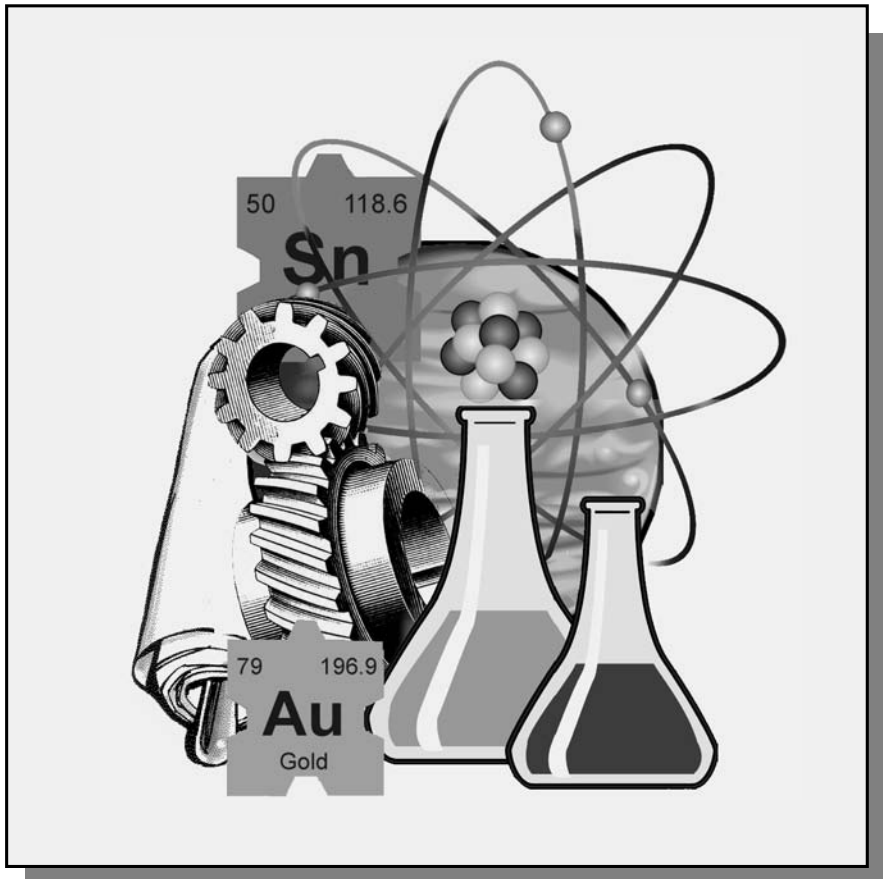
Integrated Physics & Chemistry

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



Chapter 1

IPC 76161 Revision: 030208

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Integrated Physics & Chemistry

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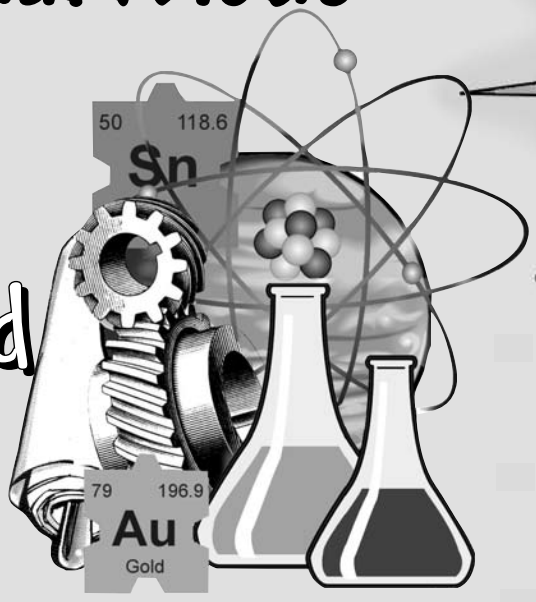
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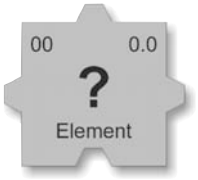
"The study of science is the chronicle of man's quest to discover the essence of life and how the marvelous laws of creation are applied to human needs."



—Ronald Johnson, Ph.D.

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Integrated Physics & Chemistry



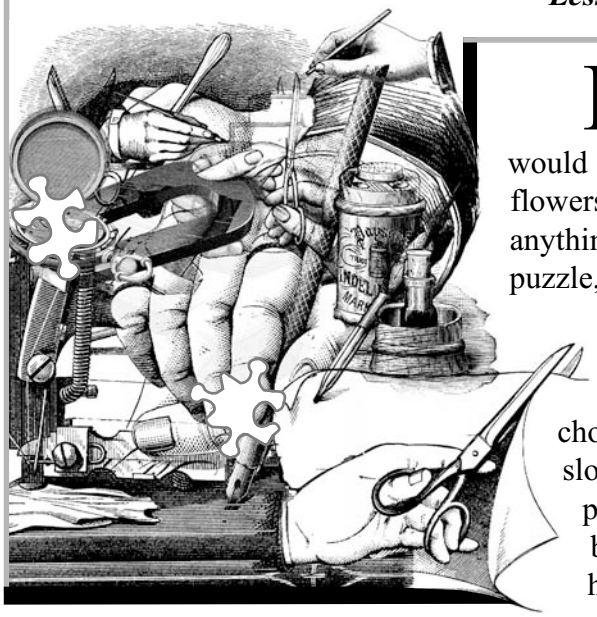
Lesson 1
Elements

Chapter 1

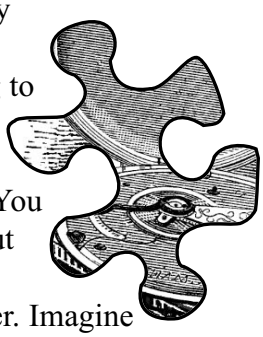
PUTTING TOGETHER THE PIECES

Section 1

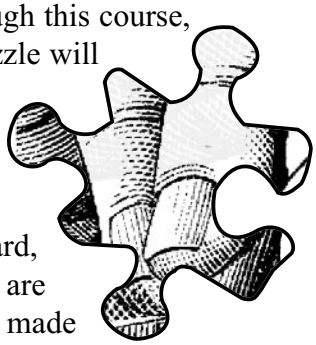
Lessons 1-5



Imagine that you are about to put together a big puzzle. Think about what kind of picture you would like to assemble. You might think about pretty flowers, a spewing volcano, a fast car, a hot air balloon or anything else in the world. As you begin to work your puzzle, you might look at individual pieces to find several that might connect. You would probably find all the pieces with straight edges and put them together first. Regardless of the method you choose for assembling your puzzle, the pieces will slowly emerge into a painting or photograph. As you put together more of the pieces, your picture will become clearer until you finally have a complete image.



In this course, you are going to journey through history to learn how scientists all over the world have been working on something like a giant puzzle. You will discover how early scientists started out with just a few pieces of the puzzle and yet were able to put many of the pieces together. Imagine visualizing the picture on this page using only the two puzzle pieces shown here! As you progress through this course, the more beautiful and complete your puzzle will become. You will watch each scientist's contributions, with the big picture becoming clearer.



You may be thinking about a particular kind of puzzle made of cardboard, but the pieces of the puzzle in this course are basic pieces of the universe. The world is made up of tiny pieces of energy and substance. Look around you. Whether you are looking at the poster on the wall, the countryside, your pet dog or your lunch, you will see big things

VOCABULARY

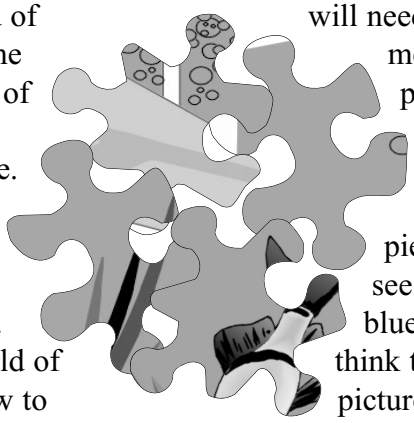
Physics: the science that deals with the properties of matter and energy

Chemistry: the study of the composition, structure and properties of matter and the changes it undergoes

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made from smaller things. Everything is not made out of the same kind of "stuff."

You will learn about the kind of "stuff" scientists believe makes up the world. You will begin at the process of learning the basic substance of the universe by constructing a big puzzle. With most puzzles, you can look at the box to see the final picture. You may not know what the final picture will be right now, but that's all right. You will see how wonderful the world of science can be if you understand how to assemble the pieces of the big puzzle.



People have asked questions about their universe since the beginning of time. Scientists have been able to discover the Earth's's basic substances by using the *scientific method*. Science itself can be thought of as a process of applying the scientific method to the world. The scientific method is basically a way to understand how the world functions. The scientific method involves the following steps:

(1) Observation— Scientists observe something in the material world.

(2) Question— Scientists ask questions about what they have observed.

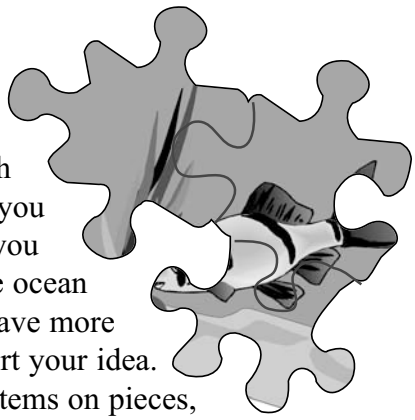
(3) Hypothesis— Scientists predict what the answers will be.

(4) Method— Scientists test by experiments whether the hypothesis is correct.

(5) Result— Scientists record the results of their experimentation.

(6) Conclusion— Scientists conclude whether their prediction was correct.

You may think that only scientists practice the scientific method, but you use it all the time! For example, think about starting a new puzzle. Imagine you have several pieces, but you know that many pieces are missing. You have also lost your puzzle box. To put the pieces together, you will need to use the scientific method. First, identify the problem. In this case, the problem is to figure out what the puzzle will look like. Then, observe many pieces of the puzzle. You can see part of a fish and some blue water, and you might think that your puzzle is a picture of the ocean. This is your *hypothesis.* Then, test your hypothesis by experimentation. Find more puzzle pieces and put them together with the puzzle pieces you already have. As you keep finding more ocean pieces, you will have more evidence to support your idea. If you find other items on pieces, then you will have to change your hypothesis. This picture on the puzzle is of an aquarium.



If experiments do not prove the scientists' predictions, then another hypothesis will be chosen.

People affected cultures through application of the scientific method. That is all science is—a process of looking at the world around you and exploring how it works.

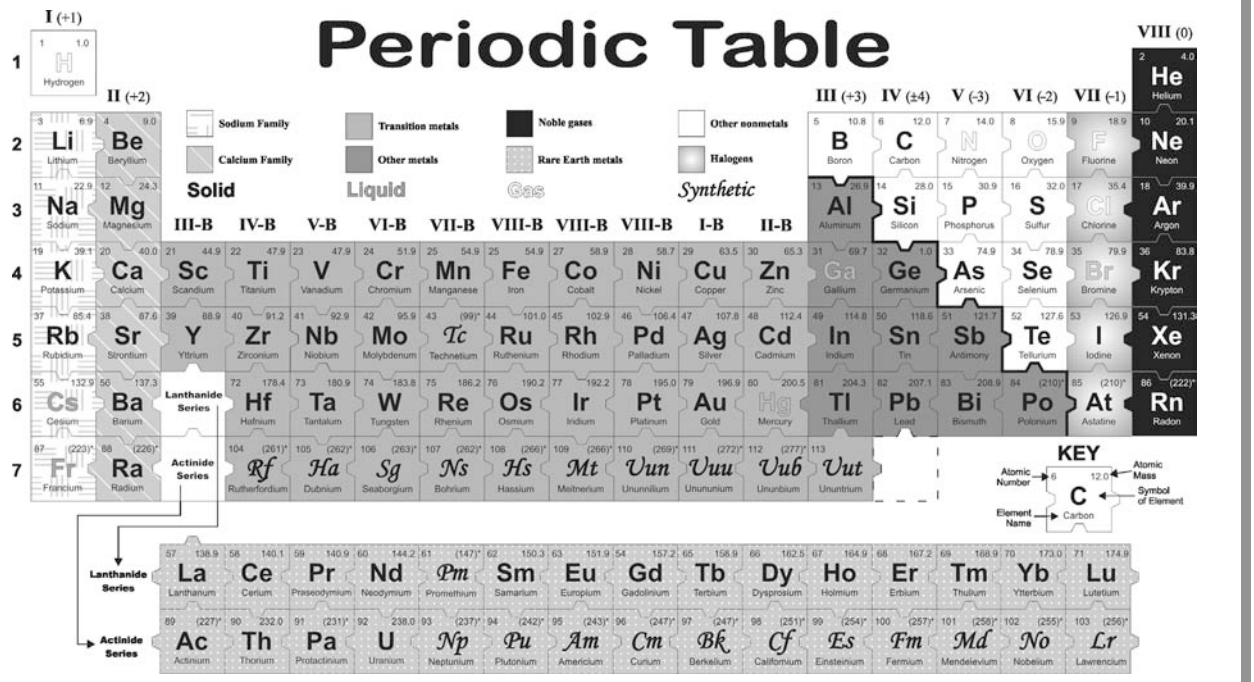


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Begin your journey through history with many of the scientists who helped describe the world through observation. Science is not really difficult, but it is complex. Because various scientific forces operate and interact with each other, you need models to help you understand what is happening around you. These models create branches of science such as astronomy, biology, chemistry and geology. This course will focus on the branches of science called *physics* and *chemistry*. These sciences will help you understand matter and energy. *Matter* refers to the "stuff" that you see and touch and of what this "stuff" is made. For example, a ball tossed into the air will fall, regardless of how high the ball is thrown. The ball and your hand are made of matter. *Energy* refers to the movement and action of this matter. The force that is used to throw the ball into the air and the gravity that makes it fall again applies the energy that causes the ball to move.

Physics is the study of how matter and energy interact with each other. A physicist would be interested in how hard you threw the ball, how high it went, and how fast it fell to the ground. ***Chemistry*** is the study of matter. Chemistry describes the contents of matter and the qualities of matter. A chemist would be interested in what kind of ball was thrown, of what materials the ball was made, and ways that you could change the materials in the ball to make it go higher. You will use the basic tools of both chemistry and physics to comprehend the physical world. Begin your journey by looking at chemistry.

The main tool of chemistry is the *Periodic Table of the Elements*. You will become accustomed to seeing it, and the information the table contains will slowly become understandable to you. Each piece of the science puzzle will hold a different kind of basic "stuff" of which the universe is built. You will discover the *elements* one at a time, and what each element is and where it is found in the environment. Every time a new kind of element (matter) is discovered, one more piece of the puzzle will be completed. Once you realize how everything you see is built of combinations of the elements in the



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periodic table, you will notice things about the world which you have never dreamed. Your world will begin to make sense.

As you begin your study, keep in mind that science is a way of exploring the mysteries of nature. All matter ("stuff") existed long before their discovery by scientists. Scientific research shows you some of the incredible order and amazing patterns evident in nature. Understanding this order has helped to create all the wonderful gadgets and products that surround you. Without science, you would have no radios, televisions, computers, cars, jets, CDs, processed food, microwave ovens, plastic or even most of the clothes you wear. You can be like a scientist by becoming more aware of all the exciting inventions and natural events that make up your reality. This course will give you the basic tools needed to understand the marvelous physical universe around you.

You are ready for the journey. Let's begin to put together the puzzle by learning about gold and the dark ages.

LIFE PRINCIPLE

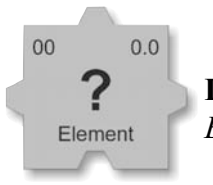


"Most people are drifting along in a childish sleep. To live our dreams we must wake up."

—John-Roger and Peter McWilliams

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Integrated Physics & Chemistry



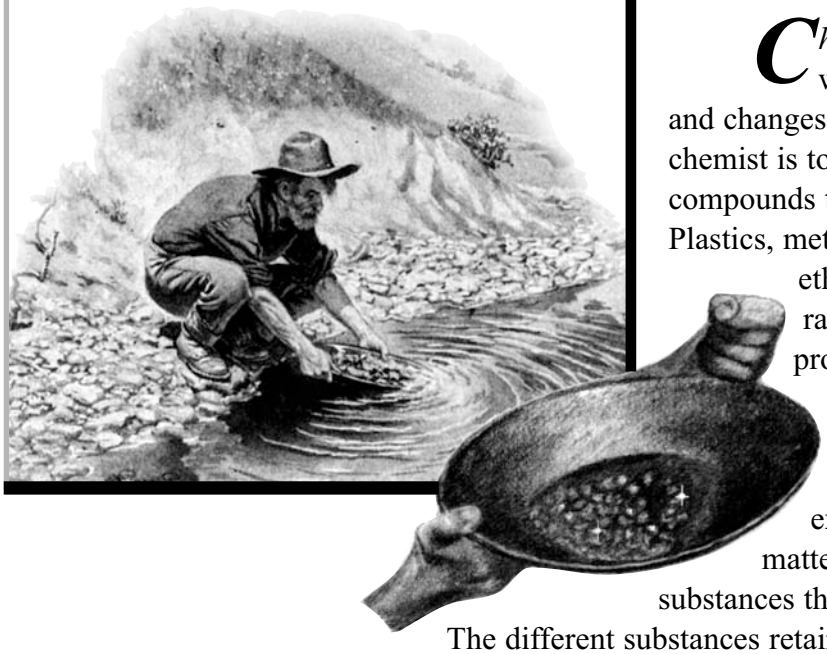
Lesson 2
Elements

Chapter 1

Section 1

Lessons 1-5

CHEMISTS WHO WANTED TO MAKE GOLD



Chemistry is the science that deals with the composition, properties and changes of matter. One activity of a chemist is to combine two or more chemical compounds to produce a new substance. Plastics, metal alloys, some fuels such as ethanol, and many fabrics such as rayon, are new substances produced by the clever application of chemical combinations.

Sometimes, a chemical substance is merely a mixture of existing chemicals. A *mixture* is matter made of two or more substances that are not combined chemically. The different substances retain their own chemical properties. They can be separated by mechanical means; shaking, sorting, filtering or sifting.

A gold prospector pans for gold by swirling a pan of water containing sand, gravel and gold flakes. Each of these is an independent substance and not in chemical combination with one another. Because gold is heavier than the other materials in the pan, a skilled prospector can swirl the water so that the sand, grit and gravel fly out of the pan. Tiny flakes of gold are left behind. The prospector then places the gold flakes in a small jar or leather pouch.

This combination of water, sand, gravel and gold is a mixture. Usually the mixture is not uniform. As the gold prospector moves down the creek bed, the amount of gold and sand changes. Some places contain much gold; other places contain less gold. Gold and other items in the pan make a heterogeneous mixture. ***Hetero-*** means *different*.

VOCABULARY

Hetero-: a prefix meaning "different"
Element: a substance made of the same type of atoms
Atoms: the basic building blocks of matter
Inert: does not readily react with other chemical elements or compounds

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The atmosphere is another example of a mixture. The atmosphere contains oxygen, nitrogen, carbon dioxide, water vapor, trace amounts of other gases and suspended particles, such as sulfur and ash. The composition of the atmosphere changes from one location to another. If you take a sample of air from high on a mountain, such as a peak on the island of Maui, Hawaii, compare that sample with one taken along a busy highway in a large industrial city, the composition will not be the same. Even at the same location, a sample of air taken on one day will probably be different from a sample taken on another day.



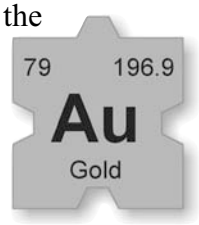
element **mixture** **compound**

A *compound* is made of two or more different ***elements*** chemically combined in definite proportions by weight. Pure water is a compound. It has oxygen and hydrogen atoms in the proportion of one oxygen atom for two hydrogen atoms. The elements that make up compounds are always found in exact proportions. For instance, salt has one chlorine atom for each sodium atom. Carbon dioxide has two oxygen atoms for each carbon atom. A diamond is a form of the element carbon.

A mixture of certain elements produces vastly different compound properties. For instance, hydrogen burns explosively in air while oxygen displays a chemical change. Both are gases. Oxygen and hydrogen combined make water, a substance essential for life. A more extreme example is salt, a compound of chlorine and sodium. Chlorine is a heavy green gas while sodium is a soft, silver-white metal that reacts violently with water. Both are poisonous. The compound of these two elements is salt: the harmless, even beneficial, white crystal.

Think about gold. It is neither a compound nor a mixture but is an element. Gold is made of atoms of only one type, gold atoms. ***Atoms*** are the basic building blocks of matter. An element is a substance made of atoms that are all of the same kind. The concept of atoms and elements is an important one in chemistry. The puzzle pieces you will be assembling consist of elements. These elements will be explored in detail throughout the course. The first piece of the puzzle we will discover is the element, gold.

Gold is one of the oldest metals known. Egyptian inscriptions dating back to 2600 B.C. describe gold. In the Old Testament of the Bible, gold is the first metal mentioned. Genesis 2:11 states that gold can be found in the land of Havilah. Ancient people prized gold above all other metals.



Gold has a beautiful yellow color and shines with metallic luster. Gold was probably the first metal discovered. Early people collected gold as jewelry. As time passed, gold was used for money, decoration, fillings in teeth and for plating surfaces. Many space vehicles are wrapped in gold foil because it reflects infrared heat rays. The foil also protects delicate electronic



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equipment from the Sun's rays, which otherwise would overheat the instruments.

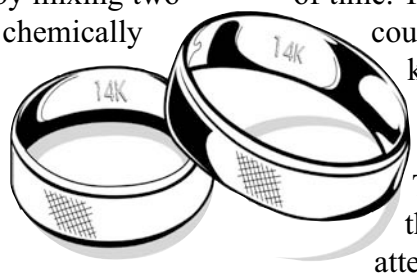
The atmosphere contains oxygen and sulfur. Many metals rust when reacting with oxygen and tarnish when they react with sulfur. Gold is an exception, however, and is relatively ***inert***, which means it is without power to move or to resist. Jewelry and statues of gold will retain their golden glow for centuries without tarnishing.

Gold is also *malleable*. It can be beaten flat into very thin sheets. One ounce (28 grams) of gold is about the size of two quarters stacked together. A sample that size can be flattened into a sheet with an area of 300 square feet. That is enough gold foil to cover the ceiling of an average size living room.

A small nugget of gold beaten flat by a goldsmith can cover large statues or other ornaments. Today, gold foil (flattened gold) is sometimes used for embossing letters on doors of offices, for names on Bibles and for special inlays in paintings. Gold foil is attractive and does not tarnish or fade. Gold foil is so thin it is not very expensive.

One disadvantage of gold is its softness. When used for jewelry or for coins, gold can wear away with use. Mixing it with another metal gives gold greater strength and durability. Gold is most often mixed with copper. The term *carat* describes the amount of gold present. Pure gold is 24 carats. If 14 parts of gold by weight are mixed with 10 parts of copper by weight, the result is 14 carat gold.

Gold cannot be made by mixing two cheaper metals together or by chemically uniting two other compounds. Egyptian chemists and scientists who followed the Egyptians became obsessed with creating gold through secret formulas.



The Egyptians were the most successful chemists of ancient times. They learned to make glass, glaze pottery, extract metals from raw ore, bake, ferment wine, dye cloth, produce perfumes and embalm bodies. Egyptians were unable, however, to produce gold.



The next great civilization in the chronology of world history after the Egyptians was the Greeks. By observation and reasoning, the Greeks arrived at the idea that everything was made of four elements. The four elements identified by the Greeks were earth, water, air and fire. This was one of the first attempts to identify and name the pieces of the puzzle of the elements. The Greeks claimed all substances could be made by combining the four elements in one proportion or another.

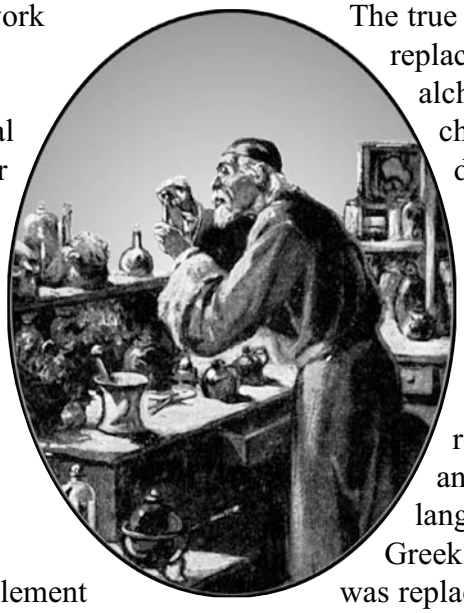
The Greek theory of four elements led chemists to believe they might be able to make gold. Because lead is a heavy metal, and sulfur is a yellow nonmetal, Greeks thought the two items could be mixed in some way to produce gold.

Romans also took the whole idea of making gold very seriously. One Roman emperor was so alarmed with the idea that he ordered all chemistry books destroyed. Romans passed laws proclaiming production of gold as a crime.

From 600 A.D. to 1400 A.D., Europe fell into the Dark Ages (also called the Middle Ages). Science did not advance during this era of time. The Bible was forbidden in many countries, thus, learning and knowledge came to a standstill in Europe. Chemists in the Arab world were known as *alchemists*. Their study of chemistry during the Dark Ages was devoted to attempts to make gold.

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Alchemists did their work secretly. They guarded their discoveries by writing secret codes and speaking in mystical languages. They revealed their methods only to trusted assistants. The alchemists worked under the motto, "Never reveal clearly to anyone any discovery."



Neither the Egyptians nor the Greeks discovered how to make gold. The Arabs and the medieval alchemists could not make gold. Their understanding of a chemical element was faulty and hindered chemistry because of their policy of secrecy.

Consequently, chemical discoveries were made time and again only to be lost when an alchemist died. The amount of chemical discovery to survive from the time of Aristotle to the 1600s – almost 2,000 years – was very slight. The period was truly the Dark Ages of academic advancement.

The true science of chemistry replaced the false science of alchemy in the 1600s when church reformers began to demand that common people should be able to read the Bible and write about its application to everyday life and science. The study and publication of chemistry developed because church reformers provided the Bible and other books in the common language of the people; thus, the Greek idea of just four elements was replaced with a more accurate understanding of chemical elements.

The next lesson is about an Englishman who became known as the Father of Modern Chemistry.

Life Principle

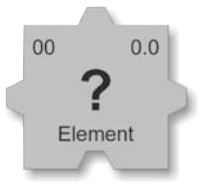


"All who have thought about the art of governing are convinced that the fate of empires depends on the education of youth."

—Aristotle

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Integrated Physics & Chemistry



Lesson 3
Elements

Chapter 1

THE MAN WHO DEFINED AN ELEMENT

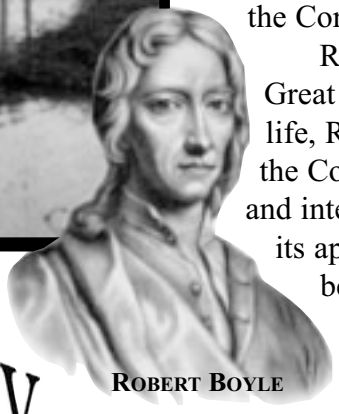
Section 1

Lessons 1-5



The Great Earl of Cork was perhaps the richest man in the world. He was an Englishman who lived at Lismore Castle on his vast estate in Ireland. If not the richest man in the world, then certainly he was the richest Englishman. He did not want his children to grow up to be spoiled and idle. A few months after birth, the children were moved into the homes of tenant farmers who lived on the Cork estate.

Robert Boyle was the seventh son of the Great Earl of Cork. For the first few years of his life, Robert Boyle lived with a peasant family on the Cork estate. Robert Boyle grew to be humble and intelligent and was interested in the Bible and its application to all things scientific. Boyle became a scientist and is generally credited with being the Father of Modern Chemistry. Robert Boyle lived in the 1600s when science was recovering from the Middle Ages (also called the Dark Ages). Galileo had discovered the use of the telescope to study the heavens. During this time, Isaac Newton was born. Isaac Newton would not make his many discoveries about predictable force, motion and gravity until the late 1600s.



ROBERT BOYLE

The word *chemistry* was derived from Chemeia (a local name for Egypt), establishing that chemistry indeed had its roots in ancient Egypt. The most important river in Egypt was the Nile. When the Nile River flooded, it left behind rich black soil. *Chemeia* is an Egyptian word meaning *black*. In ancient times, one name for Egypt was *Chemeia*, which meant *land of the black soil.*

The first scientists were called natural philosophers. The word *philosopher* means *one who loves knowledge*. To gain knowledge, a natural philosopher studied nature. Many Greek

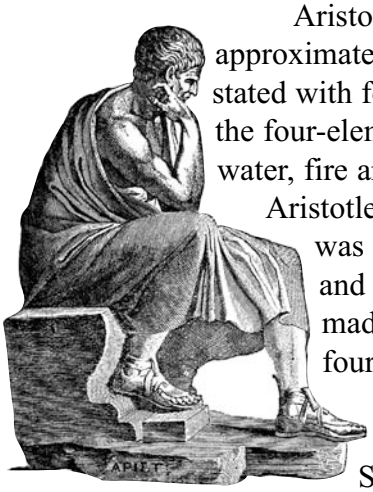
VOCABULARY

Smelting: to extract a desired metal from an ore that is a mixture of metals
Density: the mass of a substance compared to its volume
Mass: a measure of the amount of matter that a body contains; Weight and mass are often used as if they have the same meaning.
Toxic: a chemical substance that poses a health risk; capable of causing injury or death

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natural philosophers believed observations and reasoning alone would reveal all that could be learned.

The Greeks stressed the value of human reason so much that they failed to experiment properly. They did not test their ideas with experiments. Aristotle was one of the great Greek philosophers. He was the tutor of Alexander the Great in 342 B.C. Aristotle was a careful observer and a logical thinker. However, he failed to perform the simplest of experiments.



Aristotle wrote approximately 150 books. He stated with force and vigor the four-element theory (air, water, fire and earth). Aristotle believed gold was not an element and that it could be made by mixing the four elements of water, air, earth and fire. Scientists after Aristotle applied his ideas to the study of chemistry. In the 1600s, Aristotle's control over science began to vanish as scientists met to exchange ideas and discuss new discoveries.

Like many scientists, Robert Boyle asked, "Can you make gold?" He took a different approach. Rather than putting two or more substances together to produce gold, he asked, "Can you separate gold into two or more substances?" He proposed to separate gold into two other chemical substances, which could then be combined to make more gold.

As Robert Boyle experimented, he became convinced that the four-element theory for matter was incorrect. Instead, he developed a new definition for an element. "A chemical element," he said, "cannot be separated into other elements nor can other elements be combined to give it." A chemical element is a pure substance that cannot be broken down into any simpler substances by chemical means.

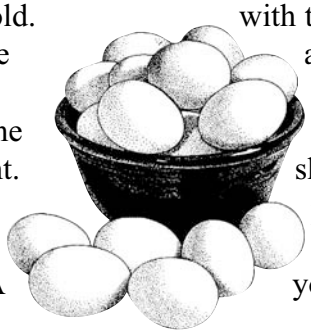
A current definition is that a chemical element contains atoms of only one type. At the time Robert Boyle lived, chemists had not yet learned that atoms existed. Chemists could not analyze a sample of gold to see if all of its atoms were the same. Robert Boyle's definition of an element remained popular among chemists for two hundred years.

Robert Boyle stated that a compound is a substance that can be separated into two or more elements by chemical action. Today, we conclude that a compound contains atoms of two or more different elements in chemical union.

Although you could memorize the definitions, a more important point is to understand the concept. We can illustrate the concept through galena. Galena is a compound that looks metallic. When galena is heated in air, it breaks down into lead and sulfur. The fact that galena can be separated into two other substances, proves that it is not an element.

Alchemists treated gold to thousands of tests for more than two thousand years. They heated gold in furnaces, boiled it in pots and cauldrons, pounded and grounded it. The alchemists treated gold with acids and coated it with other substances, but they never did create more gold.

The alchemists also tried to combine a variety of substances in an effort to create gold. Picture an image of an old laboratory with the crude equipment used by an alchemist as he tried to make gold. He cracked open two thousand hen eggs. The shells were then placed in one pot, the whites of the egg in another pot and the yellow yokes in a third pot. The shells



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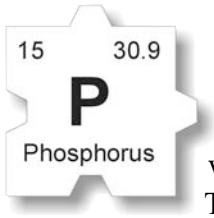
were treated with fire until they crumbled into a brilliant white powder. The whites of the eggs were boiled until they hardened then covered with horse manure (a fertilizer that helps plants grow). This was supposed to contribute some vital force to the egg whites. Next, the yellow yoke was mixed with oil, and the liquid that formed was then distilled. That experiment took a year or more. The conclusion of the experiment was a horrible, smelly and gummy mess.

Because gold is an element, it cannot be made by the chemical combination of other materials. Neither can it be separated into two or more simple substances. A bar of pure gold contains nothing but gold atoms.



As Robert Boyle increased in age, he lived in London and was often met with scholars interested in learning new concepts. He talked with doctors, chemists, astronomers and others. They exchanged ideas ranging from the use of the microscope to the ***smelting*** of metals from raw ores. Boyle had been educated by many tutors and never attended college. Robert Boyle called his group of friends the "Invisible College." Later, they became a formal organization known as the *Royal Society*. This was the first group of scientists to meet on a regular basis to exchange ideas. It still meets today. The purpose of the Royal Society was to help scientists publicize their discoveries. The Royal Society also hired a full time employee to demonstrate interesting experiments in order to stimulate further research.

In 1680, Robert Boyle prepared what he thought was a new chemical element, phosphorus. Its chemical symbol is *P*. Phosphorus is the next piece of the puzzle.



Phosphorus is a highly reactive, poisonous and nonmetallic element. It is a waxy, white solid that glows in the dark. The word *phosphorus* is a Greek word meaning *bringing light.* Phosphorus glows because it combines slowly with oxygen in the air. California beaches glow after sunset because of the high phosphorous content in the beach sand. It is a difficult, dangerous substance that can burst into flames when the reaction with oxygen is more rapid.

Robert Boyle observed that the mere heat of friction caused the new phosphorus chemical to burn. Boyle soaked paper in phosphorus and let it dry. A splinter of wood was dipped in sulfur then drawn across the paper. The splinter of wood caught fire. Boyle had made the first match by applying sulfur to phosphorus.

Because Robert Boyle was a chemist and not an alchemist, he published his discoveries. He described the physical and chemical properties of phosphorus in such detail that two hundred years passed before any new facts about it became known. Later, chemists learned that an alchemist had discovered phosphorus but kept the discovery secret.

Physical properties include color, hardness, odor and density. ***Density*** is the ***mass*** of a substance compared to its volume.

$$d = m/v$$

d: density
m: mass
/: divided by
v: volume

Chemical properties describe the conditions about chemical reactions with a substance. The fact that gold will not tarnish or rust is a chemical property. Copper will react with sulfur (tarnish), and iron will react with oxygen (rust). The fact that sulfur will burn (react with oxygen) is a chemical property.

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The chemical properties of phosphorus make a match possible. A "strike anywhere" match contains a compound of phosphorus and sulfur. It is very sensitive to heat. The friction caused by rubbing the head of a match across a rough surface is enough to cause it to burn, which lights the matchstick.

The first matches used white phosphorus, which is ***toxic***. Not only did they pose a health risk they also could burst into flame without warning.

Did you know?

A match with a white tip of phosphorus is a 'strike-anywhere' match. A match with a red tip must be struck on the box from which the match came.

Another form of phosphorus, known as red phosphorus, is much less dangerous than white phosphorus. It is also less likely to start fires spontaneously.

Safety matches are even less likely to start accidental fires. Safety matches contain no phosphorus. Instead, the phosphorus is contained in finely ground glass glued on a strike strip of the matchbox or matchbook. When the head of the match is drawn across the strike strip, a spark ignites the match.

Phosphorus and its compounds are used in firework displays, firebombs and tracer bullets. These compounds are also used in fertilizers, in the production of special glass and water softeners.

The next lesson informs you about silver mirrors, copper money and the bronze statue of a magnificent young man.

Life Principle



"The superior woman stands erect by bending above the fallen. She rises by lifting others."

—Anonymous

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Chapter 1

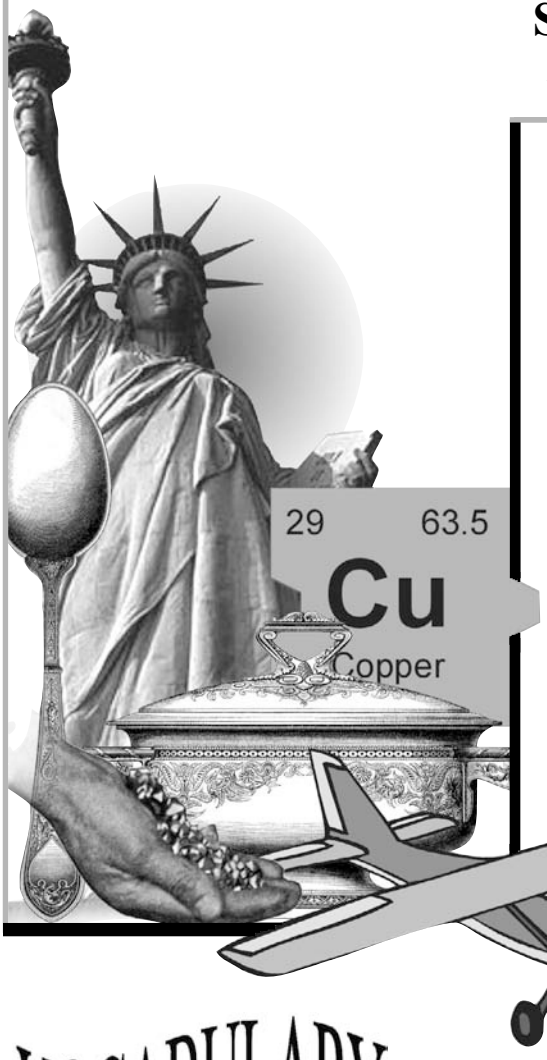
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Element

Lesson 4
Elements

THE MONEY METALS

Section 1

Lessons 1-5



When Robert Boyle's definition of an element was accepted, chemists began searching for true chemical elements. They found that nine substances, known since ancient times, were elements. Seven of them are *metals*: gold, silver, copper, iron, lead, tin and mercury. Two are *nonmetals*: carbon and sulfur.

Three of the ancient metals are gold, silver and copper. As the result of their long history as mediums of exchange, these three metals are sometimes known as the *money metals.*

GOLD

Gold is a soft, dense and bright yellow metallic element. It is the most valuable of the money metals. The chemical symbol is *Au* from the Latin (Roman) word for gold, *aurum*. In a chemical symbol, the first letter is always written in upper case, and the second letter, if any, is always written in lowercase. Notice the chemical symbol, *Au*, above.

79 196.9
Au
Gold

Most metals are *malleable*. They are easily beaten into thin sheets. Most metals are also ***ductile***, meaning they are easily drawn to form thin wires. Pure gold is the most malleable and ductile of all metals. An ounce of gold can be drawn into a wire 62 miles in length.

Gold is heavy. A cubic foot of gold weighs more than 1,200 pounds. Gold's *specific gravity* is 19.3. Specific gravity compares the weight of gold to that of water. With a specific gravity of 19.3, gold weighs 19.3 times as much as an equal volume of water.



VOCABULARY

Ductile: easily drawn into a wire
Emulsion: a mixture of liquids that do not dissolve in each other; a colloidal mixture
Impurity: component in a substance that is not expected or wanted; a contaminant

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Gold is relatively inactive chemically. Most acids do not react with it. However, the acid *aqua regia* (Latin for *water royal)* will react vigorously with gold. Aqua regia is a mixture of nitric acid and hydrochloric acid. When they mix, chlorine is freed. The chlorine attacks the gold and dissolves it.

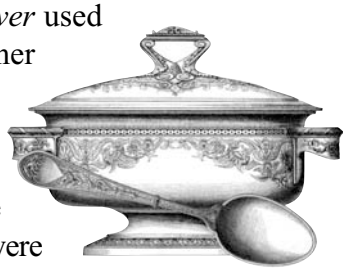
SILVER

After gold, *silver* is the most ductile and malleable metal. Silver is a white, lustrous metallic element. The most common ore of silver is *Argentite*, a silver sulfide. The chemical symbol for silver is *Ag* from its Latin (Roman) name *argentum*. It is the most efficient conductor of heat and electricity. During World War II, when copper came in short supply, silver was used for some electrical wiring for national defense applications. Silver has a specific gravity of 10.5. A cubic foot of silver weighs more than 600 pounds.



Consider the properties of silver. It is shiny, can be hammered into different shapes and conducts electricity. Silver is both beautiful and rare. It has a long history for use as tableware, ornaments and money. Joseph, during biblical times, was sold into slavery for twenty pieces of silver. Later, when he became governor of Egypt, Joseph sold grain to people who paid in silver, copper and gold coins.

Silver is harder than gold but softer than copper. To help silver resist wear, a small amount of copper is added. An alloy is a mixture of two or more metals melted together. *Sterling silver* used for tableware and other objects is 92.5 percent silver and 7.5 percent copper. For many years in the United States, coins were made of silver alloy, which consists of 90 percent silver and 10 percent copper. In 1965, silver was eliminated from dimes and quarters.

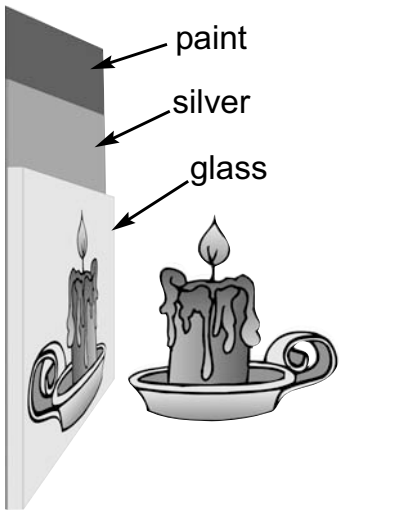


Like gold, silver is relatively inert. It does not unite with oxygen in the air, even when heated. Silver does not rust; however, it will tarnish when exposed to sulfur. Eggs, which contain a considerable quantity of sulfur, tarnish silver very quickly. Sulfur coats the surface of silver with a brownish-black layer of the compound, silver sulfide. The chemical formula for silver sulfide is Ag_2S. The subscript 2 shows that two silver atoms are present for each sulfur atom.

Sulfur is found naturally in the air. Factories that burn coal add more sulfur to the air. Sulfur is added to natural gas as a safety signal. In case of a gas leak, a sulfur compound is added to natural gas to give gas a penetrating odor like the smell of rotten eggs.

Pure silver has a brilliant, white luster. It reflects visible light better than any other metal. In ancient times, mirrors were made of polished silver. In the 1800s, with the start of the industrial age, the extra sulfur in the air from factories caused silver mirrors to tarnish quickly. To keep the silver shiny, it was coated with paint on the backside, and the front layer of silver was protected with a glass. Sealed against the air in this way, the silver mirror was protected from tarnish caused by sulfur.

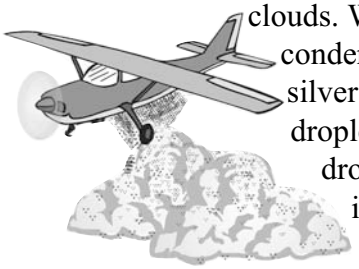
Diagram of ancient mirror



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One of the most important uses of silver is in photographic film. A compound of silver with the nonmetal bromide becomes sensitive to light. Most photographic ***emulsions*** contain silver bromide. When light strikes the film, a latent (hidden) image is formed. The latent image can be made visible by the application of a development solution.

Scientists use silver to make rain. Cloud seeding is done from an aircraft by dropping silver iodide flares into rain-bearing clouds. Water vapor condenses around the silver iodide to form tiny droplets. The smaller droplets then merge into larger raindrops that eventually fall to the Earth. Because of the unpredictable nature of this process, rain made by seeding clouds is not guaranteed to succeed.

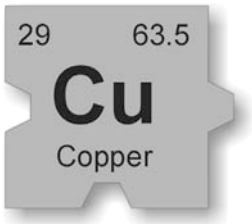


Usually, silver is extracted from raw ore while other metals are processed. Silver is often found with copper, lead and zinc. Because it is so valuable, silver is recycled. Most new silver products are the result of recycling existing silver objects. Photographic film is saved and processed so the silver can be recovered and used again.

COPPER

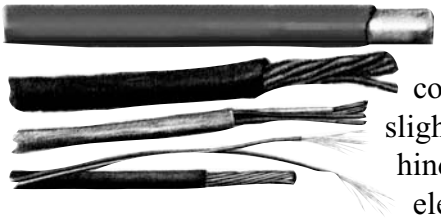
Copper is a metallic element. It is an excellent conductor of heat and electricity. The chemical symbol of copper is *Cu,* from the Latin (Roman) word *cuprum*. Cuprum is the ancient name for the island of Cyprus, famous in earlier times for its copper mines.

Pure copper has a reddish brown color. Pure copper and gold are the only two colored metals. All other metallic elements are silver white in color.



Copper's specific gravity is 8.96. A cubic foot of copper weighs more than 500 pounds. Gold's specific gravity is 19.3. A bar of copper weighs about half as much as a bar of gold the same size (8.96/19.3 = 0.464, or about ½ as expressed in fraction form).

Copper has many uses. It conducts electricity and heat, resists corrosion, can be hammered and drawn and has a pleasing luster. Copper's principal use today is in electrical applications. Copper is not the best conductor of electricity. Silver is better, but copper is a close second. If silver were rated as 100 for its conductive properties, then copper would be a 96. Gold is 67. Copper is almost as good as silver and considerably cheaper; therefore, copper is used for electric wires. Copper is very ductile and can be drawn into wires of almost any size (from wires one inch thick to wires only 1/1000 inch in diameter).



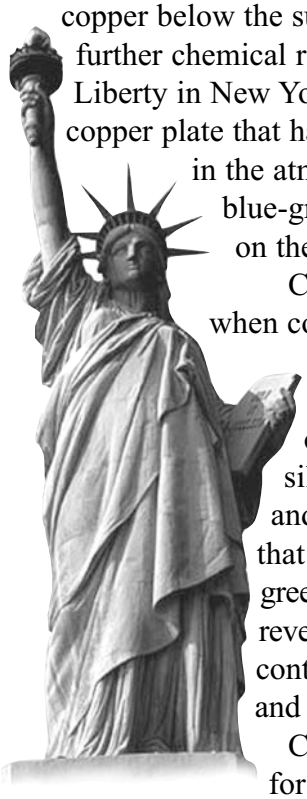
Wires must be made of pure copper because the slightest ***impurity*** will hinder the flow of electricity. An impurity is a part in a substance that is not expected or wanted. Two of the impurities usually found in copper are silver and gold. The cost of mining and refining copper is offset by the recovery of these more expensive impurities.

Malachite is the best known copper ore. Freeing copper from malachite is not difficult. A hot fire made by burning wood will do it. Malachite has a rich, green color. It can be polished and used as an ornament or in making jewelry.

Copper is not as inert as gold or silver. Copper slowly turns green as it combines with sulfur compounds in the air, especially in moist climates. This green tarnish forms a protective coating that shields the

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copper below the surface from any further chemical reaction. The Statue of Liberty in New York Harbor is made of copper plate that has reacted with sulfur in the atmosphere causing a blue-green coating to form on the copper.



Care must be taken when copper is alloyed with other metals such as silver. If too much copper is used, the silver alloy will tarnish and turn green. A ring that turns your finger green, for example, reveals the fact that it contains a cheaper alloy and is not pure silver.

Copper has been used for coins throughout recorded history and has also been fashioned into utensils such as knives and swords.

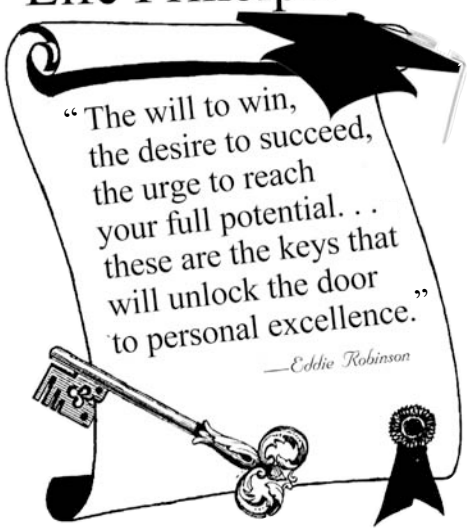
Pure copper is too soft for good knife blades or other cutting tools. It dulls too easily. As an alloy with other metals, however, copper becomes very useful. *Bronze* is an alloy of copper mixed with tin. *Brass* is an alloy of copper with zinc. Either alloy gives copper superior strength. Knives made of bronze have a hard edge.

In ancient times, bronze was used to make knives, swords, shields and tools. In Egypt, bronze tools were used to cut and shape stones used to make the pyramids. In Greece, one of the great statues of the ancient world, the Colossus of Rhodes, was made of bronze. The Colossus, a one hundred-foot high statue, was considered one of the seven wonders of the ancient world. The Colossus was located on a small island in the Aegean Sea off the port of Rhodes, Greece.



The next lesson tells why iron rusts and how tin cans caused the death of explorers in the South Pole.

Life Principle



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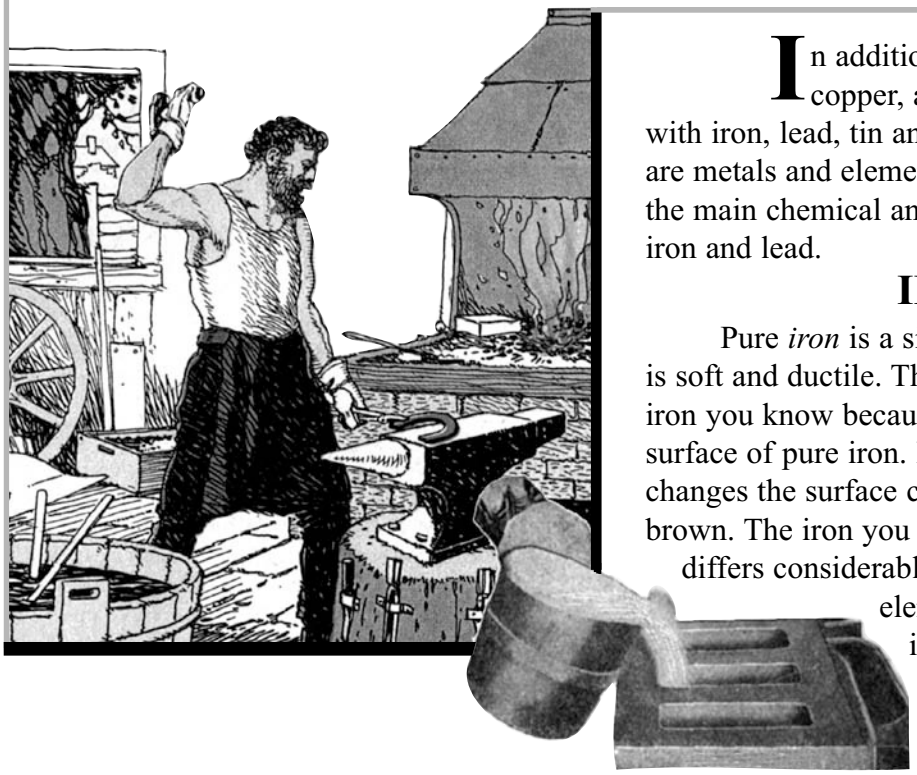
Chapter 1

Lesson 5
Elements

Section 1

Lessons 1-5

THE WORKING METALS



In addition to gold, silver and copper, ancient people worked with iron, lead, tin and mercury. All of these are metals and elements. This lesson describes the main chemical and physical properties of iron and lead.

IRON

Pure *iron* is a silvery, lustrous metal that is soft and ductile. This does not sound like the iron you know because you seldom see the surface of pure iron. Iron rusts quickly. Rust changes the surface color to a scaly dark red or brown. The iron you see in everyday life differs considerably from pure iron. Other elements are added to create iron mixtures conducive to various tasks. Most iron in everyday use contains carbon that makes utensils harder than pure iron.

The symbol for iron is *Fe*. It comes from *ferrum,* the Latin (Roman) word for *iron*. One of the most surprising aspects of iron is its magnetic property. *Magnetite*, also known as *lodestone*, is a naturally occurring magnetic iron ore. The word *lodestone* means *leading stone.* When lodestone is suspended from a string, it aligns itself to the North Pole. The first crude compasses were made from lodestone.



Iron is the fourth most abundant element in Earth's crust at 4.5 percent by weight. It is the second most common metal. Aluminum, which is almost twice as abundant, is the most common. Iron is easier to smelt than aluminum. The word *smelt* means to separate a metal from its ore. Iron is the least

VOCABULARY

Ore: a compound from which a metal can be profitably mined and extracted
Sulfide: a compound that contains sulfur
Oxide: a compound that contains oxygen
Reduction: a chemical reaction that removes oxygen from a compound

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expensive and most used metal. From every 100 pounds of metal used in industry, iron makes up 96 pounds.

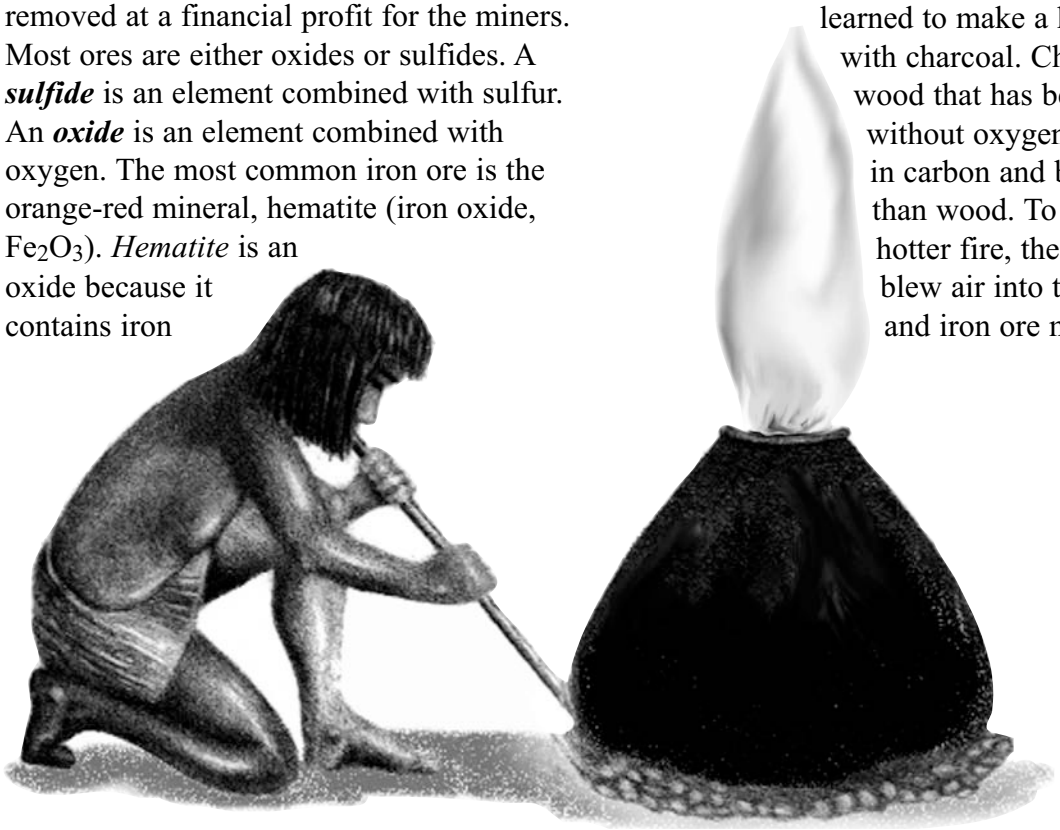
The ancient money metals of gold, silver and copper can be found in the free state and in ores. They are easy to extract from their ores. Copper can be separated from its ore by a hot fire. Iron, on the other hand, is seldom found in the free state because it reacts too quickly with oxygen in the air.

Although iron is abundant in the Earth's's crust, it cannot be removed easily except in locations where its ores are found. An ore is not merely a compound containing a metal. An ***ore*** is a compound that contains the metal in a form that is profitable to extract and mine. Of course, the value of a metal may increase dramatically depending on the difficulty of mining and extracting. Alternatively, a chemist may develop a cheaper way to free the metal from a compound. In either case, a compound is not considered an ore until the metal can be removed at a financial profit for the miners. Most ores are either oxides or sulfides. A ***sulfide*** is an element combined with sulfur. An ***oxide*** is an element combined with oxygen. The most common iron ore is the orange-red mineral, hematite (iron oxide, Fe_2O_3). *Hematite* is an oxide because it contains iron with oxygen. Iron is found in other minerals such as magnetite or lodestone. Black sand beaches are rich in magnetite.

Another well-known iron compound is *pyrite*, ($FeS_{2)}$, or iron disulfide. It is a yellow mineral known as *fool's gold.* It received that name because inexperienced gold prospectors were misled into thinking they had found gold. Because it contains sulfur, pyrite is a sulfide. Pyrite is not processed for iron because removal of sulfur is too difficult. It is a compound of iron but not an ore of iron.

Ancient people learned how to smelt iron to form implements. The book of Genesis, from the Old Testament, states that Tubal-Cain "forged all kinds of tools out of bronze and iron." Smelted iron artifacts dated around 3000 B.C. have been discovered.

Iron is harder to extract than copper. A hot fire is needed to smelt iron. A wood fire is hot enough to extract copper, but a greater heat is needed for iron. The Egyptians learned to make a hotter fire with charcoal. Charcoal is wood that has been baked without oxygen. It is richer in carbon and burns better than wood. To make a hotter fire, the Egyptians blew air into the charcoal and iron ore mixture.

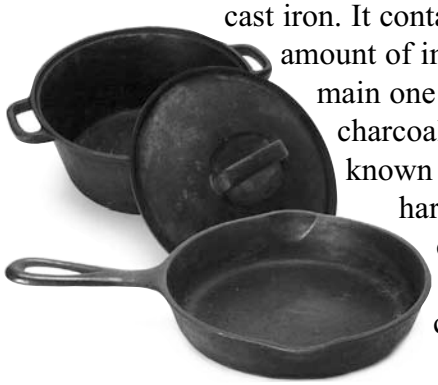


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An Egyptian blast furnace was made of clay and stone and shaped like a beehive. It had a hole at the top for tossing in the charcoal and iron ore. Around the bottom were smaller openings for sending in the blast of air. Men blew air into the fire through clay tipped hollow reeds.

Charcoal supplies carbon as part of the chemical reaction. Charcoal does more than merely supply heat. Carbon from the charcoal enhances iron production by drawing oxygen from the iron. This leaves iron in the free state. The removal of oxygen from a compound is known as ***reduction***. More iron can be extracted by adding an additional source of carbon, such as limestone.

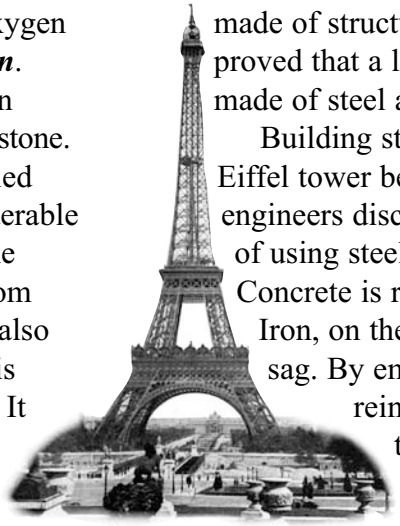
Iron produced in this way is called cast iron. It contains a considerable amount of impurities. The main one is carbon from charcoal. *Cast iron*, also known as pig iron, is hard but brittle. It contains about 3% carbon.



Heating it with iron ore and limestone refines cast iron. The impurities are removed. When refined, the pure iron is known as *wrought iron*. It can be beaten into decorative designs. Metal fences, handrails and ornamental fixtures around windows are made of wrought iron. Except for making ornamental designs, wrought iron is much too soft for most commercial products.

Between brittle cast iron and soft wrought iron is steel, the most useful and strongest form of iron. Cast iron, steel and wrought iron differ only in the amount of carbon they contain. Wrought iron has the least amount of carbon, while cast iron has the most. The amount of carbon in steel is between 0.5 and 1.5 percent. The smelting process that the Egyptians and others of the ancient world used contained the right amount of carbon to make a good grade of steel. By heating the steel and then plunging it quickly into water, the steel becomes tempered. It becomes hard and retains a sharp edge. Tempered steel is used for cutting blades, such as saws, knives and chisels.

Iron has been used in construction since the 1800s. In 1889, Gustav Eiffel, a French engineer, designed the Eiffel Tower. The Eiffel Tower is 948 feet high and made of structural steel. Gustav Eiffel proved that a large structure could be made of steel alone.



Building structures higher than the Eiffel tower became possible when engineers discovered the advantages of using steel with concrete. Concrete is rigid but not very strong. Iron, on the other hand, tends to sag. By embedding steel reinforcing rods in concrete, the combination is both rigid and strong. Steel is the most common form of iron used in construction today.

Iron is cheap and strong but has one major flaw, it easily combines with oxygen. *Oxidation* is a chemical combination of a substance with oxygen. Oxidation may be rapid or slow. *Burning* is rapid oxidation. Iron itself will burn under certain conditions. If a lighted match is touched to fine steel wool, the steel will burst into flames and burn. Holiday sparklers are made of iron particles coated on a metal holder. The sparklers present a huge surface area to the air. This makes rapid oxidation possible. *Rusting* is a form of slow oxidation. Even though the oxide coating protects the metal underneath, iron exposed to a moist climate will rust rapidly. The moisture causes a slight electrical current that aids the formation of

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additional iron oxide. The upper layers of rust flake away to expose a new layer to the air. Rust continues to do its damage on iron.

To prevent rust, iron can be coated with another substance, such as paint or a layer of another metal, such as zinc. Iron coated with zinc is called *galvanized* iron.

Iron compounds are essential to all life. For example, iron carries oxygen in the hemoglobin molecule found in the blood stream. *Hemoglobin* transports oxygen from the lungs throughout the body. The iron atoms in hemoglobin readily accept oxygen atoms from the lungs. Just as readily, they release the oxygen to the cells of body tissues. Blood is red because of the hemoglobin which contains iron.

TIN

Tin is a silver white metal with a very slight bluish tinge. The chemical symbol for tin is *Sn*, from its Latin (Roman) name of *stannum*.

The primary use of tin in ancient times was as an alloy. Bronze is an alloy of copper and tin. Another important alloy of tin is pewter, a bright and shiny mixture of tin with another metal, such as copper or lead. Pewter was used to make inexpensive kitchen utensils and tableware as a substitute for the more expensive silver dishes. Lead pewter, however, is poisonous to humans and should not be used to prepare food. Another common alloy is *solder*, which is tin mixed with lead. It is used to join metal parts, such as pipes for water systems.


Bronze

Compared to other metals in everyday use, tin is rare and expensive. It is used only in applications where its chemical and physical properties are clearly superior to other substances that could be used. Tin can be beaten into thin sheets and used as tin foil to wrap foods. However, cheaper aluminum has replaced tin as a food wrapper.



Tin is relatively inert and may be safer than aluminum for processing food. Tin does not tarnish or corrode, and it can withstand weak acids. Tin does combine with oxygen to form a thin, invisible film of stannic oxide (SnO_2). The oxide layer does not affect tin's shiny surface. Instead, the oxide layer protects the tin from further reaction.

Tin is not toxic and does not discolor food. Because of these properties, the metal is used to make tin cans. Cans of pure tin would be too expensive. Instead, a thin layer of tin is plated on steel. A tin can is actually a steel can coated with a layer of tin only about 0.01 millimeter ($1/250^{th}$ inch) thick.

The main ore of tin is *cassiterite*, (SnO_2) stannic oxide. A small amount of tin is mined each year. The principle source of tin is the recovery from scrap metal.

As temperatures fall below 13°C (55°F), tin begins a dramatic change. It turns gray in color and becomes brittle. This changed form is known as gray tin. It is more like a nonmetal. As the temperature falls, tin crumbles into a powder.

One of the great tragedies of Antarctic exploration occurred when tin was used to weld the seams of kerosene cans. In 1911, Captain Robert Scott, a British explorer, organized an expedition to reach the South Pole. He led his party across 1,800 miles of ice and snow. Along the way men stored caches of fuel and food to be used on the return trip.

The Scott expedition reached the South Pole on January 18, 1912, only to discover that a marker was left there one

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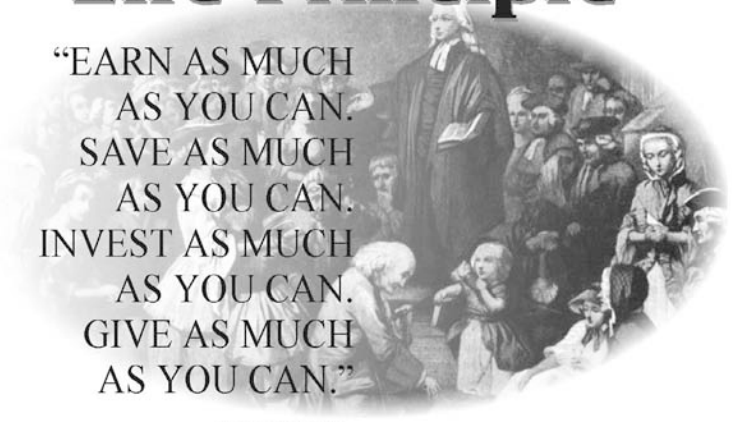
month earlier by Roald Amundsen, a Norwegian explorer. Disheartened, Scott's men retraced their journey while fighting a blizzard. When the weary men arrived at the cache, the tin had turned to powder and their kerosene fuel had leaked through the seams. The desperate men raced to the next cache. The cans there were empty, too. The entire expedition party froze to death. They perished partly because of the little known fact that tin turns brittle in extremely cold temperatures.



Roald Amundsen

The next lesson provides an inside look at "the Mad Hatter."

Life Principle



—John Wesley

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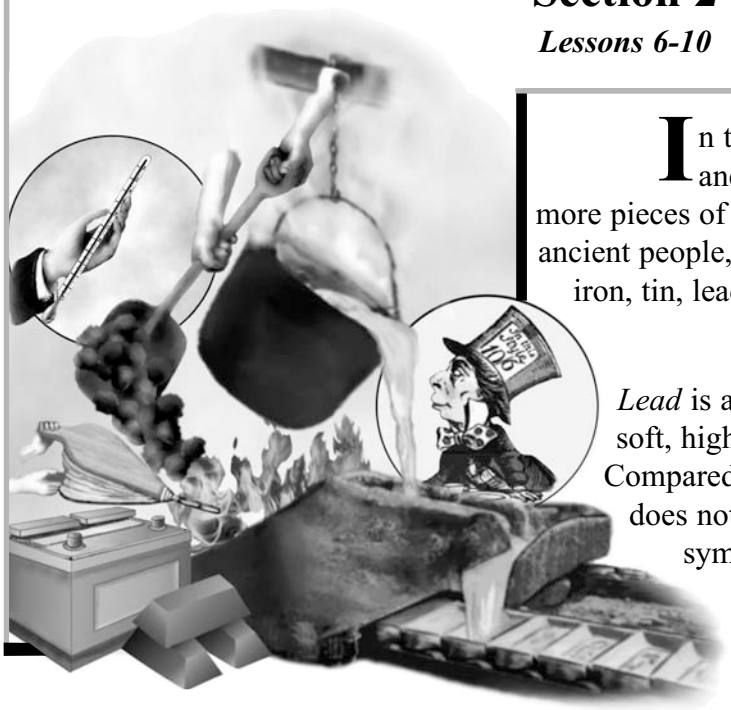
Lesson 6
Elements

Chapter 1

METALS AND NONMETALS

Section 2

Lessons 6-10



In this lesson you will learn about two more ancient metals: lead and mercury, two more pieces of the big puzzle. Of the metals known to ancient people, seven are elements: gold, silver, copper, iron, tin, lead and mercury.

LEAD



Lead is a dull, white metal. It is very soft, highly malleable and ductile. Compared with silver and copper, lead does not conduct electricity well. The chemical symbol for lead is *Pb*, from the Latin (Roman) word, *plumbum*. The word *plumber*, a person who installs and repairs pipes carrying water, comes from *plumbum*. In previous years, water and sewer pipes were connected with lead seals. Thus, the men who installed the pipes were called plumbers.

Lead has been known for ages and is mentioned in the Bible from the Old Testament book of Exodus, when Pharaoh's chariots are described as sinking like lead in water. Alchemists spent a lot of time trying to convert lead into gold. Lead has a specific gravity of 11.3. It is dense but not as dense as gold, which has a specific gravity of 19.3. Lead is soft and easy to shape. The Romans stored water in cisterns lined with lead sheeting and made city water pipes of lead connected with lead and tin solder. Lead pipes were used to drain baths. Lead pipes from the baths bearing the insignia of Roman emperors are still in service. Lead is toxic or poisonous. It is not a good choice for carrying or storing drinking water. If the water is the least bit acidic, the lead corrodes and releases lead compounds.



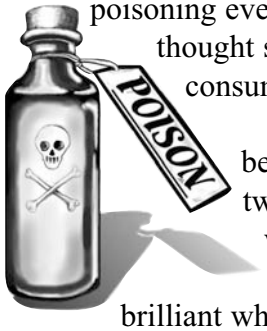
VOCABULARY

Amalgam: an alloy of mercury with other metals such as tin or silver

Barometer: an instrument used for measuring air pressure

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Lead is a *cumulative* poison. The body cannot get rid of lead, except very slowly. If more lead enters the body than can be eliminated, it accumulates. Even if the daily exposure is slight, over time it can build to toxic levels. Even though lead is removed from the drinking water, the health problems may continue to last for years. Children are at a high risk from lead poisoning even in quantities once thought safe for human consumption.



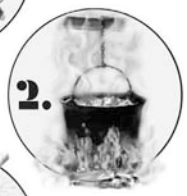
A lead compound has been used for more than two thousand years as a white *pigment*, or coloring, to make a brilliant white paint. The compound is also used as a glaze on clay pots. Because of the dangers of lead poisoning, the use of lead in paints has been reduced.

Recipe for Lead



Source of HEAT

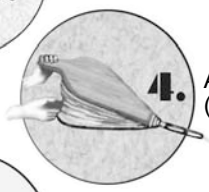




Large container.



Mix GALENA and CHARCOAL in container over extremely high heat.



Add a blast of OXYGEN (air), to free the metal.



Pour liquid metal, (LEAD), into ingot molds. Let molds stand until cool enough to touch.



Remove lead ingots, stack and store them until they are ready for use.

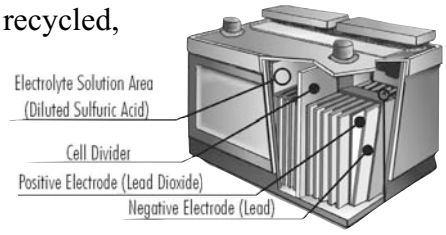
The main ore of lead is *galena*, called lead sulfide. *PbS* is its chemical formula, which means that the compound contains lead (Pb) and sulfur (S). Galena is found throughout the world.

In order for lead to be extracted from galena, oxygen or sulfur must be removed to free the metal. Galena contains sulfur. Oxygen is more reactive than sulfur. By roasting the ore, oxygen replaces the sulfur. The result is an oxide.

To eliminate oxygen in many oxide ores, carbon will react with the oxygen and free the metal. That scientific principle discovered by the ancient Egyptians is still used today. The crushed ore is mixed with charcoal and placed in a furnace. The charcoal acts as both a fuel and source of carbon. Additional carbon can be provided by limestone. With a blast of air, the carbon reacts with the oxygen and frees the metal (lead).

Galena often has other minerals associated with it. Crude lead that is obtained from the smelting process contains other metals such as copper, zinc, silver and gold as impurities. Separating these precious metals from lead ores often allows as much profit to the smaller industry as the extracted lead.

The largest single use for lead is in electrical storage batteries. Storage batteries contain alternating plates of lead (Pb) and lead oxide (PbO_2) immersed in sulfuric acid. Lead can be recycled, therefore recovery from battery scrap is an important source of lead. Another industrial product is lead bullets for rifles and pistols. Millions of bullets are molded annually to equip armies, police units and sportsmen with ammunition. Military bullets are coated with a thin layer of copper.



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MERCURY

Mercury has a silver metallic luster and is dense like the other ancient metals. It remains in a liquid condition at room temperature. Ancient metal workers correctly classified it as a metal because of its density and metallic luster.

The chemical symbol of mercury is *Hg*, from *hydrargyrum*, a Greek word meaning *water silver.*



This is an obvious reference to the fact that mercury, which looks like molten silver, is liquid at room temperature. Mercury is the only common metal liquid at ordinary temperatures. A drop of mercury in a container will roll about at the slightest tilt of the container. For that reason, mercury is sometimes called *quicksilver.* The word *quick* means *alive.*

Mercury is the heaviest known liquid at room temperature. With a specific gravity of 13.5, it is twice as dense as iron and even more dense than lead. A lead block would float in a pool of mercury.

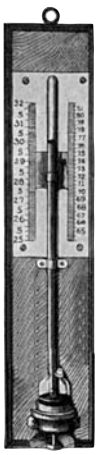
When mercury is cooled to -40ºC, it becomes a solid. Mercury as a solid has a bluish tinge like lead in appearance. All mercury compounds are extremely toxic. These compounds can cause brain, kidney and liver damage. Mercury can be absorbed into the body by ingesting it, breathing its fumes or absorbing it through the skin. Even holding it casually in your hands is dangerous. Mercury is a cumulative poison; the body can eliminate mercury in only a few ways. Chemical workers take extra care to keep mercury securely sealed in containers to avoid spillage. People in possession of mercury should take it to a properly qualified chemist for safe disposal. It should never be accessible to children.

Mercury affects the central nervous system. At one time, mercury was used in the tanning process of animal skins. When beaver skin top hats were popular, people who treated the pelts often suffered from mercury poisoning. The Mad Hatter from Lewis Carroll's *Alice's Adventures in Wonderland* and the phrase "mad as a hatter" refer to the effect of mercury poisoning on human sanity.



Mercury forms alloys easily with many metals such as gold, silver and tin. An alloy of mercury is called an ***amalgam***. Amalgams of gold and silver are soft and can be molded when first formed. After a few minutes, they harden. Most dentists still use amalgams for fillings in teeth. The way mercury atoms are held by gold or silver reduces health danger from mercury poisoning in dental fillings. Fillings without mercury are the safest.

Like most metals, mercury expands when heated and contracts when cooled. Mercury as a liquid finds numerous uses in such instruments as thermometers, ***barometers*** and other devices for laboratory work. The change in volume for each temperature rise or fall is the same; thus, mercury is especially useful for measuring temperature. Precision thermometers contain mercury.



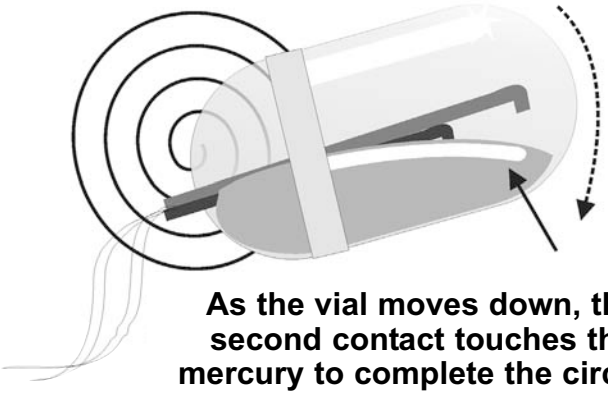
In the 1600s, scientists learned that the height of a column of water in a container sealed at the top varied with air pressure. A barometer is a device for measuring air pressure. The column of water had to be more than 30 feet high in a water barometer. However, mercury is 13.5 times as dense as water. A mercury column for measuring air

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pressure has to be only about 760 millimeters high (about 30 inches). Weather forecasters watch the air pressure because changing barometric pressure indicates a change in weather. On a rainy day, the barometer may be at 29 inches of mercury. Rising pressure indicates the weather is improving. If the barometer is 29 inches of mercury and falling, the weather will deteriorate. The 29 inches refer to the height of the column of mercury in the barometer.

Electrical engineers learned that mercury switches were practical to complete an electric circuit. A furnace thermostat contains a small container of mercury attached to a coil of flat metal. The mercury touches one of the two terminals in the vial. The metal coil contracts and rotates as the temperature cools. The vial of mercury tilts. When the vial tilts far enough, the mercury touches the second terminal, completing the circuit and switching on the furnace.

Mercury Switch



As the vial moves down, the second contact touches the mercury to complete the circuit.

Mercury seldom occurs freely in nature. Its main ore is *cinnabar* (HgS) which is found in Spain and Italy. Mercury boils at 357ºC (662ºF). Heating smelts the mercury until it boils and condenses to a liquid.

You will learn more about mercury later. In the next lesson, you will learn how scientists began to put together the puzzle, and how the press that printed the Bible increased scientific learning.

Life Principle

"A real friend is one who walks in when the rest of the world walks out."

—Walter Winchell



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Integrated Physics & Chemistry

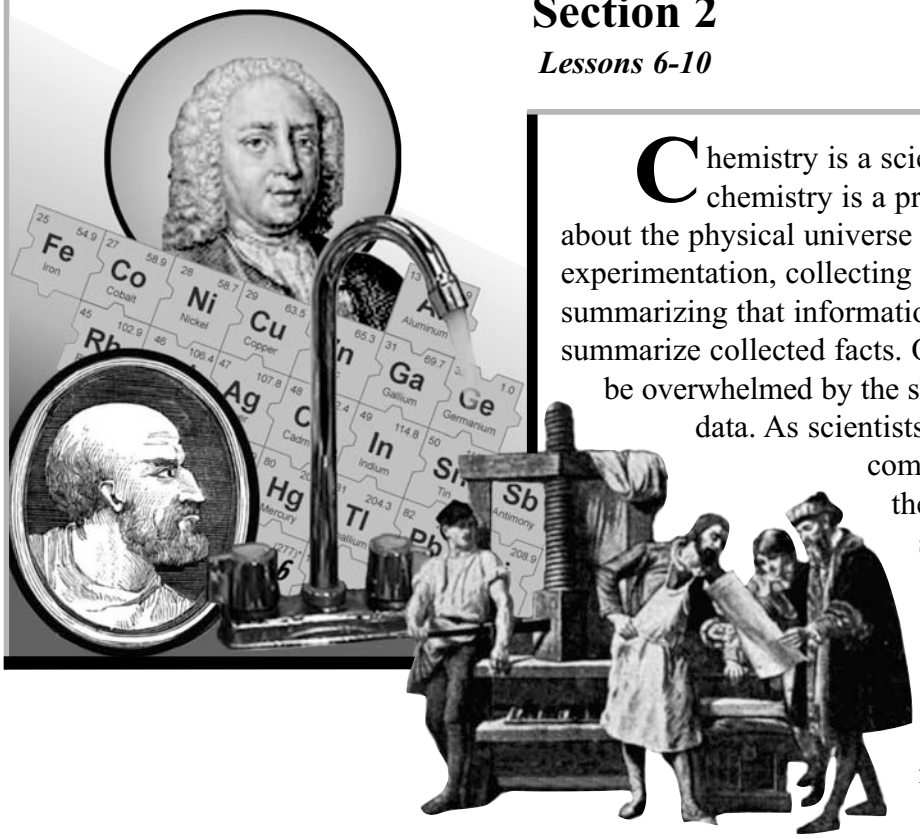
Chapter 1

Lesson 7
Energy

MAKING CHEMISTRY EASIER

Section 2

Lessons 6-10



Chemistry is a science. Like all sciences, chemistry is a process of learning more about the physical universe by observation, experimentation, collecting information and summarizing that information. Scientists must summarize collected facts. Otherwise, chemists would be overwhelmed by the sheer amount of collectable data. As scientists collect facts, scientists combine and summarize what they have learned. The summary can be in the form of a table, a scientific law or some other form that reveals the design of nature.

Another way information is summarized is by classification. *Classification* is grouping objects into categories based on the way the objects are alike. Organizing information into categories enables scientists to understand data. Classification not only summarizes information in a convenient form but also reveals patterns and relationships as they actually exist in nature. Classifying the elements into metals and nonmetals is another stage in understanding the big puzzle of chemistry.

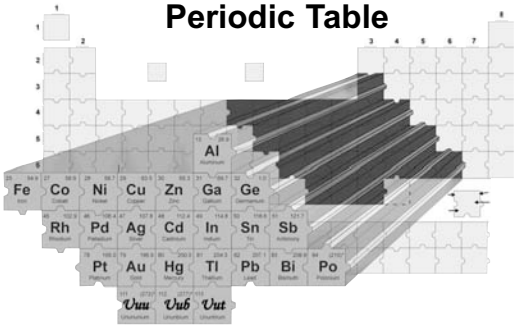
Early scientists grouped chemical substances as *metals* or *nonmetals*. Generally, metals are heavy, shiny and can be beaten into sheets. More recently, chemists learned that metals conduct heat and electricity easily. On the other hand, nonmetals have a dull surface and are brittle. The nonmetals conduct heat and electricity poorly. Examples of metals include gold (Au), silver (Ag), copper (Cu), iron (Fe), tin (Sn), lead (Pb) and mercury (Hg). Examples of nonmetals include phosphorus (P) and sulfur (S).

VOCABULARY

Atom: from a Greek word meaning indivisible; smallest unit of an element that contains all characteristics of that element
Atomic Theory: the idea that all matter is made of atoms
Gas: has no definite volume and no definite shape; spreads to fill its container

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Pieces of the Puzzle build the Periodic Table



Grouping objects into classes as metals or nonmetals is an example of classification. The classification of substances helps chemists. Information they discover about one substance can be applied to another substance in the same class. The earlier chemists correctly identified mercury as a metal because of its shiny surface and weight. Chemists also realized that the method they discovered for removing copper from its ore could also be applied to iron.

Identifying substances as mixtures and pure chemical substances is another example of classification. A *mixture* is a composition of two or more substances that are not chemically combined with each other and are capable of being separated by physical means. For example, the contents of a box of raisin bran cereal can be separated. The raisins can be picked out of the cereal. An automobile's oil filter removes bits of steel and grit from the engine's oil. The oil and solid particles form a mixture.

A chemical substance can be separated only by chemical methods. The iron ore *magnetite* is an example of a chemical substance. Iron can be separated from its ore only by chemical methods.

A chemical substance may be an element or a compound. An *element* cannot be separated into more simple substances by normal chemical means. An element is composed of atoms that are all alike. A *compound* has atoms of two or more different elements that cannot be separated by physical means. Salt is a compound because it contains sodium (Na) and chlorine (Cl). A compound can have properties unlike those of the elements that form it.

THE ATOM

Democritus, who lived about 425 B.C., proposed the idea of atoms. He believed everything in the world was made of very tiny particles too small to be divided further. Democritus called them atoms. The term ***atom*** is from a Greek word meaning *indivisible.* Democritus thought the whole world was made of atoms and between them was empty space. Atoms could not be destroyed. Rearranging the atoms could produce different substances.

Democritus summarized his ***Atomic Theory*** by stating, "The only existing things are the atoms and empty space." He believed atoms of each substance carried the physical properties of that substance.

Most Greek philosophers disagreed with Democritus and rejected his atomic theory. They believed matter was continuous. The philosophers claimed that a gold coin could be cut in half and each piece beaten into sheets of gold, which could be cut in half again then flattened again. The process could be continued without ever coming to a single, indivisible particle of gold. Gold and all other matter supposedly continued without end, getting smaller and smaller.

Democritus wrote 72 books. Before Gutenberg invented the printing press, books could be reproduced by hand copying them one by one. Democritus' books were seldom copied. As time passed, the books became lost and destroyed. Not even one exists today. However, even without the books, the idea of atoms did not entirely disappear. About 50 B.C. Lucretius, a Roman scholar, scientist and professor, read books by Greek

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philosophers who mentioned Democritus' concept about atoms. Lucretius agreed with Democritus on the theory that matter was made of atoms. Lucretius promoted Democritus' ideas through a long epic poem he wrote on the subject, *On the Nature of Things*. In this poem, Lucretius restated the Atomic Theory.



With the collapse of the Roman Empire, Europe fell into a period known as the *Middle Ages*. For about a thousand years, from the 600s to the 1400s, learning declined. Most people could neither read nor write. This period of time is also known as the *Dark Ages*. Much of the scientific progress made by the Greeks and Romans became lost. People forgot about atoms.

In the 1400s, Europe experienced a revival of learning. Scholars began searching for the earlier handwritten books. They began to copy and preserve books that made references to Democritus and Lucretius. Not one book written by either Democritus or Lucretius could be found. In 1417, a single, damaged copy of *On the Nature of Things* was found in an attic.

In 1450, Johann Gutenberg invented the printing press to reproduce Bibles. The printing press helped to preserve and promote learning not only about the Bible but also about scientific discoveries. Lucretius' poem was set to type and many copies were made.



The first printing press

The single copy that was found in the attic is the only one discovered before the invention of the printing press.

By the 1600s, most chemists had heard of the atomic theory. They did not accept the idea because it lacked experimental proof. The Atomic Theory was an interesting concept without any observations or experiments to confirm it. Because of the lack of solid evidence in its favor, scholars did not take the Atomic Theory seriously.

Robert Boyle was the first person to do experiments that seemed to show that atoms might exist. Remember that Robert Boyle lived in the 1600s. He defined an element, helped start the Royal Society and described the chemical properties of phosphorus. Boyle was one of the first scientists to study air. Until then, chemists had limited their studies to experiments with solids and liquids.

Matter can exist in three forms: solid, liquid and gas. A *solid* has a definite shape and a definite volume. Ice is an example of a solid. A *liquid* has a definite volume, but not a definite shape. A liquid flows to the lowest point and takes the shape of its container. Water is an example of a liquid. A ***gas*** has neither a definite shape nor a definite volume. It expands to fill its container completely. Steam is an example of a gas.



Most solids and liquids cannot be compressed. Those that can be compressed do so because they have extra space in them. A loaf of bread can be compressed when something heavier, like a gallon of milk, is carelessly placed on the bread. Bread has many holes in it. The heavier milk causes the slices of bread to fill in the air holes. The bread takes up less space

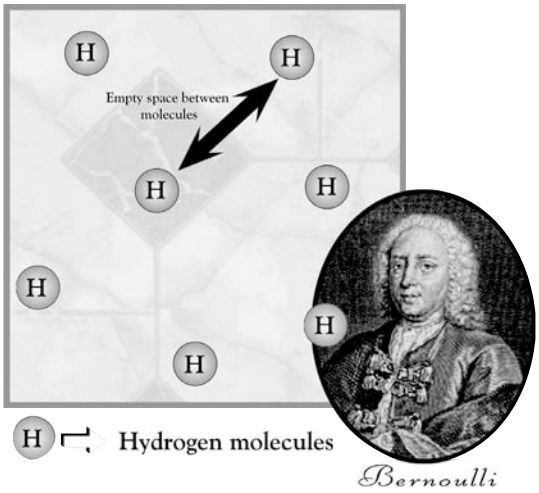
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because of the holes. However, most solids and liquids do not compress. A block of steel or a tank of water resists changes in their volume.

Gases are especially easy to compress. Robert Boyle was one of the first scientists to study gases. He showed that the pressure put on a gas and its volume have an *inverse relationship*. As one increases, the other decreases. The greater the pressure, the smaller the volume. Robert Boyle wondered whether air could be compressed and squeezed into a smaller space.

Robert Boyle believed his experiments confirmed the Atomic Theory. Boyle believed air must be made of very tiny particles separated from one another by nothing at all and compressing the air would force the tiny particles closer together. Although Boyle had no conclusive proof, his observations were evidence in favor of the idea that matter is made of atoms — small, indivisible particles.

During the early 1700s, scientists discovered several other laws about gases. In 1738, a talented Swiss mathematician, Daniel Bernoulli decided to apply his mathematical skill to the problem of the gas laws. Bernoulli assumed that gases were made of atoms which consisted of a vast number of extremely tiny particles. Bernoulli believed that the sizes of the gas particles were small compared to the distances separating them, and that gas was mostly empty space.



Calculations based on these simple assumptions agreed with what chemists knew about gases. Bernoulli's calculations tended to confirm the Atomic Theory, at least for gases. Other chemists would later offer more convincing proof that all matter is made of atoms.

You are beginning to understand how the study of science developed. The next lesson reveals how war and measurement affected the big puzzle.

Life Principle

"The best job goes to the person who can get it done without passing the buck or coming back with excuses."
—Napolean Hill



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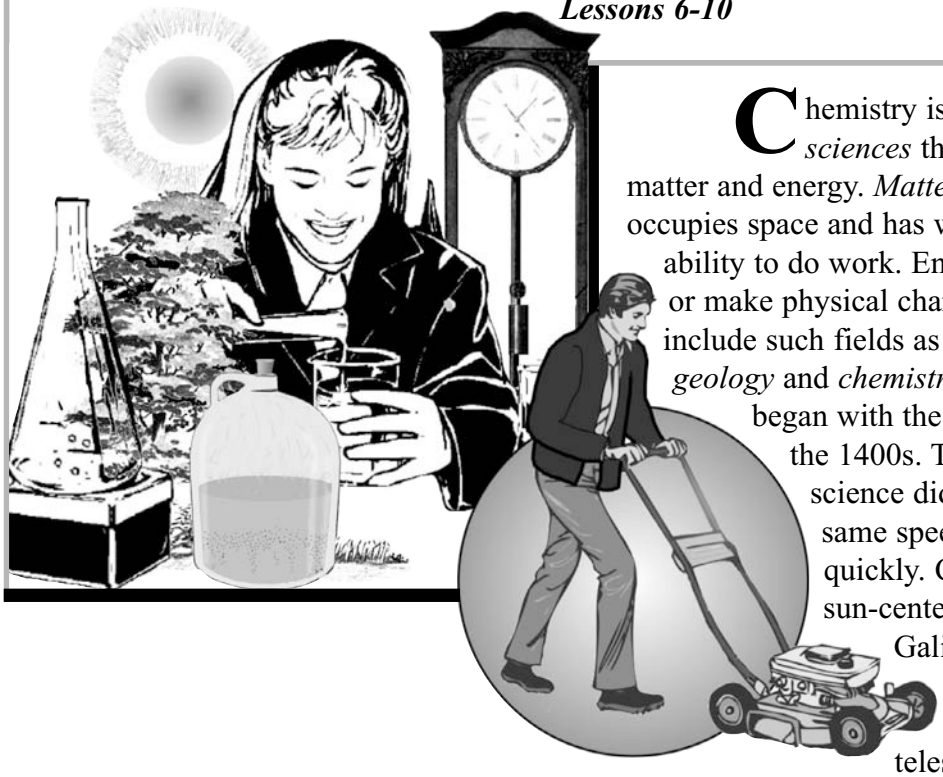
Lesson 8
Inventions & Discoveries

Chapter 1

CHEMISTRY MATTERS

Section 2

Lessons 6-10



Chemistry is one of the *physical sciences* that explore non-living matter and energy. *Matter* is anything that occupies space and has weight. ***Energy*** is the ability to do work. Energy can move matter or make physical changes. Physical sciences include such fields as *astronomy*, *physics*, *geology* and *chemistry*. Modern science began with the revival of learning in the 1400s. The various fields of science did not advance at the same speed. Astronomy advanced quickly. Copernicus proposed the sun-centered, planetary system. Galileo studied the Moon, planets and stars with the newly invented telescope. Johannes Kepler and Isaac Newton developed laws about planetary motions.

Chemistry advanced more slowly than most other physical sciences. By the end of the 1600s, astronomers understood the motion of the Moon better than chemists understood chemistry. Chemists understood the properties of only ordinary, everyday substances, such as water. Learning the composition of common materials was not easy. Predicting how one substance would chemically combine with another was even more difficult. Each discovery improved predictability.

During the 1600s, chemists made better use of *experiments* that were controlled observations. At Robert Boyle's urging, scientists published what they learned so other chemists could verify scientific theories by experimentation. Certain facts had to be known before experiments could be repeated. Chemists had to list compounds, equipment used and directions on how to perform experiments. The ***conditions*** of the experiment also had to be explained.

VOCABULARY

Energy: the ability to do work, put matter in motion or make physical changes
Conditions: the compounds, equipment and procedures necessary to repeat an experiment
Reactants: the ingredients at the start of a chemical reaction
Products: the compounds produced by a chemical reaction
Balance: a device for measuring weight

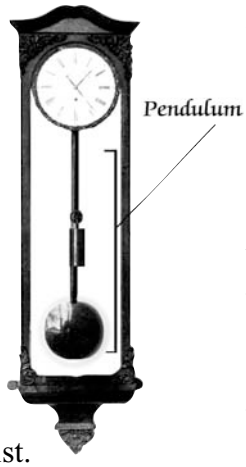
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The ingredients that start an experiment are ***reactants***. The compounds produced by a chemical reaction are ***products***. For an experiment to be repeated, the amount of each reactant had to be explained. Solids are usually measured by their weight. Liquids and gases are usually measured by volume. Because merchants sold their products by weight and volume, they had accurate ways to measure those quantities.

Other quantities that needed to be measured were time and temperature. In the early 1600s, neither could be measured accurately because clocks and thermometers did not exist. Galileo discovered the Principle of the Pendulum. The pendulum's regular back-and-forth motion led to the invention of the first accurate timekeepers. Galileo experimented with measuring temperature, although the thermometers he made were crude and inaccurate. By the end of the 1600s, accurate clocks and thermometers were coming into use. Jan Baptista van Helmont (1577-1644) was one of the first scientists to see the importance of measurement. Jan Baptista van Helmont was a Belgian physician and chemist. He came from a wealthy family and he could afford to devote whatever time he wished to study. He offered his medical treatment without charge.

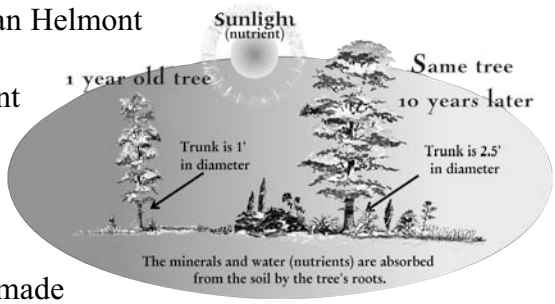


When you combine the reactants (ingredients), the result is the product (mixture of ingredients).



Jan Baptista van Helmont planted a willow tree in a large container of soil. He weighed the tree and the soil in the pot. After five years of watering the tree and letting it grow, he weighed the tree and the soil again. The willow tree had gained 164 pounds, and the soil had lost very little weight. Van Helmont suggested that the willow had gained weight by absorbing only water.

Van Helmont cited this experiment as evidence that solid objects could be made from water. He was partially correct. About fifty percent of the tree is water. Van Helmont overlooked the possibility that some of the tree's nourishment came from the atmosphere. Part of the tree's nourishment came from oxygen in the atmosphere.



Although wrong in his conclusion, van Helmont introduced the idea of measurement as an important part of scientific discovery. Robert Boyle, who lived a few years after van Helmont, agreed that measurement would promote chemical discovery. Robert Boyle urged other chemists to report the circumstances surrounding their experiments. The idea persisted that water could produce a solid substance under certain circumstances. Jan Baptista van Helmont boiled water in a glass container and as the water boiled, flecks of scaly-like material collected at the bottom of the flask. The Belgian scientist claimed heating changed water into solid material.

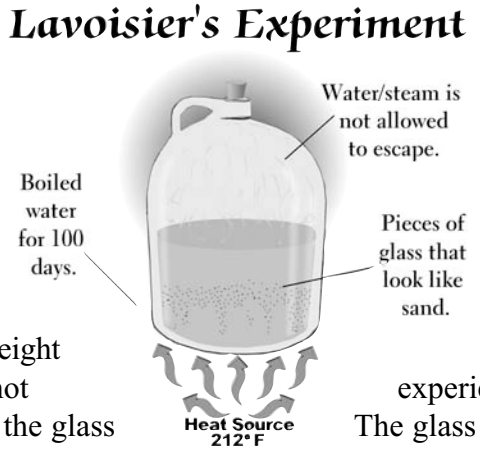
Antoine Laurent Lavoisier (1743-1794), a French chemist, agreed that measurement was an essential part of chemistry. Antoine Laurent Lavoisier said, "The usefulness and accuracy of chemistry depend entirely upon the determination of the weights of the ingredients and products. Too much exactness cannot be employed in this part of the subject. For this purpose, we must be provided with good instruments."

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Because of Antoine Laurent Lavoisier's position in the French government, he could borrow a very accurate ***balance*** scale from the French mint. (A *mint* is a place where coins are made.) The balance was a sensitive scale for measuring weight. Lavoisier weighed a silk bag, had an assistant breathe into the bag and then remeasured the weight of the bag. The bag weighed slightly more the second time because of the air in it. In fact, the scales were so sensitive they could detect a difference in his assistant's weight after inhaling a breath of air.

The sensitive balance scale was used to repeat several well-known experiments. Lavoisier repeated van Helmont's experiment that seemed to verify that boiled water gave way to a scaly solid. Lavoisier began with pure distilled water then he used a closed glass container that condensed steam to a liquid and returned it for further boiling. He boiled the water for a hundred days. Tiny flakes of sand-like material did form in the bottom of the container. Lavoisier weighed the water and discovered that none of the water had boiled away. The water weighed the same both before and after the experiment. Lavoisier weighed the glass container. It had lost an amount of weight exactly equal to the weight of the sand-like flakes. The hot water had dissolved some of the glass and deposited it as flakes. The boiling had not created the tiny sand-like flakes.

Antoine Laurent Lavoisier concluded that matter is neither created nor destroyed during chemical change. He believed all the products and ingredients that caused a reaction would weigh the same after the reaction ended.



This is known as the *Law of Conservation of Matter*. Matter is neither created nor destroyed during a chemical change. The total weight of the reactants in any chemical reaction is equal to the total weight of the products.

Lavoisier also burned various substances in a sealed glass globe and weighed the container after the objects burned. The globe as a whole did not gain or lose weight, although the ashes often weighed more than the object that was burned. The ash gained weight because it combined with the oxygen in the globe. After the experiment was completed, Lavoisier opened the container. Air rushed in to replace missing oxygen.

Because of his interest in combustion, Antoine Laurent Lavoisier tested whether a diamond would burn. He placed the diamond in a closed glass globe. By focusing the rays of the Sun onto the diamond, he set it on fire. In this case, no ash was produced. The diamond was totally consumed.

Diamond is made of carbon. Like coal, diamond undergoes rapid combustion (burns) with oxygen. The diamond combined with oxygen from the air in the container and changed into carbon dioxide. Despite changing from a solid to a gas, the diamond experienced no change in weight. The glass container weighed the same both before and after the diamond burned.

These experiments and many others helped establish the Law of Conservation of Matter. The weight of matter is the same at the end as at the beginning of every chemical reaction. Of course, all of the products must be captured and weighed, including any that change into gases.

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Lavoisier's experiments tended to agree with the Atomic Theory of Matter. The Law of Conservation of Matter supports the principle that atoms cannot be made or destroyed. Chemical reactions merely change their arrangement. The diamond contained carbon atoms, and the air contained oxygen atoms. When the carbon burned, the atoms changed their arrangement. They combined with oxygen atoms in the air to produce carbon dioxide.

Lavoisier's success proved that his insistence on measurement was important for chemical discovery. Galileo had exerted the same effect on astronomy and physics two hundred years earlier. Lavoisier's work helped chemistry catch up with the rest of science. Chemists began recording information about the conditions of experiments.

Unfortunately, Antoine Laurent Lavoisier lived at the time of the French Revolution. In 1793, the fate of the country was put in the hands of the Committee of Public Safety. The committee began the Reign of Terror in which many government officials were arrested and charged with treason. Lavoisier held many high posts in the French government, including commissioner of weights and measures. He invested money in a company that collected taxes for the government. Leaders of the Reign of Terror of the French Revolution arrested Lavoisier. Friends pointed out that Antoine Laurent Lavoisier had shown unselfish devotion to his country and that he was also a great scientist. One of the leaders of the Reign of Terror said, "France has no use for scientists."

On May 8, 1794, Antoine Laurent Lavoisier was taken from the dungeon. One of the powerful leaders of the revolution was an enemy of Lavoisier. In quick order Lavoisier was tried, convicted and sentenced to death. On the same day as his trial Lavoisier was taken to the guillotine, which was a machine used during the French Revolution to behead people. To the sound of the drumbeat, the guillotine blade flashed down. This senseless act ended the life of the greatest chemist in France's history.

Within two months, the French came to their senses and tossed out the vengeful leaders of the Reign of Terror. Within two years, Frenchmen were building statues honoring Antoine Laurent Lavoisier.

Before his execution, Antoine Laurent Lavoisier made many contributions to chemistry. His *Elements of Chemistry* was the first modern textbook on the subject. Lavoisier's discoveries are so many and his influence so vast, he is often named as the greatest chemist of all time. In fact, he — rather than Robert Boyle — is sometimes called the Father of Modern Chemistry.

Advance to the next Lesson!

Life Principle



"Never, never, never, never give up."

—Winston Churchill

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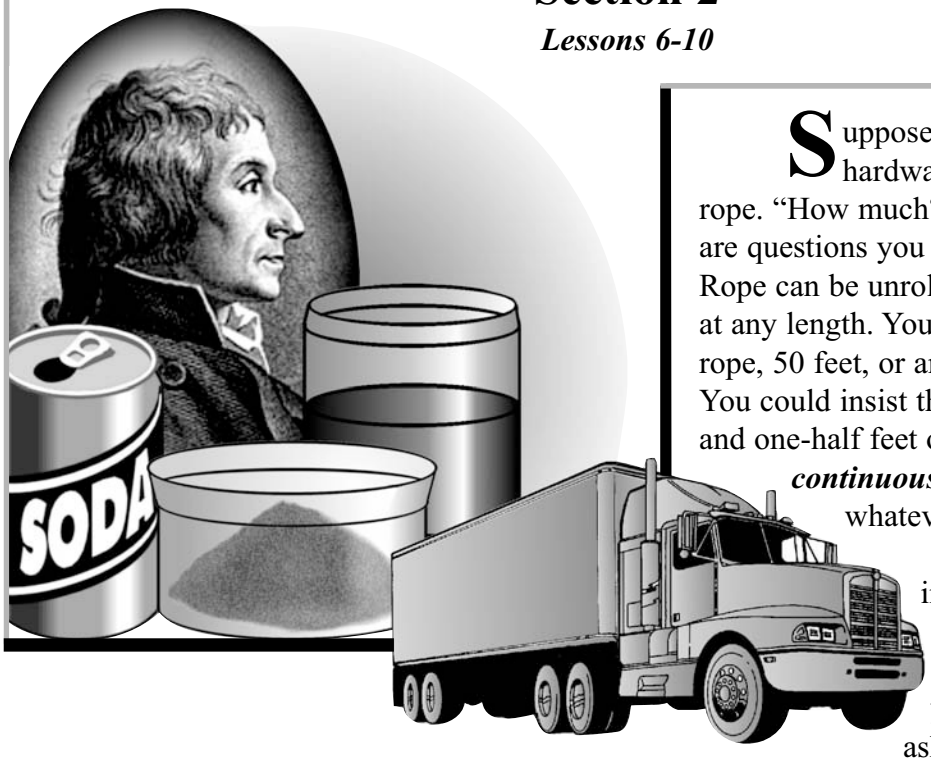
Chapter 1

Lesson 9
Compounds

CONTINUOUS AND DISCRETE

Section 2

Lessons 6-10

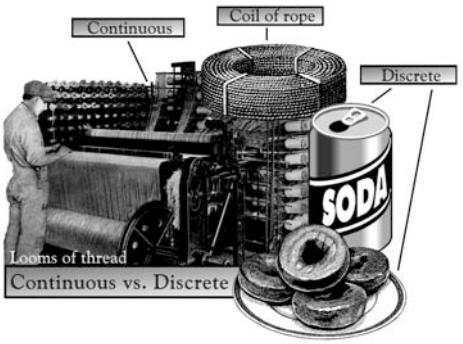


Suppose you walked into a hardware store and asked for rope. "How much?" or "How many feet?" are questions you are likely to be asked. Rope can be unrolled from a spool and cut at any length. You can order three feet of rope, 50 feet, or any length in between. You could insist that you want exactly nine and one-half feet of rope. Rope is a ***continuous*** product that comes in whatever length you desire.

Suppose you walked into a bakery and asked for doughnuts. "How many?" is a question you are likely to be asked. You can buy three doughnuts, 50 doughnuts, or any whole number in between. However, you would not expect to be able to buy nine and one-half doughnuts. Doughnuts are ***discrete*** products.

Cloth is manufactured on a loom that is continuously fed with thread. Hundreds of spools supply thread to the loom. When a spool is empty, workers hastily replace it. The ends of the thread are twisted together so the thread never runs out. As long as the spools are replace cloth is woven by the loom in single, unending strip. Cloth i an example of a continuous product.

When you buy a soft drink from a vending machine you expect to get one can fro the machine, not one and



VOCABULARY

Continuous: going without interruption or end; unbroken
Discrete: consisting of separate parts
Definite: clearly defined limits
Proportion: a part compared to the whole

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one-half cans. The cans are discrete. You can probably think of other examples of continuous and discrete products.

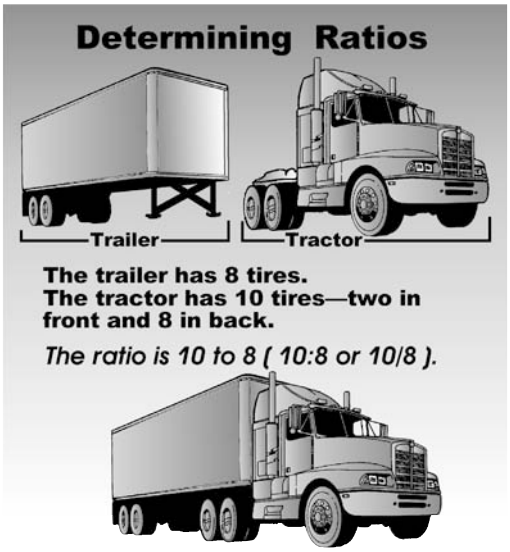
Chemists have debated the question as to whether matter is continuous or discrete. In the 1700s, those who believed that atoms made matter believed that matter was discrete. A compound might contain one oxygen atom or even 50 oxygen atoms, but not nine and one-half oxygen atoms. Others insisted that matter was continuous and that oxygen could come in any amount, no matter how small.

Scientists who believed matter was continuous also believed compounds varied in the amount of each element they contained. Copper carbonate is found throughout the world and contains copper, carbon and oxygen. Chemists believed that the amount of the three elements in a sample could be different. They claimed a sample made in the laboratory could contain different amounts of carbon for example than a sample of the same substance found in nature.

The argument was about ***definite proportions***. The compound copper carbonate can be prepared in the laboratory by a variety of ways. Samples of it can also be found in nature. Regardless of their origin, copper, carbon and oxygen always have the same proportion by weight.

A *proportion* compares a part against the whole. The comparison is made based on number, weight, volume or some other physical feature. The large, cross-country big rig trucks are known as 18-wheelers. They have that name because the total number of wheels on the truck and trailer is 18. Of that number, 10 are on the truck, sometimes called the tractor. Eight of the wheels are on the trailer. The proportion of wheels on the tractor to the total number of wheels is 10 to 18. This can be written as 10:18. The colon is pronounced as "to." It can also be written as a fraction, 10/18. This is read as "10/18^{ths}" or "10 divided by 18." The number of wheels on the tractor is compared to the number of total wheels.

We expect the number of tractor wheels in relation to the total number of wheels on big rigs to be in this proportion of 10/18. The wheels are found in definite proportions. This proportion stays the same whether you are talking about one truck or ten. The number of wheels on the ten tractors is greater but so is the total number of total wheels. The proportion for 10 big rigs stays the same: 100/180 = 10/18.



In the same way, atoms are found in compounds in definite proportions. The water molecule has two hydrogen atoms for each oxygen atom, H_2O. The ratio of hydrogen atoms to oxygen atoms is 2:1. A *ratio* is a relationship between two quantities expressed as a fraction. Two hydrogen atoms exist for each oxygen atom. This ratio is the same for a single molecule or millions of molecules. The ratio of the number of hydrogen atoms to the number of oxygen atoms is 2:1, regardless of the size of the sample.

In the previous examples, the comparison is based on numbers — number of wheels and number of atoms. Elements in a compound can be compared in a variety of ways including their numbers, their volumes

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or their weights. Chemists of the 1700s had to use weight to compare elements because scientists did not know how many atoms were in chemical compounds.

THE LAW OF DEFINITE PROPORTIONS

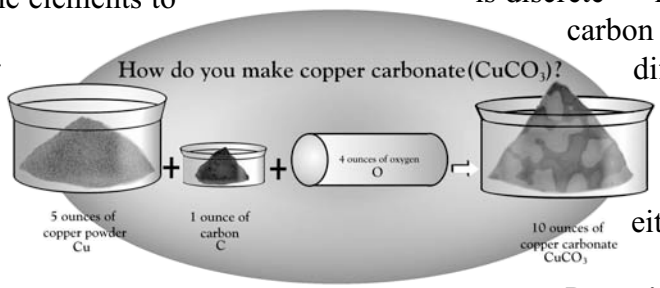
The first person to make a careful study of the proportions of elements in chemical reactions was Joseph Louis Proust, 1754-1826. He was a French chemist who lived at the time of the French Revolution. Joseph Proust was a member of French nobility. He had been visiting Spain when the French Revolution began. Proust decided to stay in Spain where he was welcomed by the king of Spain. The king built a fine chemical laboratory and put Joseph Proust in charge.



Joseph Proust

Joseph Proust prepared copper carbonate ($CuCO_3$) in the laboratory. He also analyzed the same compound from nature. In every case, Proust found that copper carbonate contained copper, carbon and oxygen in definite proportions by weight: 5 ounces of copper to 1 ounce of carbon to 4 ounces of oxygen. Regardless of the unit of weight—pound, ounce, kilogram or gram—used in experiments, the total weight could not change because of the Law of Conservation of Matter.

The ratios had to be followed when combining the elements to form copper carbonate. If Joseph Proust used too much of one element, the reaction simply ignored the excess. The extra was left uncombined. If he used 8 ounces of copper instead of 5 but kept the amount of carbon (1 ounce) and the amount oxygen (4 ounces) the same, Proust still concluded with 10 ounces of copper carbonate. Three ounces of copper would be left over. When the correct proportion was used, 5:1:4, all of the reactants were combined with none left over. If Proust began with other proportions, one of the elements was always left uncombined.



Joseph Proust showed that this was true of other compounds. He concluded that a compound always contains elements in certain definite proportions and in no other combinations.

In 1799, Joseph Proust announced his discovery as the *Law of Definite Proportions.* In any sample of a compound, the elements of which it is composed are in the same proportion by weight. This is proven for any sample of the pure substance, regardless of the way it is prepared in the laboratory or from where it is taken in a natural source.

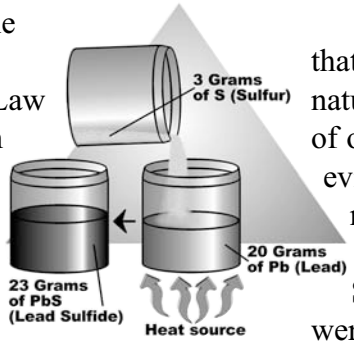
Chemists today can see why the Law of Definite Proportions should be true. Copper carbonate ($CuCO_3$) has one atom of copper (Cu), one atom of carbon (C) and three atoms of oxygen (O). The proportion by number is 1:1:3. Whether the sample is large or small or how it is prepared, copper carbonate always has atoms in exact proportions. Proust's law showed that matter is discrete — it is made of atoms. Copper, carbon and oxygen atoms have different weights. When their weights are used, the proportion is 5:1:4 because copper weighs more than either carbon or oxygen.

At first, chemists did not accept Proust's Law of Definite Proportions. A few years later, another chemist, Jons

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Jakob Berzelius, tested the law. He heated 20 grams of lead (Pb) with varying amounts of sulfur (S) to form lead sulfide (PbS). Lead is a soft, grayish metal. Sulfur is a yellow solid. Lead sulfide is a shiny, black solid. Berzelius noted when all the lead had reacted. He used at least 3 grams of sulfur and 20 grams of lead to obtain 23 grams of lead sulfide. If he used more than 3 grams of sulfur, it was left over, and it did not take part in the reaction. When he used more than 20 grams of lead with 3 grams of sulfur, the excess lead was left over.

Jons Jakob Berzelius did not stop with a single experiment. Over ten years, he ran two thousand analyses. Chemical analysis separates a compound into its elements and measures the amount of each one. Berzelius confirmed the Law of Definite Proportions in so many different ways that no one could seriously doubt its truth. Jons Jakob Berzelius became a famous and respected chemist, thus Proust's Law of Definite Proportions became widely accepted.

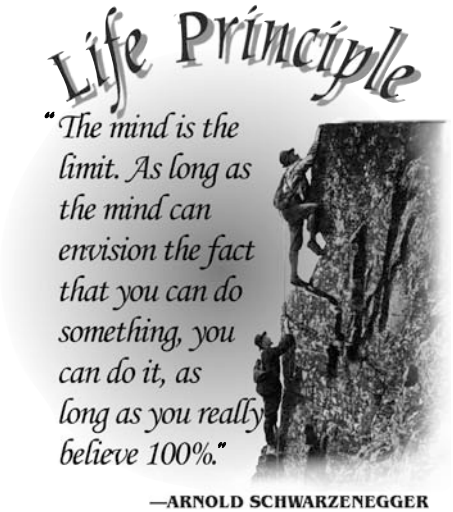


Joseph Proust stayed in Spain for 20 years. In 1808, Napoleon's army invaded Spain. French soldiers looted Proust's laboratory and destroyed it. Joseph Proust returned to France and lived in poverty. Napoleon offered a grant to enable Proust to continue his research. Proust's health was too poor to accept the assignment. He refused it. Later, after Napoleon's fall, the new French king gave Proust a pension. In 1816, Joseph Proust was elected to the French Academy of Sciences.

Joseph Proust had not been seeking to prove that atoms exist. However, his experiments supported the idea of atoms. If matter were made of atoms, only whole atoms would combine during chemical reactions. When elements joined to form a compound, a set number of atoms of one element would combine with a set number of atoms of another.

Knowing that chemicals combine in definite proportions is important for commercial processes. When making sulfuric acid, the most common acid used for commercial purposes, the amount of sulfur (S) by weight must be exactly right. Otherwise, part of the sulfur will be wasted and reduce the profit of the company making it. Understanding the Law of Definite Proportions is important to chemists who work in business and industry.

You have probably begun to notice that as scientists made discoveries about natural things, they became aware of a sense of order and design in the universe. This evidence of design enabled scientists to make predictions and form theories and hypotheses about physics and chemistry. Scientists saw order and design, thus, they were able to advance their research through documentation of laboratory experiments. **Scientific documents began to piece together the puzzle of the Periodic Table of the Elements, as you will learn next.**



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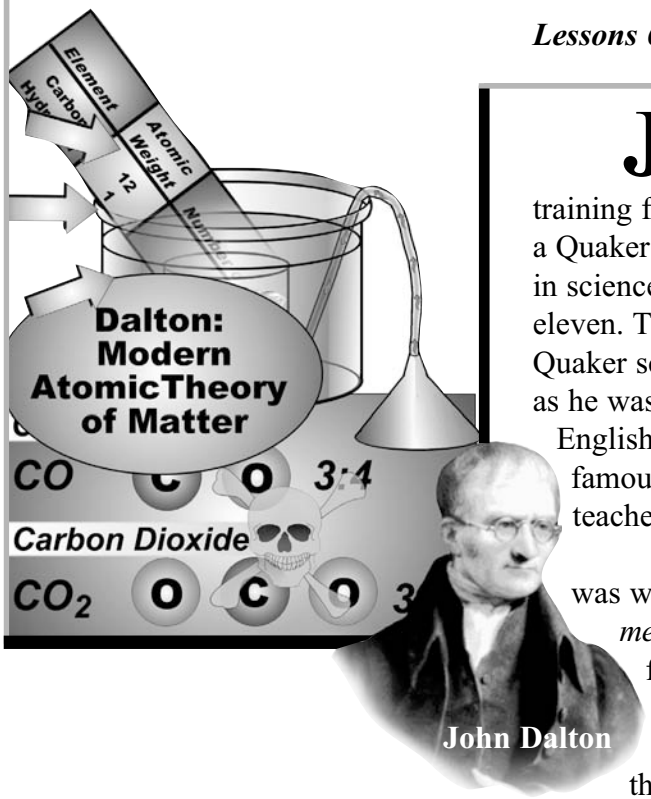
Lesson 10
Compounds

Chapter 1

CHEMICAL FORMULAS OF COMPOUNDS

Section 2

Lessons 6-10



John Dalton

John Dalton (1766-1844), an English chemist, was the son of a weaver. He received his early training from his father. Dalton attended a few years at a Quaker elementary school. He was entirely self taught in science. His formal schooling ended at the age of eleven. The next year John Dalton began teaching at the Quaker school. Some of Dalton's students were as old as he was. In 1793, John Dalton moved to the large English town of Manchester. Although he became famous as a chemist, Dalton earned his living as a teacher or private tutor.

The first scientific subject to interest Dalton was weather. The study of weather is called *meteorology.* John Dalton made his own instruments for measuring weather conditions. Dalton recorded the readings from his weather gauges in a daily weather journal. In 1793, he wrote the book, *Meteorological Observations and Essays*. This was one of the first scientific accounts of weather.

The next year, Dalton presented a paper on *colorblindness*. Colorblindness is a condition in which a person is unable to distinguish between certain colors. John Dalton could write as an authority on the subject because he was colorblind himself, as was his brother. John Dalton's paper was the first scientific description of colorblindness.

Although he studied other subjects, Dalton continued his weather observations all of his life. He entered 200,000 observations and measurements about the weather in his logbooks.

Dalton's interest in weather led him to a study of the *atmosphere*, which is a mixture of gases. About 200 years earlier, chemists considered the atmosphere to be a single substance and not a mixture. The term *gas* had not been invented. According to ancient philosophers, any vapor entering

VOCABULARY

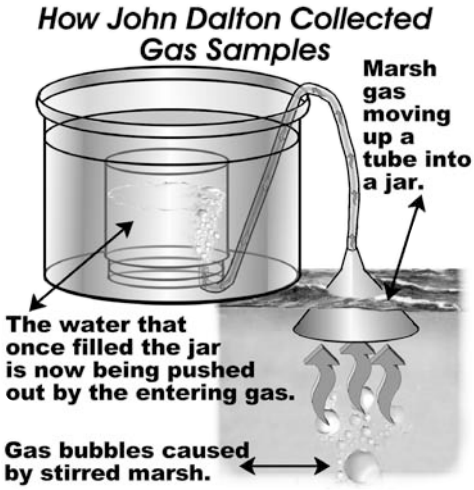
Hydrocarbon: any compound made of hydrogen and carbon
Atomic weight: the weight of a single atom
Relative weight: the weight of an atom of an element compared to the weight of the atom of some other element

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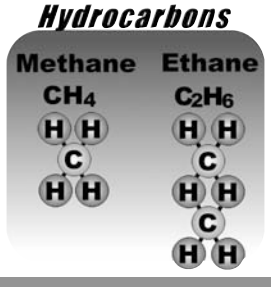
the atmosphere instantly became exactly like it. These philosophers claimed that the gas produced by burning wood became identical to the gas of the air.

Jan Baptista van Helmont, about whom we learned in the previous lesson, had weighed the willow tree as it grew. He also studied the vapors given off during chemical reactions. Van Helmont invented the name *gas* for such vapors. He studied the gas produced by burning wood. This gas showed properties quite distinct from air. The gas from wood would put out a candle flame. The modern name for van Helmont's gas is carbon dioxide (CO_2). Carbon dioxide is a gas made of one carbon atom and two oxygen atoms.

John Dalton collected various gases and studied them. This was accomplished by filling a jar with water and holding it upside down in a larger container of water. A tube carried the gas to the jar. The gas bubbled into the jar and collected at the top, forcing out the water. This ensured that the jar contained only the gas to be studied. John Dalton took his students to a marshy pond. They stirred the bottom of the pond to release bubbles that John Dalton collected in his jar. He actually collected samples of *marsh gas*, better known as *methane*.



The chemical formula for methane is CH_4. It is a ***hydrocarbon***: a compound that contains hydrogen and carbon. Methane is an odorless, colorless and flammable gas. Natural gas contains mostly methane and ethane (C_2H_6). Natural gas is brought to the Earth's's surface through petroleum wells drilled to extract oil. Some wells produce only natural gas. Homes that have gas service use natural gas for heating and cooking. In industry, gas serves as a fuel and as a source of carbon and hydrogen in the production of plastics.



Chemists today know that the methane molecule contains one carbon atom and four hydrogen atoms. The ratio of carbon to hydrogen is 1:4 by number. John Dalton did not know the number of atoms in methane. He compared the weights of the elements that made up the gas. Dalton found that methane contained three ounces of carbon and one ounce of hydrogen. The ratio of carbon to hydrogen is 3:1 by weight. For the same compound, the ratio of atoms based on their number is not the same as the ratio of atoms based on their weight.

John Dalton made one of the first attempts to learn the ***atomic weights*** of different elements. A single atom could not be weighed, so Dalton used ***relative weights***. Dalton compared the weight of atoms of one element with the weight of atoms of another element. He set the hydrogen atom equal to 1. Hydrogen is the lightest atom; therefore, all other atoms will weigh more than hydrogen. The weight of the other atoms can be expressed in terms of the hydrogen atom. Experiments show that carbon has an atomic weight of 12, and oxygen has an atomic weight of 16. A carbon atom weighs 12 times as much as a hydrogen atom. An oxygen atom weighs about 16 times as much as a hydrogen atom.

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Look at the methane molecule, CH_4. It contains one carbon atom with a weight of 12. It contains four hydrogen atoms, each weighing 1, for a combined weight of 1 * 4 = 4. The ratio of carbon to hydrogen by weight is 12:4, which is equal to 3:1. Divide both 12 and 4 by 4 to give 3:1. The ratio of carbon to hydrogen in methane is 3:1 by weight. The ratio of carbon to hydrogen in methane (CH_4) is 12:4 = 3:1

Ratio of carbon to hydrogen in methane (CH_4) is 12:4 = 3:1

Element	Atomic Weight	Number of Atoms	Total Weight
Carbon	12	1	12
Hydrogen	1	4	4

Look at carbon dioxide (CO_2). The carbon by weight is 12. CO_2 has two oxygen atoms, each weighing 16, for a total for oxygen by weight of 2 * 16 = 32. The ratio of carbon to oxygen in carbon dioxide is 12:32 by weight. The ratio of 12:32 can be reduced to 3:8 by dividing both 12 and 32 by 4. The ratio of carbon to oxygen in carbon dioxide (CO_2) is 12:32 = 3:8.

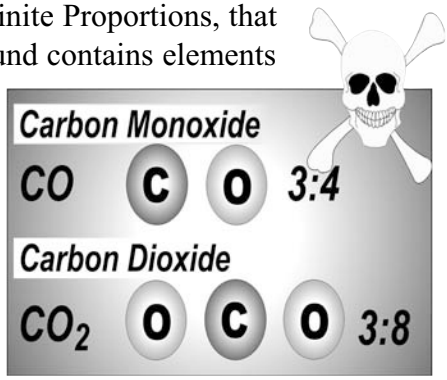
Ratio of carbon to oxygen in carbon dioxide (CO_2) is 12:32 = 3:8

Element	Atomic Weight	Number of Atoms	Total Weight
Carbon	12	1	12
Oxygen	16	2	32

John Dalton compared the weight of elements that produced various gases. He found them in set and exact amounts that never varied regardless of how the gas was produced. He showed that the *Law of Definite Proportions* applied to gaseous compounds as well as solid compounds.

John Dalton discovered something new. He noticed that sometimes the same elements would combine in various proportions to produce different compounds. The elements, carbon and oxygen, combined to form the compound carbon dioxide (CO_2). Their ratio by weight was 3:8. Three ounces of carbon combined with eight ounces of oxygen produced carbon dioxide. However, carbon and oxygen also combined to form the compound carbon monoxide (CO). Carbon monoxide had but one oxygen atom. In that case, the ratio of carbon to oxygen by weight was 12:16 = 3:4. Three ounces of carbon combined with four ounces of oxygen produced carbon monoxide.

Dalton's observations verified the Law of Definite Proportions, that any compound contains elements in definite proportion by weight. The fact that the proportion of carbon and oxygen is different in carbon dioxide and carbon monoxide does not violate the Law of Definite Proportions. The two gases are different compounds. The Law of Definite Proportions applies to the same compound.



When atoms combine, they form molecules. Any two molecules of the same chemical compound have the same combination of atoms. The atoms are always present in the same proportion. The water molecule has one oxygen atom and two hydrogen atoms. The ratio of oxygen to hydrogen by weight is 16:2 = 8:1.
The ratio of oxygen to hydrogen in water, H_2O, is 16:2 = 8:1.

Ratio of oxygen to hydrogen in water (H_2O) is 16:2 = 8:1

Element	Atomic Weight	Number of Atoms	Total Weight
Oxygen	16	1	16
Hydrogen	1	2	2

Should the molecule of water gain an oxygen atom, it would no longer be water. It would be hydrogen peroxide (H_2O_2). In hydrogen peroxide, the ratio of oxygen to hydrogen by weight is 32:2 = 16:1. The ratio

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of oxygen to hydrogen in hydrogen peroxide (H_2O_2) is 32:2 = 16:1

Ratio of oxygen to hydrogen in hydrogen peroxide (H_2O_2) is 32:2 = 16:1

Element	Atomic Weight	Number of Atoms	Total Weight
Oxygen	16	2	32
Hydrogen	1	2	2

As scientists learned facts and laws, occasionally a person would combine these facts into an overall explanation. In the case of John Dalton, he combined the hazy and incomplete Atomic Theory of Democritus, the Law of Conservation of Matter of Lavoisier, and the Law of Definite Proportions of Proust into the *Modern Atomic Theory of Matter.*

John Dalton knew of the idea of atoms as did most other chemists. He took the idea of atoms and set them on a firm scientific footing. Dalton said that all atoms of the same element are identical in all their properties, including their weight. Atoms of different elements differ from one another, especially in their weight. Atoms join in simple definite numbers to form molecules.

John Dalton first announced his atomic theory in 1803. In 1808, he published his book, *New System of Chemical Philosophy,* which explained many theories and ideas that had puzzled chemists. Dalton's book was quickly accepted. His atomic theory of matter is the foundation on which most of modern chemistry rests. The book also contained a table of atomic weights, the first of its kind. Through hard work and a quick mind, Dalton was able to overcome his poor rural background. Although John Dalton continued as a teacher and tutor, people recognized him as one of England's greatest scientists.

John Dalton's religious beliefs led him to avoid any form of glory. When he was nominated for membership in the Royal Society, Dalton declined the honor. Several years later, he was elected without his knowledge. Friends tried to arrange for Dalton to meet the King of England. Dalton refused when he learned he would have to wear royal court clothes with a sword. John Dalton was a Quaker who believed the Bible forbids men to carry weapons or wear bright colored clothes.

In 1832, Oxford University honored John Dalton with a doctor's degree. As part of the ceremony, he wore the college robes. The King would receive him in the college robe, which did not include a sword. The audience with the King did take place. The Oxford robes were a bright scarlet. Because he was colorblind, John Dalton saw the royal scarlet as gray.

As the result of John Dalton's contributions to English science, the government gave him a retirement pension of 150 pounds a year. At that time, a person could support a family on 100 pounds a year. Because of his simple ways, John Dalton could live quite comfortably on that amount. Later, the King increased the amount of the pension to 300 pounds. Dalton died in 1844; a statue was erected to his memory in Manchester, England.

You are doing well.

Life Principle

"Real joy comes not from ease or riches or from the praise of men, but from doing something worthwhile."



—Pierre Coneille

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Integrated Physics & Chemistry

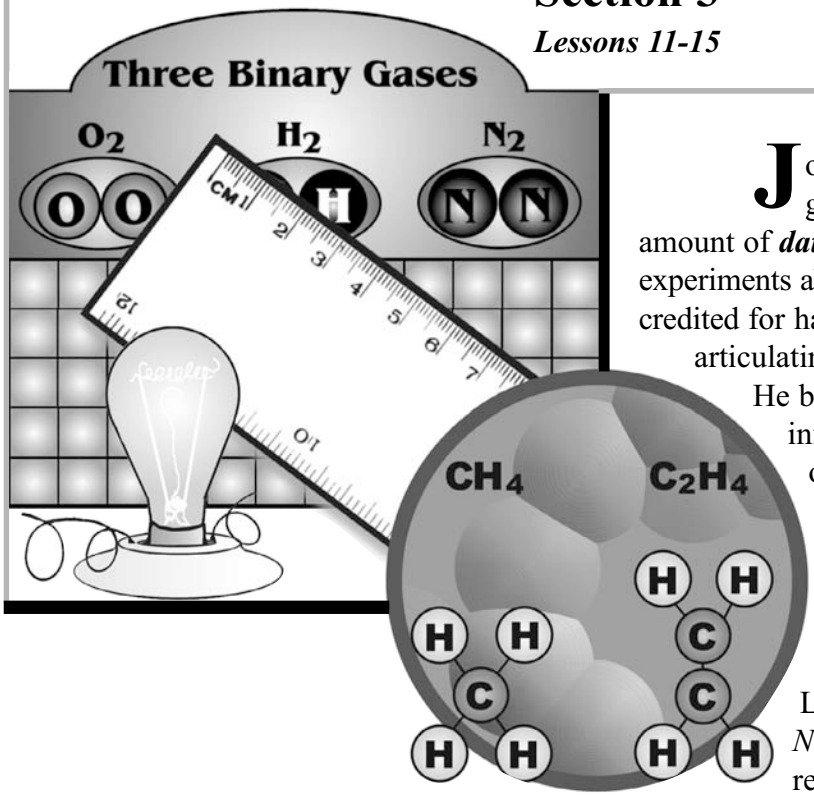


Lesson 11
Compounds

Chapter 1

Section 3
Lessons 11-15

LEARNING CHEMICAL FORMULAS



John Dalton's atomic theory was a great success. It explained a large amount of ***data*** compiled from scientific experiments about matter. John Dalton is credited for having discovered atoms and articulating the Atomic Theory of Matter. He based his ideas on experimental information rather than mere opinions. The ancient Greeks had no evidence to prove their ideas about atoms. John Dalton had data to verify his claims were true.

In this short passage from Lucretius' long poem, *On the Nature of Things,* the word *seed* refers to an atom:

But solid seeds exist, which fill their place;
And make a difference betwixt full and space.
These, as I proved before, no active flame,
No subtle cold can pierce, and break their frame,
Tho' every compound yields no powerful blow,
No subtle wedges divide, or break in two.

VOCABULARY

Data: information
Binary: molecules that consist of two atoms; most gases are binary
Process: a series of actions that causes continuous improvement

John Dalton's ideas about the nature of matter and the role of atoms are much more specific. His ideas can be summarized as follows:

Matter is composed of a large number of tiny particles called atoms. Atoms are the smallest particles that make up matter. They can neither be created nor destroyed. Their presence merely awaited discovery and label. All the atoms of

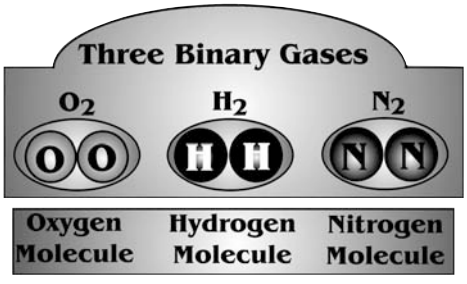
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the same element are identical in all respects. In particular, they have the same weight. Various elements have atoms that differ in weight. Combining elements with whole numbers of atoms forms molecules. All the molecules of any compound are identical in all aspects.

Dalton clearly defined the four terms — atom, element, molecule and compound. An atom is the smallest particle that contains the chemical properties of a particular element. The atoms of a particular element are alike. A molecule is made of two or more atoms that can be different. A molecule is the smallest particle that contains the chemical properties of a particular compound. All of the molecules in a particular compound are identical.

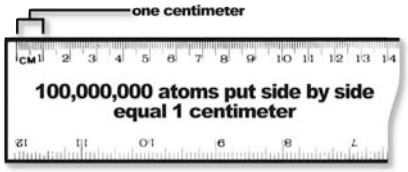
Hydrogen is an element. A sample of hydrogen contains only hydrogen atoms. Water is a compound. A sample of pure water contains only water molecules, H_2O.

An element can be made of molecules under one special case; the molecules must be of the same type of atoms. Most gases are ***binary***. They contain molecules made of two identical atoms. *Chlorine gas* (Cl_2) is binary. Chlorine gas contains only chlorine atoms but these atoms are not found alone. Instead, two chlorine atoms chemically combine to form a molecule, Cl_2. Gases of hydrogen, oxygen and nitrogen are also binary — H_2, O_2 and N_2.



A compound has a definite *composition*. The atoms that make up that compound are arranged in the same way every time. The ratio of elements that make up a compound is fixed. Regardless of the shape of the samples or their sizes, a compound always has the same elements in the same proportion. This absolute enables scientists to predict certain outcomes.

Think of elements as being made of atoms that are all the same. Compounds are made of molecules that are all the same. Chemists of the 1800s became interested in knowing the number and type of atoms in each molecule. Atoms are extremely small. About one hundred million (100,000,000) atoms arranged side by side make a line one centimeter long. (An inch is about two and a half centimeters long.) Observing atoms and molecules was impossible for chemists of the 1800s. It remains difficult today. Only the



most powerful electron microscopes can reveal the arrangement of atoms and molecules.

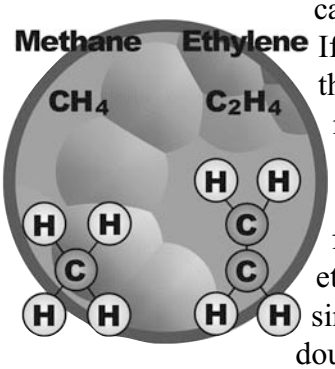
Chemists gradually learned the composition of compounds. For example, methane (CH_4) has four hydrogen atoms, but only one carbon atom; copper carbonate ($CuCO_3$) is made of one copper and carbon atom each, but has three oxygen atoms; the chemical formula for water anywhere in the universe is always H_2O.

The expressions CH_4, $CuCO_3$ and H_2O are *chemical formulas*. They show which atoms are present and in what numbers. Take a look at the periodic table and you will find *C*, *H*, *Cu*, and *O*. These pieces of the elemental puzzle are combined to form compounds, as expressed by the chemical formulas mentioned above.

Look again at some of John Dalton's experimental results. He found that one

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ounce of hydrogen can combine with three ounces of carbon to form the compound methane. One ounce of hydrogen can combine with six ounces of carbon to form a different gas, ethylene. Notice that the six is two times three. Ethylene has twice as much carbon as methane. If Dalton knew the formula for methane, then he would have the formula for ethylene by simply doubling the number of carbon atoms. We know today that the formula for methane is CH_4. Based on John Dalton's experiments, we can predict that the formula for ethylene is C_2H_4.

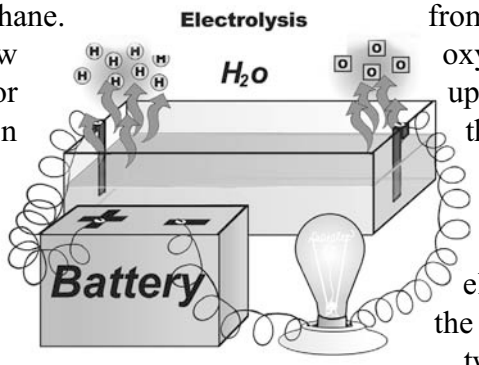


Once the chemists of the 1800s learned the chemical formulas for a few basic compounds, the chemists could work out the formulas for other compounds.

Once the chemical formula is known, the chemists could also calculate atomic weights of atoms and molecules. No one can weigh a single atom; it is too small to see or weigh. Instead, John Dalton and other chemists compared the weight of one atom with another. Some used hydrogen as the reference because it is the lightest element. Others used carbon because it forms many compounds. Some used oxygen as the reference because it was found in many common compounds.

John Dalton worked with hydrogen and found that one ounce of hydrogen combined with eight ounces of oxygen. He assumed that the formula for water was *HO* and that oxygen weighed eight times as much as hydrogen. He was in error. The formula for water is H_2O, so the oxygen weighs 16 times as much as hydrogen.

In the late 1700s and early 1800s, chemists began experimenting with electricity. They put a wire from each terminal of a battery into a container of water. Electricity caused the water molecules to come apart. Hydrogen gas bubbled up from one wire and from the other wire oxygen gas bubbled up. Chemists captured the gases and measured the volume. They found that when electricity separates the water molecule; twice as much hydrogen gas was formed as oxygen gas. This proved that the water molecule was made of twice as many hydrogen atoms as oxygen atoms.



$$2H_2 + O_2 \longrightarrow 2(H_2O)$$

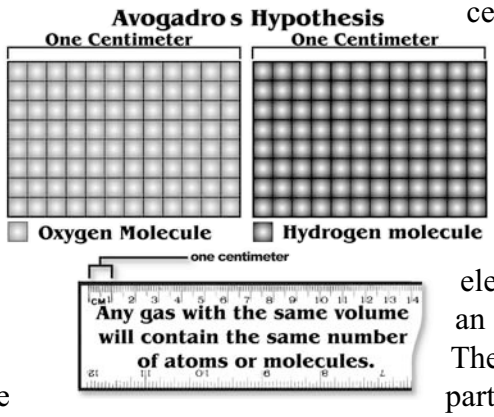
In the early 1800s, Joseph Louis Gay-Lussac, a French chemist, experimented with the production of gaseous compounds. He measured the volumes of the gases that made up the compounds. When combining hydrogen and chlorine to form hydrogen chloride, the volume of hydrogen was equal to the volume of chlorine. He made ammonia (NH_3) by combining hydrogen with nitrogen. He had to use three times as much hydrogen by volume as nitrogen by volume to form ammonia.

Joseph Louis Gay-Lussac concluded that when gases combined, they did so by small whole number amounts by volume. This became known as the *Law of Combining Volumes*.

In 1811, Amedeo Avogadro, an Italian physicist, looked at Joseph Louis Gay-Lussac's discovery and made a bold prediction. He said that the same volume of gas always contained the same number of particles regardless of the gas. The particles could be individual atoms or they could be

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molecules. This idea became known as Avogadro's *hypothesis*. A hypothesis is an explanation that has not been fully developed.



Imagine a container filled with oxygen gas. Count the oxygen molecules. Next, empty the container of the oxygen and fill it with hydrogen. Count the hydrogen molecules again. The number of hydrogen molecules would be the same as the number of oxygen molecules. At first, this may go against common sense. The oxygen molecule weighs 16 times as much as the hydrogen molecule. You might think that because oxygen molecules are so much heavier, they would take up more space. The explanation is that gas is mostly empty space. The extra size of the oxygen molecule does not make much difference compared to the vast distance between the gas molecules. The number of particles is the same whether the gas is oxygen or hydrogen.

Avogadro's possible explanation proved to be exceptionally useful. Measuring the volume of the gases would tell chemists the ratio of atoms in any gaseous compound. For instance, twice as much hydrogen combines with oxygen to form water, making the formula for water (H_2O). Hydrogen and chlorine in equal volumes combine to form hydrogen chloride. The formula must be *HCl*. Ammonia contains three times as much hydrogen gas as nitrogen gas. The formula for ammonia is NH_3.

This allowed chemists to discover how many atoms of each element make up a compound. Once the chemical formula is known, atomic weights can be calculated.

Today the evidence is overwhelming that matter is made of atoms. The atoms of certain elements have actually been photographed. This is not done by ordinary means. An optical microscope, one that uses glass lenses, has a maximum magnification of about 2,000 times. An electron microscope can magnify an object about one million times. The electron microscope uses tiny particles to bounce through the object to be magnified. We will talk about these tiny objects, called *electrons,* later.

Atoms are made of smaller particles. Nuclear reactions at nuclear power plants, inside atomic bombs and even inside the Sun can separate an atom into smaller particles. For that reason, chemists say that an atom cannot be separated into smaller parts by ordinary chemical methods.

The way the role of the atom was discovered illustrates another characteristic of chemistry. It is a ***process*** that tells us that chemistry is always changing and evolving even though the basic laws are absolute. Each year new information comes to light that may cause earlier laws to be improved or changed to conform with the new information.

Chemists who lived after John Dalton found exceptions to almost everything John Dalton said about atoms. Atoms can be broken into smaller particles. Atoms of the same element may not have exactly the same weight. We should not be upset about this, but instead recognize that the study of chemistry is a process of continuous improvement. Science does not have the answer for everything, but instead provides pictures of how things work according to available information. If the data changes, so do scientific explanations.

The next lesson describes how scientists began to agree on the use of common symbols.

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LIFE PRINCIPLE

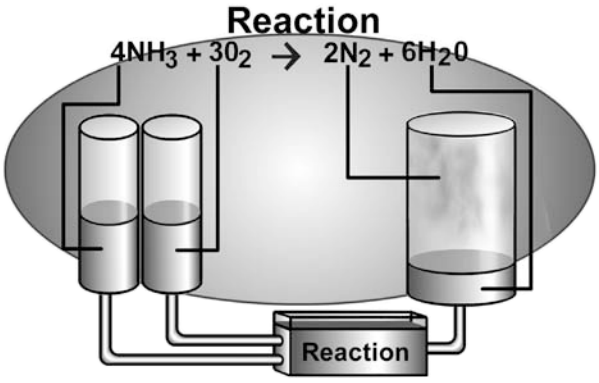


"Give yourself a choice and not a change. Give 100% to your school work and 100% to your sport . . . then when the time comes, you are able to make your choice about what you wish to do in life."

—Gordie Howe



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Integrated Physics & Chemistry

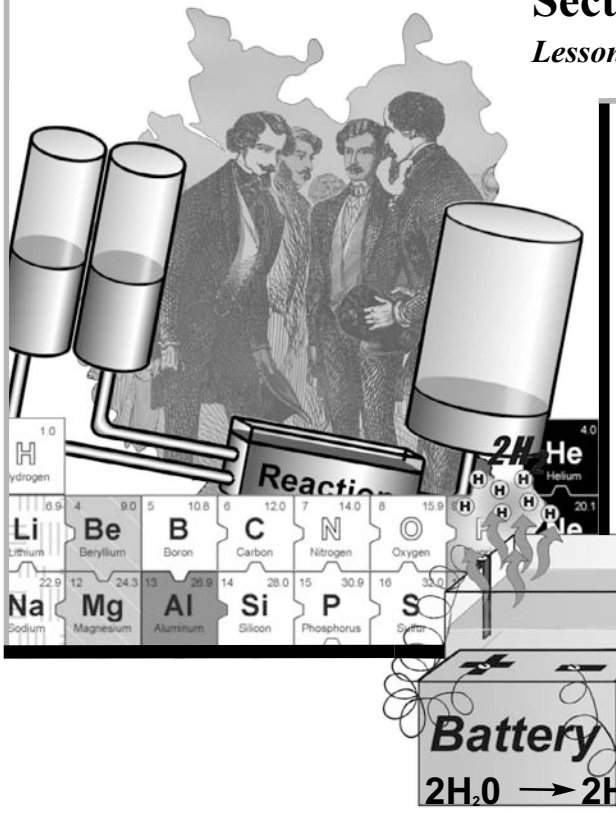


Lesson 12
Compounds

Chapter 1

CHEMICAL SHORTHAND

Section 3
Lessons 11-15

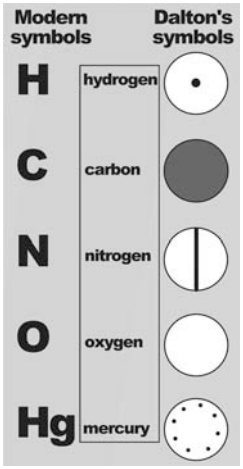


In a ***chemical symbol***, the first letter is always capitalized, and the second letter, if any, is always lowercase. A ***chemical formula*** is the shorthand name for a compound. A ***chemical equation*** is a brief way of writing a ***chemical reaction***.

CHEMICAL SYMBOLS

Chemists began their pursuit of elements in earnest in the early 1800s. Some pieces to the grand chemical puzzle had already been discovered. People before the time of Christ had found nine elements. By the time of Lavoisier, in the late 1700s, about 30 elements had been found. By the 1850s, the number had doubled. By the end of the 1800s, chemists believed the Periodic Table of the Elements (the big puzzle) included 92 naturally occurring elements. In order to understand and to record data of the many elements and write the formulae of compounds, chemists developed shorthand methods.

John Dalton used figures enclosed in circles for the chemical elements. He drew hydrogen as a circle with a black dot in the center. Oxygen was a clear circle, and carbon as an entirely black circle. Nitrogen was a circle with a bar dividing it in half. Mercury was a circle with a series of dots around the edge. To show how various atoms combined



VOCABULARY

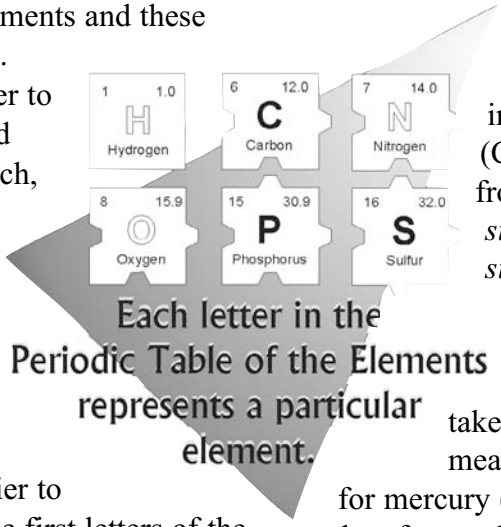
Chemical symbol: a letter abbreviation that identifies the element exactly
Chemical formula: letters and numbers that show the number of atoms of each element in a molecule of a compound

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to form compounds, Dalton put different circles together. His shorthand formulae for complex compounds became very intricate. His code for elements became difficult to remember and difficult to print in books. In addition, as more elements were discovered, chemists had difficulty making a new symbol for each new element.

Each chemist came up with his own scheme for representing elements. This made communication difficult. Many chemists used the open circle to stand for gold. This came from the ancient symbol for the Sun, which is golden in color. For iron, chemists used the shield and lance symbol for the planet Mars. Mars has the red color of rusted iron.

Jons Jakob Berzelius was the Swedish chemist who confirmed Proust's Law of Definite Proportions and made an extensive study of atomic weights. In 1813, Berzelius made another great advance for chemistry. He suggested that all chemists use the same set of symbols for the elements and these symbols should be letters. Berzelius said, "It is easier to write an abbreviated word than to draw a figure which, to be legible, must be made of a larger size than our ordinary writing."



Letters were easier to write and set to type than figures. Berzelius made them easier to remember by choosing the first letters of the elements:

carbon,	C
oxygen,	O
hydrogen,	H
phosphorus,	P
nitrogen,	N
sulfur,	S

The names for some elements began with the same letter. In such cases, Berzelius added a second letter that made its symbol different from any others. Carbon, chlorine, calcium and cobalt all begin with *C*. Berzelius left carbon's letter as *C*, and chlorine became *Cl*. Calcium is *Ca*, and cobalt is *Co*. Later, as other elements were discovered and given names that began with *C*, a second letter gave them a distinctive symbol, also. The second letter is not always the second letter in the name for the element. Chlorine's symbol is made of the first and third letters: Chlorine, (Cl).

The first letter is always capitalized and the second letter, if any, is always written in lowercase. All naturally occurring chemical elements have symbols of one or two letters. Only three letters are used when an element is first discovered and has not yet received an official name. Nine elements have names that come from their Latin (Roman) names: sodium (Na from *natrium*), potassium (K from *kalium*), iron (Fe from *ferrum*), copper (Cu from *cuprum*), silver (Ag from *argentium*), tin (Sn from *stannum*), antimony (Sb from *stibium*), gold (Au from *aurum*) and lead (Pb from *plumbum*). In addition, the symbol for tungsten (W from *wolfram*) is taken from a Swedish word meaning *heavy stone.* The symbol for mercury (Hg from *hydrargyrum*) is taken from a Greek word meaning *silver water.*

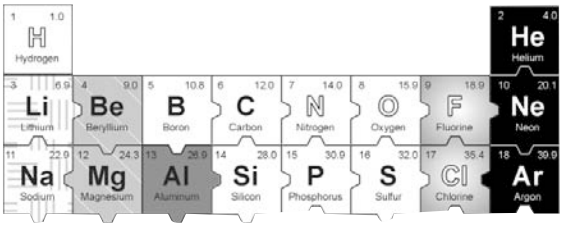
Sitting down and memorizing the name of these elements is not essential. Instead, as you encounter them and work with them, the elements will become familiar to you. You already know the symbol for many elements. Notice the short table that

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provides some of the more common elements. This table is part of a larger table known as the *Periodic Table of the Elements*, which we will study in more detail later. The Periodic Table of the Elements is the puzzle you have been discovering as you study this chapter.

You have worked with many of these symbols. Reading across and then down,

A selection from the Periodic Table of the Elements



these symbols are hydrogen (H), helium (He), lithium (Li), beryllium (Be), boron (B), carbon (C), nitrogen (N), oxygen (O), fluorine (F), neon (Ne), sodium (Na), magnesium (Mg), aluminum (Al), silicon (Si), phosphorus (P), sulfur (S), chlorine (Cl) and argon (Ar). Take a moment to "fix" in your mind the names of the elements with their symbols. In addition to those in the table, you have worked with gold (Au), silver (Ag), copper (Cu), iron (Fe), lead (Pb), tin (Sn) and mercury (Hg).

Berzelius's idea of using capital letters was not immediately accepted. Many scientists had memorized their own symbols for the elements and did not want to change. Even John Dalton chose not to use Berzelius's system. However, as years passed, more and more chemists saw the advantages of using capital letters.

In 1860, about 140 chemists from all over the world gathered in Germany. They held the first international gathering of scientists. At the First International Chemical Congress, chemists solved their disagreements on many subjects, including chemical symbols. The 140 chemists decided to use Berzelius's abbreviations as shorthand symbols for the elements. The original symbols of Berzelius were not only accepted, but they also formed the basis for the naming and writing of newly discovered elements.

The agreements reached at the First International Chemical Congress are considered as important as any discovery. The agreements helped chemists communicate more effectively by using common names and symbols for the elements. The giant puzzle became more easily understood.

CHEMICAL FORMULAS

The formula for a compound shows the type and number of atoms in the compound. The symbols of the elements are used to write the formula. The formula for carbon monoxide is *CO*. This formula shows that carbon monoxide has one carbon atom and one oxygen atom. When only one atom of an element is present in the compound, the formula does not have any subscripts (small numbers). The formula for carbon dioxide is CO_2. The subscript 2 shows that two oxygen atoms are present. The symbol for carbon does not have a subscript. Only one atom of carbon is present, so the subscript "1" is understood, but not written.

VOCABULARY

Chemical equation: letters, numbers and symbols that show the reactants and products of a chemical reaction by using the chemical formula of each compound or element in the reaction

Chemical reaction: a process in which new substances are formed or a chemical change occurs

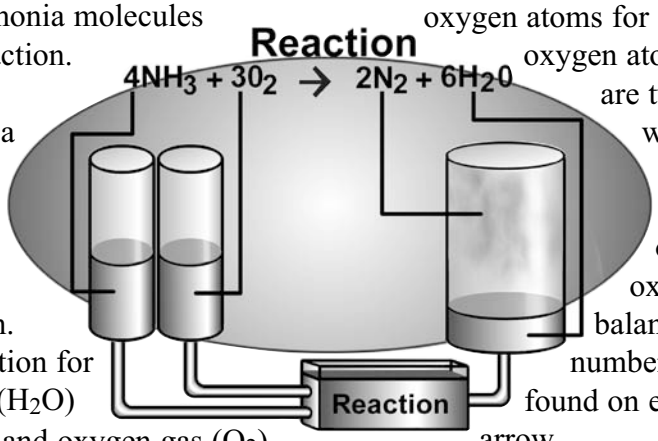
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You have already worked with the chemical formulas for several compounds including water (H_2O); ammonia (NH_3), copper carbonate ($CuCO_3$) and methane (CH_4). These are examples of chemical formulas. Chemical formulas are merely the combined expressions of elements on the Periodic Table of the Elements. They are combined pieces of the puzzle.

CHEMICAL EQUATIONS

A chemical equation is a shorthand way of showing a chemical reaction. The reactants are written on the left side of the equation. The products are written on the right side of the equation. An arrow separates the reactants from the products. The arrow shows the direction of the reaction. Look at the example below of a chemical equation showing the reaction of ammonia (NH_3) with oxygen gas (O_2) to give nitrogen gas (N_2) and water (H_2O). $4NH_3 + 3O_2 \rightarrow 2N_2 + 6H_2O$

The numbers in front of the molecules show how many molecules are present. The "4" shows that four ammonia molecules are taking part in the reaction. Because of the Law of Conservation of Matter, a chemical equation must *balance*. The same number of each type of atom must be found on each side of the equation.



Look at the equation for the production of water (H_2O) from hydrogen gas (H_2) and oxygen gas (O_2).

$H_2 + O_2 \rightarrow H_2O$ (not balanced)

The equation is incorrect because two oxygen atoms are on the left-hand side, but only one oxygen atom on the right-hand side. The solution is to show that the right-hand side has two water molecules. This is written as $2H_2O$. The "2" in front of H_2O means that two water molecules are present and that both contain two hydrogen atoms and one oxygen atom. The "2" in front of the molecular formula applies to both the hydrogen and oxygen.

$H_2 + O_2 \rightarrow 2H_2O$ (still not balanced)

The oxygen atoms now agree because two oxygen atoms are on the left, and two oxygen atoms on the right. However, the hydrogen atoms are out of balance. On the left are two hydrogen atoms in H_2. However, four hydrogen atoms are on the right (2 in each of the two molecules). The solution is to put a "2" in front of the hydrogen gas molecule on the left side of the equation.

$2H_2 + O_2 \rightarrow 2H_2O$ (balanced)

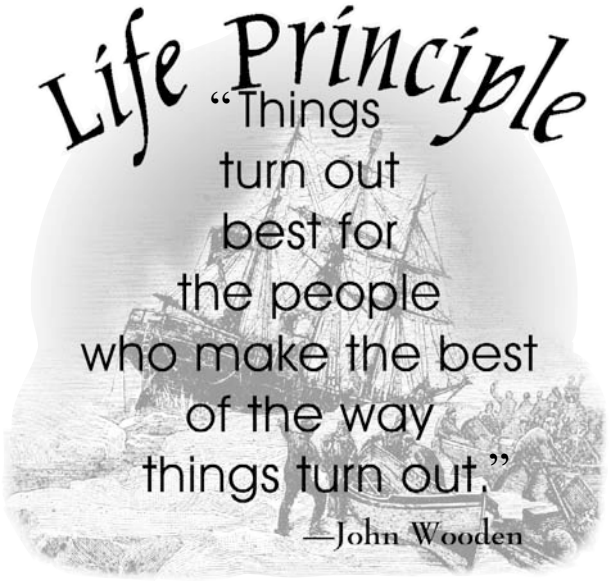
Count the atoms on each side to confirm that this is correct. On the left are two hydrogen gas molecules, each containing two hydrogen atoms for a total of four hydrogen atoms. On the right are two water molecules with each containing two hydrogen atoms for a total of four hydrogen atoms. The hydrogen atoms balance. On the left is one oxygen molecule containing two oxygen atoms for a total of two oxygen atoms. On the right are two water molecules with each containing one oxygen atom for a total of two oxygen atoms. The oxygen atoms balance. The same number of atoms can be found on each side of the arrow.

Look at the previous chemical equation, $4NH_3 + 3O_2 \rightarrow 2N_2 + 6H_2O$. Count the number of nitrogen atoms on the left and right, the number of hydrogen atoms on the left and right, and the number of oxygen atoms on the left and right. They agree because both sides have four nitrogen atoms, 12 hydrogen atoms and six oxygen atoms.

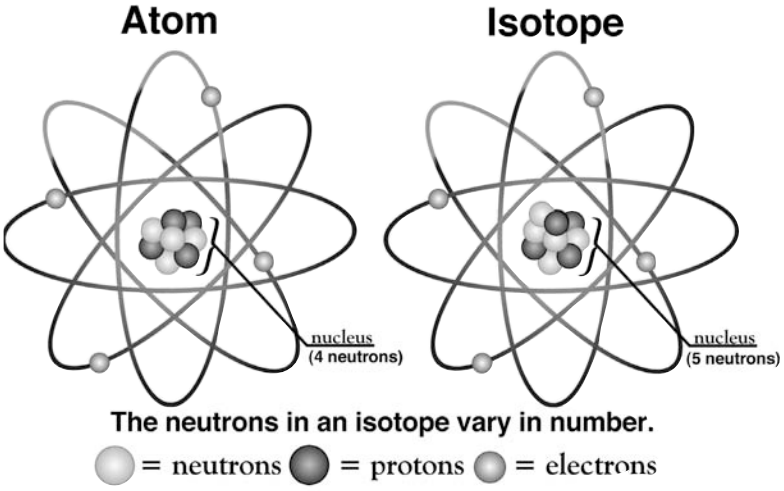
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The purpose here is not to learn how to balance chemical equations. That task takes skill, experience and patience to master. Instead, the purpose is to understand why a chemical equation must be balanced. A chemical equation must balance as a result of the Law of Conservation of Matter. The number of atoms of each reactant must agree in the products.

You have now added more understanding to your chemical puzzle and are ready to learn about atoms themselves.

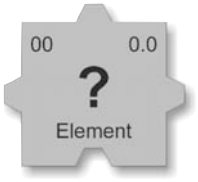


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Integrated Physics & Chemistry



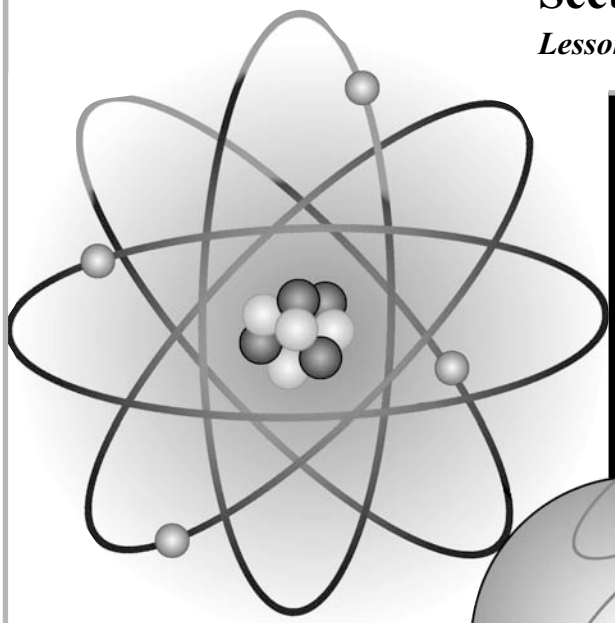
Lesson 13
Elements

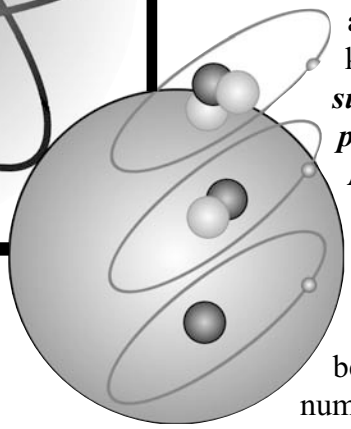
Chapter 1

ATOMIC WEIGHTS

Section 3

Lessons 11-15





Chemists who worked with the atoms of some elements became convinced that atoms of a given element are not all identical. Elements do vary in atomic weight, which is contrary to what John Dalton said. The scientists gave the name ***isotope*** to the atoms of the same element that varied in atomic weight. Chemists now know that atoms are made of ***subatomic*** particles, such as ***protons***, ***neutrons*** and ***electrons***. Atoms of the same element may vary in the number of neutrons which causes atomic weight to vary. Isotopes of the same element have various weights because they contain different numbers of neutrons.

A proton has about the same mass as a hydrogen atom. A neutron has about the same mass as a proton. The ***nucleus*** contains protons and neutrons. Almost all of the weight of an atom is found in the nucleus.

Electrons are found outside the nucleus of the atoms and have a negative charge. Electrons are light in weight compared to protons and neutrons. About 1,847 electrons weigh as much as a single proton.

An element is known by the number of protons it possesses. Hydrogen has but one proton. Helium has two protons. Lithium (Li) a light metal, has three protons. Carbon has six protons,

VOCABULARY

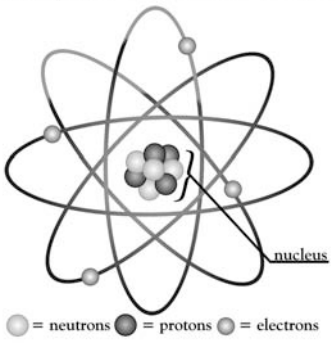
Isotope: atoms of the same element that have different atomic weights; Isotopes differ in having different numbers of neutrons

Subatomic: smaller than an atom

Proton: a subatomic particle with a positive charge; Atoms of the same element always have the same number of protons

Neutron: a subatomic particle with a mass almost equal to the mass of a proton; has no electric charge

Components of an Atom



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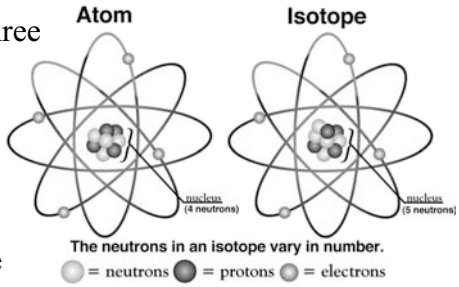
and oxygen has eight. Chemists say that the atomic number of hydrogen is 1. The atomic number of helium is 2; the atomic number of lithium is 3. Carbon is 6, and Oxygen has an atomic number of 8. The ***atomic number*** is the number of protons in the nucleus of the atom. Look at the periodic table. You can identify the number of protons in an atom by looking at the order of the elements. The 1st element has one proton, and the 83rd element has 83 protons. The puzzle is simplified by placing the elements on the periodic table in order according to the number of protons. All atoms of the same element have the same number of protons and the same atomic number. The atomic number for gold is 79. Should a gold atom gain another proton it would no longer be gold. It would be mercury, with an atomic number of 80. How chemists learned about protons, neutrons and electrons and how they assigned atomic numbers will be described later. Remember that elements have atomic numbers based on the number of protons in their nucleus. Each element has a unique atomic number.

The weight of an atom is the combined weight of the protons, neutrons and electrons. Electrons are so light that they can usually be ignored. The atomic weight, then, is the sum of the number of protons and neutrons in the element.

The most common isotope of hydrogen has no neutrons. Its atomic weight is essentially equal to the weight of the proton, 1. The electron is so light in weight that its weight does not matter. Sometimes a hydrogen atom has one neutron, which gives it a weight of 2, (one proton and one neutron). These hydrogen atoms with different weights are isotopes. Atoms of the same element are isotopes if the number of neutrons varies. If an atom of gold gained a neutron, the atom would still be gold but a different isotope of gold.

Almost all of the elements have isotopes. This causes the atomic weights not to be whole numbers. If all hydrogen atoms had but one proton and no neutrons, the atomic weight for hydrogen would be 1.0000. A few hydrogen atoms have neutrons, which causes the atomic weight on average to be a little higher, (1.0080).

Not all isotopes are equally abundant. The relative numbers of each isotope must be taken into account when figuring the average atomic weight. Hydrogen has three isotopes. The regular hydrogen atom has a single proton and a weight of 1. The atom with one proton and one neutron has a weight of 2, and a very rare isotope of hydrogen with one proton and two neutrons has a weight of 3. Of 10,000 atoms of hydrogen, the vast majority (9,851) is the regular hydrogen isotope. Only 149 are hydrogen isotopes with the weight of 2. The hydrogen isotope with the weight of 3 is so rare it is not likely to be present. The average mass of hydrogen is

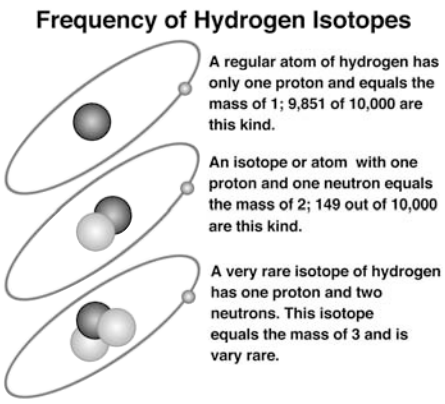


VOCABULARY

Electron: a subatomic particle with a negative electric charge whose weight is far less than the weight of a proton or neutron
Nucleus: the dense central core of an atom consists of protons and neutrons; Almost all of the weight of an atom is found in the nucleus.
Atomic number: equals the number of protons in the nucleus of an atom of an element
Amu: abbreviation for atomic mass unit

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closer to 1 than to 2, because the vast majority of the atoms have a mass of 1.



The element, chlorine, has an atomic number of 17. It is found in nature as two isotopes. About three-fourths of all the chlorine atoms have 18 neutrons which gives an atomic weight of 35 (17 protons + 18 neutrons = 35 atomic weight). About one-fourth of all the chlorine atoms have 20 neutrons for an atomic weight of 37 (17 protons + 20 neutrons = 37 atomic weight). When the relative abundance of chlorine atoms is taken into account, the average atomic weight for chlorine is 35.45. It is closer to 35 than 37 because the isotope with an atomic weight of 35 is more common.

Perhaps you find this confusing, but imagine how the chemists of the 1850s must have felt. They knew nothing of protons, neutrons and electrons. Yet, the chemists managed to assign atomic numbers to the elements. They calculated very accurate tables of atomic weights.

We have been using weight and mass as if they were the same things. Many scientists, especially physicists, reject such practice. They point out that weight can change depending on where an object is, and mass always remains the same. However, many chemists use either term but you do not have to worry about this detail right now.

In 1960, chemists agreed to measure atomic weight in terms of *carbon 12*. This is an isotope of carbon with 6 protons and 6 neutrons. One *atomic mass unit* is defined as 1/12 the mass of carbon 12. The symbol for atomic mass unit is ***amu***. One amu is about the same as the mass of a single hydrogen atom. Often chemists ignore the unit, amu, and write only the number. Instead of the atomic weight of oxygen being written as 15.999 amu, it is merely written as 15.999.

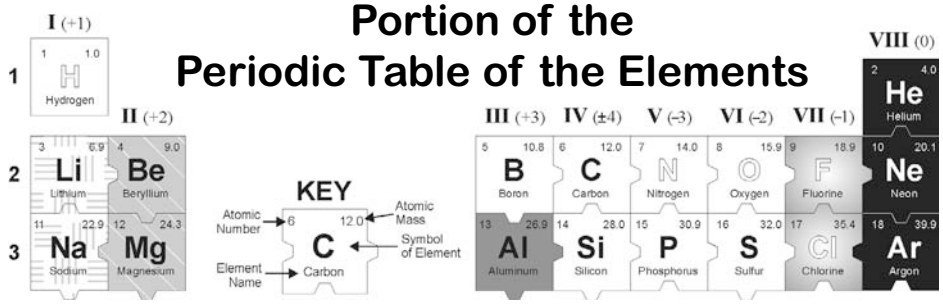
MOLECULAR WEIGHT

The *molecular weight* of a compound is the total weight of the atoms that compose a molecule of the substance. Below is a portion of the Periodic Table of the Elements. It shows the atomic number, element name, element symbol and atomic weight.

The number in the top left corner of each element square is the atomic number. The atomic number tells how many protons are in the nucleus of the atom. The first element in the table is hydrogen, with one proton. The last element in the table is argon, with 18 protons. The atomic numbers go smoothly from 1 to 18 in this table.

The number in the top right corner of the element square is the *atomic weight*. The atomic weight gives the average weight of the atoms of that particular element. The first element in the table is hydrogen, with an atomic weight of 1.0080. The last element in this partial table is argon, with an atomic weight of 39.948.

Portion of the Periodic Table of the Elements



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The atomic number of phosphorus is 15, and atomic weight of phosphorus is 30.974. Phosphorus is found on the bottom row of the chart.

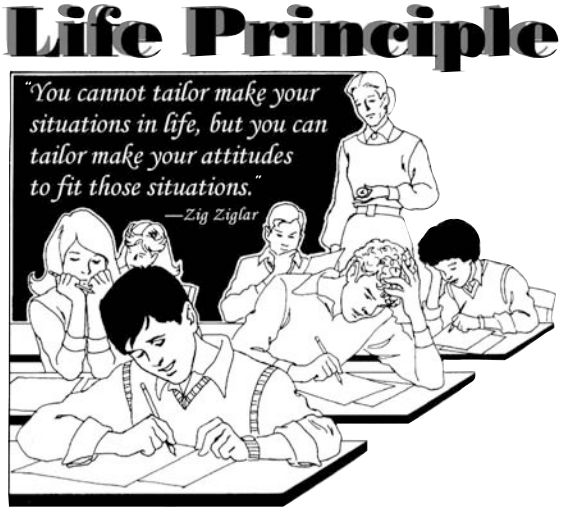
The Periodic Table of the Elements shows why the word *isotope* was chosen. The word is made of two Greek words, *iso-* which means *same* and *-tope*, which means *place.* Isotopes of the same element occupy the same place on the periodic table. Atomic weight is used in calculating the molecular weight of a compound. The individual weights of all the atoms in the compound are added together. Calculating atomic weight involves math of the simplest sort. If you can add and multiply small numbers, you can calculate molecular weight.

Example:
The molecular weight of methane (CH_4)
Solution:
Carbon = 12.001 * 1 atom = 12.001
Hydrogen = 1.008 * 4 atoms = 4.032
Molecular weight of methane = 16.033

Example:
The molecular weight of carbon dioxide (CO_2)
Solution:
Carbon: 12.001 * 1 atom = 12.001
Oxygen: 15.999 * 2 atoms = 31.998
Molecular weight of carbon dioxide = 43.999

The molecular weight of hydrogen cyanide (HCN) is determined by the atomic weight of hydrogen, carbon and nitrogen, which can be found in the partial periodic table. Add the atomic weights of each atom: 1.0080 + 12.011 + 14.001 = 27.020. The atomic weight of the hydrogen cyanide molecule is 27.020.

Wow! This part of your study of the big puzzle (Periodic Table of the Elements) is a bit challenging. Do not try to memorize all this information. Just complete the activities carefully. You are beginning to grasp the main concepts of chemistry and physics.



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Integrated Physics & Chemistry

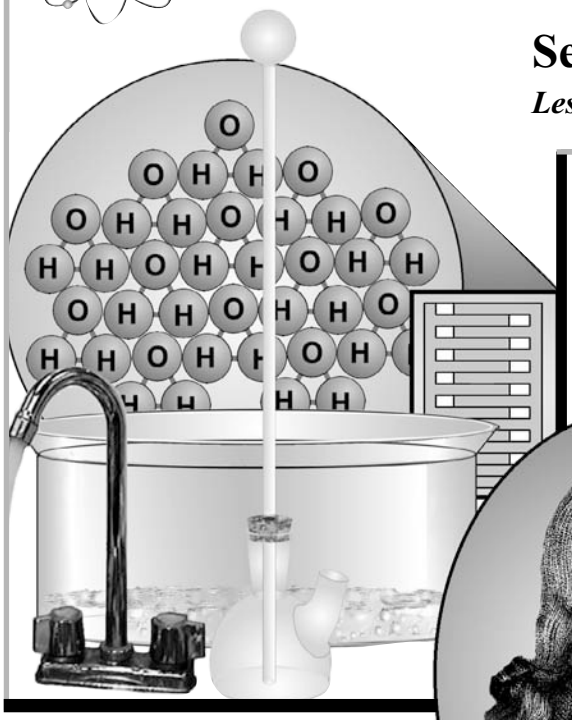
Lesson 14
Energy

Chapter 1

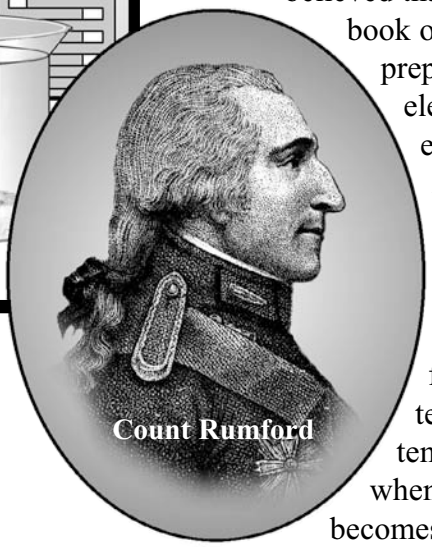
HEAT

Section 3

Lessons 11-15



One of the most difficult problems scientists faced in the 18th century was understanding the basic cause of ***heat***. Even the great Antoine Lavoisier became confused. He and most other chemists of the 1700s incorrectly believed that heat was a substance. In his book on chemistry, Antoine Lavoisier prepared a list of the known elements. He included heat as an element and called it *caloric*. According to Lavoisier, heat was a substance that flowed, as does water. Water flows from a high point to a lower point. In the same way, heat flowed from a warmer temperature to a cooler temperature. A body becomes hot when caloric flows into it. A body becomes cool when caloric flows out of it. Caloric even explained why most bodies expand as they are heated. The caloric flows into the body, making it take up more room. Evidence against caloric came from Benjamin Thompson, better known as Count Rumford. Benjamin Thompson was born in Boston, Massachusetts, in 1753. When the American War for Independence started in 1776, Thompson sided with the British and went to England. Being on the losing side, Thompson could not come back to the United States. Thompson traveled to Bavaria where he supervised the production of cannons.


Count Rumford

The factory drilled barrels from blocks of brass. The friction of the boring caused the metal to become intensely hot. Workers continually had to pour water over the machinery to cool it. Apparently, the boring freed caloric from the metal. The

VOCABULARY

Heat: energy due to the kinetic energy of the atoms and molecules of a substance; heat of the body is equal to the total kinetic energy of its atoms and molecules
Kinetic: having to do with motion
Kinetic energy: energy produced by motion
Temperature: a measure of how hot or cold a body is; temperature of a substance equals the average kinetic energy of its atoms or molecules

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heating continued as long as the boring did. Thompson's calculations showed that if the caloric were restored to the metal, the brass would have melted. More heat was being taken from the metal than it could possibly have contained. If heat were an element, its weight and volume would not have changed.

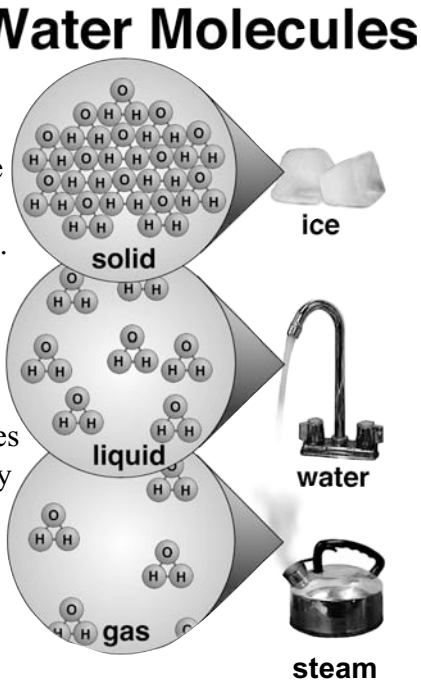
An endless supply of caloric came from the friction of the drill against the brass cannon. Lavoisier had stated that matter could neither be created nor destroyed. If caloric were a material substance (an element), it was being created by the drilling process where none had previously existed. Count Rumford concluded that heat was a form of energy created by physical motion and friction.

In 1799, Count Rumford moved back to England where he assembled more evidence against caloric by weighing a block of ice on a sensitive balance. He heated the ice until it melted. Rumford then weighed the water, and he detected no difference. If caloric were a substance, it would be nearly weightless. Count Rumford summarized his findings in an article, "Inquiry Concerning the Source of Heat Which Is Excited by Friction," which he presented to the Royal Society. Rumford declared that heat is a form of motion rather than a material substance.

Scientists did not immediately accept Count Rumford's ***Kinetic*** Theory of Heat. They asked, "If heat is motion, what moves? As the energy of the rotating drill entered the brass block, what moved in the block? As the ice changed to water, what moved in the water to produce heat?"

Before Count Rumford died, John Dalton publicized his Atomic Theory of Matter. Recall that the Atomic Theory of Matter states that matter is made of small particles. A strong connection exists between Dalton's Theory and Rumford's Kinetic Theory of Heat. The small particles, atoms and molecules, possess the heat energy of a substance. As a substance grows hotter, the atoms and molecules move faster.

The combination of the Atomic Theory of Matter with the Kinetic Theory of Heat made clear that heat is the motion of atoms and molecules. In a solid, molecules seem to be fixed in place. Heat actually causes them to vibrate. If the heat becomes too great, the molecules separate, and the solid melts. In a liquid, the molecules can move about more freely. They move over, around and among one another. Molecules in gases have the greatest freedom of all. They charge about as independent bodies. Their motion changes only when they strike the walls of the container or each other.



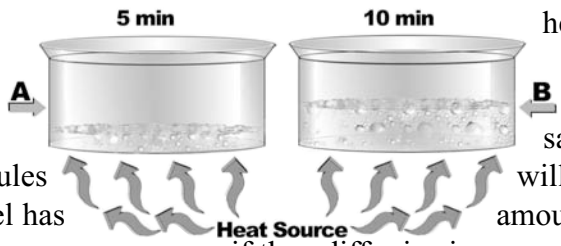
VOCABULARY

Gram: a unit of mass in the International System (metric system)
Calorie: a quantity of heat required to raise the temperature of 1 gram of water by 1 degree Celsius
Kilogram: a unit of mass equal to 1,000 grams
Kilocalorie: a quantity of heat equal to 1,000 calories

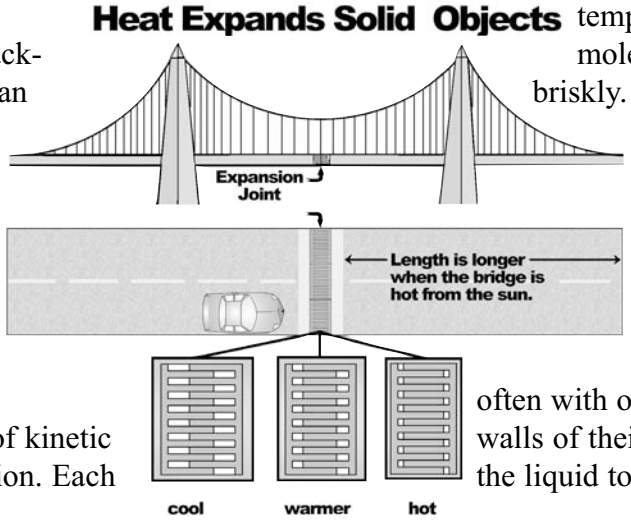
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As you drive a nail into a hard board, the hammer has ***kinetic energy***, or energy of motion. Once it strikes the nail, the kinetic energy appears to vanish. The energy is not lost. If the nail is particularly difficult to drive, it will become warm to the touch. The energy of motion of the hammer is transferred into motion of the atoms that make up the nail. As heat is added to a substance, the molecules move more rapidly. The faster they move, the greater the heat. Heat is the total kinetic energy of all the atoms or molecules of a substance.

Scientists describe different properties of matter. ***Temperature*** is the average kinetic energy of the molecules of a substance. In other words, heat describes the total amount of motion; temperature describes the average amount of motion of the molecules. Suppose a cup of water and a barrel of water are at the same temperature. The molecules of water in each container are traveling at the same speed. However, the barrel has more heat energy because it contains more molecules of water than the cup. The barrel has greater mass.



In most solids, the atoms are locked into position. They are not free to move around. The atoms express their heat energy as rapid vibrations. *Vibrations* are rapid back-and-forth motions. As an object is heated, the vibrations become more vigorous. This increased vibration, not caloric, is what causes solid objects to expand when heated.



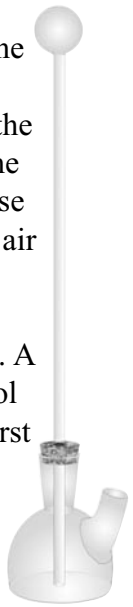
Heat is a type of kinetic energy created by motion. Each molecule of a compound has kinetic energy because it is in constant motion. The heat of a body is the total kinetic energy of all the molecules. Temperature is a measure of the average kinetic energy of a typical molecule in the compound.

Heat and temperature are not the same. You could prove this with a simple experiment by placing a cupful of water in a pan on the stove. On the burner beside the pan, place an identical pan containing four cups of water. Heat them at the same setting until they boil. The single cup of water will begin boiling first. Less heat energy is used to heat the smaller amount of water. The change in temperature, is the same. Both start at room temperature, and both are raised to the boiling point of water, 100°C. Both have the same temperature, but the pan with four cups of water has four times as much potential heat energy. Two samples of the same compound at the same temperature will have different amounts of heat energy, if they differ in size.

Chemists do not measure the speed of individual molecules. They measure the collective effect of the molecules. As the temperature increases, the molecules move more briskly. In a solid, molecules vibrate quickly which causes the solid to expand slightly. In a liquid, molecules move around, over and among one another. They collide more often with one another and with the walls of their container. This causes the liquid to expand.

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Gas also expands in a predictable way as the temperature increases. Galileo, the Italian physicist and astronomer, made the first *thermometer*. It used the air that was trapped in a tube with a bulb at the end that led to a tube of water. As air expanded with a rise in temperature, the water was forced to a higher level. The device was clumsy and inexact because it was open to the air, and changes in air pressure caused the readings to be inaccurate.

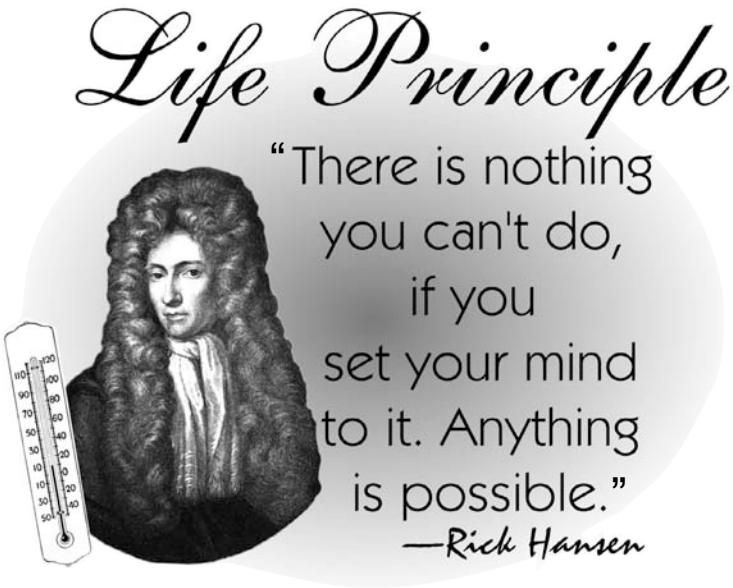

Galileo's Thermometer

Air was replaced with alcohol. A red dye was added to make the alcohol more visible. Robert Boyle was the first scientist to use the thermometer for a practical purpose. He consulted a thermometer placed outside his home to decide how heavy a garment to wear. Early scientists used a variety of temperature scales, making comparisons of data difficult.

Once an accurate thermometer became available, chemists could then define heat. You remember the word "caloric" in Antoine Lavoisier's heat substance discovery. Although Lavoisier's idea was shown to be in error, the word "caloric" gives the name to the standard unit of heat. *Caloric* means *heat.* The quantity of heat required to raise the temperature of 1 ***gram*** of water by 1°C is called the ***calorie***. The abbreviation is cal.

If a ***kilogram*** (1,000 grams) of water is heated so that its temperature changes by 1°C, then the water has gained 1°C * 1,000 grams = 1,000 calories. This quantity of heat is called a ***kilocalorie***. The prefix *kilo-* means *1,000.*

The final lesson in this chapter provides understanding about the two types of thermometers used by scientists and homemakers.



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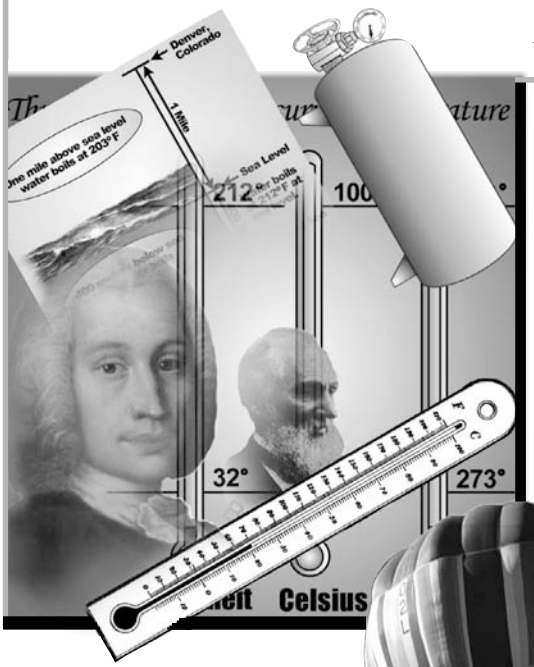
Chapter 1

Lesson 15
Energy

MEASURING TEMPERATURE

Section 3

Lessons 11-15

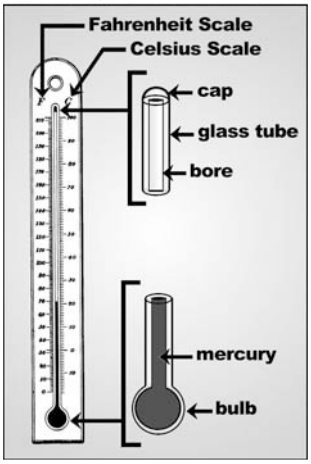


In 1714, Gabriel Daniel Fahrenheit invented both an accurate thermometer and a standard temperature scale. He was born in Germany in 1686 but moved to the Netherlands in 1717. Fahrenheit made weather instruments, which included an improved thermometer.

Daniel Fahrenheit was the first scientist to use mercury in a thermometer. The expansion and contraction of mercury due to changes in temperature is known as *uniform*. The expansion is constant for the same increase in temperature whether at the cool end of the scale or at the warm end of the scale. A one-degree rise in temperature causes the mercury column to rise by the same amount—one degree.

Look at the mercury thermometer to understand how it works. It is a long glass tube with a fine bore down the center and a small bulb at the bottom. This bulb is the ***reservoir*** or storage place. During manufacture, it is filled with heated mercury and the upper end is sealed. The mercury cools and contracts as it collects in the reservoir bulb at the bottom. A vacuum is in the glass tube above the reservoir.

Mercury Thermometer



As the temperature rises, the mercury expands up the tube. The hotter the mercury becomes, the higher it rises. The scale along the side of the tube helps a person to determine if the temperature has risen or fallen.

Daniel Fahrenheit did not want

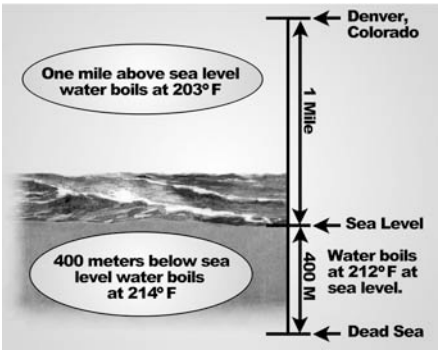
VOCABULARY

Reservoir: a container for the storage of a fluid
Elevation: height above or below sea level
Centigrade: the original name for the Celsius scale

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to measure temperatures that were below zero. He decided to set his zero, or starting point, as low as possible so he would not have negative degrees. Fahrenheit mixed salt and ice to get as low a temperature as possible. He called that 0 degrees on his temperature scale. He questioned as to what the upper end of the scale should be. Fahrenheit knew that a healthy human has a set body temperature. He set the temperature of the human body at 96 on his scale.

In 1724, Fahrenheit reported his new device. Although he was living in the Netherlands, his invention earned him a position in the Royal Society. Great Britain and most of the English speaking countries adopted Daniel Fahrenheit's temperature scale.



Using his improved thermometer, Fahrenheit made a useful discovery. Each liquid has a set boiling temperature. As the liquid is heated, its temperature rises until it reaches the boiling point. Liquid does not get any hotter after the boiling point. When more heat is added, the liquid boils more briskly, but it does not get any hotter than the boiling point until all of the liquid boils away. Various liquids have set boiling points. Fahrenheit adjusted the scale on his thermometer, so that water boils at exactly 212°F. The adjustment caused normal human body temperature to be read as 98.6°F.

Daniel Fahrenheit cooled a container of water and discovered that liquids also have set freezing points. On Fahrenheit's scale, water froze at 32°F. When the temperature dropped to 32°F, ice began to form. The temperature fell no lower than 32°F until all of the water changed into ice.

An exception to this law of fixed freezing and boiling points of liquids occurs when the atmospheric pressure is greater or lower than normal. Higher pressure causes a higher boiling point. Reduced pressure causes a lower boiling point. Air pressure affects the freezing temperature but not as much as the boiling temperature. Atmospheric pressure can change because of weather conditions and the distances above or below sea level.

Changes in ***elevation*** causes changes in the boiling point of water. The elevation is the height above or below sea level. The city of Denver, Colorado, is a mile (5,280 feet) above sea level. The boiling point of water there is 203°F, not 212°F as it is at sea level. The Dead Sea is located in the Middle East between Israel and Jordan. The Dead Sea is 400 meters below sea level. Along its shores, the increased air pressure causes water to boil at 214°F.

Chemists who measure the temperatures of boiling liquids take into account the changes caused by variations in air pressure. They adjust their readings to reflect *standard air pressure*, the average pressure of the atmosphere at sea level.

Anders Celsius, Swedish astronomer, (1701-1744), devised the centigrade temperature scale. He used Daniel Fahrenheit's discovery that the boiling and freezing points of water are fixed. Those set temperatures are used to calibrate a thermometer. To *calibrate* a thermometer means to place the measurement markings on the side of the glass accurately. Anders Celsius put a mercury thermometer in a mixture of water and ice. Celsius marked the level of the


Anders Celsius

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mercury on the thermometer and called it 0°C. Then, he held the thermometer in the steam above boiling water and marked this reading on the thermometer and called it 100°C. He divided the space between the two marks into 100 equal divisions.

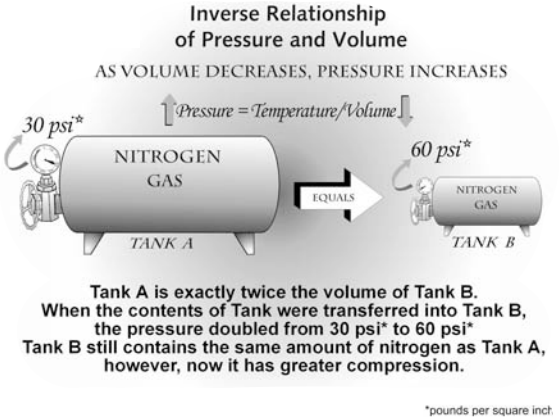
Anders Celsius first described the scale in 1742. He called it a ***centigrade*** scale. The word *centigrade* comes from *centi-,* meaning *1/100* and *grade* meaning *steps*. In 1948, scientists honored Celsius by renaming the centigrade scale to the Celsius scale.

Absolute Zero

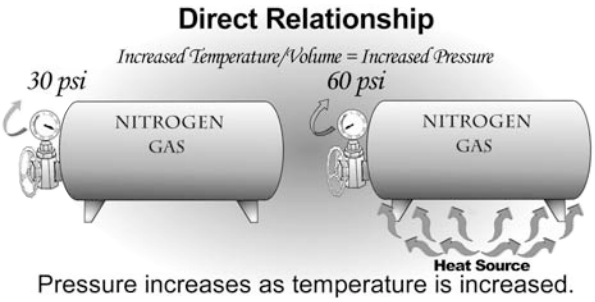
Jacques Charles was a French chemist who lived in the 1700s, about the same time as Antoine Lavoisier and Count Rumford. Charles became interested in balloon flight. He believed that hydrogen, rather than hot air, could be used to give lift to balloons. Charles constructed the first hydrogen-filled balloons. He made several balloon flights for scientific purposes, including measurement of air pressure and temperature at various altitudes. He described vividly the wonders of the Earth from high altitudes. Because of Charles' enthusiasm, ballooning became a popular sport.



Jacques Charles is best known for his study of gases. He repeated Robert Boyle's experiments involving pressure on a specific volume of gas. Robert Boyle found that the relationship between pressure and volume is an *inverse relationship*. *Boyle's Law* states that with temperature held constant, pressure and volume are inversely proportional. Doubling the pressure squeezes a gas into one-half its original space. The law applied equally well to any gas. Hydrogen, oxygen and nitrogen follow Boyle's Law, as well as mixtures of gases in the atmosphere.



Robert Boyle kept the temperature constant during experiments. Boyle knew that heating a gas causes it to expand. The relationship between temperature and the volume of a gas is a *direct relationship*. A gas expands as it is heated and contracts as it cools.



Pressure increases as temperature is increased.

Jacques Charles found the exact factor by which a gas expands when heated. The volume increases by 1/273 of its volume at 0° Celsius. When the gas cools by 1° Celsius, the volume decreases by 1/273 of its volume at 0° Celsius. Like Boyle's Law, this factor found by Charles applies equally to any gas; oxygen, nitrogen, hydrogen and to mixtures of gases in the atmosphere.

Jacques Charles' discovery brought up an interesting question: what would happen to a gas that is chilled to -273°C? According to Charles' Law, the volume of the chilled gas would shrink to zero. Charles wondered if a gas would disappear entirely. Research verified that before a gas reached -273°C, the gas condensed to a liquid. Boyle's Law and Charles' Law apply only to gases, not to liquids.

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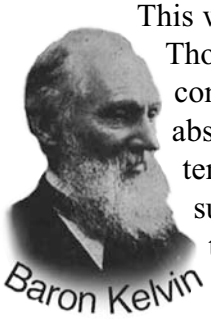
Helium remains a gas after all other gases become liquids; therefore, helium changes into a liquid at -268.8°C only 4.2 degrees before -273°C is reached.

As a substance cools, its molecules move more slowly. As temperature declines, the average velocity of the gas molecules decreases. The total heat energy becomes less and less under cool conditions.

In the 1850s, William Thomson investigated heat. Thomson was only 11 years old when he entered the University of Glasgow. He proceeded to study science at Cambridge and traveled to Paris for advanced study. William Thomson became a college professor by the time he was 22 years old and taught science at the University of Glasgow, Scotland.

When William Thomson began to study heat, he knew that when a substance cools, its atoms move more slowly. He asked himself, "How cold must a substance be for its atoms to stop moving?" He imagined a temperature so cold that all motion would cease. This would be the coldest temperature possible. A body at this temperature would not be able to be cooled any further because its atoms would have lost all motion. Without its atoms in motion, kinetic energy would be zero. It would have zero heat energy.

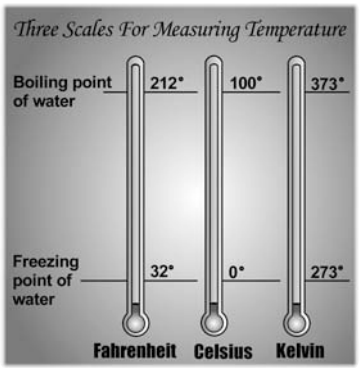
William Thomson called this temperature *absolute zero*. He recalled the discovery made by Jacques Charles. When Jacques Charles cooled any gas by one degree Celsius, the gas lost a volume equal to 1/273 of its volume at zero degrees Celsius.



This was the clue that William Thomson needed. He was convinced that -273°C was absolute zero; the coldest temperature possible. He suggested that scientists use a temperature scale that begins at absolute zero. Consequently, the absolute temperature scale begins with zero, which is absolute zero degrees.

In later life, William Thomson received the title of Baron Kelvin, and he became known by that name. Scientists named the absolute temperature scale in Kelvin's honor. It became known as the Kelvin scale. The freezing point of water is 273 degrees Kelvin (273°K).

The Celsius degree and the Kelvin degree are the same size. If a body becomes warmer by 1°C, it has also become warmer by 1°K. The difference is that the Kelvin temperature scale starts at absolute zero, while the Celsius temperature scale starts at the freezing point of water. The Kelvin scale has no negative readings. Every temperature is positive. Converting from Celsius to Kelvin is especially easy. Add 273 degrees to the Celsius temperature to get Kelvin temperature. Example: Room temperature is about 18°C. Look at this on the Kelvin scale.



Solution: 18°+ 273°= 291°K

"The heights by
great men reached
and kept were not attained
by sudden flight, but they, while
their companions slept,
were toiling upward in the night."
—Henry
Wadsworth
Longfellow



Life Principle

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