those of silicon and a valence of –2, while iodine has properties like those of chlorine and a valence of –1. Mendeleev ignored the atomic weight and put iodine in its proper place with the chlorine family.

Astatine (At) is the last of the chlorine family of elements. It is produced by the ***radioactive decay*** of other elements. Astatine is radioactive itself, so the small amount that is produced in one day is likely to have undergone radioactive decay and disappeared by the next day. Astatine received its name from a Greek word meaning *unstable*. Little is known about astatine because its high radioactivity makes it difficult to study. Many of its properties are based on what is known about the other members of the chlorine family.



The chlorine family is the vertical group next to the inert gases in the periodic table. A gradual reduction in the chemical activity in the chlorine family is evident in going from fluorine to astatine. Astatine is the least active of the family. Suppose astatine and fluorine were introduced in a container of lithium. In the competition for lithium's electron, fluorine is easily the winner. Notice that the activity of the nonmetals on the right of the periodic table is reversed compared to the metals on the left of the table. The least active metals in a particular family, such as lithium in the sodium family, are at the top of the periodic table. The least active nonmetals, such as astatine in the chlorine family, are at the bottom of the periodic table. Despite being the least active of the chlorine family, astatine is still too chemically active to be found free in nature, therefore, is always found in combination with another element.

The chlorine family is also known as the ***halogen*** group. The word *halogen* is derived from a Greek word meaning *salt producing*. The five elements (fluorine, chlorine, bromine, iodine and astatine) are called halogens because they are salt formers.



All members of the halogen family react with metals to form salts. If the metal has a valence of +1, then only one atom of a halogen is needed because the halogens have a valence of –1. Sodium has a valence of +1. Sodium metal reacts with chlorine gas to give sodium chloride:

$2Na + Cl_2 \rightarrow 2NaCl$

The subscript 2 in Cl_2 shows that chlorine is a gas molecule, containing two atoms. The 2 in front of *Na* shows that two atoms of sodium are present, but are not chemically combined. Writing the equation as $Na + Cl_2 \rightarrow NaCl$ would be incorrect because it would not be a ***balanced equation***. The Law of Conservation of Matter states that chemical reactions can neither create matter nor destroy it. If one side of the equation had more atoms than the other had, the reaction would be creating or destroying atoms, which is not possible. Putting a 2 in front of *Na* on the left and a 2 in front of *NaCl* on the right balances the equation. Each side of the equation has the same number of sodium and chlorine atoms.

Potassium is a member of the sodium

family, and bromine is a member of the chlorine family. The equation showing their reaction has the same form as the equation for sodium reacting with chlorine. Potassium metal and bromine gas react to give potassium bromide:

$$2K + Br_2 \rightarrow 2KBr.$$

Whenever an entire family of elements reacts in the same way, chemists substitute a symbol, such as X, to stand for any one of the elements. In the case of the halogens with sodium (or any of the members of its family) the reaction is the same. If X stands for a halogen, then the reaction is:

$$2Na + X_2 \rightarrow 2NaX.$$

Magnesium has a valence of +2, so two atoms of a halogen such as chlorine are needed to make the salt:

$$Mg + Cl_2 \rightarrow MgCl_2.$$

Calcium has a valence of +2, so two atoms of a halogen such as iodine are needed to make the salt:

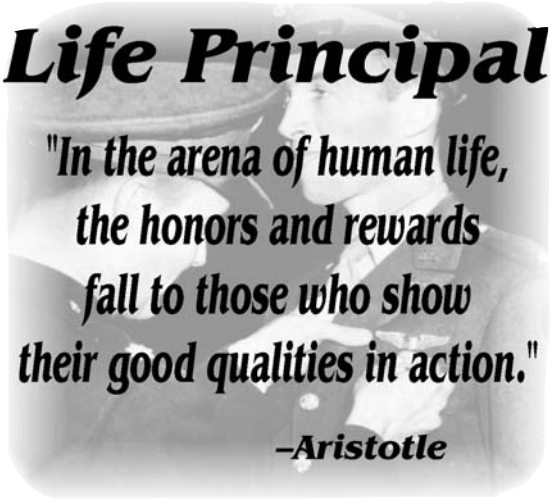
$$Ca + I_2 \rightarrow CaI_2.$$

Because X stands for a halogen, then the reaction of any of the halogens with calcium is shown as:

$$Ca + X_2 \rightarrow CaX_2.$$

Each of the halogens will combine with hydrogen. The reaction forms a colorless gas that dissolves in water to produce a strong acid. Fluorine gas reacts with hydrogen gas to give hydrogen fluoride. When hydrogen fluoride gas bubbles through water it produces hydrofluoric acid, $H_2 + F_2 \rightarrow 2HF$. Chlorine gas and hydrogen gas also react to give hydrogen chloride, or hydrochloric acid, $H_2 + Cl_2 \rightarrow 2HCl$. The formula for hydrogen chloride is HCl, the 2 in front of it shows that two hydrogen chloride molecules are present. All of the halogen gases will react with hydrogen to make an acid. The general reaction of a halogen with hydrogen to give an acid is shown as: $H_2 + X_2 \rightarrow 2HX$.

Members of the chlorine family of elements are alike in many ways, but they have some differences. Fluorine (F) is a pale yellow gas and the most reactive element known. Chlorine (Cl) a greenish-yellow gas, was the first poison gas used in World War I. Bromine (Br) a reddish-brown liquid, is noted for its strong odor, and a compound of it with silver is used in photographic film. Iodine (I), a blue-black crystal, is combined with alcohol to make an antiseptic. Astatine (At) is radioactive.



Integrated Physics & Chemistry



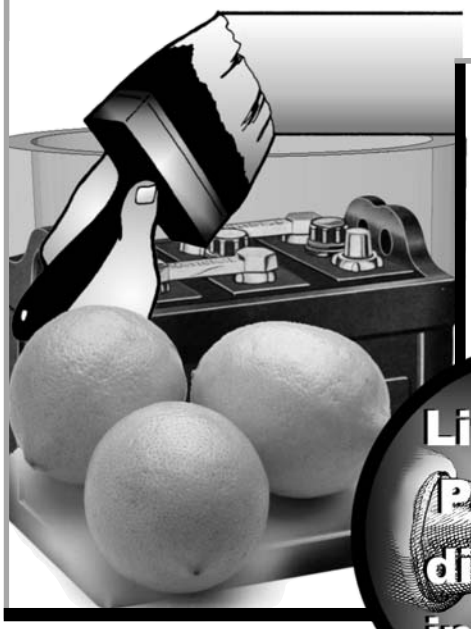
Lesson 11
Compounds

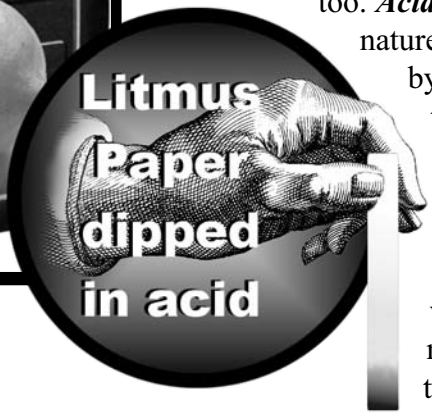
Chapter 7

ACIDS, BASES AND SALTS

Section 3

Lessons 11-15





We are used to recognizing opposites: hot or cold, big or little, fast or slow. For every property, we expect to find the opposite. Opposites are common in physics. For instance, Isaac Newton's Third Law of Motion states that for every action there is an opposite and equal reaction. Chemistry has opposites, too. ***Acids*** and ***bases*** have opposite chemical natures. An upset stomach may be caused by excess acid. A person may correct the problem by taking a base, such as bicarbonate of soda ($NaHCO_3$), to neutralize the acid.

Acids have a sour taste. They are *corrosive*, meaning that the acids will attack and pit the surfaces of metals. Acids neutralize bases and turn ***litmus paper*** red. Litmus paper is a piece of paper pretreated with a special colored dye that turns blue or red to indicate whether a substance is a base or an acid. The litmus dye comes from the leaves of certain plants.

The modern definition of an acid is that it provides hydrogen ions (H^+) to a solution. Hydrogen is always found in acids. All acid molecules tend to come apart in water to release hydrogen ions. For instance, when hydrochloric acid is mixed with water, hydrogen and chlorine go their separate ways. Each one carries a charge because the hydrogen releases its electron to the chlorine. Hydrogen becomes a positive ion (H^+), and chlorine becomes a negative ion (Cl^-).

The number of hydrogen ions that acid releases into a solution measures the strength of an acid. Some acids release more hydrogen ions than others do. Hydrochloric acid (HCl), is a ***strong acid***. When mixed with water, about 92 percent of hydrochloric acid molecules break into H^+ and Cl^- ions. When sulfuric acid (H_2SO_4), is mixed with water, about 61 percent of

VOCABULARY

Acid: a source of hydrogen ions (H^+), neutralizes bases and turns blue litmus paper red
Base: a source of hydroxyl ions (OH^-), a base has a bitter taste, feels soapy, neutralizes acids and turns red litmus paper blue
Litmus paper: a piece of paper soaked in the dye litmus that turns red for an acid or blue for a base
Strong acid: is one in which a high percentage of its molecules come apart in water to give hydrogen ions

its molecules come apart. However, each sulfuric acid molecule that does come apart releases two hydrogen ions into the solution. Sulfuric acid is a strong acid because it puts a high concentration of H^+ ions in solution.

Weak acids do not come apart as readily. Weak acids release fewer hydrogen ions into solution and give some foods and drinks, such as lemonade or grapefruit, a sour taste. Our tongues detect the H^+ of an acid as a sour taste. Citric acid ($C_6H_8O_7$) is found in lemons, grapefruit and other citric fruits. Lactic acid ($C_3H_6O_3$) forms in milk that has soured and produces a spoiled taste. Carbonic acid (H_2O_3) is found in carbonated drinks. Acetic acid (C_2H_4O) gives vinegar its sour taste. As you would expect, these weak acids have low concentrations of H^+ ions in solution. Otherwise, the acids would be too dangerous to drink. For instance, when acetic acid is mixed with water, less than 2 percent of its molecules break down into ions.



The terms strong and weak are used to describe how readily the acid makes hydrogen ions. A strong acid is a good source of hydrogen ions. A weak acid is one that does not supply many hydrogen ions.

VOCABULARY

Weak acid: is one in which only a small percentage of its molecules come apart in water to give hydrogen ions
Neutral solution: a solution which is neither an acid nor a base
Hydroxyl ions: (OH^-) produced by bases such as sodium hydroxide (NaOH)

A concentrated acid and a dilute acid differ in the amount of water they contain. A *concentrated acid* is one that has not been mixed with water, or one that contains only a small amount of water. A *dilute acid* is one that has been mixed with a lot of water. A solution of acid and water reduces the number of hydrogen ions in a given sample of the acid. Both strong and weak acids can be diluted. Sulfuric acid is so strong that even when diluted with water, it still may be stronger than concentrated acetic acid.

Tasting a solution to judge whether it is an acid or to determine its strength is not wise. A safer method is to use an indicator. *Indicators* are chemicals that change color depending upon whether the solution is acidic or basic. Most indicators are based on dyes found in plants such as the purple leaves of red cabbage. The most common indicator is litmus, which turns red with acids and blue with bases. A solution that gives litmus paper a color midway between red and blue is called a ***neutral solution***. A neutral solution contains hydrogen ions (H^+) and ***hydroxyl ions*** (OH^-) in equal amounts. Pure water is neutral.

Red cabbage is often used to make chemical indicators.



A *pH meter* measures not only whether a solution is an acid but also the strength of an acid solution. The letters *pH* are from French words meaning *power of hydrogen*. A pH meter has special electrons that measure how well the water conducts electricity and the concentration of hydrogen ions in the water. In pure water, the pH meter returns a reading of 7. Acids have a pH less than 7. A pH of 6 is a weak acid, and a pH of 0 indicates the solution is a very strong acid.

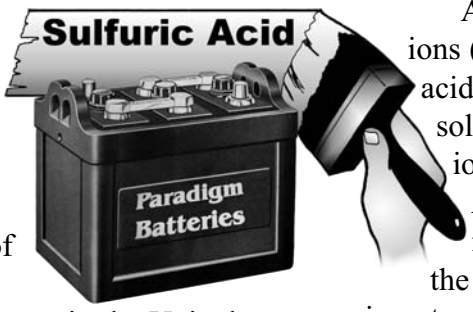
Whenever a strong acid is mixed with

water, the reaction generates heat. The safety rules are: (1) use containers that can withstand changes in temperature, (2) wear protective gloves and goggles, (3) add the acid to the water slowly and stir frequently. When mixed too rapidly, the water can be heated so hot it boils and splatters the acid. Concentrated acid destroys skin and flesh and can cause blindness.

Acids attack metals. *Corrosion* is the process by which a metal is dissolved by chemical action. The word *corrode* is from a Latin word meaning *to gnaw to pieces*. Should an iron nail be put in a solution of sulfuric acid, the acid corrodes the metal, and it becomes pitted as the iron goes into solution. The iron atoms replace the hydrogen, and it bubbles out of the solution as hydrogen gas. The equation for the reaction uses an up arrow to show that the hydrogen leaves the solution as a gas:

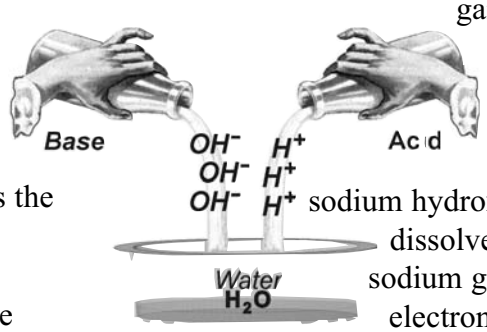
$Fe + H_2SO_4 \rightarrow FeSO_4 + H_2\uparrow$.

Three of the most used acids are *sulfuric acid* (H_2SO_4), *hydrochloric acid* (HCl) and *nitric acid* (HNO_3). Sulfuric acid (H_2SO_4) is used in the manufacture of automobile batteries, fertilizers, paints, metal processing and many other products. About a half-gallon of sulfuric acid is used each day for every person in the United States. Hydrochloric acid is used in ore reduction, food processing and cleaning solutions for metal surfaces. Small amounts of hydrochloric acid are produced by the stomach to aid in the digestion of food. Nitric acid is used in the manufacture of fertilizers and in making dyes and explosives.



Although all acids contain hydrogen, a compound can contain hydrogen and not be an acid. Water (H_2O), methane (CH_4) and ammonia (NH_3) all contain hydrogen but are not acids. An acid releases hydrogen ions into a water solution. Water, methane and ammonia do not release hydrogen ions in high enough numbers to be classified as acids.

The opposite of an acid is a base. A base has a bitter taste, feels soapy, turns litmus paper blue, and removes hydrogen ions from solution to neutralize acids. Usually, the base removes hydrogen ions by supplying the hydroxyl group (OH^-), to the solution. The hydroxyl group (OH^-) is a bonding of one hydrogen atom with one oxygen atom. The group as a whole has gained an extra electron, so it carries a negative charge. For instance, when sodium hydroxide (NaOH) dissolves in water, the sodium gives up an electron to the *OH* group. The sodium becomes a positive ion, Na^+, and the *OH* becomes a negative group, OH^-.



A base provides a source of hydroxyl ions (OH^-). When a base is mixed with an acid, the OH^- unites with the H^+ in the solution to produce water. Some bases ionize more completely than others do. A strong base is one that readily ionizes so that it is a good source of the OH^- ion. Sodium hydroxide (NaOH) is a strong base because more than 90 percent of its molecules come apart in solution to give hydroxyl ions (OH^-). Another strong base is lithium hydroxide (LiOH). Ammonium hydroxide (NH_4OH) is a weak base because only about one percent of its molecules come apart to give NH_4^+ and OH^- ions.

The OH^- of the base neutralizes the H^+ of the acid. For instance, if hydrochloric acid is mixed in the right proportion into a

solution that contains lithium hydroxide, the reaction produces water and a salt:

$$LiOH + HCl \rightarrow H_2O + LiCl$$

$$acid + base \rightarrow water + salt.$$

In summary, an acid has a sour taste, reacts with metals to release hydrogen gas, turns litmus paper red, releases H^+ ions in solution and neutralizes bases. A base has a bitter taste, feels soapy, turns litmus paper blue, releases OH^- ions in solution and neutralizes acids. The reaction of an acid with a base produces water and a salt.

Life Principle



Integrated Physics & Chemistry



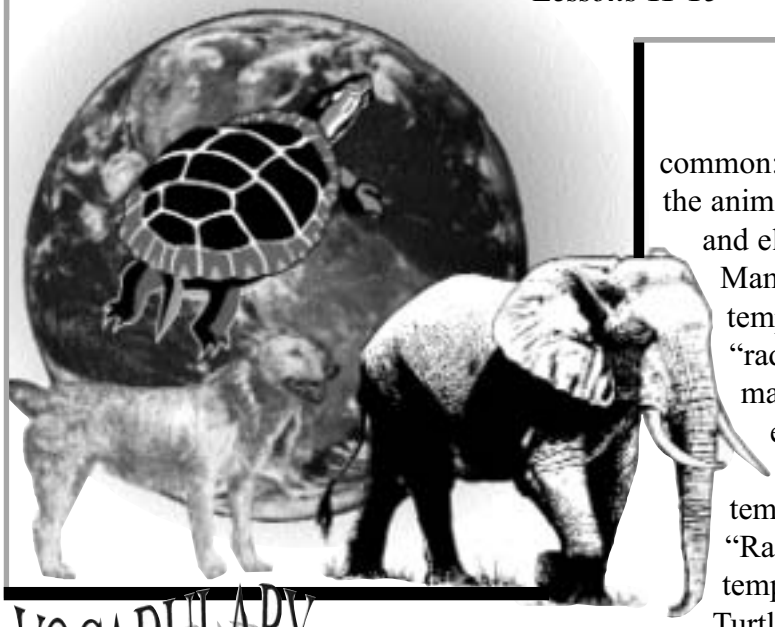
Lesson 12
Compounds

Chapter 7

COVALENT COMPOUNDS AND WATER

Section 3

Lessons 11-15



Dogs' tongues and elephants' ears have one thing in common: they are "water radiators" to cool the animals. All mammals, including dogs and elephants, are warm-blooded. Mammals maintain a constant body temperature through use of their "radiators." The body temperature of a mammal is usually warmer than the environment. Reptiles, such as turtles, are cold-blooded. Their temperature varies with the environment. "Radiators" cannot regulate the body temperature of cold-blooded animals. Turtles gain heat during the day by sunning themselves. They have thick layers of fat under their shells. Once this fat becomes warm, it helps keep the turtle warm throughout the day and into the night. In this section, you will learn how the strange properties of water contribute to the regulation of the internal body temperature of animals.

Water has several properties that are not shared by other liquids. These properties help living organisms maintain the right body temperatures. Water (H_2O) is a well-known example of a ***covalent compound***. Covalent compounds share electrons. Hydrogen has one electron and needs to gain another one for the more stable arrangement like that of the inert gas helium. Oxygen has six electrons in its outer level. Two more electrons give oxygen the more stable arrangement of eight electrons in its outer shell. By sharing electrons, both hydrogen and oxygen have the preferred arrangement of electrons.

Because they do not gain or lose electrons, hydrogen and oxygen atoms remain electrically neutral. Overall, the water molecule is electrically neutral, too. However, the electric charge is not evenly distributed or equally shared. The oxygen atom holds the electrons more tightly than the hydrogen atoms.

VOCABULARY

Covalent compound: a compound that is made by atoms that share electrons
Polar: a molecule that is electrically neutral overall but has two regions with opposite electric poles
Universal solvent: the description given to water because it can dissolve so many different types of chemicals
Specific heat: the amount of heat required to change the temperature of one gram of a substance by one degree Celsius, water has one of the highest specific heats of any liquid
Moderate: to keep within reasonable limits

When around an oxygen atom, the molecule has a negative charge, but around the hydrogen atoms, the molecule has a positive charge.

Although electrically neutral, a water molecule is ***polar***. It has a region with a positive electric pole and a region with a negative electric pole. Imagine a mouse face with two big ears. The oxygen atom is the face and the hydrogen atoms are the two ears. In the vicinity of the ears, the water molecule has a positive charge. At the bottom of the face, the water molecule has a negative charge.

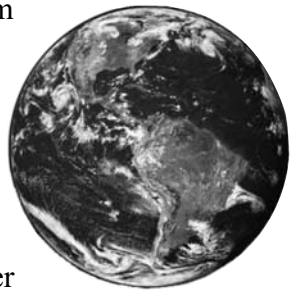


Water (H_2O) a covalent, polar compound

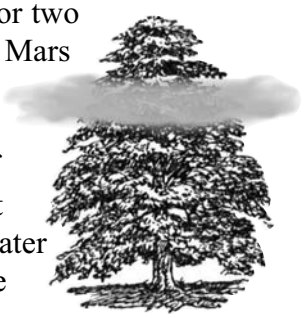
The charged regions give water the ability to dissolve many different substances, especially ionic compounds, such as sodium chloride. The charged regions of water interfere with the electric attraction holding the sodium and chlorine atoms together. Salt separates and dissolves in water. Acids, bases, salts, sugars, starches and proteins will dissolve in water. Many other non-ionic substances such as alcohol mix thoroughly with water. Blood is about 80 percent water and circulates throughout the body. Blood carries nutrients to the cells and removes waste products. Chemicals dissolve in blood because of the action of the positively and negatively charged regions of the water molecule. Because so many different substances dissolve so well in water, it is called the ***universal solvent***.

The properties of pure water contrast sharply with the water that comes from a faucet. Water from a faucet often has a taste from the minerals or an odor from the gases dissolved in it. Pure water, however, is odorless and tasteless. In small amounts, pure water is colorless, but in great depths, such as the ocean, water has a blue-green color. Pure water is a poor conductor of electricity. However, most water is not pure; it contains dissolved ionic compounds. The impure water solution readily conducts electricity.

Water is the most common liquid on Earth. No other substance comes close to being as abundant. From space, viewers can see that about three fourths of Earth's surface is covered by oceans. Glaciers, salt-water seas, fresh water lakes, swamps and rivers cover another portion of Earth's surface. During winter, part of the land is covered by snow. Clouds, which are made of water, can obscure the surface of Earth throughout the year. Occasionally, as much as 90 percent of Earth can be hidden from view by one form of water or another. From space, Earth has the appearance of a misty water-covered planet.



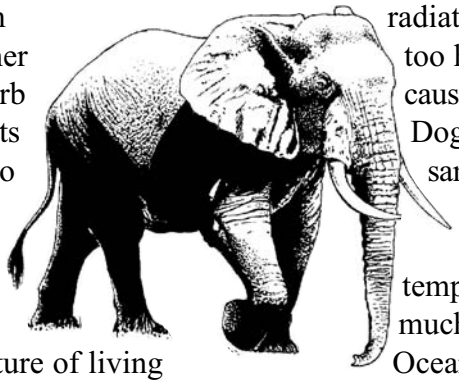
Earth is the only planet positioned in the universe at the precise distance from the Sun to sustain climates and seasons that support life. Earth is the only planet in which water is found in all three states, as a solid (ice, snow and glaciers), liquid (oceans, lakes, rivers), and gas (fog, steam, water vapor in the atmosphere as clouds). If the orbit of Earth differed only slightly, the water would be found in one or two states, but not all three. Mars is farther from the Sun than Earth, making Mars a colder planet. If Earth orbited the Sun at the distance of Mars, water vapor in the atmosphere



would fall as snow and evaporation would nearly cease. Rivers would stop flowing and lakes and oceans would freeze. Venus is closer to the Sun than Earth, making Venus a planet as hot as an oven. If Earth orbited the Sun at the distance of Venus, all of its water would boil to a vapor and enclose Earth in dense clouds.

Water acts as a heat bank, it readily accepting and storing heat. Liquid water holds heat better than any other liquids. Water has a particularly high ***specific heat***, or heat capacity. One calorie of heat is needed to raise the temperature of one gram of water by one degree Celsius. This is more than most other liquids require. For instance, only ½ of a calorie will heat one gram of alcohol by one degree Celsius. Only 1/30th of a calorie will heat one gram of mercury by one degree Celsius.

Water resists changes in temperature better than any other common fluid. Water will absorb heat energy without changing its temperature much. Water is also a good heat source. A small amount of water releases heat energy as the surrounding temperature falls. Water helps regulate internal body temperature of living organisms. Under normal circumstances, the human body is kept at a constant temperature of about 98.6ºF. Health can be damaged if body temperature falls below 88ºF or rises above 106ºF. This seldom occurs because of the ***moderating*** effect of water.



Should the body become too cold, the muscles generate heat energy. The chattering of teeth and shivering in cold weather is a sign that the muscles are trying to generate heat. Once the muscles generate heat, blood that is mostly water carries the warmth throughout the body.

Should the body be exposed to too much heat, the blood veins next to the skin will enlarge and allow the blood to flow closer to the surface to be cooled by the air. At the same time, perspiration from sweat glands in the skin and water vapor expelled in the breath carry away excess heat. The process of evaporation is one in which a large amount of heat is removed from a body. A total of 540 calories of heat energy must be absorbed by a gram of water to change it from water at 100ºC to steam at the same temperature. Evaporation is a cooling process. As the body sweats, the perspiration changes to vapor and evaporates from the skin. Every gram of water that changes to a vapor carries away 540 calories of heat energy.

The body temperatures of animals that do not have sweat glands are controlled in other ways. Elephants have large ears that contain a network of blood vessels that act as radiators. When elephants become too hot, they flap their ears, causing air to cool the blood. Dogs use their tongues for the same purpose.

The waters of Earth resist sudden changes in temperature. Vast oceans cover much of the surface of Earth. Ocean water absorbs heat in summer and releases it in winter, which prevents sudden swings in temperature. The moderating, or stabilizing, effect of water can be seen on islands such as Puerto Rico. The island is surrounded on all sides by water. On the south is the Caribbean Sea, and on the north is the Atlantic Ocean. The temperature is pleasant year around. On the other hand, the Sahara Desert which is about the same distance from the equator as Puerto Rico is far from any water source and suffers



extreme temperatures. In the Sahara Desert, the days are blazing hot, and the evenings are cool.

The amount of heat that water absorbs or releases when it changes state is high compared to other liquids. A total of 80 calories of heat energy must be removed from a gram of water to change the temperature from water at 0º Celsius to ice at 0º Celsius. In other words, each gram of water gives up 80 calories of heat when changing from a liquid (water) to a solid (ice). This fact is useful to citrus farmers who spray their groves with water on cold nights to keep oranges from freezing. Spraying the crops with water would seem to cause the citrus fruit to freeze quicker. However, because so much heat is required to change water into ice, adding water to the surface of the fruit increases the amount of energy necessary to freeze the fruit itself. The extra heat the water provides is sometimes enough to keep the cold night air from damaging the crop of fruit.

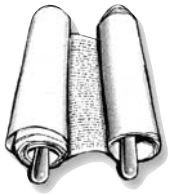
Life Principle

"If you want to be successful, it's just this simple. Know what you are doing. Love what you are doing. And believe in what you are doing."

—Will Rogers

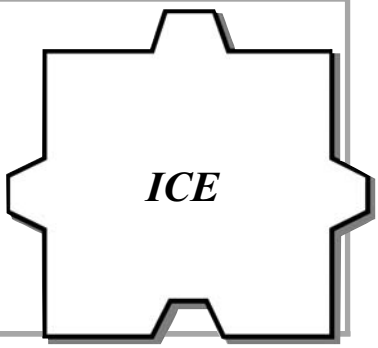


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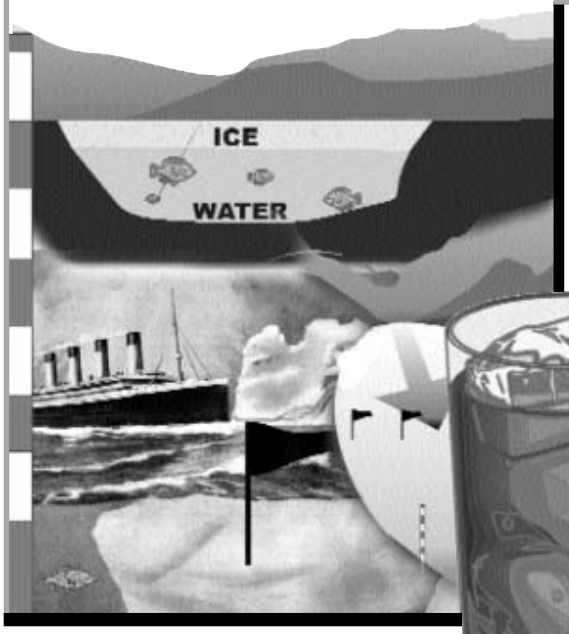
Lesson 13
Scientific Laws

Chapter 7

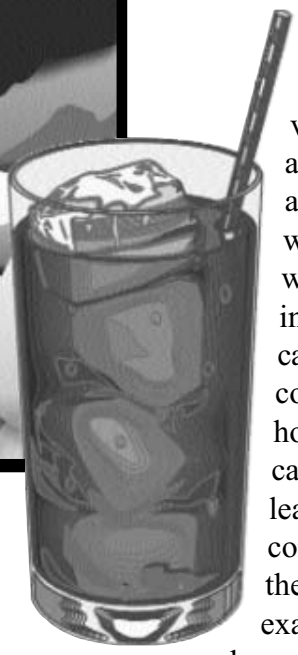


Section 3

Lessons 11-15



Water expands as it freezes. This can cause problems if the water is confined without room to expand in a closed container, such as automobile radiators, water pipes or other containers. As winter approaches, vehicle drivers make certain their automobile radiators contain adequate antifreeze for the impending cold weather. Without sufficient antifreeze, water will change to ice and expand. Ice in the radiator pushes the joints apart, causing the radiator to leak. In exceptionally cold weather, unprotected water pipes in houses can freeze. The expanding ice will cause the pipes to crack, and the pipes leak once the ice thaws. When cans that contain water are left too long in a freezer, the cans may burst open. All of these examples show that water expands as it changes to ice.



VOCABULARY

Glacier: a large layer of slowly flowing ice which forms from snow that accumulates at a greater rate than it melts
Shipping lanes: certain ocean routes followed by ships, most efficient commercial water routes
Hexagon: a mathematical shape with six sides
Ice cap: a large layer of ice that covers an extensive area of land, Greenland and Antarctica are covered with thick ice caps

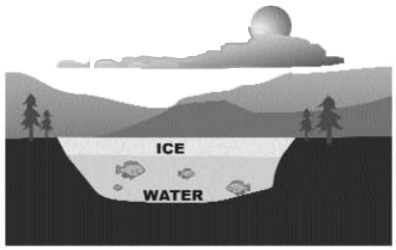
When ice expands, it becomes less dense than water and will float. Icebergs break from the large ***glacier*** that covers most of Greenland. A glacier is a large mass of slowly moving ice. Rather than sinking, icebergs float in water. Wind and ocean currents carry the icebergs into ***shipping lanes*** and pose a threat to ships.

The fact that water expands as it freezes and that ice floats in water is unusual. All other liquids contract when cooled to freezing. Water is the only liquid that expands. Water boils at 100ºC (212ºF) and freezes at 0ºC (32ºF). In cooling from 100ºC to 0ºC, water contracts like all other liquids. However, that general trend reverses as water nears its freezing temperature. Below 4ºC (39ºF), water expands and continues to

expand as it changes into ice. Water at a temperature of 4ºC is most dense.

Because of this reversal of density, ice is less dense than most unfrozen water and can be seen floating on the top of a pond in winter. Most solid substances do not float in their liquid counterpart. For instance, a bar of iron dropped into molten iron will sink to the bottom. With water, this general rule is reversed. Solid water as ice floats in liquid water. This is important for living things, for if ice sank in water, the results would be disastrous to living organisms.

In winter, the cold weather causes ice to form on a lake. The ice floats on the surface of the lake, and the warmer water, which is denser, sinks to the bottom of the lake. When a lake freezes, the layer of ice on the surface acts as an insulating covering. The layer of ice protects the rest of the water against exposure to cold air. The pond never freezes all the way to the bottom, unless it is quite small. Fish and other pond life survive in the warmer water at the bottom of the pond.



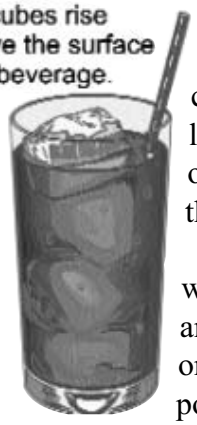
Cut-Away View of an Iced-Over Pond

Cranberry farmers make use of water to protect their plants when the temperature threatens to fall below freezing. The farmers flood the fields with water to cover the cranberry plants. Freezing takes place only on the surface of the water. The plants are surrounded by water that is at 39ºF, which is far enough above freezing to avoid damage.

Water expands as it freezes, and ice is lighter than water. A clue to the reason for this comes from the shape of snowflakes. Snow is made of small crystals of frozen water. The crystals form as water vapor freezes around solid particles in the air. Snowflakes are alike in that all have a six-sided shape, a ***hexagon***. The hexagon patterns reveal how water molecules interact with one another. The water molecule is neutral overall, but does have a positive region around the hydrogen atoms and a negative region around the oxygen atom. The positive electric pole of one water molecule attracts the negative electric pole of a nearby water molecule. The water molecules arrange themselves in an open, hexagonal pattern. So intriguing is the purity of snowflakes that one of the oldest pieces of literature in the world, the Book of Job in the Bible, measures virtue by the purity of snowflakes.

Heat energy at room temperature sets the water molecules in motion. Water molecules move too fast for the electrical poles to hold the molecules in any particular pattern. As the water cools, the molecules slow down. Their electric fields interact with one another and take up the hexagon pattern. This leaves a lot of empty space. The open structure explains why ice is lighter than liquid water. When water freezes, it expands to about 1.1 times its original size. A cubic centimeter of water has a mass of 1.0 gram. A cubic centimeter of ice has a mass of 0.9 gram. A cubic centimeter of ice is lighter than a cubic centimeter of water, which is the reason that ice floats on water.

Ice cubes rise above the surface of a beverage.



Water molecules have a weak attraction for one another. The negative pole of one water molecule attracts the positive pole of a nearby water molecule. The attraction is only about one-twentieth as strong as the force of a covalent chemical bond. Despite being weak, this attraction is responsible for the unusual properties of water such as its high heat capacity. Attraction between water molecules causes them to resist flying away

from each other. Additional heat is needed to separate the water molecules and make them change into a gas.

The fact that water is a liquid at room temperature is another way that water differs from other compounds. All other compounds of similar molecular weight are gases at room temperature. For instance, methane (CH_4) has about the same molecular weight as water. It is a covalent compound, too. However, methane turns to a gas (boils) at far cooler temperatures than water. Methane boils at –161ºC (-258ºF). Water, on the other hand, boils at a much higher temperature, 100ºC (212ºF). The difference between the boiling temperature of methane and the boiling temperature of water is 261ºC.

Water can be found on earth as a solid, liquid or gas. The single greatest amount of water is as a liquid in the oceans. The second largest amount of water is as solid ice in glaciers and polar ***ice caps***. The largest ice cap is located at the South Pole and covers the entire Antarctic continent. The ice cap's average thickness is about 1.5 miles. Greenland also has a vast storehouse of ice. An ice cap covers Greenland to a depth of one mile. About 96 percent of all the ice on earth is found in the polar ice caps or in Greenland. The rest of the ice consists of smaller glaciers in Iceland, Alaska, and along mountain ranges around the world. Ice composes about seven percent of all of the water on Earth.



Because liquid water is a good solvent, it usually contains dissolved minerals. The oceans are solutions of various minerals and salts. Seawater is too salty for human consumption and will kill most plants. Other sources of water also contain minerals. However, water that evaporates and falls as snow is especially pure. In the high mountains and at the North and South Polar Regions where glaciers form, the air has few pollutants. Glaciers are a natural source of very pure water.

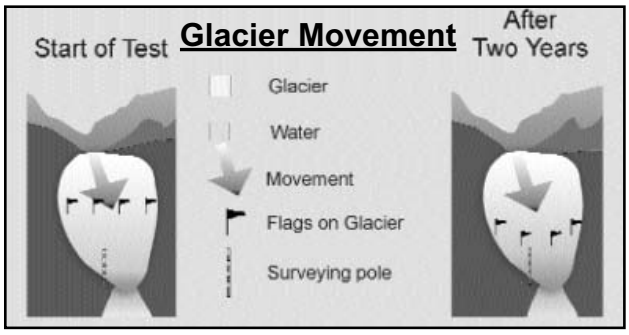
A glacier is made by snow that falls in greater amounts than melts. As the snow accumulates, the lower levels become compressed. The added pressure turns the snow to ice. The weight of a glacier has enough pressure to cause the ice to flow like a thick fluid. Although snow continues to fall, the glacier does not get any bigger because it flows to warmer valleys where it melts, or continues to flow into the ocean where large pieces break off. An iceberg is a chunk of ice that has broken from a glacier. You may recall that an iceberg floating in the North Atlantic Ocean in 1912 collided with and sank the Titanic ocean liner.

Glaciers vary in size. The Antarctica ice cap, with a size of almost five million square miles, is an entire continent. Some of the glaciers in Glacier National Park, Montana, are less than a mile across. When a glacier becomes so small that the ice no longer flows, it ceases being a true glacier. It is merely a snow or ice field. A glacier flows like a river in ever-so-slow motion.

Louis Agassiz was the first person to explore glaciers and learn that glaciers do move. Louis Agassiz was born in Switzerland in 1807. His family lived in poverty so Louis could attend the University of Heidelberg, one of the best schools of Europe. At the University of Heidelberg, Louis Agassiz earned a medical degree. However, instead of practicing medicine, Louis returned to Switzerland to be near the glaciers that he wanted to explore.

At that time, scientists believed that great changes did not occur in the climate of Earth. The scientists did not believe in great catastrophes such as massive glaciers pouring down into valleys. One of the first evidences that Louis Agassiz found was that ice flows made deep scratches in the rock of valley walls. Agassiz believed that high in the mountains, boulders had become embedded in moving glaciers. The glaciers pressed the boulders against the valley walls with enough force to cut deep grooves into the solid rock. Agassiz also knew that boulders in the valleys were the result of some form of movement. Louis Agassiz concluded that glaciers had carried the giant stones to their present locations and dropped them when warmer weather melted the ice.

Louis Agassiz drilled a straight line of holes all the way across a glacier and placed stakes with flags in the holes. Over the next two years, the flags moved forward with the ice. The stakes in the center moved faster than those at the edge. The movement of glaciers varied in different areas, from a few inches per day to several feet per day. Agassiz concluded that as a glacier moved into a valley, action smoothed the rocks, cut out valleys, and scraped away loose soil to bedrock. In the United States, scientists theorize that the magnificent Yosemite Valley as well as The Great Lakes were carved out by glacial action that took place over a period of several thousand years.



LIFE PRINCIPLE

"Act as if what you do makes a difference. It does."

—William James



Integrated Physics & Chemistry



Lesson 14
Compounds

Chapter 7

SOLUTIONS

Section 3

Lessons 11-15



When a person takes a shower or bath, a ***solution*** of water and soap removes the grease, oil and dirt particles. Life processes depend on the fact that water is a good ***solvent***. Water-based saps that carry minerals from the soil to all parts of the plants nourish the plants by capillary action. Human beings drink many solutions such as milk, soda, tea and lemonade. Blood transports oxygen and food throughout the body and carries away the waste products. Blood is a water solution.

A solution is a special type of ***mixture***. A mixture is not the same as a compound. A mixture contains two or more substances that are not chemically combined. A *compound* contains two or more elements that are found in exactly the same proportion and are combined chemically. Settling, filtering, evaporation or other physical means can separate the chemicals in a mixture. The ingredients of a compound can be separated only by chemical reactions.

VOCABULARY

Solution: process by which a solid, liquid or gas is uniformly mixed with another solid, liquid or gas
Solvent: a substance capable of dissolving another substance
Mixture: a combination of two or more substances that are not chemically combined and are capable of being separated by physical means such as settling, filtering or distilling
Solute: the component of a solution that is present in the lesser amount



Muddy water is a mixture. By letting it set, the mud and grit will settle to the bottom. Pure water is a compound, made of two atoms of hydrogen for every one atom of oxygen. The only way water can be separated into hydrogen and oxygen is by a chemical reaction.

A solution is a uniform mixture. Suppose sugar has been added to tea. The sugar, tea and water make a solution. A spoonful of the water taken from the top of the cup has the same amount of tea, sugar and water as a sample taken at the bottom of the cup. The solution is the

same regardless of where it is taken. A mixture that is a true solution does not separate. A closed container of water and sugar can sit still for days and the sugar stays in solution. It does not settle out. However, the sugar can be separated from the water by physical means. If the water is allowed to evaporate, the sugar is left behind.

The substance being dissolved, such as sugar, is the ***solute***. The substance into which the sugar is dissolved, such as water, is the solvent. A solution can be a combination of solids, liquids or gases. For instance, silver with mercury in it is an example of a solution that is made of a solid solvent (silver) with a liquid solute (mercury). However, we usually think of a solution as a liquid. The liquid can have solids, liquids or gases dissolved in it: water with sugar (solid), water with cream (liquid), water with carbon dioxide (gas).





Coffee, tea, lemonade and most other drinks are solutions. When a person makes coffee, the solute is the oil that comes from the coffee beans. The solvent is the hot water that drips through the coffee. Because coffee is not a compound, the amount of solute (coffee) can be increased in proportion to the solvent (water). A container of strong black coffee has a higher concentration of dissolved coffee than a cup of weaker coffee. Strong coffee results from using more coffee grounds or allowing water to stay in the grounds for a longer time. Some coffee makers perk the coffee, sending hot water through the grounds. Using hotter water causes more coffee to dissolve.

One way to make a solution form faster is by grinding the solute to increase its surface area. Coffee beans, for instance, are made into small grounds. This increases the number of molecules of the solute exposed to water. Water molecules attach to the molecules of the solute and take them away.

When dissolving a cube of granulated sugar or fine powdered sugar, the powdered sugar goes into solution faster because it has more surface area. A sugar cube one inch on the side has six square inches exposed to water. If the sugar cube is broken up into particles that are 1/100th of an inch on a side, the amount of surface area exposed to water goes up dramatically. The total surface area exposed becomes 600 square inches. This

VOCABULARY

Saturated: a solution that is holding the greatest amount of solute possible at a particular temperature and pressure
Solubility: the amount of a substance that can be dissolved in a given amount of solvent
Miscible: liquids that will thoroughly mix to form a solution
Immiscible: liquids that will not blend together and form a solution
Insoluble: a compound that cannot be dissolved
Precipitate: (verb) to cause a solid substance to separate from a solution; (noun) a reactant that does not dissolve in a solvent

exposes more surfaces to the action of the water.

Another way to increase the speed of forming a solution is by using hot water. Solids and liquids dissolve more quickly in hot water. Heat energy puts the molecules in motion. Sugar dissolves faster in hot water than in cold, because the sugar molecules have enough energy to break free of the sugar cube. Water molecules collide more frequently with sugar molecules and mix them throughout the solution.



Still another way to increase the speed at which a solution forms is by stirring or shaking. When dry powder creamer is added to coffee, stirring the creamer will help dissolve it more quickly. The extra agitation brings more water molecules into contact with molecules of the solute and helps dissolve them.

Increased quantities of sugar added to coffee, reduces the ability of sugar to dissolve. Water and other solvents have a limit to the amount of solute that can be accepted. Water that has dissolved as much solute as possible is referred to as being ***saturated***.

The ***solubility*** of a substance is the number of grams of the substance that will dissolve in 100 grams of water at a given temperature. The amount is different depending on the substance and the temperature. At 20ºC (68ºF), about 37 grams of ordinary table salt will dissolve in 100 grams of water. At that same temperature, about 85 grams of sodium nitrate will dissolve in water. For solids and liquids, the higher the temperature, the greater the amount of solute that will dissolve. Heating water from 20ºC to 40ºC (104ºF) increases from 85 grams to 105 grams the amount of sodium nitrate that will dissolve.

When substances are added to water, the physical properties of water will change. Usually, the freezing temperature is lowered and the boiling temperature is raised. An automobile radiator contains a solution of water and antifreeze such as ethylene glycol. The solution has a lower freezing temperature than water alone to prevent freezing in winter. The solution also has a higher boiling temperature than water alone to prevent the radiator from boiling over during hot summer days.

Temperature affects gases differently than solids and liquids. A higher temperature helps solids and liquids dissolve more readily. For gases, the effect is reversed. Gases dissolve more readily in cold water. The fact that a cold solution will hold dissolved gases better than a hot solution is illustrated by a soft drink. Most sodas contain water, artificial color, artificial flavor and carbon dioxide, which is a gas. A soda that is opened while warm will spew as the carbon dioxide gas is suddenly released from the solution. In a cold soda, the carbon dioxide gas is less likely to spray.

Another factor that controls how much gas will dissolve in water is the pressure. The amount of gas that will dissolve is directly proportional to the pressure. If a certain amount of gas will dissolve in a liquid, then doubling the pressure will dissolve twice as much gas. Dissolving carbon dioxide gas in water under pressure makes the carbonation in soft drinks. After dissolving the carbon dioxide gas, the drinks are capped. Once the cap is removed, the carbon dioxide gas

bubbles out of the drink because the pressure is removed.

The solvent for making a solution does not have to be water. Solutions can have alcohol, carbon tetrachloride, gasoline and a variety of other substances as the solvent. Carbon tetrachloride (CCl_4) is a liquid that will dissolve greases and oils. Some motors for lawn mowers and chain saws require oil to be mixed with the fuel. Oil is the solute and gasoline is the solvent. Oil and gasoline are ***miscible***, capable of forming a solution with one another. Two liquids that mix easily are miscible.



Oil and water do not mix. When oil is mixed with water, the oil will either float to the top or stay separate as bubbles that float around in the water. Two liquids that do not mix are ***immiscible***. Oil and water are immiscible because they do not form a solution with one another. One example of water and oil being immiscible is in vinegar and oil salad dressing.

Sometimes solutions help a chemical reaction take place. As an example, lead nitrate ($Pb(NO_3)_2$) and potassium iodides (KI) are both dry powders. They do not react when shaken together. In a solution, however, they do react with one another. One solution is made of lead nitrate and water, and another solution is made of potassium iodide and water. Both are clear solutions. When a chemist combines the two solutions, a chemical reaction takes place. The reason for the chemical reaction is that lead nitrate and potassium iodide are both salts, and both solutions dissociate in water. The lead, nitrate, potassium and iodine are all charged ions in the solution. The lead switches places with potassium and makes a compound, lead iodide, that is ***insoluble*** in water and which ***precipitates*** as yellow particles. A precipitate is a reactant that does not dissolve in solvent, so it settles to the bottom of the solution.

Life Principle

"We must adjust to changing times and still hold to unchanging principles."

—Jimmy Carter, former U.S. President



Integrated Physics & Chemistry

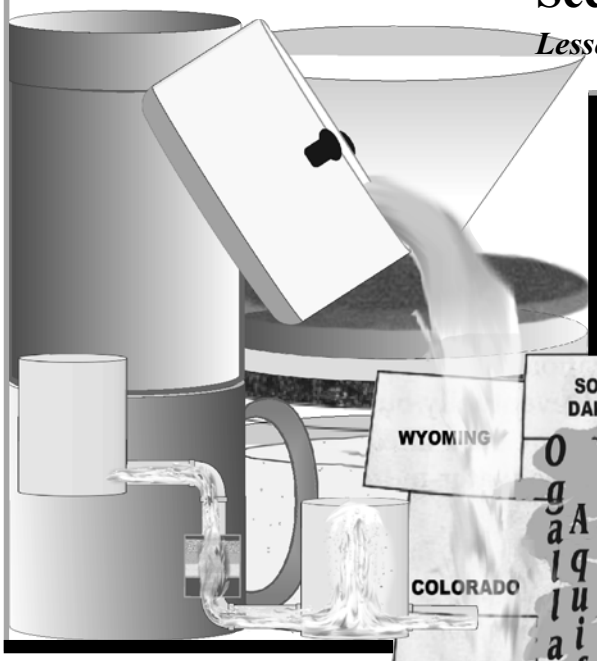
Chapter 7

Lesson 15
Inventions and Discoveries

Section 3

Lessons 11-15

COOL, CLEAR WATER



One concern of people who travel extensively is finding good sources of fresh drinking water. Sometimes water has an objectionable taste, peculiar odor or may even contain harmful minerals or bacteria.

One solution would be to buy bottled water that comes from an approved source. Most convenience and food stores now stock bottled water for customers who do not trust the local water supply.

Water is the most common liquid on Earth and the one that all life needs. The greatest source of water is the sea, but it contains chemicals that make seawater unhealthy to drink. The amount of pure water suitable for human consumption is limited. Glaciers are a huge source of pure water, but are inaccessible for the majority of the world's population. About half of the lakes are salt-water lakes and have too high a concentration of salt. Water that is unhealthy to drink is often unhealthy for commercial uses, too. Some minerals found in unhealthy water clog boilers, radiators and pipes and reduce efficiency.



VOCABULARY

Aquifer: an underground layer of porous stone that contains water
Freshwater lakes: lakes whose water contains only a small amount of dissolved salt
Settling: to form sediment by keeping a liquid still, settling is the first step in purifying water
Ceramic filter: a filter with extremely fine holes made of the same material that is used to make pottery
Aeration: exposing water to oxygen in the air to oxidize chemicals or kill bacteria

The two sources of pure water used by most communities are surface water and ***aquifers***. An aquifer is an underground reservoir. Not all of the rain water or melted snow flows into rivers. Some of the water seeps into the ground until it reaches a layer of rock that is too solid for water to pass through. In the Great Plains of the United States east of the Rocky Mountains, the Ogallala Aquifer is an important source of water. Farmers use



this vast store of groundwater for irrigation. Throughout the 1900s, wells were dug down to the aquifer. Water was pumped out 100 times faster than it was being replaced by natural seepage. Consequently, the aquifer shows signs of being exhausted. Some wells have dried up and new ones have to be dug.

Communities along the coast find that the groundwater is replaced from the ocean, but the replacement water contains a high concentration of salt. Other sources of groundwater are polluted by seepage from tanks holding hazardous chemicals. Because groundwater is replaced slowly, once an aquifer is polluted, recovery may take centuries.

Freshwater lakes stay free of minerals and salts because the water is constantly being replenished by fresh water from rivers. The constant movement of the water keeps the lake water fresh. When water fails to circulate, the lake gains minerals that make the water unhealthy for human consumption. For example, the Jordan River feeds the Dead Sea in the Middle East. The only way water leaves the Dead Sea is by evaporation because the sea has no outlet. The minerals left behind make the water seven times saltier than ocean water. Only a few hardy strains of bacteria can survive in the Dead Sea. The Great Salt Lake in Utah is also salty. The Great Salt Lake was once part of the Bonneville Lake, a freshwater lake. However, changes in the climate and terrain cut off the outflow, and the Bonneville Lake dried up, leaving behind a vast salt flat.

The water in a lake can be no better than the rivers that flow through the lake. A river, regardless of its length or size, is an important part of the water system of Earth. On the average, a river cleanses the land of minerals, chemicals and waste every two weeks. However, the population of people who live in a river region can become so great that the river water becomes polluted and has to be treated before being consumed by humans or dairy animals.

Polluted river water is a mixture containing small particles such as mud and grit. Polluted water is a solution containing dissolved minerals, agricultural chemicals, metals absorbed from the soil and factory wastes. River water contains living organisms, some of which are harmful bacteria. Countries like the United States need about one million gallons of water per person every year for irrigation, manufacturing, cleaning and drinking.

To change polluted water into pure water is the same as "unmaking" a solution.



Each of the harmful chemicals and dangerous microorganisms must be eliminated. The process requires several steps.

To understand the steps, imagine a modern explorer who must drink from a polluted river such as the Congo River in Africa. In addition to having the usual material that is found in most rivers, the Congo is especially dangerous because of animal life that dies and floats in the river. Crocodiles, for instance, lodge their freshly killed meat underwater among roots along the river banks. The meat is left in the river to age. Crocodiles have poor digestive systems and prefer to eat meat that has partially decomposed.

As a first step in treating the Congo River water, the explorer fills a large container with water from the river. He lets the water sit. After a time, the larger mud and sand particles settle to the bottom of the container. This process is called ***settling***. Some very fine particles, however, do not settle out. They are so small that the random motion of the molecules of the water keeps

the particles from going to the bottom.

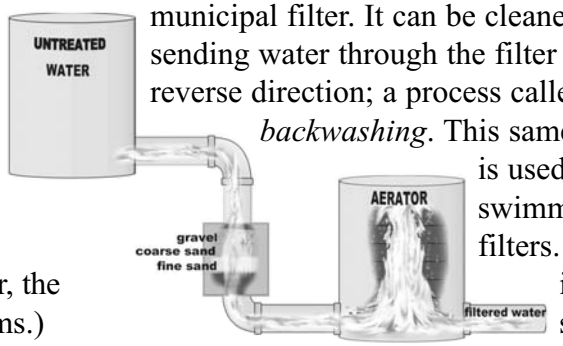
The explorer next filters the water by pumping it through a coarse filter, such as a sponge. Then he sends the water through a material with much smaller openings, such as a ***ceramic filter***. Some ceramic filters have holes so fine they will filter out all but the smallest bacteria. The next step is to kill the bacteria and other living organisms that might have survived through the filtering process. The ceramic filter is charged with iodine that kills bacteria. (Or, the water can be boiled to kill microorganisms.)



Some water still has pollutants that include heavy metals such as lead, copper and zinc. These metals are present in the water as ions. In addition, the water may have an unpleasant taste or disagreeable odor due to chlorine or iodine. The explorer's water filter has a charcoal filter that is charged with an *ion exchange resin*. The charcoal removes chlorine, iodine and other chemicals that cause bad smells and odors. The ion exchange resin removes most of the metal ions. An ion exchange resin replaces ions of heavy metals with less dangerous ions such as those of sodium or calcium.

The water is safe to drink after being settled, filtered both physically and with ion exchange resins treated with iodine or boiled. Some people think the water prepared in this way has a flat taste. A solution to the flat taste is to take a partially filled, closed container of treated water and shake it vigorously. Shaking the water will cause some air to dissolve in the water and make the water taste more like what was expected.

A large city uses many of the same methods in treating water for its residents. First, the water is poured into large tanks to settle out the particles. Chemicals, such as aluminum sulfate, can be added to react with the sediment and hasten the settlement process. Next, the water is sent in stages through finer and finer filters, then the water goes through layers of gravel, coarse sand and fine sand. Eventually, the materials the filter has removed from the water clog the municipal filter. It can be cleaned by sending water through the filter in the reverse direction; a process called *backwashing*. This same process is used to clean swimming pool filters. The water is then sprayed into the air or sent over a series of cascades. Exposure to oxygen in the air removes bad odors and tastes by oxidation. ***Aeration*** also kills most bacteria. After aeration, the water may be made softer with treatments of calcium hydroxide or sodium carbonate. Usually chlorine is added to kill any bacteria that may have begun growing in water pipes.



Settling and filtering removes only unwanted material from mixtures, but does not remove solutions. Filters can separate a mixture. For instance, clay mixed with water is a mixture, because sending the water through a filter can eliminate the fine particles of clay. Settling and filtering cannot remove chemicals that are dissolved in the water.

Some sources of water, such as rivers and lakes, contain chemicals in solution. Farm chemicals, such as insecticides and fertilizers, can leach out of the soil and go into rivers. Water that runs through the tailings of mining operations may pick up

heavy metals, such as lead and mercury. Usually, the contamination is too low to pose a health risk. However, if the water goes into a lake in which most of the water escapes by evaporation, the chemicals are left behind. These chemicals can become concentrated to dangerous levels. Because they are in a solution, normal settling and filtering cannot remove them. The purifier the explorer used (ion exchange resins) is too expensive for large cities or factories. Instead, alternate sources of purer water have to be found.

One way to reduce the cost of making water safe to drink, is to reduce the pollutants that go into it. This is a difficult task because keeping a river clean requires the cooperation of everyone who lives in the area into which the river and its tributaries drain, as well as those who live along its banks.

In the laboratory, distillation and condensation produce pure water. The water is boiled, the vapor caught and passed through cooling pipes where the vapor condenses back into liquid water. Repeated distillation and condensation produces pure water.

