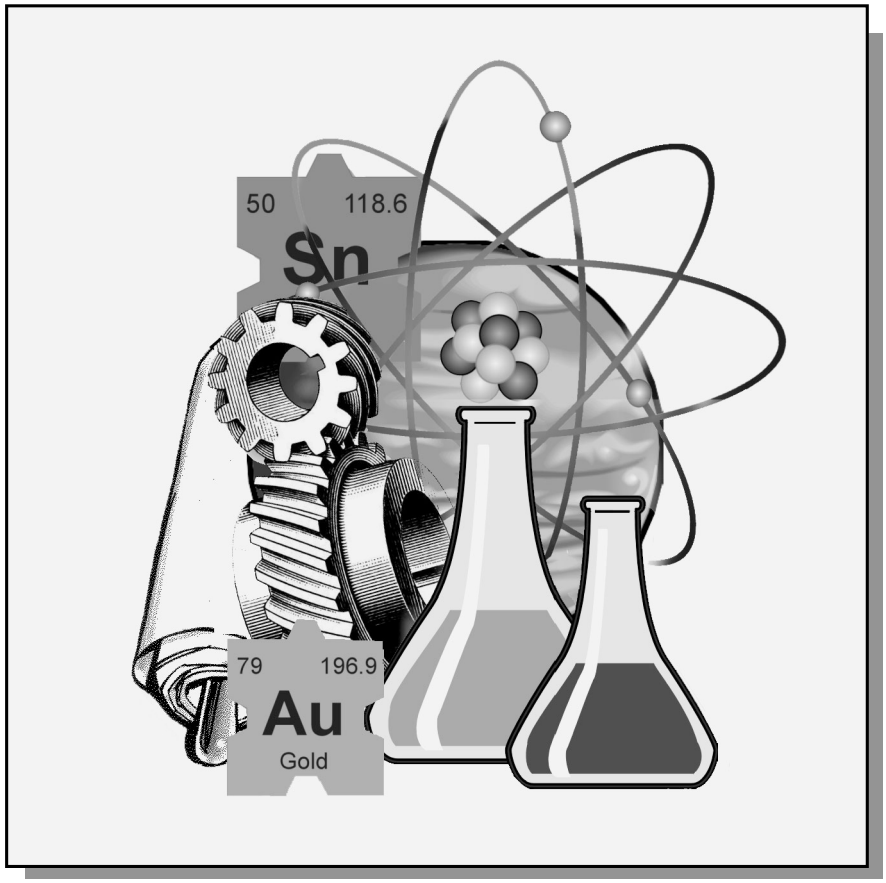
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This chapter requires a companion activity book in which students respond to questions on text content. Answers are found in the *Teacher's Resource Kit*.



Chapter 5

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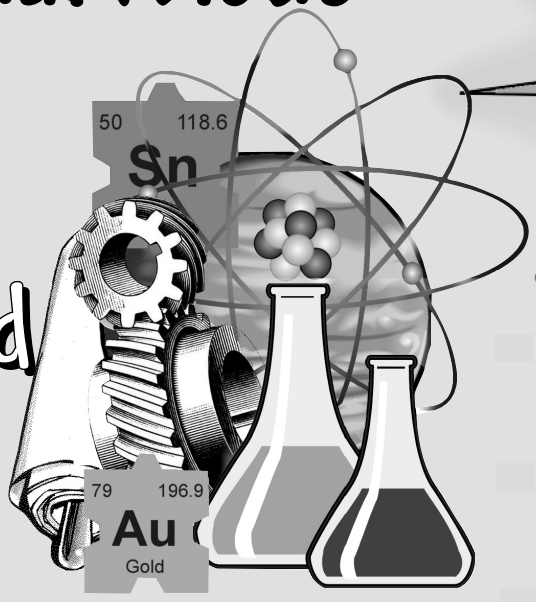
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"The study of science is the chronicle of man's quest to discover the essence of life and how the marvelous laws of creation are applied to human needs."



—Ronald Johnson, Ph.D.

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Integrated Physics & Chemistry

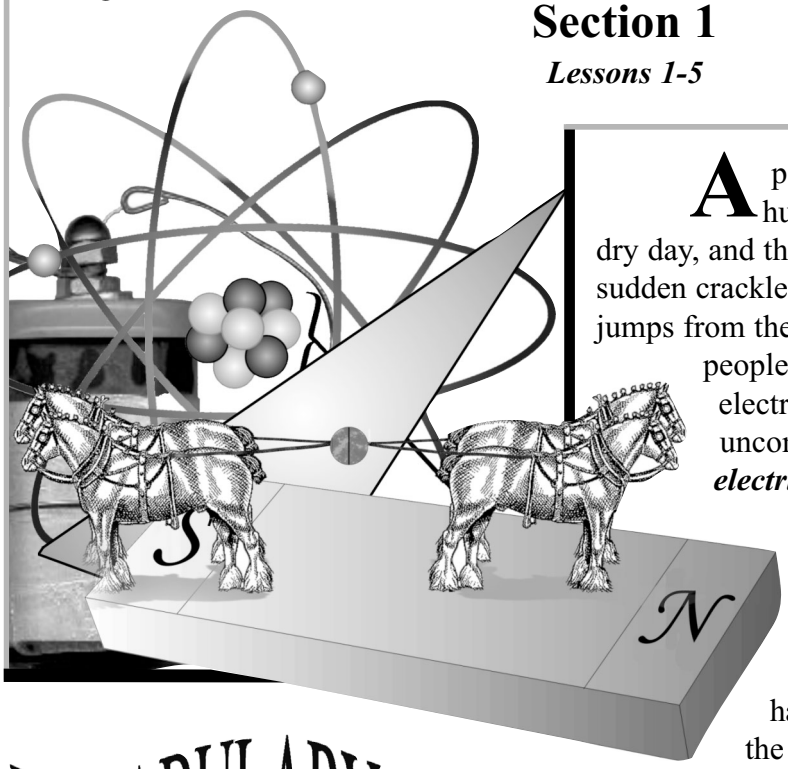
Lesson 1
Energy

Chapter 5

STATIC ELECTRICITY

Section 1

Lessons 1-5



A person walks across carpet when the humidity is low, such as on a cold, dry day, and then touches a metal doorknob. A sudden crackle is heard, and an electric charge jumps from the hand to the doorknob. For some people who are especially sensitive to electricity, the shock can be an uncomfortable experience. ***Static electricity*** also causes clothes to cling. Rubbing a plastic comb briskly through clean, dry hair gives the comb a static charge. The comb will attract small pieces of paper. The hair through which the comb has been brushed may stand away from the scalp. All of these observations are examples of static electricity.

The first scientist to report about static electricity lived more than 600 years before Christ. Thales of Miletus, a Greek scientist, noticed that when he stroked amber with wool, the amber would pick up feathers or straw. *Amber* is a hard fossil resin that forms naturally from tree sap. This mineral has a beautiful yellow color. Amber is sometimes used for jewelry. The words *electricity* and *electron* are from *elektron*, the Greek word for *amber*.

In the 1500s, William Gilbert, an English physician, showed that substances other than amber could have an electric charge. He found that glass, hard rubber, quartz crystals and gemstones, such as diamond and sapphire, would take a charge when rubbed with wool, fur or silk.

Water is attracted to a charged body. This can be demonstrated by running a thin stream of water from a faucet. When a charged object, such as a comb, is brought nearby, the stream of water is pulled toward the comb.

VOCABULARY

Static electricity: electricity at rest, a charge caused by an excess or deficit of electrons
North pole: the pole of a magnet that points north, also known as a north seeking pole
South pole: the pole of a magnet that points south, also known as a south seeking pole
Proton: a subatomic particle found in the nucleus of an atom, has a mass 1,836 times that of an electron, carries a positive electrical charge that is equal in magnitude but opposite in sign to that of an electron

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William Gilbert also experimented with magnets and showed that a magnet has two poles. One is a ***north pole*** or *north-seeking pole* and the other is a ***south pole*** or *south-seeking pole*. Unlike magnetic poles attract one another, but like magnetic poles repel one another. A north pole repels a north pole, and a south pole repels a south pole. However, if the north pole of one magnet is brought close to the south pole of the other magnet, they will attract one another.



Some scientists believed static electricity came in two different types, but almost two hundred years passed from the time of Gilbert before a scientist responded to the idea of two types of electricity. Charles Du Fay, a French physicist, was given the post of Superintendent of Gardens for the King of France. Du Fay's duties allowed time to experiment. Charles Du Fay found that an electric charge could be detected by bringing a charged body near a piece of cork suspended from a thin thread. If the body had a static charge, it would attract the cork. If the cork touched the charged body, the cork took on the same charge as the body it touched. Charles Du Fay stroked a glass rod with silk and touched it to a cork ball. He stroked a rubber rod with wool and touched it to another cork ball. The two balls attracted one another. Du Fay took two balls that he charged with a glass rod and noticed that they repelled one another. The two balls that he charged with a rubber rod also repelled one another. Charles Du Fay interpreted his experiments to mean that electricity existed in two forms. He created one type by rubbing a resin rod with wool. He made the other type by rubbing glass with silk.

Other scientists disagreed that electricity had two forms. Many scientists visualized electricity as a single fluid that flowed because of the friction of the rubbing. If two rods had an excess of the fluid, they resisted coming together as would two rods that were missing some of the fluid. Only when one rod had too much and the other had too little would they attract one another to equalize the share of electric fluid.

Benjamin Franklin agreed with the view that only one electric fluid existed. An electrically charged body had either too much of the fluid or too little of the fluid. He used the plus (**+**) and minus (**–**) signs to show the difference. In the Middle Ages, merchants weighed the produce they sold. If a crate was underweight, it was marked it with a bar (–) to show it was below the right amount. Then, more produce was added to bring the package up to weight, and a vertical mark was drawn through the bar (+) to show its weight had been corrected. Benjamin Franklin introduced the + and – to show an excess or scarcity of electric fluid. He identified the glass rod rubbed with silk as having a positive (+) or excess amount of the fluid. He identified the rubber rod rubbed with wool as having a negative (–) amount of electric fluid.

VOCABULARY

Electron: a subatomic particle that orbits outside the nucleus of an atom and can move more freely than the proton, carries a negative electrical charge that is equal in magnitude but opposite in sign to that of a proton

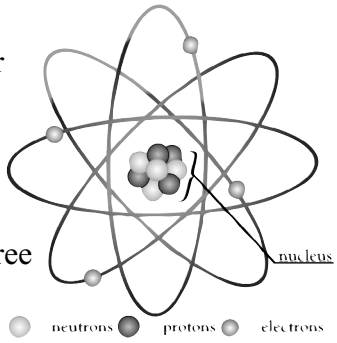
Law of Conservation of Electric Charge: electric charge cannot be created nor destroyed but can be moved from one place to another

Three Laws of Static Electricity: unlike charges attract, like charges repel, a charged object attracts an uncharged object

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Neither Benjamin Franklin nor Charles Du Fay could see electricity. As later experiments showed, an electric charge has two forms. One type is carried by the ***proton***, which has a positive charge. The other type is carried by the ***electron***, which has a negative charge. Yet, Benjamin Franklin was not entirely wrong, either. Although matter contains both protons and electrons, in most instances, only the electrons move. The protons are in the center of the atom in the nucleus and are not free to move from one place to another. Electrons, on the other hand, are in a cloud around the nucleus of the atom but are lightly held by some atoms. Electrons are free to wander away. The friction of rubbing can pull them away from the atom.

Components of an Atom



An object that has more protons than electrons has a positive charge. An object that has more electrons than protons has a negative charge. Electric charge can neither be created nor destroyed. It is merely transferred from one object to another. This is the ***Law of Conservation of Electric Charge***. Almost all descriptions of electrical activities through solid objects are stated in terms of the movement of electrons. A glass rod has a positive charge because it has lost electrons. Left behind is an excess of protons that carry a positive charge. A rubber rod has a negative charge because it has gained electrons. The extra electrons give it a negative charge. During chemical reactions, electrons move from one atom to another, or they are shared between two atoms. Protons, on the other hand, do not move and are not shared. The electron has the primary role in chemical reactions.

Benjamin Franklin continued to experiment with electricity and did such a thorough job that he is considered the Father of Modern Electrical Experimentation. He summarized what had gone before him and stated the ***Three Laws of Static Electricity***.

First, Benjamin Franklin observed that bodies charged with static electricity attract uncharged bodies. If a charged glass rod is brought near small pieces of paper, the paper is attracted to the glass rod. The paper is also attracted to a charged rubber rod. A body with a positive electric charge or one with a negative electric charge attracts paper equally well.

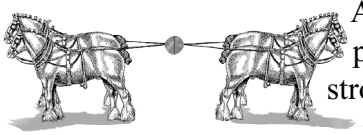
Secondly, like electric charges repel one another. Benjamin Franklin tested this statement by hanging a charged rubber rod from a string. He brought the rod close to another rubber rod that had been charged in exactly the same way. The two rubber rods each had a negative charge, and they repelled one another. He repeated the experiment with two glass rods. They both had positive charges, and they, too, repelled one another.

Thirdly, unlike charges attract one another. Benjamin Franklin brought a charged glass rod near a charged rubber rod hanging from a string. The two rods attracted one another. Benjamin Franklin continued to experiment with electricity. One of the tools to aid him was the electrostatic generator.

In 1672, Otto von Guericke of Germany built an electro-static generator, the first machine that made static electricity easily. The generator had a sulfur ball turned by a crank. A brush barely touched the ball and drew away the static electricity. Later, other devices were made that used glass cylinders. All of the machines generated electricity by friction caused when two dissimilar substances were rubbed together.

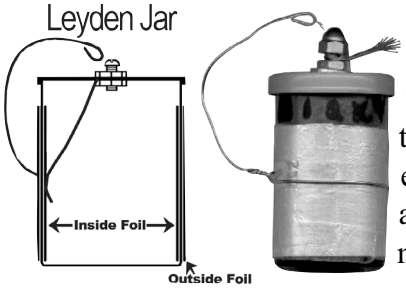
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Twenty years earlier von Guericke had built an air pump which removed air from a sphere made of two parts.



Atmospheric pressure was so strong two teams of powerful horses could not pull the hemispheres apart. When Von Guericke opened a valve and let air back into the sphere, the two halves fell apart. This showed that air pressure, rather than a vacuum, kept the two hemispheres together.

Although scientists could make static electricity, they could not store it. About 50 years later, scientists invented the Leyden jar, which could store a static charge for a short period of time. The Leyden jar was a glass jar with metal foil on the inside and outside. The glass of the jar separated the foils. The lid was an insulating cork stopper.



In the center of the cork stopper was a metal knob on a rod. The rod was inserted into the jar and connected to the inner foil. Scientists touched the knob of the Leyden jar to a source of static electricity. The electricity entered the jar where it could be contained for a short period of time. Scientists know now that one layer of the foil took a positive charge, and the other layer of foil took a negative charge. The two layers of foil were positioned so closely together that protons attracted the electrons through the thin layer of glass. The electrons did not go away because they were held in place by electrical attraction. The Leyden jar allowed electrical experimenters to capture and transport static electricity. Today, a similar device for the temporary storage of an electric charge is a capacitor, about which you will learn more in the next topic.

LIFE PRINCIPLE



"Lost time is never found again."

— Benjamin Franklin

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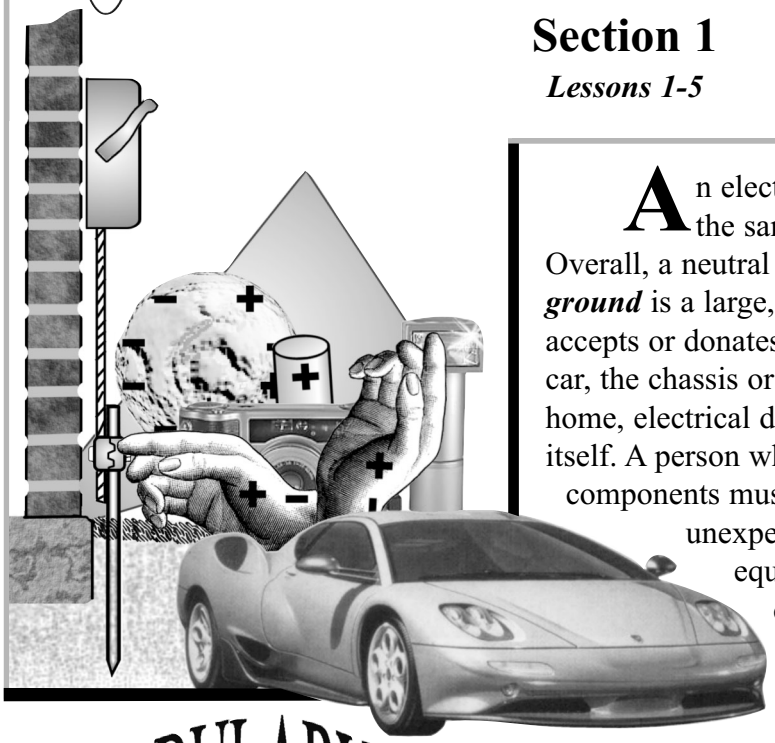
Chapter 5

Lesson 2
Energy

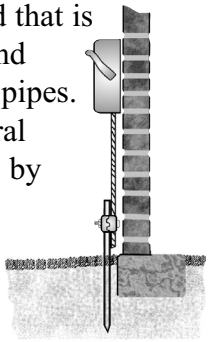
ELECTRIC CHARGE

Section 1

Lessons 1-5



An electrically ***neutral*** object is one that has the same number of protons as neutrons. Overall, a neutral object has no net electric charge. A ***ground*** is a large, neutral conducting body that freely accepts or donates electrons. For the sound system in a car, the chassis or frame of the car is the ground. In the home, electrical devices are grounded to the earth itself. A person who works on sensitive electrical components must be grounded to avoid an unexpected static discharge damaging the equipment. The person wears a conducting wristband that is connected to a ground such as metal water pipes. An electrically neutral object can be given a static charge by rubbing, by contact or by ***induction***.



Amber rubbed by fur causes a negative charge in the amber. Benjamin Franklin also examined the fur and showed that it had the opposite charge, a positive charge. Friction caused the fur to give up electrons, which were transferred to the amber. Electric charge was not created. Instead, electrons left the fur and entered the amber. One had an excess of electrons, and the other had a deficit of electrons. When the friction of one object against another causes objects to be charged, one will have a positive charge, and the other will have a negative charge.

Electrons repel one another; so if a path is open for their travel, they will leave a piece of charged amber and enter another body. When a piece of charged amber touches an electrically neutral cork ball, some of the electrons leave the amber and enter the cork. The cork that receives the electrons has more electrons than protons. The cork is charged by

VOCABULARY

Neutral: a body with a net electrical charge of zero, the total positive charge equals the total negative charge
Ground: a neutral body of sufficient size that it can accept or donate electrons without taking on a charge itself; more technically, a ground has zero electric potential
Induction: charging an object by momentarily grounding it while a charged body is nearby, the object will gain a charge opposite to that of the body in its vicinity

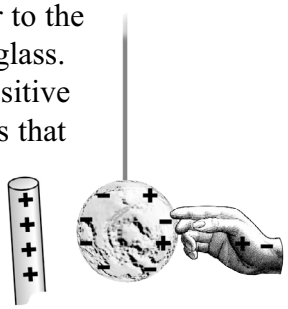
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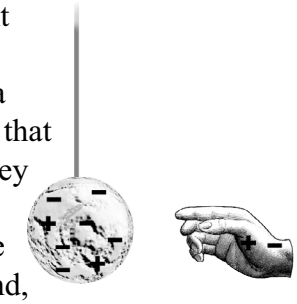
contact. An object charged by contact has the same charge as the object that touched it.

Induction is a two-step process by which a neutral body becomes charged. First, suppose a glass rod with a positive charge is brought close but does not touch a large ball of cork hanging from a string. The positive charge of the glass rod attracts negative electrons in the cork because unlike charges attract. The electrons move to be as near the glass rod as possible. Although the cork is still neutral, the charge is not evenly distributed. One side has a negative charge from the electrons that moved to be closer to the positive charge on the glass. The other side has a positive charge from the protons that were left behind.



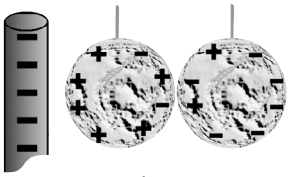
While the glass rod is near, but not touching, the cork ball is grounded. A person can touch the far side of the cork ball for a moment. In this case, the static charge is so slight that the human body is large enough to act as a ground. Protons are on that side of the cork, and they attract electrons from the person's hands. The person removes his hand, and the glass rod is moved away. The cork ball is no longer neutral because it has gained electrons. The cork ball has been given a negative charge by induction. An object charged by induction has the opposite charge as the object brought near to it. Suppose two cork balls are hanging by threads and just touching one another. A rubber rod with a negative charge is brought near the far side of one of the cork balls. The rod repels electrons so that they move around to the other side of the cork ball. The cork ball on the far side accepts these electrons from the first ball because the balls are in contact. If you were to separate the two balls without moving the rubber rod, the ball nearest the rubber rod would have an overall positive charge, while the ball farthest from the rubber rod would have an overall negative charge. The two balls started out neutral, but each ended with a charge. The ball nearest the rubber rod ended up with a positive charge.













Charging by induction explains why a charged rubber comb will pick up small pieces of uncharged paper that are lying on a table. The comb has a negative charge. The paper is neutral. Bringing the comb near the paper repels electrons in the paper. They escape into the table. Protons cannot move, so they stay in the paper. The paper becomes positively charged. The negative charges in the comb attract the positive charges in the paper. The paper jumps toward the comb.

VOCABULARY

Charged body: an object that has too many electrons (-) or not enough electrons (+)
Capacitor: a device to temporarily accumulate and store an electric charge

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The paper was charged by induction. Sometimes a person will see a small piece of paper fly away as soon as it touches a comb. That is because the paper receives electrons from the comb. Now the paper and comb both have an excess of electrons. Both have a negative charge. Like charges repel, so the paper flies away. The above discussion and examples show that a body can be charged in three ways: friction, direct contact and induction.

A static charge is on the surface of a ***charged body***. If a charged body is spherical, the charge is evenly distributed all over the surface of the body. For instance, if a cork ball has a negative charge, the electrons distribute themselves so they are equally spaced all over the ball. William Gilbert confirmed this when he invented a little device to detect static charge. He had been working with a compass which used a metal needle to align itself with the earth's magnetic field. William Gilbert decided to build a compass from a wooden needle. The wooden needle would respond to a static charge. By moving the needle all around a spherical object that has a charge, Gilbert found that the charge is the same all over the surface.

Suppose the object is egg shaped and more pointed on one end than the other. If a body is smooth and well rounded in all areas except for a sharp spike, then the charge becomes more concentrated at the end that is pointed more sharply.

Suppose a person walks across a room and picks up a charge from the carpet. Just before the person touches a doorknob, electricity jumps between the finger and the metal knob. Assume that the person has a negative charge. As his hand nears the door, the electrons in his hand repel the electrons in the metal of the doorknob. Like charges repel. The electrons in the metal move away from the surface of the doorknob. The protons cannot move, so they stay in place. This gives the doorknob a positive charge. The person's hand and the doorknob now have opposite charges. Unlike charges attract. Although air is an electrical insulator, it is not a perfect one. When the gap becomes small enough, the excess electrons in the person's fingers jump across the gap to join the protons on the doorknob.



A ***capacitor*** is a device to store a static charge temporarily. A *Leyden jar* was the first type of capacitor. Capacitors have two conductors, with a nonconductor separating them. The nonconductor can be any electrical insulating material such as air, glass or ceramic tile. The conductors are usually of metal such as aluminum or copper. Suppose two sheets of metal are separated by a pane of glass. If one of the metal plates is given a negative charge and the other plate a positive charge, the charges will stay in place as they attract one another across the insulating layer of glass. If a wire is touched from one metal plate to the other, the capacitor will discharge. Electrons will flow from one metal plate to the other one to equalize the charge. A capacitor can be made smaller by using strips of metal foil with a flexible strip of nonconducting material between them. The three strips can be rolled to make a small cylinder. The capacitor is small enough to be installed in a small place on electric circuits.



Leyden jar

Capacitors are found in a variety of everyday electrical devices including stereo sound systems, televisions and flashes for cameras. A camera with a built-in flash has a capacitor to provide a high voltage surge of

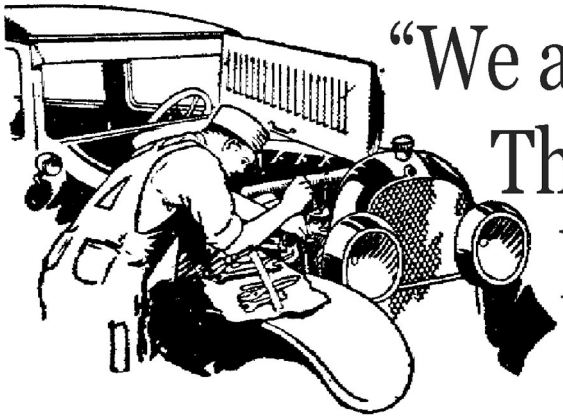
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electricity to the flash unit. The battery that comes with the camera is too small and too slow to provide the necessary electricity at the moment it is needed. Instead, the capacitor is charged over several seconds by the battery. When the picture is taken, the capacitor gives up the charge in a sudden surge to fire the flash. A capacitor can accumulate a charge, sometimes to dangerously high levels. Like the capacitor in the flash camera, a Leyden jar accepts and accumulates an electric charge. The Leyden jar continues to accept a charge as long as it is in contact with the source of electricity. The static charge grows increasingly powerful.

In 1745, Dutch professor, Peter van Musschenbroek, taught at the University of Leyden in the Netherlands. During this time he built the first Leyden jar. After charging the Leyden jar, Musschenbroek held it in one hand and touched the knob with his other hand. He expected to receive a tiny spark. Instead, Peter van Musschenbroek got a jolt that nearly knocked him unconscious. He felt as if someone had hit him with a club. Musschenbroek spent two days recovering in bed. Working with more care, he built other jars which became common in the laboratories of electrical experimenters.

Benjamin Franklin had a Leyden jar sent to him by a friend. With it, Benjamin Franklin demonstrated the power of electricity by preparing his Christmas turkey. The turkey died instantly with a powerful shock from a Leyden jar. Then, with an electrical spark Benjamin Franklin set afire the wood to roast the turkey.

LIFE PRINCIPLE



"We all have ability. The difference is how we use it."

—Stevie Wonder

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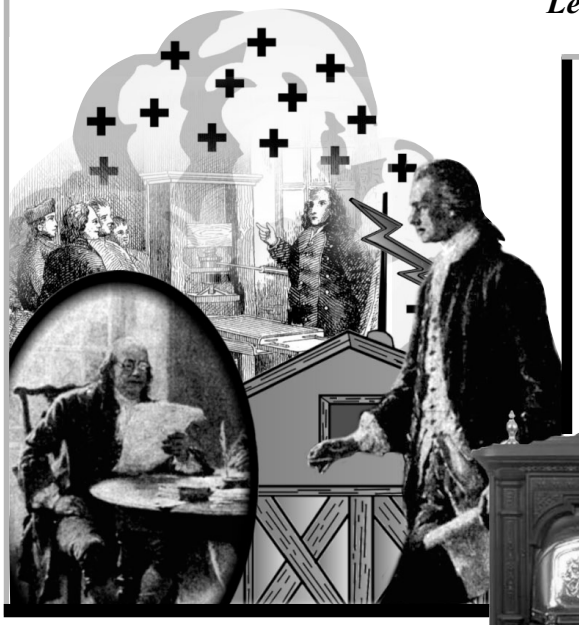
Lesson 3
Energy

Chapter 5

LIGHTNING — A KEY EXPERIMENT

Section 1

Lessons 1-5





VOCABULARY

Lightning arresters: pointed conductors along the roof line designed to drain away a static charge between earth and sky before the charge becomes so great as to cause a lightning strike, also known as lightning rods

Coulomb's Law of Electrostatic Force: the force between two charged bodies is directly proportional to the product of their charge and inversely proportional to the square of the distance separating them

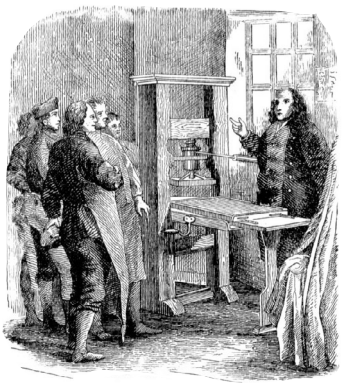
Benjamin Franklin was born in 1706 when the Colonies still belonged to Britain. Franklin was the best known scientist in the American Colonies, although the rest of the world did not know much about him. His notoriety changed with his most spectacular experiment. He compared the tiny spark of static electricity with the mighty bolt of lightning.

Benjamin Franklin captured lightning in a Leyden jar. Once he had a sample of lightning, Franklin carried it back to the laboratory to use as an experiment. To capture electricity, Benjamin Franklin had to do an extremely dangerous experiment. In 1752, he flew a kite during a lightning storm. Franklin realized the danger and took precautions. He stood under a porch with a metal roof and held the string of the kite by a dry silk ribbon. The lightning struck a metal rod he had put on the kite. Lightning came down the wet string to a key. Franklin directed the charged key to the knob of a Leyden jar sitting on a table. The jar captured some of the lightning. Franklin used the captured lightning to conduct experiments with electricity. Benjamin Franklin proved that lightning and electricity have the same properties. This difficult and exceedingly dangerous kite experiment settled the matter. Lightning is a powerful discharge of static electricity. The experiment is dangerous. The next two scientists who tried to repeat Franklin's kite experiment died.

Until then, the American Colonies were considered backward and certainly not the place where first-rate scientific

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achievements could be done. Benjamin Franklin's experiment caused Europeans to want to know more about Franklin, the colonist. Benjamin Franklin was the youngest son of thirteen children. His family was Puritan. He received only two years of formal education. As a teenager, he worked in a print shop owned by his brother. In 1723, Benjamin Franklin left Boston and journeyed to Philadelphia. He arrived penniless and unknown. A storeowner hired Franklin to go to London to buy goods for resale in America. Only after Ben Franklin crossed the Atlantic Ocean did he learn that the storeowner was dishonest. Franklin was stranded in London without a return fare; so, he decided to study printing while searching for a way back home. To earn extra money, Franklin taught people how to swim, a skill very few people possessed at that time.



BENJAMIN FRANKLIN'S PRESS

A friend offered to introduce Franklin to Isaac Newton, the most famous scientist in the world. Isaac Newton was 83 years old. Before the meeting could take place, Benjamin Franklin unexpectedly found passage back to America. Once he returned to Philadelphia, Benjamin Franklin opened his own print shop. It prospered, and he began to print *Poor Richard's Almanac*. Benjamin Franklin had an unusual ability to express difficult ideas in short, meaningful sayings. He wrote, "A penny saved is a penny earned," as well as, "A man is no taller than when he is on his knees [to pray]." One of his most quoted sayings is, "Early to bed, early to rise, makes a man healthy, wealthy and wise." Franklin lived by that standard. He arose at four o'clock to begin the day with prayer.

In 1748, Benjamin Franklin decided to retire from business and devote himself to other matters. He wanted to perfect some of his inventions, such as a better stove. Most homes had fireplaces for both cooking and heating. Yet, a fireplace was particularly poor at heating. Most of the heat, about four-fifths, escaped up the chimney. The fire for heating needed to be more in the middle of the room. Franklin made a cast iron stove and connected it to the chimney by stovepipe. Benjamin Franklin did not patent the invention so people would be able to use it more quickly. Although he called it the Philadelphia stove, it became known as the Franklin stove. As the years passed, Franklin's stove became a common fixture in both the Colonies and in Europe.



By 1750, Benjamin Franklin had become well known as a civic leader, writer and inventor. He turned to electricity next. Once he proved that lightning and static electricity were the same, he put that knowledge to use. Benjamin Franklin made the first invention to apply the laws of science to lightning. He invented ***lightning arresters***, also known as lightning rods.

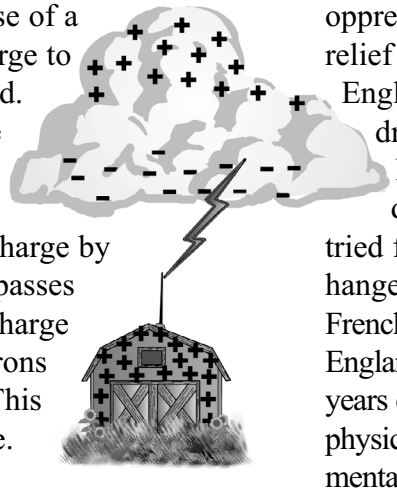
Many buildings in Franklin's time were made of wood. Lightning strikes often set fire to these buildings. Most cities had inadequate means of fighting fires. For that reason, lightning was a frightening force of nature. For farmers with barns filled with hay, grain and farm animals, a lightning strike could destroy the farmers' livelihood.

Benjamin Franklin knew that a conductor would carry away static electricity. He also learned that static electricity will discharge to a pointed surface more readily

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than to a rounded surface. Benjamin Franklin put this knowledge to work to make lightning rods. The purpose of his lightning rods was to prevent lightning strikes. He suggested that pointed metal rods connected to the ground by conductors be placed along roof ridges and chimneys to reduce the possibility of lightning strikes. Benjamin Franklin believed the rods would drain away the static electricity in the sky before static electricity built to a dangerous level. However, even if the building were struck by lightning, the wire would usually conduct the lightning harmlessly to the ground. The lightning rods worked and became popular.

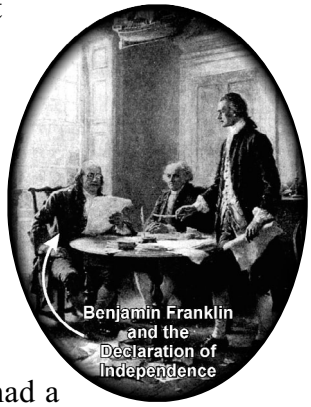
Although the cause of lightning is not fully understood today, scientists believe that air currents in the cloud cause a negative charge to form at the base of a cloud and a positive charge to form at the top of a cloud. A tall object, such as the roof of a barn, a tree or a clock tower on a city hall is given a positive charge by induction. As the cloud passes overhead, the negative charge in the cloud repels electrons at the top of the tower. This gives it a positive charge. The electrons giving the cloud a negative charge are attracted to the positive charge in the tall building. If the charge becomes great enough, electrons will zap through the air as a lightning bolt. Lightning rods act to equalize the charge harmlessly. The pointed rods are pathways to equalize the charge between ground and clouds before the static charge becomes so great as to cause a bolt of lightning. Lightning rods were put on buildings around the world. Today, many buildings are equipped with rods. They are even used to prevent lightning from destroying ancient trees.



Rather than boasting about his invention of lightning rods, Benjamin Franklin wrote in the 1753 edition of *Poor Richard's Almanac*, "It has pleased God in His goodness to mankind, at length to discover in them the means of securing their habitation and other buildings from mischief by thunder and lightning."

After these scientific achievements, Benjamin Franklin began the next stage of his life. Voters elected him to the Pennsylvania Assembly. As years passed, he gained the reputation as an honest and fair politician. He became a champion of self-government. He believed ordinary people should have a role in the political affairs that governed their lives.

British rule was growing more oppressive in the Colonies. Clearly, the only relief would be through independence from England. In 1776, Benjamin Franklin helped draft the Declaration of Independence. He signed the document. It was a dangerous step because he could be tried for treason and put in prison or even hanged. Franklin sailed to France to enlist French support against England. He was 80 years old but still physically and mentally active. He preferred peace to conflict. He represented the new United States at secret peace talks. Benjamin Franklin had a major role in developing the ideas on which the United States government is based. When the war ended, he helped get the Constitution enacted and George Washington elected as the first president. Religion played a daily role in Franklin's life. He also worked for better treatment of



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American Indians and was an active member of a group that opposed slavery.

As an inventor, he designed many practical things including bifocal reading glasses, the Franklin stove, the rocking chair and lightning rods. As a scientist he proposed the use of the terms positive (+) and negative (–) to identify electrical charges, stated the Three Laws of Static Electricity and proved that lightning is a form of electricity.

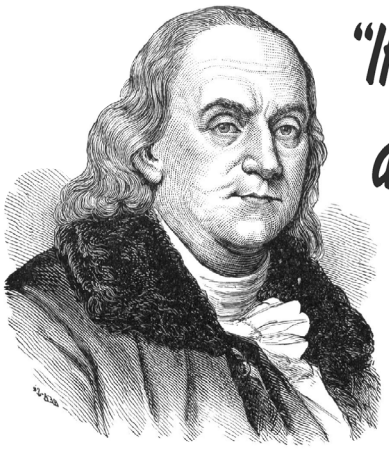
Research in static electricity continued. In 1776, the year the American Colonies declared their independence, Charles Coulomb, a French engineer, moved to Paris. He had given up a military life because of poor health. He began a series of delicate experiments to measure the attraction between two charged bodies.

Coulomb proved that the force of attraction, or repulsion if two bodies have like charges, follows the Inverse Square Law. If two charged bodies are moved so they are twice as far away, the force between them is only one-fourth as great. If they are separated three times as far, the force between them is only one-ninth as great.

Thus, Charles Coulomb developed the ***Law of Electrostatic Force*** and proved it to be accurate. The law has the same form as Isaac Newton's Law of Gravity but with charge replacing mass. Coulomb's Law of Electrostatic Force states that "the force between two charged bodies is directly proportional to the product of their charge and inversely proportional to the square of the distance separating them."

You will learn more about Coulomb's law. The law is not as complex as you might assume, and has application to many things which you might take for granted.

LIFE PRINCIPLE



"If you would not be forgotten,
as soon as you are gone,
either write things worth reading,
or do things worth the writing."

—Benjamin Franklin

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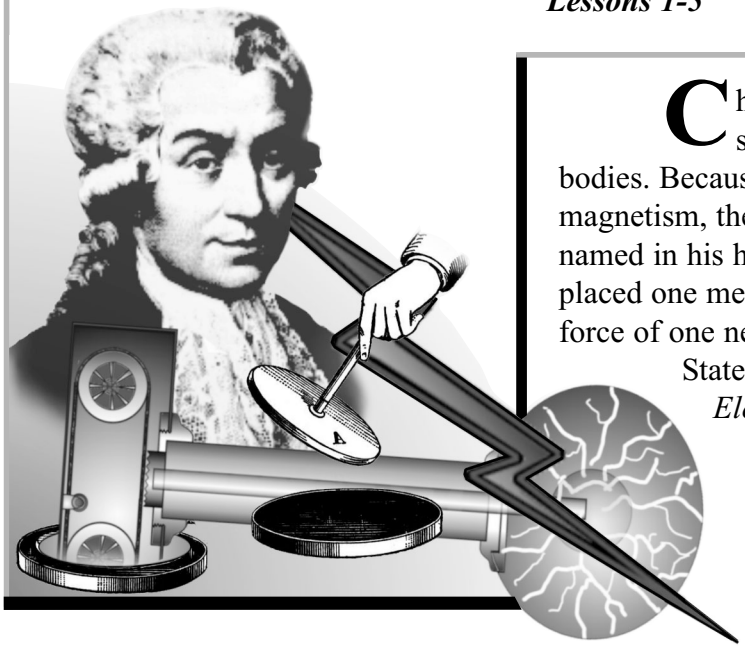
Integrated Physics & Chemistry

Lesson 4
Energy

Chapter 5

ELECTRIC POTENTIAL

Section 1
Lessons 1-5



Charles Coulomb developed the law that specifies the force between two charged bodies. Because of his work in electricity and magnetism, the unit of charge in the metric system is named in his honor. A *coulomb, coul*, of charge placed one meter from a like charge will produce a force of one newton.

Stated in symbols, *Coulomb's Law of Electrostatic Force* is:

$$F = k \frac{Q_1 * Q_2}{r^2}$$

with *F* the force, *k* the proportional constant, Q_1 the first charge, Q_2 the second charge and *r* the distance between them. This equation shows two main ideas. The first idea is that the bigger the charges, the bigger the force of attraction between the charges (directly proportional). The second idea is that the further away the charges are from each other, the less the force of attraction (inversely proportional). In this equation, *k* has a value of $8.99 * 10^9$. This is a large number, 8,990,000,000 (almost nine billion.)

Coulomb's Law of Electrostatic Force and Newton's Law of Gravity make possible comparison of the two forces. Two electrons that are one meter apart will be attracted by their gravity but repelled because they have the same charge. The electrons will move either toward or away from each other. When scientists do the calculation, they find that the electric forces are vastly more powerful than the gravitational attraction. The electrostatic forces are about $4.15 * 10^{42}$ times stronger. This number is almost unimaginably huge. The repulsion from the two electrons' electrostatic forces will be vastly greater than the attraction of their gravitational forces.

VOCABULARY

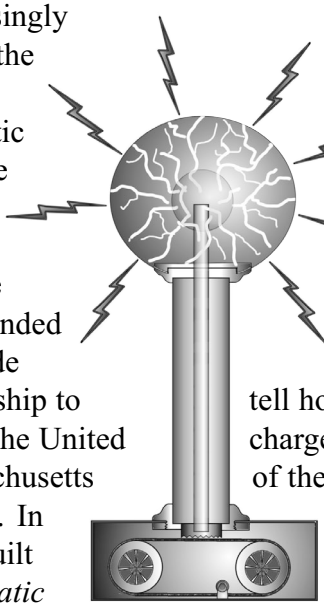
Electric potential (difference): work per unit charge required to move an electric charge from one point to another in an electric field, in symbols V = E/Q, in metric units volt = joule/coulomb.
Volt: metric unit for electric potential, equal to one joule per coulomb
Voltage: electric potential difference, also known as electromotive force, measured in volts
Static electricity: electric charge at rest

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The electrons will fly away from each other. Both electrical and magnetic forces are far stronger than gravitational attraction. Gravitational force is by far the weakest force known in nature.

During the 1700s, the only way to generate electricity was with a friction generator. As scientists continued to experiment, they made increasingly powerful static generators. In the 1900s, Robert Van de Graaff built a high-voltage electrostatic generator. As a student, Van de Graaff studied at the University of Alabama to be a mechanical engineer. Later, he traveled to Paris where he attended lectures by Marie Curie. Van de Graaff also received a scholarship to Oxford. When he returned to the United States, he taught at the Massachusetts Institute of Technology (MIT). In 1931, Robert Van de Graaff built the first *high-voltage electrostatic generator*. It made use of two facts about static electricity. First, sharply pointed conductors readily receive and release electrons. Secondly, no matter how charged the surface of a hollow metal sphere becomes, the inside of the sphere has no electric field. It is electrically neutral.

At the bottom of the Van de Graaff generator is a solid glass tube that rubs against a moving rubber belt. The glass is grounded and can supply a continuous source of electrons. A hand crank or an electric motor turns the rubber belt. The belt picks up electrons from the glass and carries them to a large, hollow spherical shell. A conductor with metal teeth is positioned nearly touching the rubber belt. The teeth accept the electrons from the belt and carry them to the inside of the sphere. Because the inside of a sphere is neutral, the electrons jump from the belt to the hollow sphere. They then migrate to the outer surface. The Van de Graaff machine generates high electric potential.



Electric potential difference is the difference in electric potential energy between two points around a charged body. You can also think of electric potential as a way to tell how great the shock would be from a charged body. As you can see in the picture of the Van de Graaff machine, the sparks of static electricity are huge and powerful. The sparks are big because the machine creates very high electric potential. When you shuffle your feet across the floor and see a spark, you have generated a low electric potential. When no sparks generate between two objects, the electric potential is zero.

Think of 'revving up' a car. If you push down on the accelerator pedal when the car is in park, the engine will roar loudly. This is like having a high electric potential. If you suddenly put the car in drive when the engine is 'revved up,' the car will go fast very quickly. This would be like having a huge spark of electricity released suddenly. If the car is not 'revved up' at all, (like having a small amount of electric potential) then when you put the car in drive, it will just barely move forward. This would be like a small spark. The more you 'rev' the engine, the more energy the car will have to be released into racing the car forward. The higher the

VOCABULARY

Current electricity: an electric charge in motion, usually electrons flowing through a conductor

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electric potential, the more energy a charged body will have to be released into a spark of electricity.

The ***volt*** is the metric unit for measuring electric potential. It is named in honor of the Italian physicist, Alessandro Volta. One *volt* is the electric potential difference between two points such that one joule of work is needed to move one coulomb of charge from one of the points to the other: *volt = joule/coulomb*. As an equation: $V = E/Q$, with V the electric potential, E the work or energy and Q the charge.

Electric potential difference is referred to as ***voltage***. The greater the voltage, the greater the electric potential. One way to think of voltage is as the electric force that puts an electron in motion. Just as water pressure causes water to move through a pipe, so voltage causes electrons to move through a wire. An electron that experiences a small voltage also experiences a slight force to cause it to move. An electron that experiences a high voltage experiences a strong force to cause it to move. A small voltage can send electricity through a good conductor such as a copper wire. A high voltage is necessary to cause electricity to spark across a non-conductor such as dry air. If conducting wires are attached to the positive and negative terminals of a nine-volt battery and touched to one another, current will flow. As they are separated, a spark will jump between them until they are about one millimeter apart. A small electrostatic generator that can produce 25,000 volts will force a static discharge to jump across one inch (25.4 mm) of dry air.

The most powerful Van de Graaff machines can create discharges up to 10 million volts. That electric potential is as high as a bolt of lightning. The energies are so great that a discharge from the machine could tear apart atoms. The Van de Graaff machine became one of the first devices that could separate atoms into even smaller particles. The Van de Graaff machine generates static electricity. Even if the machine had been available to scientists in the late 1700s, men would still have sought a better way to produce electricity. ***Static electricity*** is electricity at rest. It moves only during the brief moment of a static discharge when electrons suddenly flow into or out of a charged body. ***Current electricity*** is electricity in motion. An *electric current* is a stream of electrons moving around a circuit. Scientists who investigated electricity needed a dependable and continuous source of electricity that flowed.

The first clue that chemicals could generate an electric current came in the late 1790s, only a few years after the death of Benjamin Franklin, whose experiments had shown that lightning and static electricity had the same properties. Luigi Galvani, an Italian medical scientist, discovered that static electricity could cause muscles to twitch. Many scientists had been careless enough to touch a Leyden jar charged with static electricity. The sudden discharge caused their muscles to jerk suddenly and without control. Luigi Galvani noticed that dead muscles would contract, too. He touched the muscles of dead frog legs to a body charged with static electricity. The legs twitched. Galvani wondered if lightning would cause frog legs to twitch. He knew the dangers of working with lightning and

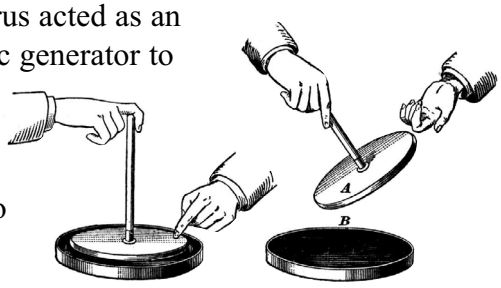


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designed his experiment so he could watch the dead frog legs from inside the safety of his laboratory. Galvani hung the legs by brass hooks against an iron lattice outside his laboratory window and waited for a passing electrical storm. The frog legs twitched during a thunderstorm. He also saw them twitch at other times, even without lightning. A leg twitched whenever it touched the brass hook and iron metal at the same time. Back in the laboratory, Galvani experimented further. He touched the legs with two different metals, such as copper and zinc. The legs would jerk. Somehow, the combination of the leg and two metals generated electricity.

Alessandro Volta, another Italian scientist, was one of nine children. He did not talk until he was four years old, and his family became worried that he might be mentally handicapped. But by age seven, he caught up with other children his age. Later, he became a successful scientist who read about Galvani's experiments.

Alessandro Volta built a device capable of both generating and storing static electricity. The *electrophorus* had an insulated hard rubber pad on bottom and a metal plate with a handle on top. The hard rubber took on a negative charge when rubbed. This repelled electrons in the upper plate. By grounding the upper plate and repeating the process, a strong charge would accumulate between the two plates. The electrophorus acted as an electrostatic generator to generate a charge and a capacitor to hold the charge.



Alessandro Volta replaced the frog legs with a cloth soaked in salt water. He touched two different types of metal to the cloth. A faint electric current flowed. His experiments showed that a chemical reaction could produce an electric current. This simple discovery led to an important invention that impacts the world every day. That invention will be discussed in the next lesson.

LIFE PRINCIPLE

"The things of highest value sometimes come hard. The gold that has the greatest value lies deepest in the earth, as do the diamonds."



—Normal Vincent Peale

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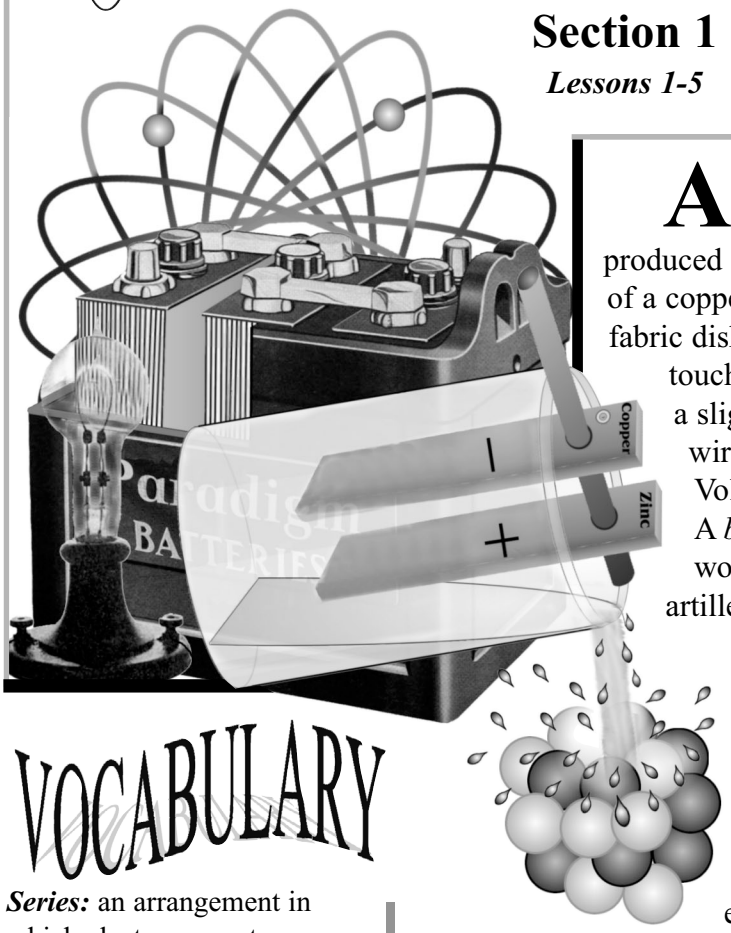
Integrated Physics & Chemistry

Chapter 5

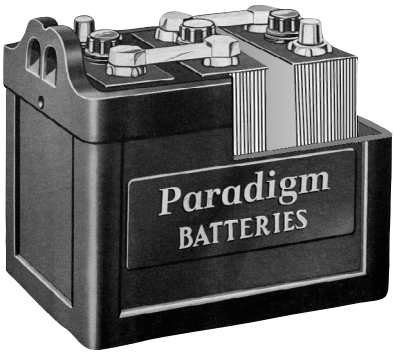
Lesson 5
Energy

ELECTRIC CURRENT

Section 1
Lessons 1-5



Alessandro Volta showed that two different metals separated by salt water produced electricity. He built a *voltaic cell* made of a copper disk separated from a zinc disk by a fabric disk soaked in salt water. When Volta touched the top and bottom disks with a wire, a slight electric current flowed around the wire. To increase the amount of electricity, Volta stacked several voltaic cells together. A *battery* is a group of similar objects that work together. For instance, several powerful artillery pieces are often placed together to protect the entrance to a bay from hostile ships. The arrangement of big guns is called a battery. An electric battery is made of voltaic cells that are connected together, usually in ***series***. A series circuit connects the positive electrode of one cell to the negative electrode of the next. The electron flow goes through all of the cells in the battery. In daily use, the term *battery* may mean a single voltaic cell or multiple cells connected together. For example, a single flashlight battery produces about 1.5 volts of electricity. A flashlight battery is a single cell made of zinc and carbon with a moist paste between them. Six of the cells put together in series will generate 9 volts of electricity. A nine-volt battery contains six smaller cells. Connecting voltaic cells in a series gives a greater voltage.



VOCABULARY

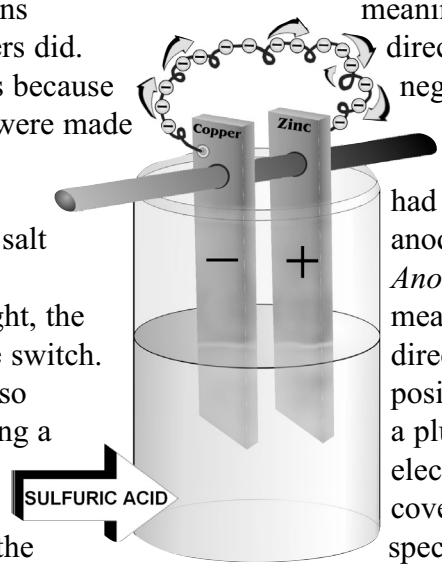
Series: an arrangement in which electrons must pass through all of the devices in an electric circuit
Anode: a positive electrode
Cathode: a negative electrode
Electrolyte: a compound that separates into ions when dissolved in water or when heated until molten
Electrode: a solid conductor in which an electric current enters or leaves a voltaic cell
Ion: an atom or group of atoms that has an electric charge by gaining or losing electrons

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By 1800, Alessandro Volta had developed the first electric battery which produced a steady stream of electricity. Because of his success in studying electricity, Volta received the French Legion of Honor medal and the noble title, Count Alessandro Volta. Later, scientists gave Volta a high honor by naming the unit of electrical potential, the volt, in his honor.

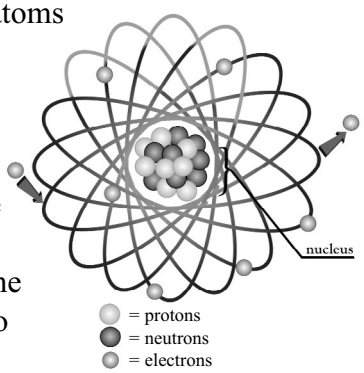
Other metals produce electricity. Chemists tried various conductors such as copper and zinc, carbon and zinc, or lead and lead oxide. Some metal combinations produced more electricity than others did. Copper and zinc were good choices because they were readily available. Coins were made of copper, and most chemical laboratories had samples of zinc. Chemists tried solutions other than salt water. Acid in water also worked.

When you operate a flashlight, the process seems simple: just push the switch. The actual scientific process is not so simple. Alessandro Volta lived during a time without flashlights, vacuum cleaners or hair dryers. All of these appliances are possible because of the complex discoveries Volta made with electrodes, acid and electric charges.



A typical battery of the early 1800s was made of three main parts, the ***anode***, the ***cathode*** and the ***electrolyte***. A strip of copper and a strip of zinc were partially immersed in a bath of sulfuric acid solution. The ***electrodes*** were the two points at which the wires were attached to the battery. Electrons entered the circuit at the cathode. Because it had an excess of electrons, it had a negative charge. The cathode was marked with a minus sign (–).

Cathode is from a Greek word meaning *below.* The downward direction was thought of as negative. Electrons were taken from the circuit at the anode. Because it had a deficit of electrons, the anode had a positive charge. *Anode* is from a Greek word meaning *above.* The upward direction was thought of as positive. It was marked with a plus sign (+). The electrodes were partially covered with water or other special liquid called the electrolyte. Special chemicals were slowly dissolved into the liquid. This reaction created positive and negative ions. ***Ions*** are groups of atoms that have either lost or gained electrons. A *positive ion* is a group of atoms that has lost electrons, and a *negative ion* is a group of atoms that has gained electrons. The negative ions gathered around the anode, and the positive ions gathered around the cathode. If the two electrodes were connected together by a copper wire, then the



VOCABULARY

Short circuit: an electric circuit that usually causes a blown fuse to shut off electricity

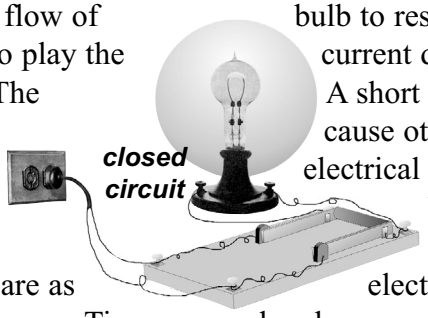
Current: the flow of electric charge, current is the amount of electric charge flowing past a particular point per unit time, in the metric system current is measured in amperes

Ampere: the metric unit of current defined as one coulomb of charge flowing in one second, abbreviated amp

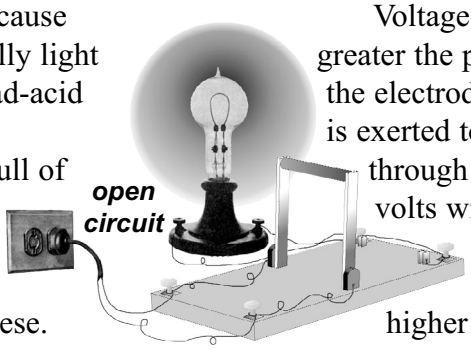
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electrons would flow to the anode through the wire and into the cathode to meet the positive ions. This flow of electrons was called an electric current. Electric current flows around an electric circuit.

Modern batteries are based on the same principles. The normal batteries you use today are "AAA," "AA" or "D." These are called *dry cells* because they use a paste instead of a liquid. The *terminals* of the batteries, (the + and – ends), are the electrodes. When you put batteries into something to be powered, like a CD player or remote control, the batteries release a flow of electrons into the device. This flow of electrons provides the power to play the music or turn up the volume. The batteries go "dead" when the chemicals inside the battery cannot give up any more electrons.



Today, battery designs are as numerous as the objects they power. Tiny watch batteries can power a watch for years. Special lithium-ion batteries are used for high quality laptop computers because lithium batteries are especially light and easily rechargeable. Lead-acid batteries, which are used in automobiles, are large and full of liquid. The small alkaline batteries with "AAA," "AA" or "D" markings are made with zinc and manganese. Batteries provide power for electric circuits. An electric circuit provides a path for electrons. The path can be closed, opened or shorted. The light bulb of a flashlight comes on when the circuit is closed. The path is completed by the switch, and electrons flow through the bulb. The light bulb of a flashlight goes off when the circuit is open. Switching the flashlight to the off setting causes a gap in the circuit. An open space is created where no electricity can flow. Battery-powered devices like flashlights and remote-control cars force the flow of electrons to energize a motor or cause a light to shine. The electrons move through a motor or a light bulb much more slowly than if the terminals were directly connected. If the terminals were directly connected, a ***short circuit*** would occur.



A short circuit connects directly from one electrode of the battery to the other electrode without going through the bulb, motor or other resistor. The electrons bypass the bulb and take a short cut. Without the bulb to resist electron flow, the electric current drains quickly from the battery. A short circuit can melt wires and cause other damage. To protect electrical equipment, fuses or circuit breakers are inserted into the circuit. A big surge of electricity will trip the circuit breaker or cause the fuse to melt. Either device creates an open circuit and stops the flow of electricity.

Voltage puts electrons in motion. The greater the potential difference between the electrodes of a battery, the more force is exerted to cause electrons to move through the wire. A battery with 9.0 volts will move electrons more readily than a battery with a voltage of 1.5 volts. The higher voltage pushes the electrons more forcibly.

An *electric current* is the flow of electrons. The amount of ***current*** is proportional to the amount of electrons that pass a particular point in a given amount of time. Most electric current is carried in wires, and electrons carry the charge. An electric current in a wire is the number of electrons that pass a particular point each second. In the metric system, the symbol for current is *I*.

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Stated in symbols:

$$I = \frac{Q}{t}$$

with *I* the current, *Q* the charge and *t* the time.

Current is measured in ***amperes***. The *ampere* is named in honor of Andre Ampere, a French physicist who investigated the magnetic effect produced by a wire that transfers current. An *ampere* is defined as the flow of one coulomb of charge in one second. Stated in electrical units:

$$1 \text{ amp} = \frac{1 \text{ coul}}{1 \text{ sec}}$$

The flow of one coulomb of charge requires 6.25 quintillion (6,250,000,000,000,000,000) electrons or 6.25×10^{18}. A wire carrying one ampere of current has 6.25×10^{18} electrons passing a particular point each second. Let us pause to answer some questions. Then, you will study a man who was responsible for discovering the electric current that lights up your home.



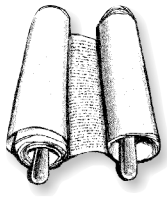
LIFE PRINCIPLE

"It is not enough to be busy.
The question is:
what are we busy about?"

—Henry David Thoreau

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Integrated Physics & Chemistry



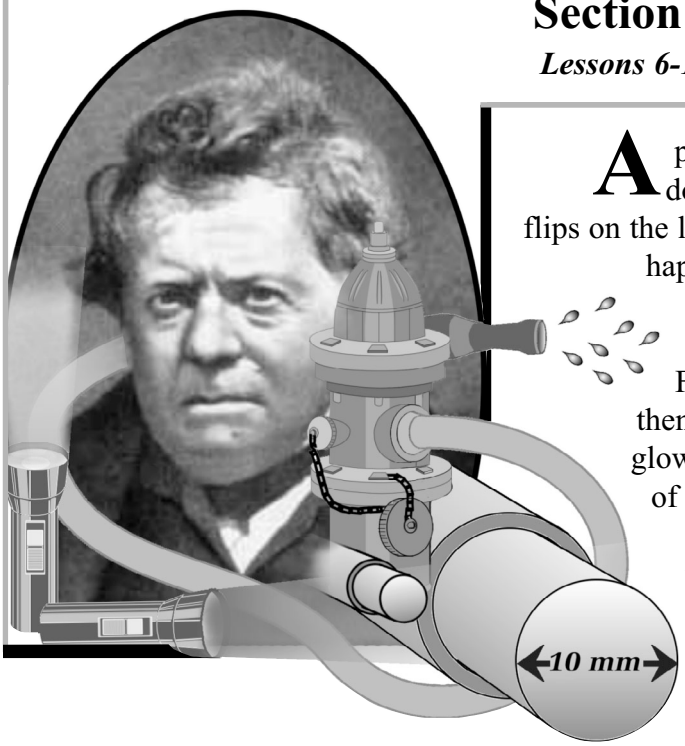
Lesson 6
Scientific Laws

Chapter 5

OHM'S LAW

Section 2

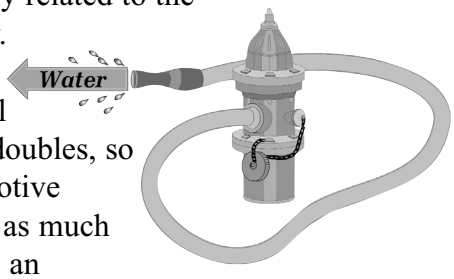
Lessons 6-10



A person stands at the top of the stairs leading down to a dark and gloomy basement. He flips on the light switch at the top of the stairs. Nothing happens. No current flows in the wire. The bulb has burned out or a fuse has blown. The person gets a flashlight and turns it on. For a moment, the bulb provides light, and then it grows dim and puts out a weak yellow glow. The batteries are going dead. The amount of current that flows is less than expected.

Current is the amount of electric ***charge*** that passes a particular point in an electric circuit in a given amount of time. In scientific terms, current, charge and time are expressed in the equation: $I = Q/t$. In metric units: *amp = coul/sec*.

The flow of electricity through a wire is often compared to the flow of water through a pipe. For a fire hose to spray water on a burning building, a pump is used. It generates pressure that causes the water to move. The amount of water flow is directly proportional to the amount of pressure generated by the pump. Similarly, a battery generates a force (voltage) that causes electrons to move. The amount of electricity that flows is directly related to the force generated by the battery.



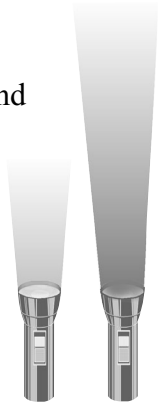
The amount of current is directly proportional to the *voltage*. If the voltage doubles, so does the current. An electromotive force of 3.0 volts sends twice as much electricity through a circuit as an electromotive force of 1.5 volts. When the batteries in a two-cell flashlight are fresh, they provide 3.0 volts. As the flashlight is used, the batteries grow weaker, and the voltage drops. An

VOCABULARY

Charge: the amount of static electricity possessed by a body, symbol is *Q*, metric unit is coulomb, equal to the charge carried by 6.25 x 10^{18} electrons
Resistance: opposition to the flow of electric current, metric unit is ohm
Diameter: a straight line that connects one side of a circle to the other and passes through the center of the circle

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electromotive force of 3.0 volts is enough to push the electrons around the circuit. At 2.0 volts, however, the electromotive force is too weak so the bulb does not light, or if it does, it is very dim. A battery tester checks the voltage of a battery to determine whether it is good or not.



Resistance is another important factor that controls the rate of flow of electric current. Although rate of flow of water depends on the amount of pressure behind the water, the rate of flow also depends on the resistance offered. The resistance varies depending on how far the water must be transported. A short pipe has less resistance than a long pipe. When petroleum is transported cross-country in buried pipelines, powerful pumping stations keep the liquid moving. The longer the pipe, the greater the resistance to the flow of a liquid. In the same way, the longer a wire, the greater the resistance to the flow of electricity. The diameter of a water pipe matters, too. A small diameter water hose has more resistance to flow than a larger diameter fire hose. For example, a person has an adequate supply of water but has a hose that is small in diameter. The small hose resists the flow of water. A high-pressure pump would force more water through the hose despite its small size. In the same way, a wire of small diameter resists the flow of electricity. A high voltage battery would force more current through the wire despite its small diameter.

The first person to answer the question as to how current, voltage and resistance are related was Georg Simon Ohm. His father was poor but made sacrifices for his son to receive an adequate education. Georg Ohm completed his basic education and became a high school teacher. Georg Ohm always worked toward improving himself and wanted to gain a university position. Schooling alone did not qualify him for a position, so he decided to investigate a new area of science to prove his skill. He began to experiment with electricity. Ohm had learned from his father, who was a mechanic, how to design and build his own laboratory equipment. Copper wire was needed for electrical experiments, but it was not available as an off-the-shelf item. Georg obtained a supply of bulk copper, from which he made his own wire. As he worked, he wrote about his research. It was solid, reliable work but nothing that other researchers had not already investigated. All of his papers disappeared without notice in the scientific world. He simply had not done anything of special notice. Yet, he did not give up. As he worked with wires of different lengths and thicknesses, he found that simple rules described the flow of electricity through the wires.



One factor that affects resistance is the length of the wire. *Resistance* is directly proportional to the length of the wire. A wire twice as long has twice the resistance. The increased resistance reduces the amount of

VOCABULARY

Cross sectional area: a section formed by making a cut at right angles to an axis, the cross section of a wire is a circle

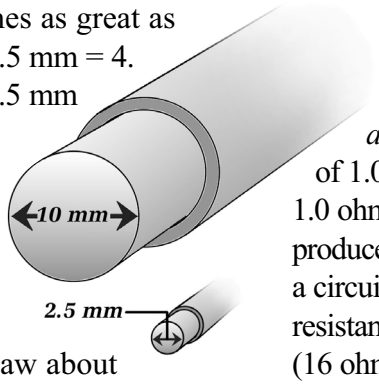
Ohm: the metric unit of resistance, a circuit in which one amp of current is produced by one volt of electromotive force has a resistance of one ohm

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electricity that flows. A current sent through a wire that is ten times as long encounters a resistance ten times as great. Only 1/10 as much current flows.

Another factor that affects resistance is the thickness of the wire. The thicker a wire, the less the resistance. Just as a hose with a large ***diameter*** will allow more water to flow, so a thicker wire will allow more electricity to flow. The thickness of a wire is measured by the size of its ***cross sectional area***. If you cut a wire straight across, the area of the cut end would be the cross sectional area.

Area is proportional to the square of the radius. To compare two wires, a person can compare the squares of their radii. *Resistance* is inversely proportional to the square of the radius of a wire. A 2.5 mm wire has a smaller radius than a wire with a radius of 10 mm and will have the greater resistance. To find out how much greater, compare the squares of their radii. The 10 mm wire has a radius 4 times as great as the 2.5 mm wire: 10 mm / 2.5 mm = 4. The square of 4 is 16. The 2.5 mm wire has 16 times as much resistance as the 10 mm wire. Only 1/16th as much current will flow through it. As he measured resistance, Georg Ohm discovered a fundamental law about current flow that relates current, voltage and resistance. Ohm's Law states that the current is directly proportional to the voltage and inversely proportional to the resistance.



Of all his results, Georg Ohm believed this discovery might justify a university position. He had written so many merely adequate papers that no one would publish his latest discovery. Georg Ohm decided to publish it himself in a small pamphlet. This was Georg Ohm's only first-class discovery. However, his little pamphlet met opposition and resistance. Some people interpreted his work to favor an electrical theory that was out of favor at the time. He was criticized so harshly that he had to resign from his high school teaching position. He lived in poverty for six years, but outside of Germany his work was becoming known. In England, the Royal Society invited him to become a member. Ohm received the Copley Medal in 1841 from the Royal Society for the discovery of Ohm's Law. Finally, his own country recognized his achievement. He was appointed professor at the University of Munich. He had made only one discovery of note, but it was enough. His discovery is the Fundamental Law of Electric Circuits. Ohm received the recognition he deserved.

Because of Georg Ohm's discovery, the unit of resistance in the metric system is named the ***ohm*** in his honor. Ohm's Law relates current, voltage and resistance, the three fundamental quantities of an electric circuit. Ohm's Law can be written in symbols as I = V/R, with *I* the current, *V* the voltage and *R* the resistance. Ohm's Law is *amp = volt/ohm*. If a potential difference of 1.0 volt acts on a circuit with a resistance of 1.0 ohm, then a current of 1.0 amp will be produced. The amount of current that will flow in a circuit of a 6.0 volt flashlight that has a 16 ohm resistance is .375 amps. I = V/R = (6.0 volts) / (16 ohms) = 0.375 amps. Suppose a 110 volt circuit runs through a lamp filament with a resistance of 100 ohms. What is the current in amperes? Solution: I = V/R = (110 volts) / (100 ohms) = 1.10 amps. An electric toaster has a resistance of 20 ohms. A light has a resistance of 100 ohms. The toaster has less resistance compared to the light filament, 20 ohms for the toaster compared to 100 ohms for the bulb. Because the toaster has less resistance, more current will pass through it. The current is I = V/R = (110 volts) / (20 ohms) = 5.5 amps.

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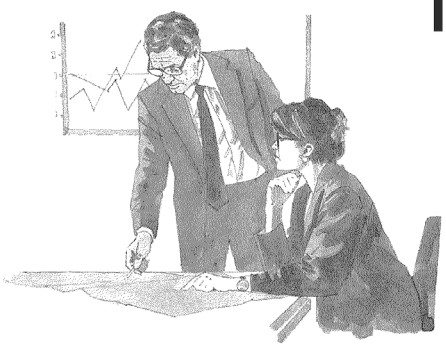
Ohm's Law is the fundamental equation for working with simple electrical circuits. By knowing any two of the three quantities, the other one can be found by rearranging Ohm's Law. The law can be written as three different equations:

$$I = \frac{V}{R} \qquad R = \frac{V}{I} \quad \text{and} \quad V = R * I$$

If any two of the three quantities are known, the third one can be found. If a 1.5 volt battery delivers 0.5 amp to a flashlight bulb, the resistance of the bulb is equal to the voltage divided by the current, R = V / I = (1.5 volts) / (0.5 amps) = 3 ohms.

This example presumes the rest of the circuit offers no resistance. That is not exactly true, but the additional resistance is slight compared to the resistance of the filament. One hundred twenty volts are required to push 10 amps through an electric waffle iron with a resistance of 12 ohms. From Ohm's Law, voltage is equal to the resistance times the current, V = R * I = (12 ohms) * (10 amps) = 120 volts.

LIFE PRINCIPLE



"Try not to become a man [person] of success but rather try to become a man [person] of value."

—Albert Einstein

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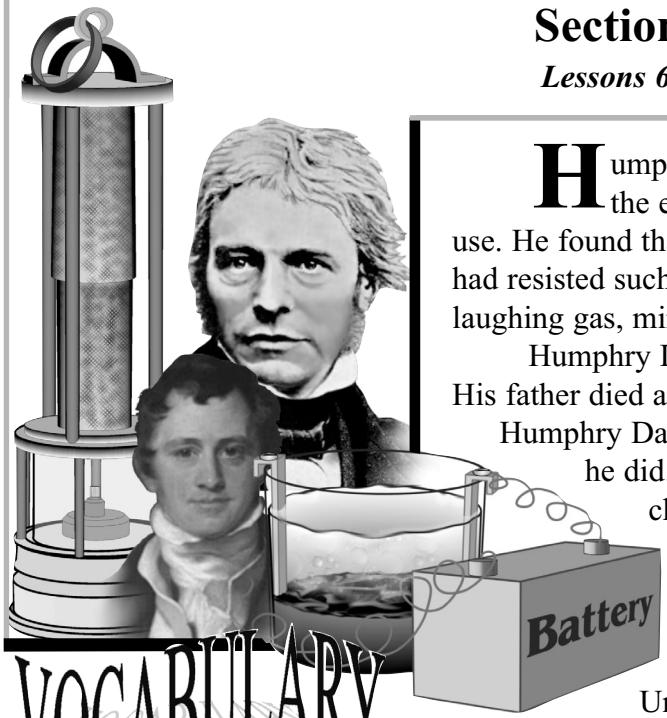
Chapter 5

Lesson 7
Compounds

HUMPHRY DAVY: CHEMICAL DETECTIVE

Section 2

Lessons 6-10

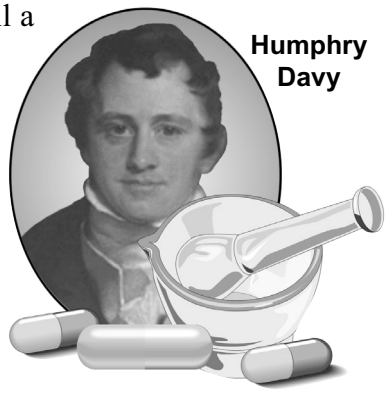


Humphry Davy, an English chemist who lived in the early 1800s, put electricity to an entirely new use. He found that electricity would pry apart molecules that had resisted such efforts in the past. His discoveries included laughing gas, miners' lamps and new metals.

Humphry Davy's life began in humble circumstances. His father died and left the family deeply in debt. Young Humphry Davy resolved to repay the debt in full, which he did. He worked for a man who prepared chemical mixtures. The chemicals found in the shop fascinated Humphry, and he experimented with many of them. He gained valuable knowledge working with the different substances in the lab.

Unfortunately, Humphry Davy seldom exercised good safety measures with chemicals. More than once his chemical experiments ended in explosions. Finally, the owner let Davy go, fearing the boy might blow up the shop.

Humphry Davy served as an assistant to a physician, Doctor Thomas Beddoes. Doctor Beddoes supervised a hospital, Pneumatic Institution, devoted to the medical uses of newly discovered gases. People believed gases such as nitrogen, oxygen and others might in some way have medical uses. While still a teenager, Davy became the chief investigator at the hospital. He unwisely tasted and sniffed new chemicals, nearly killing himself with the dangerous ones.


Humphry Davy

In 1800, Humphry Davy discovered a new gas, nitrous oxide, a combination of nitrogen and oxygen (N_2O). When inhaled,

VOCABULARY

Electrolysis: the chemical change, usually decomposition, of an electrolyte by an electric current
Smelt: to melt or fuse in order to separate the metal
Potash: a compound of potassium made by leaching wood ash with water and evaporating the solution in a pot
Potassium carbonate (K_2CO_3): the compound of potassium found in potash
Arc lamps: lamps that produce an intensely bright light by a current jumping the gap between two electrodes, usually of carbon

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the gas caused unexpected and unpredictable behavior. People who breathed the gas could not control their emotions. The gas became known as laughing gas. Humphry Davy had been testing nitrous oxide when he was called from his laboratory to make his medical rounds. He listened as patients described their ailments and pains. He responded with howls of laughter. Davy giggled out of control. Later, he applied his interest in gases to other chemical experiments.

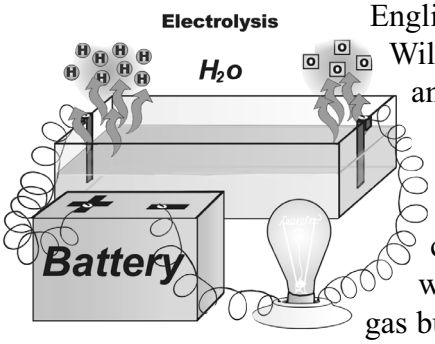
After reading an English translation of Antoine Lavoisier's chemistry textbook, *The Elements of Chemistry*, Davy decided to devote himself full-time to chemical research. He wrote a book about nitrous oxide. He suggested that nitrous oxide might prove useful in relieving pain during medical procedures. Dentists sometimes use it today for that purpose. Other scientists recognized Davy as a skilled chemist.

Humphry Davy became a chemical detective to seek out new metals. Chemical clues led him to believe several compounds contained new metallic elements. The compounds held the metals so strongly, that the usual methods of separating the metals did not work. Iron can be separated from its ore with a wood fire, and other metals are freed when burned with a hotter fire from coal. These methods did not work for some compounds, such as those that contain sodium.

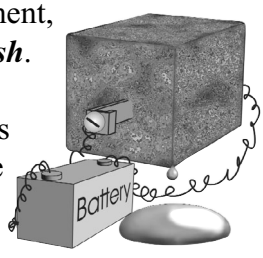
VOCABULARY

Safety lamp: A miner's lamp with a wire mesh surrounding the flame to keep the air temperature below the ignition point of flammable gases

The discovery of electricity gave chemists an entirely new tool in their attempts to pry molecules apart and separate the atoms. This came to be known as electrolysis. ***Electrolysis*** is the use of an electric current to cause a chemical reaction to take place. *Electro-* is from electricity and *-lysis* means *to loosen*. A strong electric current can break down a compound. The fact that electricity can separate a compound into its atoms was discovered in 1800 by two English chemists, William Nickolson and Anthony Carlisle. They passed an electric current through water. Oxygen gas bubbled up at the positive electrode, the anode. Hydrogen gas bubbled up at the negative terminal, the cathode. Other chemists did not find the Nickolson-Carlisle discovery surprising. They knew that water was made of oxygen and hydrogen. Henry Cavendish had discovered hydrogen about 15 years earlier. He showed that the combination of hydrogen with oxygen gave water as the product. Humphry Davy read about the Nickolson-Carlisle experiment and realized its importance. He believed that if electricity could break down water, then perhaps it could break down other compounds. Electricity might separate an unknown element from its ore. Beginning in 1805, Humphry Davy experimented with electrolysis as a tool for ***smelting*** metals.

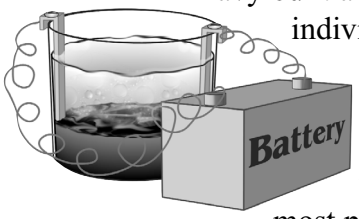


For his first experiment, Humphry Davy chose ***potash***. Potash is made by burning wood and filtering the ashes with water. Davy mixed the potash with water and ran



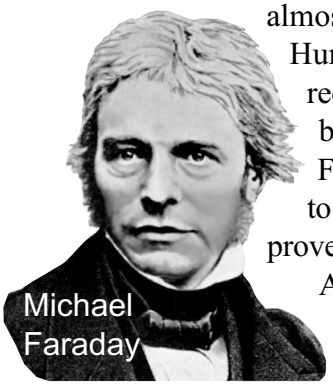
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an electric current through the mixture. The water, rather than the potash, disassociated. Instead of using water, Davy decided to build a battery so powerful it would send electricity through solid potash. Humphry Davy built a battery of 250 individual voltaic cells made of copper and zinc plates, six by four inches in size. It was the most powerful battery of his day. Using a wire of platinum alloy, Humphry Davy connected his super battery to a sample of potash. When the electricity flowed, the potash became so hot that it melted. Small globules having a high metallic shine appeared. They resembled small drops of mercury. Davy could barely contain his joy and jumped around the laboratory in delight. He had discovered a new metal that was chemically highly active. He called the new element *potassium*. He followed Lavoisier's recommendation to use the *-ium* ending to show that potassium is a metal. The chemical symbol for potassium is *K*. Chemists later showed that *potash* is a crude form of ***potassium carbonate (K_2CO_3)***.



Humphry Davy was a handsome man with a flare for dramatic presentations. He gave public lectures about his discoveries and filled his lectures with exciting displays of electricity and exploding gases. Tickets to his lectures became popular and difficult to obtain. Because of his personal charm and showmanship, Humphry Davy became one of England's best known scientists. His electrolysis experiments came to the notice of French scientists. In 1806, they awarded Davy the Napoleon Medal. During this time, the countries of England and France were enemies, and Davy noted that the governments might be at war but not the scientists. Humphry Davy accepted the medal from France.

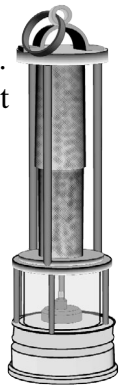
In 1812, Davy was knighted — Sir Humphry Davy. Although his health declined he had the good fortune to select the brilliant Michael Faraday as an assistant. That same year, Davy married and decided to rest by taking an extended honeymoon and tour of Europe. Michael Faraday was asked to accompany Davy on the trip. The young Michael Faraday was able to meet the great scientists of Europe. Michael Faraday proved to be a perfect assistant for Humphry Davy. Faraday had been born in poverty and was almost entirely self-taught. Humphry Davy recognized Faraday's brilliant mind and gave Faraday an opportunity to improve himself and prove his skill as a chemist. After Humphry Davy returned to England, he turned to the problem of making a safe miner's lantern. Working in mines was a difficult and dangerous profession. In the 1800s, the need for coal increased dramatically with the invention of the steam engine. The industrial revolution drove miners deeper into the ground in search of coal. Mine shafts became deeper and the tunnels longer. Sometimes the mine shafts were filled with coal dust and gases such as methane. The light in the mines came from lanterns with open flames. Often, the flame from the lantern would ignite gas and coal dust and cause an explosion. Miners and other people lost their livelihoods when mine owners had to close dangerous mines.



Davy invented a ***safety lamp*** that burned oil and had a metal screen that surrounded the flame. Oxygen could get through to feed the flame, but the screen absorbed the heat of the flame. Explosive gases outside the lamp would not ignite.

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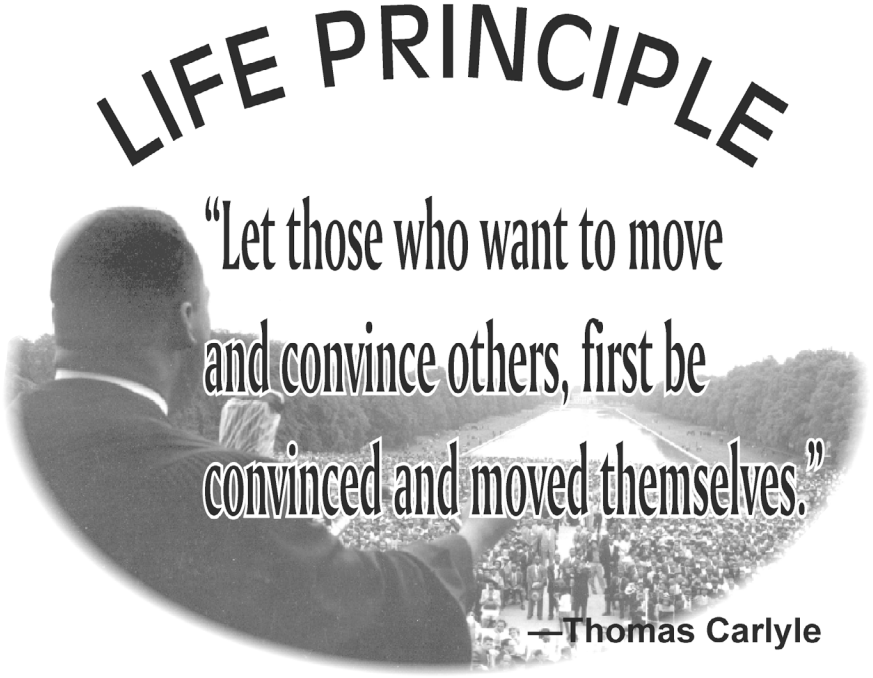
The Davy safety lamp dramatically reduced the danger of fires and explosions in mines. Humphry Davy could have made a fortune from such an invention. Instead, he refused to patent it. He let it be freely manufactured for use in coal mines. Miners showed their thanks by filling a hard hat with silver coins and giving it to Davy. Mine owners also gave Davy a special award.



In 1820, Humphry Davy became president of the British Royal Society, but his years of sniffing and tasting chemicals had left him weak. Sometimes he could not leave his bed, but his inventive mind continued to work. Davy made a blindingly bright arc light by sending a powerful current of electricity across the gap between two carbon terminals. It was the first attempt to use electricity to produce light.

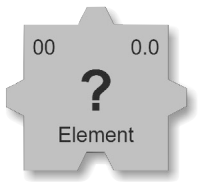
Arc lamps are still used where a brilliant display of light is needed, such as for searchlights and spotlights at stage plays. As Davy's health declined, Michael Faraday, the assistant Davy had trained so well, took over Davy's work at the Royal Institution in London. Faraday developed into one of the top scientists of all time. As life grew to a close for Humphry Davy, he was asked to name his greatest discovery. He did not hesitate to say, "Michael Faraday."

Sir Humphry Davy died in 1829 at the age of 51. Had he exercised more caution around chemicals, he might have lived another twenty-five years or more. Humphry Davy was the first chemist to use electrolysis as a tool to smelt metal ore. He separated the metallic element potassium from potash. Potassium was the first element discovered by using electricity. You will learn in the next lesson about metals that affect your life on a daily basis.



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Integrated Physics & Chemistry



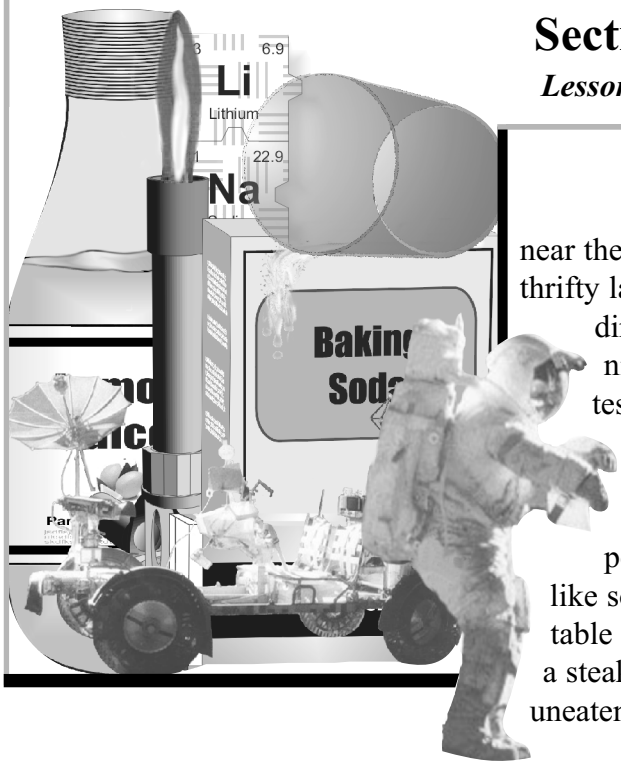
Lesson 8
Elements

Chapter 5

THE SODIUM METALS: LITHIUM

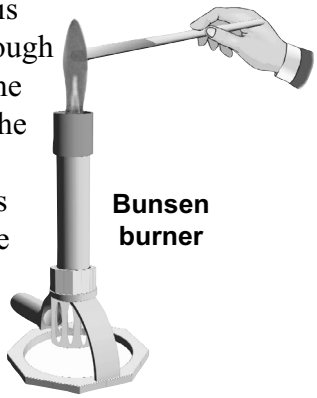
Section 2

Lessons 6-10



In 1891, Robert Wood studied chemistry in Baltimore. He stayed at a boarding house near the university. The other students suspected that the thrifty landlady often cooked their morning stew from dinner leftovers she collected from their plates the night before. Robert Wood told them that he could test to see if their suspicions were true. That evening he brought home from the chemical laboratory a small sample of lithium chloride, a type of ***salt***. Unlike some salts that are deadly poisons, this compound of lithium looks and tastes like sodium chloride. It is as harmless as ordinary table salt. For dinner that evening, the landlady served a steak. Robert Wood left several chunks of the meat uneaten and sprinkled them with lithium chloride.

When the lithium is heated until it glows, it burns with a distinctive color. Many metals reveal their presence by a *flame test*. A small amount of mineral will color the flame different colors depending on elements in the metal. Chemists dip a clean platinum wire in strong hydrochloric acid. They hold it in the flame of a Bunsen burner until all impurities are burned away. Then they dip the end of the wire in the mineral to be tested and put it in the flame. The color of the flame is then a good clue to the identity of the element. Sodium burns with a strong, yellow color. Potassium is violet, and lithium has a deep red color. Although the flame test is difficult to interpret, it became much more reliable with the introduction of the spectroscope. The *spectroscope* is an arrangement of prisms and lenses that spreads light into the various colors. The spectroscope separates white light from the sun into all of the colors of the rainbow. Sunlight contains every color including red, orange, yellow,



Bunsen burner

VOCABULARY

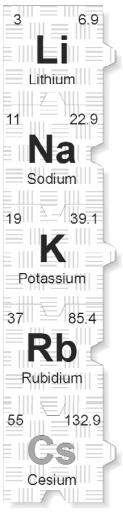
Salt: one of the products of a reaction involving an acid and a base, common table salt is sodium chloride (NaCl), but other salts include lithium chloride (LiCl)
Lithium (Li): the lightest of all metallic elements
Reduction: the removal of oxygen from a compound
Base: reacts with acids to form salts and water, a base usually contains the hydroxide group (OH^-)

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green, blue, indigo and violet. Elements such as lithium, however, are limited in the number of colors they display. When viewed through a spectroscope, lithium has a pattern of dark red lines that it shares with no other element.

The next morning, the students collected a sample of the stew that had been served for breakfast. Robert Wood examined the sample with the spectroscope. The spectroscope revealed the unmistakable deep red lines from lithium. Robert Wood concluded that the landlady indeed had been feeding her guests the scraps of old meals.

Lithium, like potassium, is a member of the sodium family of elements. All six have similar chemical properties. In order of increasing atomic weights the six sodium family metals are ***lithium*** (***Li***), sodium (Na), potassium (K), rubidium (Rb), cesium (Cs) and francium (Fr). Members of the sodium family are metals. Like most metals, they have a silvery luster and are good conductors of electricity and heat. They can be drawn out into long wires or rolled into thin sheets. Some of their properties are unusual. Compared to other metals, they are soft and can be cut with a knife. These metals melt at low temperatures and are lightweight. Lithium, sodium and potassium are less dense than water. They are lighter than water and will float. Later in this lesson, you will learn how lithium is used to save the lives of airplane pilots and sailors.



Lithium and the other sodium family metals are extremely active chemically. A simple touch will burn your fingers. The burn results from the metal stripping oxygen from the compounds found in the human body. Lithium reacts immediately with oxygen in the air. Chemists never find lithium or any of the other sodium metals free in nature. Lithium reacts vigorously to take oxygen from other compounds. Although a block of lithium is light enough to float in water, it would not last long. It reacts violently with water to form hydrogen gas and lithium hydroxide (LiOH). ***Reduction*** is the process of removing oxygen from a compound just as lithium removes oxygen from water. Lithium hydroxide (LiOH) will remove oxygen from carbon dioxide (CO_2). Lithium hydroxide is sometimes used to absorb CO_2 in closed environments such as aboard spacecraft.

Lithium also forms strong ***bases***. A base is the opposite of an ***acid***. Many kinds of acids and bases exist. Some acids are so mild they can be ingested. They give lemonade its sour taste. Almost anything you eat that tastes sour does so because of an acid. Lemon juice, grapefruit, green apples and sour milk all have their distinctive tastes because of acids. Chemists have found much stronger acids, such as hydrochloric acid, that can eat a hole through a handkerchief or dissolve many metals. Bases are common but are seldom found in foods. A base will neutralize an acid. When the soil of a field becomes too acidic for plants to grow, farmers spread chemicals (such as lime) that are weak bases to neutralize the acids. The most common base in the home is ammonia, which has a sharp pungent

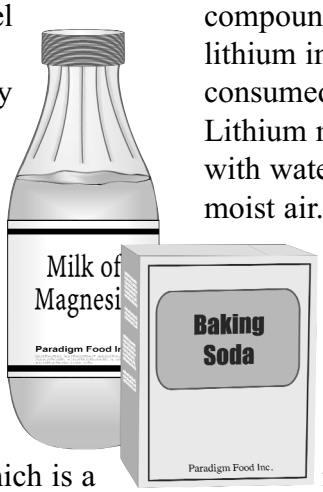


VOCABULARY

Acid: has a sour taste, dissolves greases and oils, and reacts with bases to form salts and water, an acid usually contains the hydrogen ion (H^+)

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smell and is used for cleaning. Milk of Magnesia is a base, too. Bases feel slippery like soap. Strong bases burn the skin when touched. Many foods are treated with acids or bases. Acids help change milk into cheese and cabbage into sauerkraut. Corn soaked in a strong base becomes hominy, and hominy can be ground to produce grits. Food is digested in the stomach by very dilute hydrochloric acid and carried throughout the body by blood, which is a weak base.



Chemically, acids and bases differ. An acid provides a source of hydrogen ions (H^+). Hydrochloric acid (HCl) dissolves in water to free hydrogen ions (H^+). A base provides a source of hydroxyl ions (OH^-). Lithium hydroxide (LiOH) is a strong base. It dissolves in water to free the hydroxyl group (OH^-).

When an acid and a base are mixed together in the right proportion, they react to produce a salt (not necessarily ordinary table salt) and water:

acid + base → water + salt

When lithium hydroxide (LiOH) reacts with hydrochloric acid (HCl), the result is lithium chloride (a type of salt) and water:

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

You will look at acids, bases and salts in more detail in future lessons. For now, the important concept is that lithium and other sodium metals form strong bases.

Lithium (Li) is not only the lightest sodium family metal; it is the lightest of all metallic elements. Lithium has a density of 0.53 g/cm^3, about half that of water. Lithium is lighter than most woods. In contrast, aluminum is five times heavier than lithium. A freshly cut lithium chunk is silvery, but it is so active that it tarnishes when exposed to air. Lithium does not occur in nature in the native state, although it is readily available in compounds. Some natural spring water has lithium in it, and the mineral water is consumed for its supposed health benefits. Lithium metal can catch fire if it is sprayed with water or sometimes just by being in moist air.

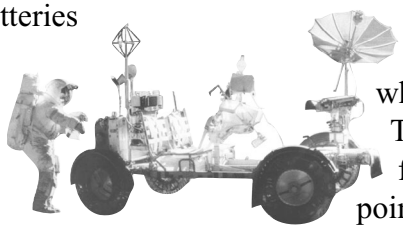
Johan August Arfvedson of Sweden is generally considered to have discovered lithium. In 1817, he ran tests on a mineral and removed all the known elements. Despite repeating the tests, he could not account for about four percent of its weight. Somehow, an element was slipping through his experiments. Arfvedson showed that the mystery element was a strong base but was lighter than sodium or potassium. He did not isolate free lithium, but the experiment convinced other chemists that a new metal did exist. A few months later, Humphry Davy freed the metal by electrolysis. As the discoverer of the new element, Johan Arfvedson could name it. Both sodium and potassium came from the ash of plant life, from matter that had once been alive. Arfvedson's new element came from a mineral, a type of stone that had never been alive. To call attention to this difference, he made the name lithium from *lithos*-, the Greek word for *stone*. He used the ending *-ium* to show that it is a metal.

Lithium, when heated red hot, will unite with hydrogen to form lithium hydride (LiH), a solid. A small amount of lithium is capable of combining with tremendous volumes of hydrogen. One kilogram of lithium hydride contains almost 3,000 liters of hydrogen. Sometimes the compound is used to transport hydrogen. During the early days of airflights across the Atlantic Ocean, pilots carried lithium hydride pellets as portable hydrogen generators. If their planes went down in the ocean, the pilots mixed the

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pellets with water and the reaction released hydrogen. The gas inflated lifeboats and balloons. The pilots used the balloons as signals or to carry aloft radio antenna for emergency broadcasts.

Compact and lightweight lithium batteries can produce an exceptional amount of current. Lithium batteries powered the lunar rover, a golf cart sized vehicle that carried the astronauts across the surface of the moon in the 1970s. Astronauts traveled about 60 miles in lunar rovers. Many cameras use lithium batteries because they are lightweight, generate power even in cold weather and have a long shelf life. Some batteries run down even when they are not being used. Lithium batteries, however, can be inactive for years and retain their full energy.





Because of its distinctive red light when burning, lithium is used in fireworks. The next time you observe a holiday fireworks display, impress your friends by pointing out that you are "enjoying the display of applied lithium."

Life Principle



"I like living.
I have sometimes
been despairingly
miserable, racked
with sorrow, but
through it all
I still know that
just to be alive
is a grand thing."

—Agatha Christie

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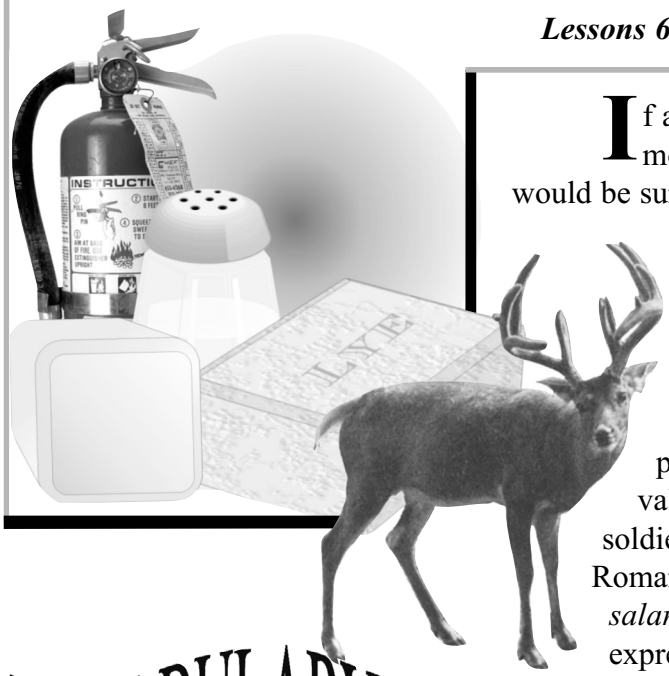
Chapter 5

Lesson 9
Elements

SODIUM

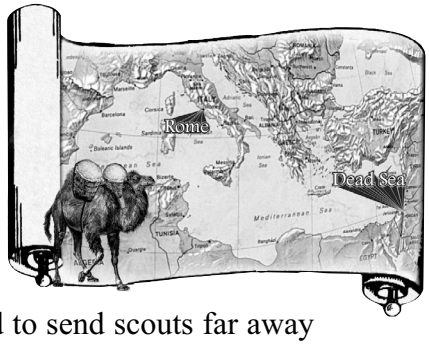
Section 2

Lessons 6-10



If a citizen of ancient Rome could come to a modern American city during the winter, he would be surprised. He would see money dumped on the streets. Street crews clear snow and ice by spreading salt on the slippery streets. Salt lowers the freezing point, the snow melts, and cars splash the slush from the pavement. People today think nothing of dumping salt on streets and sidewalks — but ancient people had few sources of salt, and it became valuable. Salt was even used for money. Roman soldiers received part of their pay in salt. The Roman word for salt, is *sal*, the root word for *salary*. The value of salt is illustrated by the expression, "He is worth his salt," which is a reference to those soldiers and other workers who earned their salaries in salt.

Two thousand years ago, the Via Salarium, an important highway in Italy, was the first highway to bring salt from the seaport at Ostia to the capital city of Rome. *Via Salarium* means *Road of Salt.* At Ostia, Romans evaporated seawater to give salt. The Romans channeled water from the Mediterranean Sea into shallow lakes. Heat from the sun evaporated the water and left behind ***brine***, a thick mixture of salt and water. Romans drained the brine into smaller pans, where the remaining water dried away.



About 400 A.D. the sea level near Ostia changed, and the salt beds became flooded. Rome had to send scouts far away from home in search of other sources of the mineral. Rome reclaimed salt by evaporation from the Dead Sea in Palestine. The Dead Sea held six times as much salt as the Mediterranean

VOCABULARY

Brine: seawater with concentrated salt
Salt dome: an underground deposit of nearly pure salt
Sodium (Na): a light, soft metal that reacts vigorously with water
Sodium chloride (NaCl): the most common sodium compound
Sodium carbonate (Na_2CO_3): a base, used as a general cleanser
Sodium bicarbonate ($NaHCO_3$): a weak base used in fire extinguishers and in baking, also known as baking soda and bicarbonate of soda

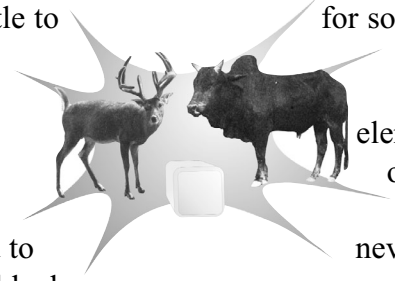
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Sea. Caravans carried the salt back to Rome. A typical caravan had a thousand camels, each carrying 500 pounds of salt.

Salt is abundant in some places in North America. The Bonneville Salt Flats in Utah is a dried lakebed. This vast bed of salt extends for miles in every direction. It is so flat that automobiles set speed records on its surface. Louisiana and Texas have huge underground deposits of nearly pure salt. Salt from these ***salt domes*** can be mined, crushed and packaged for market with no other treatment.

Common table salt (NaCl) is the best known and most abundant of any of the sodium family compounds. Salt does more than flavor food; humans need salt in their diets. Protein cannot be dissolved by water alone. Salt helps dissolve protein, which is then carried by blood to the rest of the body.

Livestock and wild animals need salt just as humans do. Farmers put salt blocks in the barnyard for their cattle to lick. Deer and other wild animals travel to natural salt licks. Animals who cannot find salt will risk danger to obtain it. Deer will jump into a barnyard to share the livestock's salt block.



In Africa, explorers came across a cave that had been dug into a mountain. The explorers saw no human footprints. The explorers discovered that elephants had entered the cave and used their tusks to scoop out the natural salt formation. Elephants in search of salt had dug the cave.

Today, about 225 million tons of salt are used each year. That is about 90 pounds per person; however, only a small part of that amount is consumed with food. The average person takes in about 1/4 ounce of salt in his or her diet each day. Most salt is used for other purposes such as preserving meat. Salt removes water from meat and thus prevents bacteria from spoiling food.

Salt is the source of ***sodium***, a highly active metal. After Humphry Davy's success in extracting potassium from potash, Mr. Davy turned his powerful battery to other compounds that chemists believed contained new metals. In the same week that he freed potassium from potash, Humphry Davy freed sodium from very dry soda ash. Mr. Davy named the metal by taking the first three letters of soda ash and attaching the suffix *-ium* to show that it is a metal. The chemical symbol for sodium (Na) is based on *natron*, an Old French word for sodium carbonate.

Sodium is the seventh most abundant element and makes up about 2.5 percent of the earth's crust by weight. Like the other sodium family metals, sodium is never found in the native state but is common in combination with other elements. Separating sodium from other elements by chemical means is just as difficult today as it was in Davy's time. Sodium metal today is prepared by electrolysis, the same method Davy used. Molten salt is used rather than soda ash. A powerful electric current flowing through the salt causes it to melt, thereby releasing the sodium. The pure metal is so reactive it must be kept out of contact with air or compounds containing oxygen. Sodium explodes when dropped in water. Sodium does not react with hydrocarbons, so it is stored in kerosene. Only limited uses have been found for sodium metal by itself.

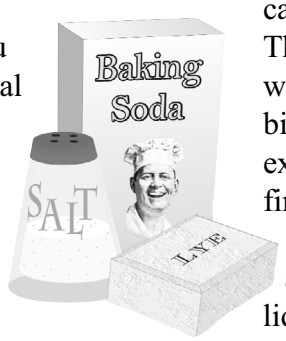
VOCABULARY

Sodium hydroxide (NaOH): a strong base that will neutralize acids
Dissociate: to separate or come apart, to break into smaller parts

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Sodium vapor streetlights use the metal. The yellow glow is especially effective in areas where fog is common because sodium vapor light can penetrate further than regular light. In chemical laboratories, sodium is used to guarantee that reactants do not have impurities containing water or oxygen. Sodium is introduced to react with the oxygen and remove it.

The compounds of sodium are far more important than the pure metal. The best known compounds of sodium are ordinary table salt (***sodium chloride***, NaCl), soda ash (also known as washing soda), ***sodium carbonate*** (Na_2CO_3), baking soda ***(sodium bicarbonate***, $NaHCO_3$) and caustic soda (also known as lye or ***sodium hydroxide***, NaOH). Compounds with a variety of names can be confusing, which is why chemists prefer to use the scientific names and formulas for compounds. You will want to learn the chemical formulas for the compounds discussed in the next few paragraphs.



Sodium hydroxide (NaOH) is a strong base and inexpensive to produce. Sodium hydroxide will neutralize acids. The hydroxyl group (OH^-), of the base combines with the hydrogen ion (H^+), of the acid to give water. Some grease molecules are a type of acid that sodium hydroxide breaks apart. When sinks become clogged with solid grease, sodium hydroxide poured into the drain will break up the grease so water will flow again. *Sodium hydroxide* is also known by two older names—*lye* and *caustic soda*. Sodium hydroxide (NaOH) is used to make soap. In the early American colonies, and until the middle of the 1900s, many farm families made their own soap. The process began by mixing animal fats collected from the drippings of cooked meats with sodium hydroxide from wood ashes. The fats contain a type of acid, and the sodium hydroxide is a base. When they react, the result is soap, a type of salt.

Sodium carbonate (Na_2CO_3) is a base; however, it is not as strong as sodium hydroxide. Sodium carbonate ***dissociates*** in water to give carbon dioxide and sodium hydroxide. Soft drinks contain carbon dioxide dissolved under pressure in water. When the bottle is opened, and the pressure is removed, the carbon dioxide bubbles out of the solution. Soda water and soda pop are improperly given those names. No soda is in them, but sodium compounds, such as sodium carbonate were originally used to provide the carbon dioxide.

Sodium bicarbonate ($NaHCO_3$) is also a base but still weaker than either sodium carbonate or the powerful sodium hydroxide. The reaction of sodium bicarbonate with water also produces carbon dioxide. Sodium bicarbonate is used in fire extinguishers. Fire extinguishers differ depending on the type of fire they are designed to extinguish. Fire extinguishers that contain sodium bicarbonate are for fires that involve flammable liquids such as oils and grease. In use, they generate carbon dioxide gas. Carbon dioxide is heavier than air and suffocates a fire by pushing aside the oxygen needed to keep a flame burning.

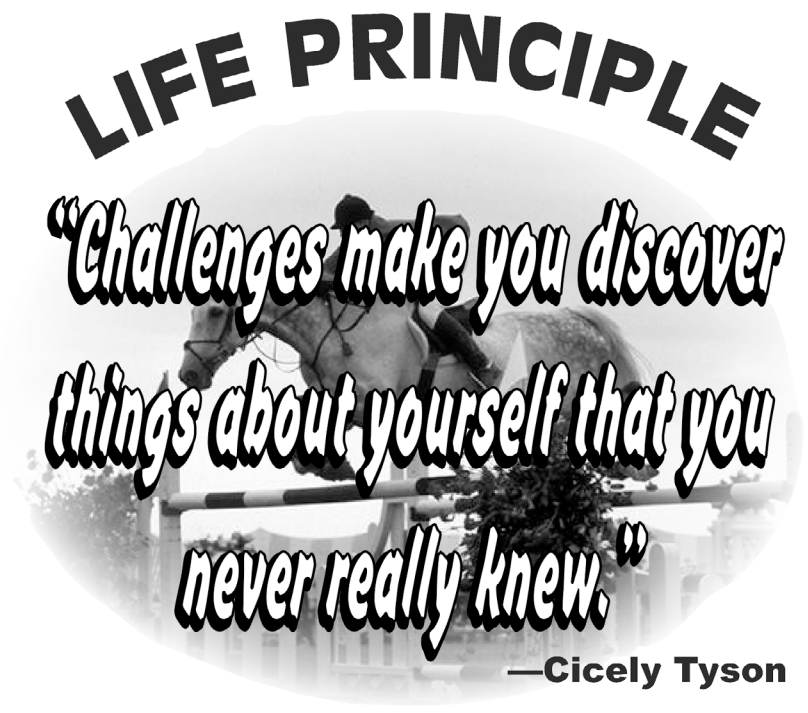


Sodium bicarbonate is a weak base used by people who suffer from gas pains or acid stomachs. In the stomach, sodium bicarbonate neutralizes some of the acid. A side effect is the production of carbon dioxide gas that escapes by way of a belch. Sodium bicarbonate is also known as bicarbonate of soda and baking soda. Bread is given a light and fluffy texture by bubbles of carbon dioxide gas.

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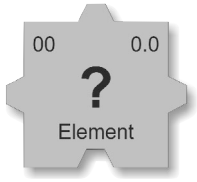
Either yeast or sodium bicarbonate can generate carbon dioxide gas. Yeast is a tiny living organism. Yeast dough must be set aside for a time to let the yeast grow and multiply. Using sodium bicarbonate takes less time than yeast because the bread does not have to rise. When bicarbonate of soda is mixed with plain flour along with a fatty acid such as shortening or milk, the reaction produces carbon dioxide. Self-rising flour has the baking soda premixed.

Sodium compounds have the advantage over other members of the sodium family of being more common and therefore cheaper. For instance, where a strong base is needed, sodium hydroxide (NaOH) is preferred over potassium hydroxide (KOH). Sodium hydroxide is cheaper and weight for weight is a more abundant source of hydroxide ions. The atomic weights are *Na*= 23.0, *K*= 39.1, *H*= 1.00, *O*= 16.0. The molecular weight is the sum of the atomic weights of the atoms found in the molecule. The molecular weight for sodium hydroxide (NaOH) is 23.0 + 16.0 + 1.00 = 40.0. The molecular weight for potassium hydroxide (KOH) is 39.1 + 1.00 + 16.0 = 56.1. Sodium hydroxide weighs only 71 percent as much as potassium hydroxide, but it contains the same amount of hydroxide ions. In other words, a smaller amount of sodium hydroxide will produce the same amount of *OH* molecules.



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Integrated Physics & Chemistry



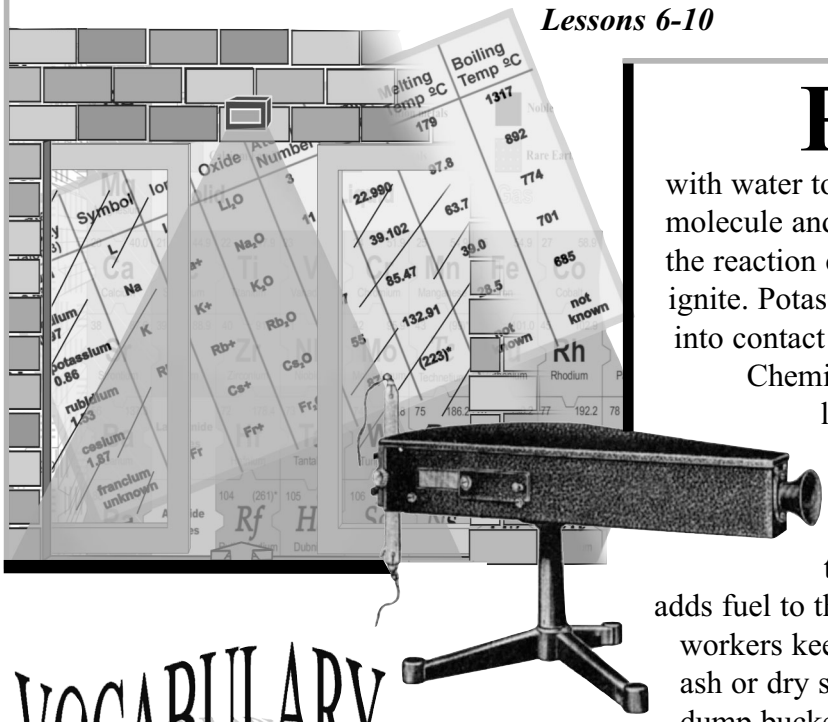
Lesson 10
Elements

Chapter 5

THE SODIUM FAMILY OF METALS

Section 2

Lessons 6-10



Potassium sets water on fire. Pure potassium reacts rapidly with water to strip oxygen from the water molecule and free hydrogen gas. The heat of the reaction causes the hydrogen gas to ignite. Potassium that is accidentally brought into contact with water burns vigorously.

Chemists dread a potassium fire in their laboratory. One reason is that once the reaction begins, the fire is difficult to extinguish. The first thought — to douse the burning metal with water — adds fuel to the reaction. Instead, laboratory workers keep buckets filled with salt, soda ash or dry sand on hand. Laboratory workers dump buckets of sand to smother the burning potassium. After the fire is out, chemists may be questioned about the use of the sand. Custodians who clean up shake their heads at chemists who clog sink drains by using sand to put out a fire, when an abundant source of water is readily available. Custodians may not understand that potassium fire cannot be put out with water, but now you know why sand is used.

Potassium (K) was the first member of the ***sodium family*** of elements to be discovered. Humphry Davy freed it in 1807 from potash. *Potash* is potassium carbonate (K_2CO_3). Davy coined the name potassium by taking the first five letters of potash and adding the suffix -*ium*, to indicate metal. The symbol is *K* from a Latin (Roman) word for ***alkali***. An alkali is a base. Potassium makes compounds that are strong bases. Like sodium, potassium is never found free in nature. Potassium is common in combination with other elements. It is abundant in minerals such as feldspar ($KAlSi_3O_8$). Feldspar is part of granite rock. The formula shows that it contains one potassium atom, one aluminum atom, three silicon atoms and eight oxygen atoms.

VOCABULARY

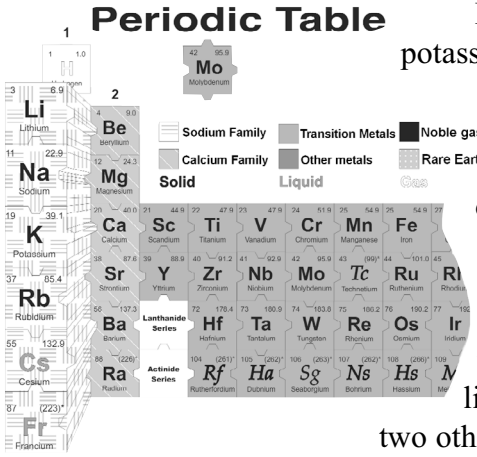
Sodium family: the elements lithium, sodium, potassium, rubidium, cesium and francium are soft, light (low density), melt at low temperatures compared to most other metals, cause burns if touched, react with oxygen in the air and are never found free in nature

Alkali: a base (the opposite of an acid), the sodium family of elements reacts explosively with water to make strong bases

Spectroscope: a device that identifies elements by the brightness and location of colored lines in their spectrum

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Potassium hydroxide (KOH) produces a soap that is softer than one made from sodium hydroxide (NaOH). Potassium carbonate (K_2CO_3) can be used in the manufacture of glass. Most glass is made with sodium carbonate (Na_2CO_3), but glass made with potassium carbonate reflects light more evenly and is preferred for some optical instruments. Potassium nitrate (KNO_3) is used to manufacture gunpowder. Potassium is essential for good plant growth. Potassium compounds are plentiful in the soil, but as plants grow and are harvested, the potassium is removed. Eventually the land becomes depleted, and chemical fertilizers must replace the potassium.



VOCABULARY

Photoelectric effect: emission of electrons from a metal by light that falls on its surface, rubidium and cesium display the photoelectric effect

Radioactive: an element that emits subatomic particles or very high energy electromagnetic waves

Valence: a number assigned to an element based on the number of electrons it donates, accepts or shares during a chemical reaction

Isotope: one of two or more atoms having the same atomic number (number of protons) but different atomic weights due to different number of neutrons, isotopes are located at the same place on the periodic table, they have the same chemical properties but may have slightly different physical properties

Lithium (Li), sodium (Na) and potassium (K) were discovered by electrolysis. The next two elements in the sodium family, rubidium (Rb) and cesium (Cs) were discovered with the ***spectroscope***.

Light from sodium passes through a spectroscope and produces two very distinctive yellow lines that are close together. Light from lithium has four lines, two that are intensely red and two others in green and blue that are less bright. Even when viewed in black and white, the number and position of the bright lines identify the element.



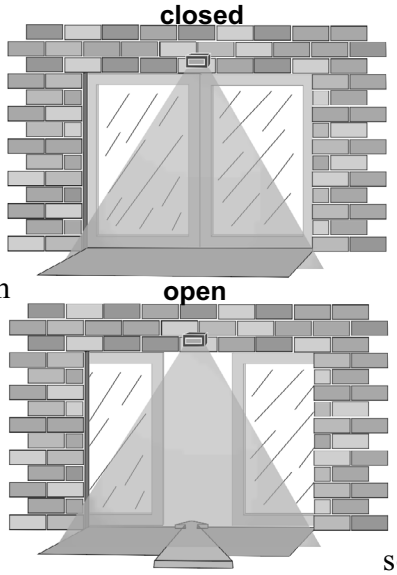
Cesium (Cs) was discovered in 1860 when scientists saw two blue lines that did not match any other known element. *Cesium* means *sky blue*, the color of the lines. Cesium gives up an electron more readily than any other element. Cesium hydroxide (CsOH) is the most powerful base known. (Francium, the last member of the sodium family metals, may exceed cesium in this regard, but it is extremely radioactive and almost nonexistent in nature. Francium is not available for any practical use.) Cesium has a melting temperature even lower than rubidium. Cesium melts at 28ºC (82ºF). The body heat of a person's hand would melt it. However, it would have to be in a safe container because it would react violently with the oxygen in human flesh. When molten, cesium looks like mercury. Mercury is the only metal with a lower melting temperature. Rubidium (Rb) was discovered one year later. *Rubidium* revealed its presence with a very distinctive, ruby-red color spectral line. Its name comes from the Latin (Roman) word *rubidus,* meaning *red*. Rubidium is not found in the native form. It

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is rarer than sodium or potassium and unlike those elements, it is not found in large deposits as chlorine compounds. It does occur as an ion in small amounts in mineral waters. Rubidium has a low melting temperature — only 39ºC (about 102ºF). On a warm day, a block of rubidium would melt on a hot pavement. If exposed to air, it will immediately catch fire as it reacts with the oxygen in the air. Rubidium is found in trace amounts in living things, especially tea, coffee and tobacco. It may be required for the life processes of those plants.

The number of electrons in a sodium family element varies from 3 for lithium to 87 for francium. In every case, one of the electrons orbits far from the nucleus. The electron is lightly held and can easily wander away. Electrons escape very easily from rubidium and cesium. Light alone is sufficient to give the electrons enough energy to fly away from the atom. This process is called the ***photoelectric effect***.

Light meters in cameras measure the level of the light by the number of electrons that escape from a cesium cell. The first electric eyes installed to open doors automatically were based on the photoelectric effect using cesium. A beam of light crosses the threshold of the door to land on a cesium photocell. A person whose body blocks the light beam interrupts an electric current generated by the cesium, causing an electric motor to open the door.



Elements that appear to have no particular use may surprise chemists as the years pass. Uranium, for instance, was practically ignored for a hundred years until its ***radioactive*** nature was discovered. Cesium could become important as a futuristic fuel for ion drives.

According to Newton's Third Law of Motion, the forward motion of a rocket is possible only by shooting something out in the opposite direction. Most rocket motors develop thrust by sending out hot gases. The faster the gas molecules expand backward, the faster the rocket accelerates forward. The faster the hot molecules fly from the motor, the greater the thrust. An ion drive uses electricity and ions rather than fuel and hot gases. The electricity, which could come from a nuclear reactor, expels charged particles such as cesium ions (Cs^+) out the back of the rocket at speeds approaching the speed of light. Although cesium ions are composed of small mass, their extreme velocity can accelerate the rocket. In 1998, NASA launched an unmanned spacecraft that developed its thrust from an ion drive. It was the first of its type to operate in space. A regular rocket would have to burn ten times as much fuel to accelerate to the same speed.

Cesium is used in *atomic clocks*. Ordinary cesium atomic clocks are accurate to one second in 60 years. The very best of the clocks are expected to keep time to within a second for centuries. Atomic clocks are accurate enough to prove that the earth is slowing in its rotation about its axis.

Francium, the last member of the sodium family metals to be discovered, is radioactive and extremely rare. *Radioactive* means that it releases high-energy waves. Francium was detected by its radioactive emissions.

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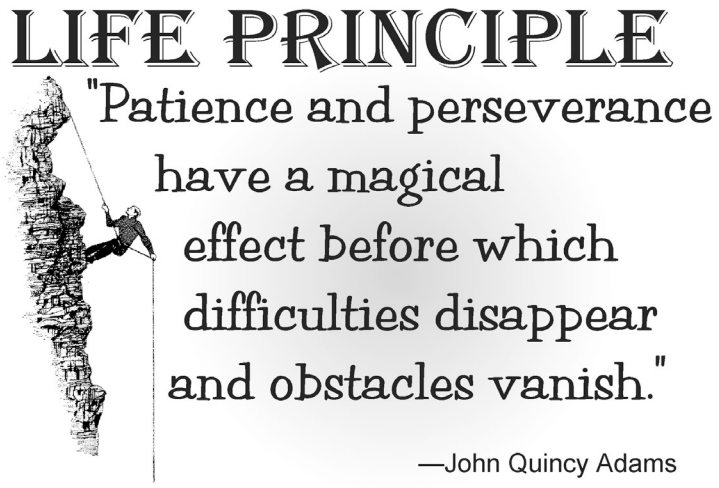
The table below gives information about the properties of the sodium family of metals. Notice that all members of the sodium family of metals have a ***valence*** of +1. *Valence* is the number of electrons an element will exchange or share. All of the sodium metals are especially willing to give up one electron when they become ions or when reacting with other elements. Sodium metals form ions with a single positive charge. Their compounds with oxygen take two metal atoms for each oxygen atom.

The table also shows how chemists can predict information about elements. From the table, chemists can predict that the melting temperature of francium is about 27ºC and the boiling temperature would be about 677ºC. Chemists would predict that density of francium is about 2.00 g/cm^3.

Sodium Family of Metals

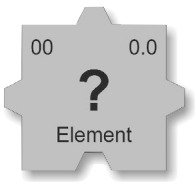
Name Density (g/cm3)	Symbol	Ion	Oxide	Atomic Number	Atomic Weight	Melting Temp ºC	Boiling Temp ºC
lithium 0.53	Li	Li+	Li_2O	3	6.939	179	1317
sodium 0.97	Na	Na+	Na_2O	11	22.990	97.8	892
potassium 0.86	K	K+	K_2O	19	39.102	63.7	774
rubidium 1.53	Rb	Rb+	Rb_2O	37	85.47	39.0	701
cesium 1.87	Cs	Cs+	Cs_2O	55	132.91	28.5	685
francium unknown	Fr	Fr+	Fr_2O	87	(223)*	not known	not known

* The atomic weight of francium is given in brackets to show that it is radioactive. The atomic weight is of francium's most stable ***isotope***. All isotopes of the same element have the same number of protons in the nucleus, but have a different number of neutrons.
** Density of water is 1.00 g/cm^3. Elements with a density less than 1.00 g/cm^3 will float in water.



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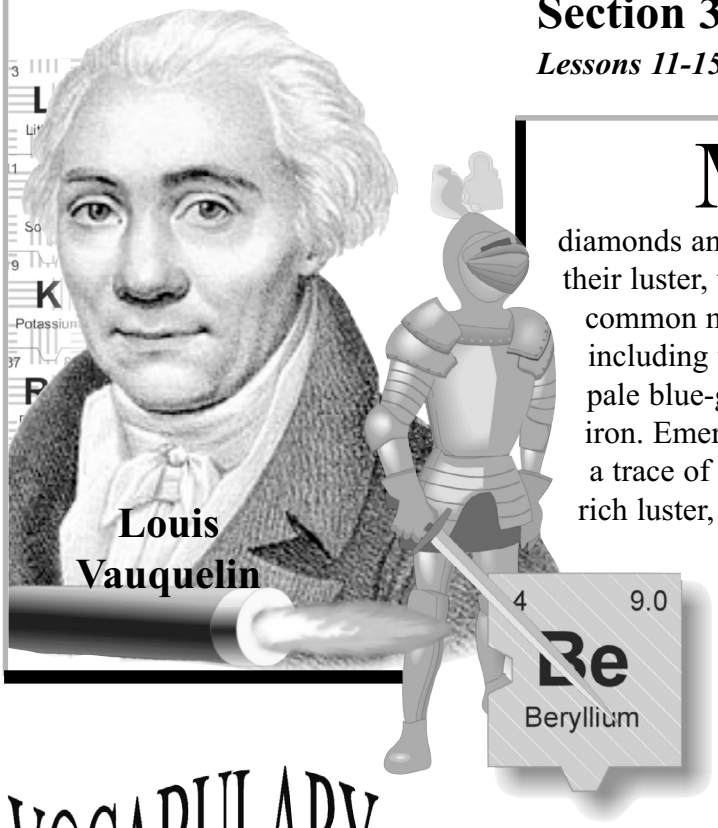
Lesson 11
Elements

Chapter 5

BERYLLIUM AND MAGNESIUM

Section 3

Lessons 11-15



Minerals take many forms, from ordinary table salt to gems such as diamonds and emeralds. Gems are prized because of their luster, transparency, color and hardness. One common mineral is ***beryl***. It has many forms, including two beautiful gemstones. Aquamarine, a pale blue-green gemstone, is beryl with a trace of iron. Emerald, a rich green gemstone, is beryl with a trace of chromium. People prized emerald for its rich luster, purity of color and light brilliance. When Queen Cleopatra ruled Egypt, emerald was mined in the Nubian Desert. Camel caravans carried emerald to the Red Sea, from where the gems were shipped throughout the Roman empire. Fifteen hundred years later, when the Spanish Conquistadors came to South America, they found natives with emeralds. The Spanish searched for years until they found the secret locations of the mines in Colombia, South America.

Beryl contains ***beryllium*** (Be) and aluminum (Al) in combination with silicon oxide. Several chemists studied beryl ($Be_3Al_2Si_6O_{18}$) but did not detect beryllium. In the 1700s, the chemical analysis of a compound was difficult and time consuming. Chemists analyzed a new compound by separating each of the suspected elements. The compound was reacted with a variety of elements such as oxygen, sulfur or carbon, or was treated with acids or bases. Chemical analysis required great patience without any real guarantee that the result would be worth the effort. Chemists turned the details of analyzing a compound over to students and laboratory assistants. Chemists did not check the analysis of beryl by lab assistants, and that lack of oversight delayed the discovery of beryllium for many years.

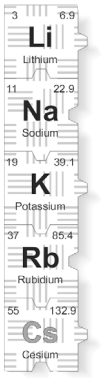


VOCABULARY

Beryl: a translucent mineral that is the chief source of beryllium, some forms of beryl are classified as gemstones
Beryllium (Be): the lightest metal in the calcium family, used as lightweight body armor and alloys
Magnesium (Mg): metallic element, discovered in 1808 by Humphry Davy, noted for its use in lightweight alloys and the bright light it generates when burning

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In 1797, Louis Vauquelin, a French chemist, convinced others that beryl contained a new element. He isolated the oxide of beryllium and determined enough of its properties to be given credit for its discovery. Vauquelin analyzed seven different procedures, some requiring 15 distinct steps. He did not free the element itself. More than thirty years passed before beryllium was freed from its compounds. Another 100 years passed before beryllium became available in commercial quantities.



For many years, chemists confused beryllium with aluminum, which is also in beryl. Chemists arrived at the wrong valence and atomic weight for it. In 1869, Dmitri Mendeleev worked out the Periodic Table of the Elements. Dmitri Mendeleev became convinced that beryllium's valence and atomic weight were in error. Dmitri Mendeleev correctly gave it a valence of +2.

Beryllium is a member of the calcium family: beryllium, magnesium, calcium, strontium, barium and radium. Like the sodium family, members of the calcium family are active metals. One essential difference is the valence. All of the sodium family metals have a valence of +1, while all of the calcium family metals have a valence of +2. Beryllium is the lightest and least metallic of the calcium family. Beryllium is not as likely to give up electrons and does not react as vigorously with oxygen. In the pure form, it is quite hard and brittle. Beryllium is lightweight because it has a low density of 1.85 gm/cm^3. Despite being lightweight, beryllium is strong. It is used as an alloying material. Some body armor is made of beryllium alloy because of its strength and lightness. It also has a high melting temperature, 1,285ºC (2,345ºF). Beryllium is used wherever weight and heat resistance are important, such as the metal skin of rockets. Heavy metals stop X-rays, but lighter metals allow X-rays to pass through them. Beryllium is especially light, and X-rays can pass right through a window made of beryllium. No other metal allows X-rays to pass so easily. Beryllium has replaced aluminum as the window in X-ray machines. When the windows were of aluminum, the machines had to operate at 17 times as much power to generate the same amount of X-rays.



Perhaps you have passed an automobile accident or seen a big rig that has broken down and cannot get completely off the highway. In some states, police warn motorists of a problem such as an accident or disabled truck by putting out flares. Most flares are made with ***magnesium (***Mg) and burn with a brilliant flame.



Magnesium will burn in air. The heat of a match is enough to set magnesium

VOCABULARY

Hydrate: a solid that contains water molecules in definite proportions as part of the compound, also known as water of crystallization

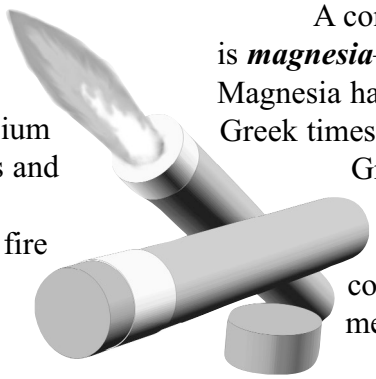
Magnesia: the natural mineral magnesium oxide (MgO) from which Davy extracted magnesium

Chlorophyll: the compound in plants that is essential for photosynthesis, a molecule of chlorophyll contains a single magnesium atom $C_{55}H_{72}MgN_4O_5$

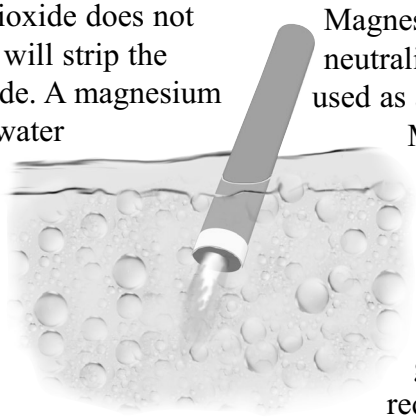
Photosynthesis: the process by which green plants convert carbon dioxide and water into carbohydrates with light as the energy source

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aflame. A ribbon of magnesium burns with a brilliant white light. Finely divided magnesium burns even more quickly and more brightly. In the early days of photography, photographers used magnesium as flash powder to provide light during photographic exposures. Magnesium is still used in flares, firecrackers and firebombs.



Putting out a magnesium fire is very difficult. Most fire companies know the best course of action when encountering a magnesium fire is to let it burn out. Once it begins burning, the extra heat makes magnesium especially active. When magnesium burns the oxygen in the atmosphere, it continues to burn by reacting with nitrogen. Smothering burning magnesium with carbon dioxide does not work because magnesium will strip the oxygen from carbon dioxide. A magnesium fire will not go out when water is put on it. Burning magnesium takes oxygen from the water and continues to burn. A magnesium flare will burn underwater.



One compound of magnesium is known as *Epsom salt*. Outside the village of Epsom in southeast England, a spring gave bitter tasting water. A farmer noticed that it seemed to heal scratches and rashes. Epsom salt acts as a mild antacid and a laxative when taken internally. Eventually, the spring water became the source of Epsom salt that was sold for medical properties. Epsom salt is magnesium sulfate ($MgSO_4$) in chemical union with seven water molecules. As a solid compound, Epsom salt contains water molecules in definite proportions as a necessary part of the compound. Such a chemical in which water is part of the chemical formula is a ***hydrate***. As you know, *hydro-* means *water*. The formula for Epsom salt is $MgSO_4(H_20)_{7.}$

A common compound of magnesium is ***magnesia***—magnesium oxide (MgO). Magnesia had been known since ancient Greek times. It came from Magnesia, a Greek province. Humphry Davy used his powerful batteries to separate a new metal from the compound magnesia. The new metal became known as magnesium.

Several medical uses of magnesium have been found. Reacting magnesium carbonate with citric acid gives magnesium citrate, which is used in medicine and effervescent beverages. Magnesium hydroxide is $Mg(OH)_2$. Magnesium hydroxide is better known as Milk of Magnesia. It is a mild base, so it will neutralize an acid. Magnesium hydroxide is used as an antacid and a laxative.

Magnesium is an important element for plant and animal life. An adult has about 21 grams (0.75 ounce) in the human body, mostly in the bones. Although found only in trace amounts, magnesium is essential for good health. The adult human requirement of magnesium is about one third of a gram each day. Plants also require magnesium. All green plants contain ***chlorophyll***. With chlorophyll, plants can use the energy of the sun to change carbon dioxide and water into carbohydrates, the building material of plant cells. This process is called ***photosynthesis***. Chlorophyll is made of a large number of atoms, all but one of them are nonmetallic. At the very heart of the chlorophyll molecule is one atom of magnesium: $C_{55}H_{72}MgN_4O_5$.

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Magnesium oxide (MgO) is the second most common compound in the crust of the earth. Magnesium is the eighth most abundant element. Magnesium occurs in nature only in chemical combination with other elements. One such compound is the building stone dolomite, $CaMg(CO_3)_2$, a double carbonate of magnesium and calcium.

Despite its abundance on land, most magnesium is extracted from seawater. A thousand kilograms of seawater (about 264 gallons) contains about 5.44 kilograms of magnesium salts from which magnesium can be extracted. Magnesium chloride ($MgCl_2$) is separated from seawater, and then the magnesium is freed by electrolysis. The chlorine leaves as a gas. What remains is a very pure form of magnesium metal. About 1.4 kg of magnesium can be produced from 1,000 kg of seawater. This lesson has informed you about chemicals and elements used in household products. You are beginning to understand that physics and chemistry affect many aspects of your life.

LIFE PRINCIPLE



"Ideas without action are worthless."

— Harvey Mackay

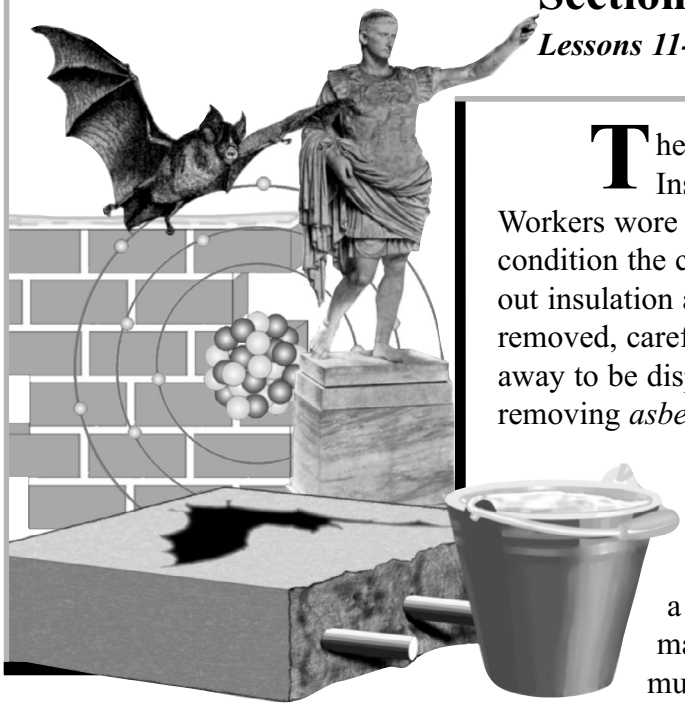
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Chapter 5

Lesson 12
Elements

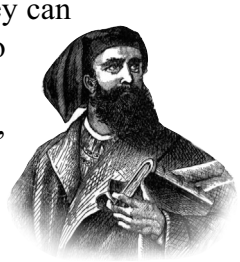
MAGNESIUM AND CALCIUM

Section 3
Lessons 11-15



The school building was closed and empty. Inside, plastic sheets covered the walls. Workers wore white suits with helmets that had filters to condition the contaminated air. The workers were ripping out insulation above the ceiling. The insulation was removed, carefully placed in sealed containers and carried away to be disposed of safely. The workers were carefully removing *asbestos*.

When Marco Polo returned from his trip to China, he told of many sights, including a rock that would burn (coal) and a fabric that would not burn (asbestos). *Asbestos* is a mineral that has long silky fibers of magnesium silicate. Some of the fibers are as much as three inches long. They can be spun and woven into fabric to make fireproof cloth. Asbestos has many desirable features, including being fire resistant, having a high melting temperature and being a good heat insulator. Asbestos was used for years in a variety of applications such as shingles, as an insulating covering for steam pipes and furnaces and as automobile brake linings. Asbestos was used in many structures, including hospitals and school buildings. Late in the 1960s, medical researchers found that asbestos can cause lung cancer. Today, asbestos usage in the United States is severely restricted by law. In some structures, the asbestos material is breaking down and must be removed at great cost.



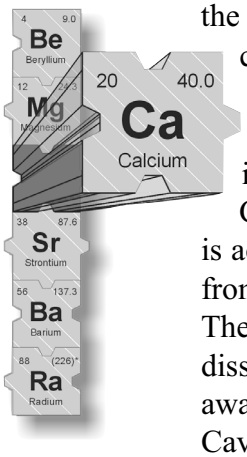
Talc is another naturally occurring magnesium mineral. It is a soft substance and feels slick to the touch. In powdered form, it is manufactured as talcum powder. Talc is a complex molecule containing magnesium, silicon, oxygen, and the hydroxyl group: $Mg_3Si_4O_{10}(OH)_2$.

VOCABULARY

Talc: a soft, slick mineral that contains magnesium, the source of talcum powder
Calcium: an abundant, highly active metallic element, never found free in nature but in combination with other elements, found in limestone and gypsum, and in the bones and teeth, its compounds make lime, cement, mortar and whitewash
Acid rain: rainwater that has become acidic because of pollutants such as sulfur in the air

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Beryllium and magnesium are the two lightest of the calcium family metals. The next member of the family is ***calcium***. Calcium (Ca*)* is abundant in the crust of the earth. Calcium is the fifth most abundant element and the third most abundant metal in the crust, yet it was not discovered until the 1800s.



An individual might think that the most common elements would be discovered first, but that is not the case. Gold, for instance, was known in ancient times, yet it is a rare element. The advantage of gold is that it is found free in nature in its native state. All of the calcium family of metals are found locked in compounds with other elements.

Calcium was not separated from its compounds until 1808. Humphry Davy attached his powerful battery to a compound of *CaO*. The mixture conducted electricity, grew hot enough to melt and then electrolysis freed the calcium. Calcium is a metal, silvery color and rather hard. Its name comes from the Latin word *calx,* meaning *lime.* The chemical symbol is *Ca*. Calcium gives its name to the calcium family of elements. These elements, in order of increasing atomic weights, are beryllium, magnesium, calcium, strontium, barium and radium. All of the calcium metals form ions with a double charge: Ca^{++}. This double charge makes a strong bond with elements such as oxygen and chlorine.

Calcium forms many compounds. One of the most useful compounds is with the carbonate group (CO_3^{--}). Limestone, calcium carbonate ($CaCO_3$), is used in the construction industry. Calcium carbonate can occur in a variety of other forms, including marble, calcite and chalk.

Calcium carbonate dissolves in water that is acidic. Rainwater absorbs carbon dioxide from the air and then seeps through the soil. The rainwater becomes a very weak acid that dissolves calcium carbonate. It is washed away to produce limestone caves. Mammoth Cave in Kentucky and Carlsbad Caverns in New Mexico were produced by water that dissolved limestone. Mammoth Cave and Carlsbad Caverns contain beautiful limestone formations. When the water containing calcium evaporates, solid calcium carbonate remains. A *stalactite* is a rock formation that grows down as water seeps through the roof of the cave. The droplets of water evaporate and leave calcium carbonate as a deposit. If the water seeps through quickly, droplets may fall to the floor of the cave. They begin the growth of a limestone formation from the floor up. The stalagmite growing from the floor may reach the stalactite growing from the ceiling and connect as a solid column. The column reaches from floor to ceiling as if it is holding up the roof of the cave. The walls, ceiling, floor and formations in the cave are all of limestone, calcium carbonate ($CaCO_3$). Pure calcium carbonate is white. Often, however, impurities give the limestone formations fantastic colors.



Marble is a harder form of limestone.

VOCABULARY

Cement: a mixture of calcium oxide, aluminum oxide and silicates that hardens when water is added

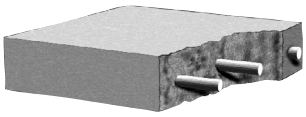
Lime: calcium oxide (CaO) made by heating calcium carbonate ($CaCO_3$)

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Chemists believe marble is formed of limestone that is put under great pressure and heat deep in the earth. Limestone is a *sedimentary rock*, which means that it was made by the gradual buildup of soil. Marble is a *metamorphic rock*, which means that it changed form from one kind of rock (limestone) to another. It is a favorite building material because it can be highly polished. Marble was used extensively by the Greeks and Romans in making their public buildings and temples. It also occurs in a pure white form and is preferred by sculptors for making statues. Marble can last for centuries in a dry climate or one in which the water is not acidic. If the water is the least bit acidic, then the marble slowly crumbles. One common modern pollutant is sulfur. When it combines with rainwater, it forms weak sulfuric acid that is known as ***acid rain***. The start of the industrial revolution in the 1700s increased the amount of sulfur in the atmosphere from the burning of coal. The effect upon the ancient Greek and Roman marble statues was dramatic. More damage has been done to them in the last two hundred years than in the previous two thousand years.

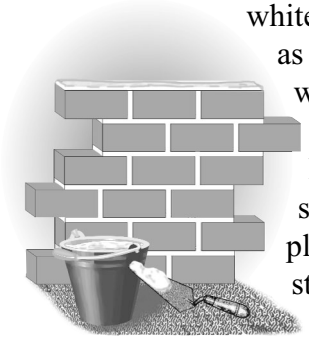


Cement is another useful product of calcium carbonate. It is a mixture of clay and dry limestone. The real advantage of cement is that it will harden under water. It is made stronger by adding sand and crushed stone to create concrete. When concrete is poured around steel reinforcing rods, the result is reinforced concrete, a building material that is both rigid and strong.



Heating calcium carbonate ($CaCO_3$) drives off the carbon dioxide (CO_2). This leaves behind only one calcium atom and one oxygen atom. The result is calcium oxide (CaO), better known by its common name of ***lime***. Many useful compounds can be made from lime, and lime itself is a powder that can be transported. From the time of the Romans, lime has been an important product valued not only for itself but also for the compounds extracted from it. It is used to tan hides, manufacture paper, neutralize acid soil and to make whitewash and mortar.

Whitewash is calcium hydroxide ($Ca(OH)_2$) in water. Unlike sodium hydroxide, calcium hydroxide dissolves only slightly in water and remains in suspension. When the whitewash is painted on wood or stone, carbon dioxide reacts with the calcium hydroxide to produce calcium carbonate. The white calcium carbonate acts as a simple but brilliant white paint.



Mortar is calcium hydroxide mixed with sand and water. Mortar is placed between building stones or bricks. Calcium hydroxide, when exposed to carbon dioxide in the air, changes to calcium carbonate which sets and holds the stones together.

Calcium and all of the metals of its family have a valence of +2. Sodium and all metals of its family have a valence of +1. Understanding valence of sodium compounds allows chemists to predict the formulas for the corresponding calcium compounds. Both the sodium and calcium families form oxides with oxygen, bases with the hydroxyl group, salts with chlorine (and members of its family) and carbonates, sulfates and nitrates. Writing the compounds becomes easier when the valence is known.

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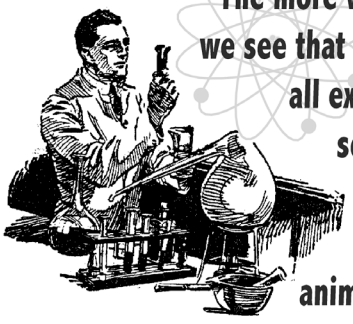
Chlorine and the members of its family (fluorine, bromine, iodine, astatine) have a valence of –1. Oxygen has a valence of –2. Several ions are made of groups of atoms that remain together during chemical reactions. These groups include hydroxyl (OH^-), nitrate (NO_3^-), carbonate (CO_3^{--}), and sulfate (SO_4^{--}). The negative sign shows their valence. OH^- and NO_3^- have a valence of –1, while CO_3^{--} and SO_4^{--} have a valence of –2. Each group of a compound is present in the proper numbers, so the valence adds to zero.

For instance, the sodium ion (Na^+), and the nitrate group (NO_3^-), have the same valence but opposite sign. The +1 valence of sodium and the –1 valence of nitrate result in a molecule with no charge $NaNO_3$. On the other hand, because calcium has a valence of +2, two nitrate groups are required to match the valence of calcium to give calcium nitrate ($Ca(NO_3)_2$). The *2* outside the parenthesis shows that the entire group is repeated.

Contrast and Compare Sodium and Calcium Compounds
Sodium (valence = 1) and Calcium (valence = 2)

sodium compounds	**formula**	**calcium compounds**	**formula**
sodium oxide	Na_2O	calcium oxide	CaO
sodium chloride	$NaCl$	calcium chloride	$CaCl_2$
sodium hydroxide	$NaOH$	calcium hydroxide	$Ca(OH)_2$
sodium carbonate	Na_2CO_3	calcium carbonate	$CaCO_3$
sodium sulfate	Na_2SO_4	calcium sulfate	$CaSO_4$

LIFE PRINCIPLE

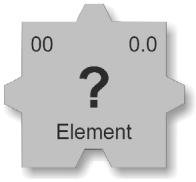


"The more we learn of science, the more we see that its wonderful mysteries are all explained by a few simple laws so connected together and so dependent upon each other, that we see the same mind animating [giving life to] them all."

—Olympia Brown

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Integrated Physics & Chemistry



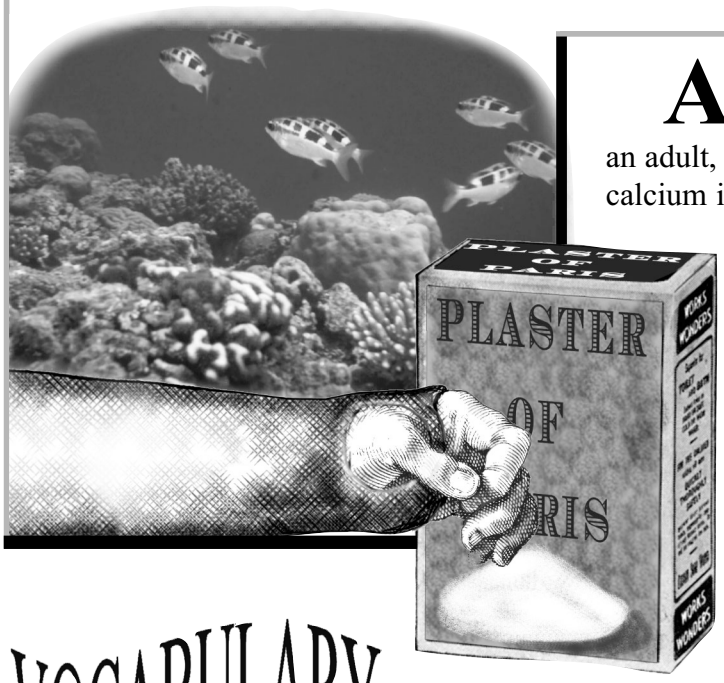
Lesson 13
Elements

Chapter 5

CALCIUM, HARD WATER AND STRONTIUM

Section 3

Lessons 11-15



A human body is supported internally by the skeleton, a framework of bones. In an adult, about one kilogram (2.2 pounds) of calcium is in the teeth and bones. Although bones can endure stress and shock, one common injury is a broken bone. For a broken bone, the treatment is first to set the bone ends so they align and then hold the leg or arm so it cannot move while the bones grow back together. Although doctors have developed various ways to hold fractured bones in place, plaster of Paris casts are commonly used, especially in poorer countries.

Plaster of Paris is made of the same ingredient as the broken bone, calcium. Plaster of Paris is a special form of gypsum which contains calcium sulfate. Because calcium and sulfate (SO_4^-) have the same valence but opposite sign, calcium sulfate has one calcium ion and one sulfate group ($CaSO_4$). Gypsum ($CaSO_4(H_2O)_2$) is a form of calcium sulfate combined with water. To make plaster of Paris, gypsum is heated to drive away some of the water and change the gypsum to a dry powder. When the dry powder is mixed with water, the plaster of Paris collects additional water molecules. It changes back to gypsum and becomes a hard, solid cast. Plaster of Paris came into use around 900 A.D. to hold limbs motionless while the broken bones repaired. Plaster of Paris expands slightly as it takes on water, and this ensures that it fills all parts of a mold. People used it to make copies of small statues. Many art and craft stores carry a variety of molds. People mix water with plaster of Paris and pour it into a mold of a statue or other desired shape. It hardens and is painted or otherwise decorated.

VOCABULARY

Mineral: a naturally occurring compound with a definite chemical composition, crystalline structure, color and hardness

Hard water: water that carries calcium or magnesium ions, hard water can leave behind calcium carbonate deposits that reduce the inner diameter of water or steam pipes

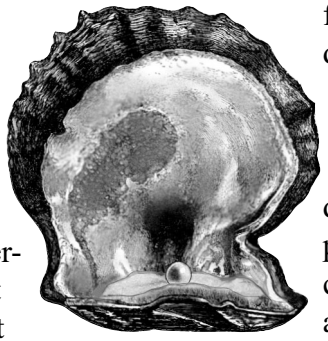
Insoluble: cannot be dissolved by water

Solvent: capable of dissolving another substance, water is an effective solvent

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Gypsum is also used in the manufacture of wall plaster and wallboard. Calcium sulfate makes alabaster. *Alabaster* is snow white with a fine but soft texture. It can be carved into intricate designs.

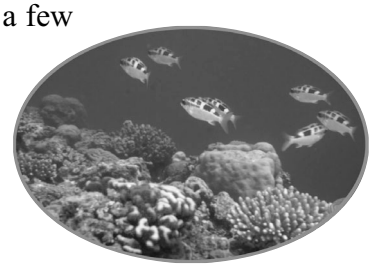
The human body is supported internally by bones. Some animals, such as mollusks, have no internal skeleton. Yet, they still use calcium. The shells of mollusks are made of calcium carbonate. Clams and oysters are types of mollusks. Sometimes a grain of sand or some other irritating particle gets into an oyster. The oyster builds a smooth calcium carbonate sphere around the offending particle. This produces a round lustrous pearl. Pearls are considered gems, although they are not ***minerals***. A mineral refers to a compound that is found in nature and is not made by a living organism. Living oysters make pearls. Perfectly formed pearls can be both beautiful and costly, yet they are made of the same substance that makes eggshells and the shells of the oysters themselves. Mother-of-pearl is a far less valuable form of calcium carbonate. It is cut from the inside of oysters or clamshells. For years, people made buttons by stamping them from the shells of clams. A button or broach made of mother-of-pearl has an iridescent shine and appears to shift colors while viewed from different angles.



VOCABULARY

Strontium (Sr): a member of the calcium family of metals, highly active, used in flares and fireworks because of its scarlet color

The sea creatures known as corals form calcium carbonate skeletons. They grow in warm, shallow waters, adding to the size of a coral reef only a few millimeters a year. Some of the corals grow in beautiful colors and shapes. They can be easily damaged by boat anchors and water pollution.



HARD WATER

The process that causes rock formations to build in caves also causes water pipes to become coated with calcium deposits. ***Hard water*** contains dissolved minerals that fall out as a solid when heated. Hard water makes cleaning with soap difficult. The calcium combines with the soap to form a calcium compound that settles on clothes or in the bathtub and is hard to remove. The calcium and magnesium in hard water combines with soap to make an ***insoluble*** scum. Today, detergents are used for washing dishes and clothes, and detergents do not form soap scum. Soap scum is not much of a problem while washing dishes and clothes. Hard water is still a problem for steam pipes, hot water tanks, coffee makers, teakettles and other household appliances that carry water. A scale of calcium carbonate clogs pipes and reduces the amount of steam or water the pipes can carry. In severe cases, a pipe with a 1.25 inch diameter may have a central opening smaller than a pencil. Water heaters run at reduced efficiency because of the calcium deposits inside the tank.



Water is a ***solvent*** for many chemicals. It is one of the best solvents known. Rain passing through the atmosphere absorbs

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carbon dioxide and sulfur dioxide as well as other gases. None of these compounds cause hard water. Water collected and put in use soon after it falls as rain, usually does not contain enough dissolved minerals to pose a problem. Rain water and water from mountain lakes that are fed by melting snow are two sources of soft water. As water percolates through the soil, the water dissolves additional minerals. This process creates hard water. Water heaters, boiler pipes, coffee makers and teakettles become clogged with calcium carbonate. One solution to hard water is to remove deposits of scaly material as it forms to prevent a severe mineral problem. Instructions for some coffee makers recommend white vinegar be run through the coffee maker at regular intervals. The vinegar is a mild acetic acid (CH_3COOH) that dissolves the accumulation of calcium carbonate. Another solution is to boil the water first. One cause of hard water is calcium bicarbonate ($Ca(HCO_3)_2$) or magnesium bicarbonate ($Mg(HCO3)_2$). These compounds can be removed by boiling the water. Calcium bicarbonate changes to calcium carbonate and settles as a solid. After boiling, the water is soft. Water that can be made soft by merely boiling is known as *temporary hard water*.

Water which contains calcium or magnesium sulfate, is called *permanent hard water*. Calcium sulfate, for instance, makes permanent hard water. The calcium (Ca^{++}), and sulfate (SO_4^{--}) are ions in hard water. Despite the name, permanent hard water can be treated. One method is to mix in sodium carbonate (Na_2CO_3). When mixed with water, sodium and calcium switch places.

$CaSO_4 + Na_2CO_3 \rightarrow CaCO_3 + Na_2SO_4$

Sodium goes into solution with the sulfate ion, and calcium takes sodium's place with the carbonate. The calcium carbonate drops out as a solid. The sodium and sulfate remain in solution as separate ions. They do not form a crust on pipes when heated.

The idea of softening water by switching one ion for another is a powerful tool in chemistry. *Ion exchange* selects one element but ignores another. It is a selective process because only certain chemicals in the solution are affected. Sodium replaces the calcium, but solutions which contain other desirable compounds are unaffected. The kidneys cleanse the blood of waste products primarily by ion exchange. Understanding that process has led to the invention of artificial kidneys to replace those that have failed in humans. Today, research into ion exchange is a field of intense activity.

Strontium (Sr) is the next metal in the calcium family. It is a soft and very active metal. Humphry Davy isolated strontium in 1808 using the same methods that worked for magnesium and calcium. He mixed strontium chloride with mercury so it would conduct electricity. The mixed paste conducted electricity.



Humphry Davy named the element *strontium* after the village of Strontiam, Scotland, where strontianite had been found in 1790. Like the other members of the calcium family, strontium is never found free in nature. Strontium is found in combination with other elements. The two best-known compounds are strontium carbonate, known as strontianite, and strontium sulfate, known as celestite. The formulas for strontium carbonate and strontium sulfate follow the same pattern as the other calcium family metals: $SrCO_3$ and $SrSO_4$. Strontium makes up about ¼ of one percent of the earth's crust by weight and is far less abundant than calcium or magnesium. Despite being less abundant than the other

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metals in its family, strontium is not a rare element. It is found in the same relative amounts as sulfur and carbon.

Strontium has the distinction of being one of the reasons for the ban on above ground nuclear weapons testing. Strontium is so nearly like calcium it will replace that element in the bones. Fallout from nuclear bombs contained a radioactive isotope of strontium. In the 1950s and 1960s, *radioactive strontium* became a concern because it was replacing calcium in bones, especially of children who drank milk. The radioactive strontium fell on grass that was eaten by cows and then concentrated in the milk. Countries with nuclear weapons agreed to test those weapons underground to prevent strontium from escaping. Uses of strontium and its compounds are limited. Strontium is between calcium and barium in the calcium family of metals. Both calcium and barium are more common and less expensive. Anything strontium can do, calcium or barium can do and at less cost. It does burn with a bright scarlet flame. Strontium compounds are used for fireworks and in signal flares.

LIFE PRINCIPLE

"Do not let a pat on the back cause your head to swell."



—Anonymous

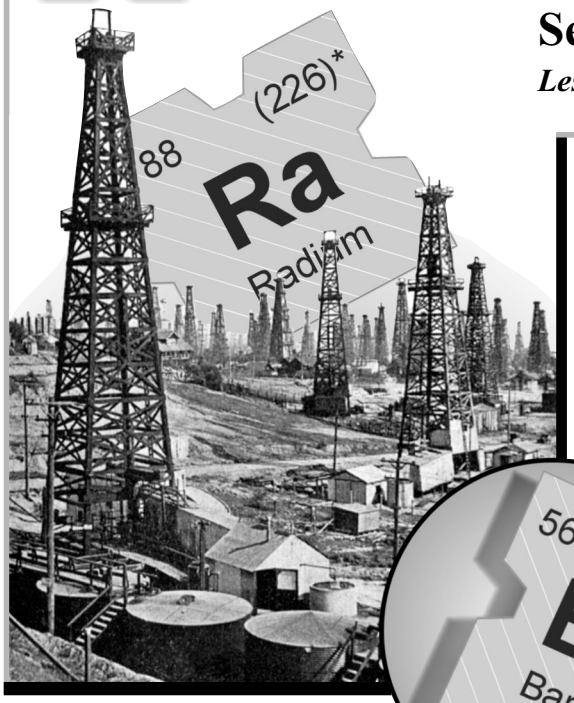
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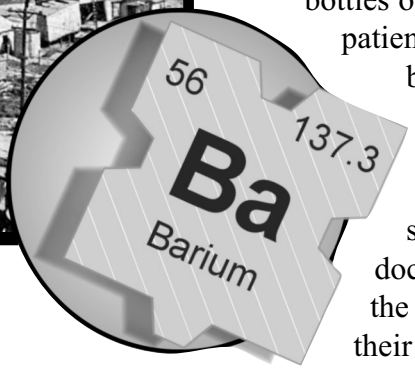
Chapter 5

Lesson 14
Elements

BARIUM AND RADIUM

Section 3
Lessons 11-15

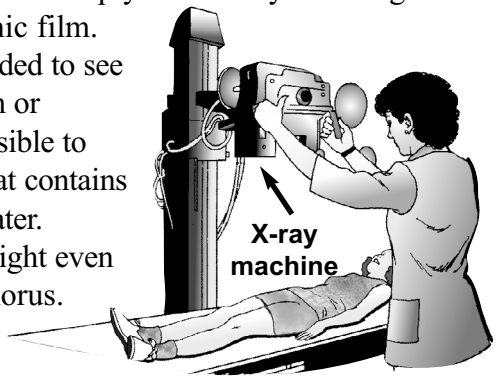




A patient had a medical condition, which appeared to be caused by a problem with the stomach or intestines. The doctor ordered that ***X-rays*** be taken. The patient knew that X-rays would reveal a person's skeleton. X-ray photographs could also show soft body parts like the stomach or intestines. The doctor gave the patient two large bottles of a heavy liquid and instructed the patient to start drinking the liquid an hour before his appointment for the X-rays. The liquid contained a variety of chemicals, but the primary ingredient was barium sulfate. The patient learned from his doctor that barium sulfate would coat the stomach and intestines and make their condition visible on X-rays.

In the early 1900s, scientists discovered that X-rays would pass through flesh but not through bones. Human tissue is made of hydrogen, carbon, nitrogen and oxygen. These elements are of low atomic weight and do not stop X-rays, which pass through soft tissues to expose photographic film. Teeth and bones are made of calcium and phosphorus. These elements are of higher atomic weight and stop X-rays. Bones and teeth are ***opaque*** rather than ***transparent***. Bones and teeth are sharply defined by the images they cast on X-ray photographic film.

Suppose the doctor needed to see the soft tissues such as stomach or intestines. They can become visible to X-rays by use of a chemical that contains barium sulfate suspended in water. ***Barium*** (Ba) has an atomic weight even greater than calcium or phosphorus.



VOCABULARY

X-ray: high-energy electromagnetic waves used to penetrate through the body and make photographs of bones and teeth

Opaque: cannot be penetrated, some materials are opaque to light but let invisible X-rays pass on through

Transparent: can be easily penetrated, materials transparent to one wavelength of light may be opaque to other wavelengths

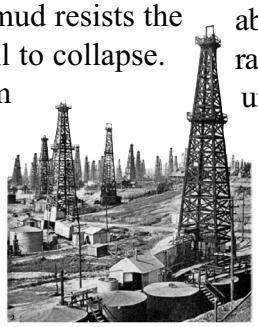
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It coats the stomach and intestines to make them visible in X-rays. Barium and most of its compounds are highly toxic. Barium sulfate, the compound used for X-rays, is safe to drink because it does not dissolve in water or in other body fluids.

Barium is heavy. It received its name from the Greek word *barys,* meaning *heavy*. Humphry Davy freed barium from barite in 1808. Most of the uses of barium are based on its density.



Barite mud is a liquid, yet it is more dense than rock. For that reason, it is used as drilling mud. Until the 1930s, drillers of oil wells sank steel castings along the wall of the hole to prevent a cave-in. However, barite drilling mud is so dense it can be pumped into the well without using a steel casting. Because of its high density, the outward pressure of the barite mud resists the forces that would cause the well to collapse. As the drill operates, the barium mud cools the drill bit and floats out the stone chips that the drill cuts. The barium mud is continuously circulated, filtered of the stone chips and reused. Another use of barium is to coat papers. Barium sulfate is a dense, white solid. It makes paper more substantial and reduces its transparency. Barite is also added to paints as filler. The common compounds of barium are its oxides, carbonates and sulfates. The formulas for these compounds follow the same form as for the other calcium metals: barium oxide (BaO) barium carbonate ($BaCO_3$) and barium sulfate ($BaSO_4$).



Radium (Ra) is a naturally occurring radioactive element. Its name is made from the Latin word *radius*, which means *ray*. Unlike francium, another radioactive element, radium does exist in sufficient quantities for its properties to be tested and measured. Radium is the heaviest and densest of the calcium metals.



Radium is intensely radioactive. It is about one hundred million times more radioactive than uranium. Most scientists did not understand the dangers related to radioactivity. Henri Becquerel carried a sample of uranium around his wrist to test its effect upon human flesh. He suffered a bad radiation burn. A *radiation burn* occurs when the energy released from radioactive materials damages human flesh. Some of the handwritten notes left by chemists who experimented with radium 100 years ago are still too radioactive to be handled safely.

Mixing luminescent substances such as zinc sulfide with radium can intensify their glow. Zinc sulfide is called *luminescent* because it emits light when struck by radioactive particles. Small amounts of radium were once used in the production of luminous paint. Radium was applied to the hands and dials of clocks and watches, but the glow in the dark came at a price. Workers in the watch factories suffered ill effects. Scientists questioned the long-term effects of radium on the people

VOCABULARY

Barium (Ba): a member of the calcium family of metals, a dense metal, highly active

Radium (Ra): the only naturally radioactive member of the calcium family of metals, extremely rare, too radioactive for most purposes but it is used to treat some cancers

Neutral: without charge, a neutral atom has as many electrons as protons

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who wore the watches. The practice of using radium paint was discontinued in the 1960s.

Many doctors believe that radium can successfully treat cancer because some cancer cells are thought to be more sensitive to radioactive rays than normal body cells. However, while killing some tumors, radiation therapy destroys much healthy tissue. Concerned doctors are searching for less hurtful treatments to replace radiation therapy.

The table below gives information about the properties of the calcium metals. Notice how they are alike, how they are different and how their orders change. The valence is +2 for all of the metals, as shown by an ion with a double positive, ++. The oxide has the same form for all of the metals. Oxygen has a valence of –2, so it takes one oxygen atom for each calcium family metal. The atomic weight, atomic number and density become progressively larger as one moves from beryllium to radium.

Notice the melting temperatures and boiling temperatures. Although they generally become less as you read down the table toward greater atomic weights, the descending pattern is not consistent.

By the 1850s, chemists had discovered about 60 elements. Organizing the elements and their properties became difficult. Chemists, like all scientists, value simplicity, and they began to search for a way to summarize what was known about the elements.

One way to bring order is to arrange elements by increasing atomic number. The *atomic number* is the number of protons in the dense, central nucleus of the atom. Atoms of the same element always have the same atomic number. All hydrogen atoms have but one proton and an atomic number of 1. Helium has two protons and its atomic number is 2. Lithium is number 3 and so on. Uranium, the last naturally occurring element, has 92 protons. Atoms of the same element must have the same atomic number. Uranium has atomic number 92. No other element has that number. All uranium atoms, no matter how they occur or how they are produced, have an atomic number of 92. Atoms of two different elements cannot have the same atomic number. Should uranium lose four protons, it would not be uranium. Instead, it would be radium with the atomic number of 88. Because atomic number is a unique way of specifying an element, chemists sometimes name an element by its atomic number. Rather than talking about uranium, they talk about element 92. Hydrogen is element 1. An atomic number is always a whole number. The atomic number is also the number of electrons in a ***neutral*** atom. An element does not gain or lose protons during chemical reactions. However, during chemical reactions, the number of electrons can change. Sodium has an atomic number of 11, which means the neutral atom has 11 protons and 11 electrons. Sodium which reacts with chlorine still has 11 protons, but gives up one electron to the

Calcium Family of Metals

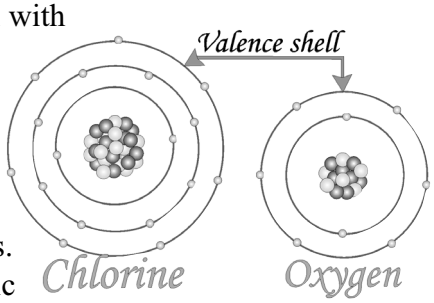
Name	Symbol	Ion	Oxide	Atomic Number	Atomic Weight	Melting Temp°C	Boiling Temp°C	Density g/cm^3
beryllium	Be	Be^{++}	BeO	4	9.012	1,278	2,970	1.85
magnesium	Mg	Mg^{++}	MgO	12	24.312	649	1,090	1.74
calcium	Ca	Ca++	CaO	20	40.08	842	1,487	1.55
strontium	Sr	Sr++	SrO	38	87.62	769	1,384	2.54
barium	Ba	Ba++	BaO	56	137.34	725	1,140	3.50
radium	Ra	Ra++	RaO	88	[226]*	700	1,737	5.5

*The atomic weight of radium is given in brackets to show that it is radioactive. The atomic weight is of its most stable isotope

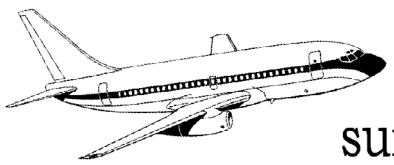
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chlorine atom. Sodium then has only 10 electrons, making it a charged ion. A charged ion has a number of electrons that differs from the atomic number.

The only problem with chemists using atomic numbers to arrange the elements was that scientists did not know about protons, electrons and neutrons in the 1850s. They could not use atomic numbers to arrange the elements in a table because the concept had not yet been developed. Instead, they had to look at the chemical and physical properties of the elements.



LIFE PRINCIPLE

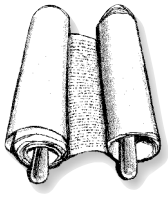


"The greater the difficulty the more glory in surmounting it. Skillful pilots gain their reputation from storms and tempests."

—Epictetus

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Integrated Physics & Chemistry



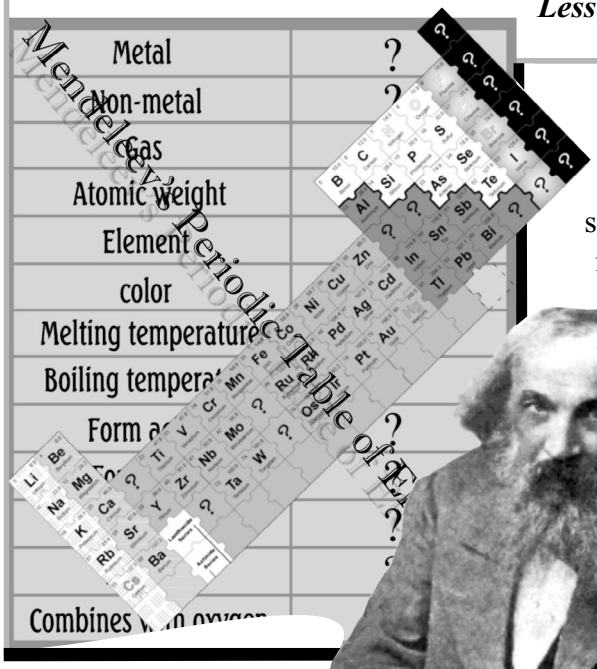
Lesson 15
Scientific Laws

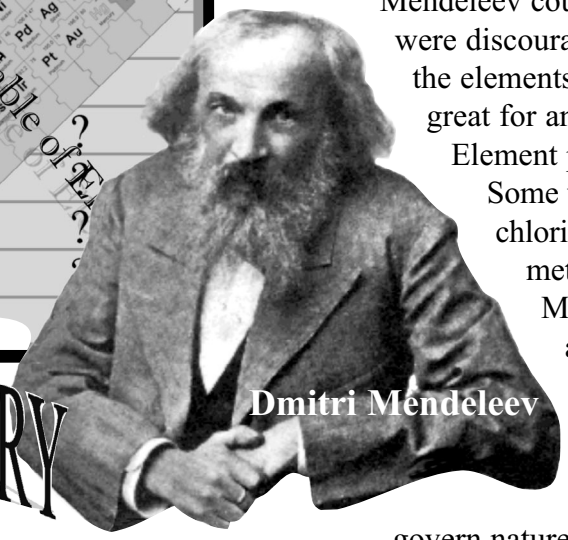
Chapter 5

Section 3

Lessons 11-15

PERIODIC LAWS





Dmitri Mendeleev

VOCABULARY

Periodic Law: states that the properties of chemical elements repeat on a regular basis

Period: a horizontal row in the periodic table in which elements change from highly active metals to inactive nonmetals to highly active nonmetals, properties of one row repeat in a similar fashion in the next row

Families: elements with similar chemical properties, chemical families make vertical columns of the periodic table

In the 1860s, Dmitri Mendeleev taught chemistry in St. Petersburg, Russia. Although he was a good teacher, many of his students became discouraged at the amount of information they had to learn to master chemistry. Mendeleev could understand why students were discouraged. Information about all of the elements had become almost too great for anyone to comprehend. Element properties varied widely. Some were poisonous gases like chlorine. Others were inactive metals like platinum. Even Mendeleev could not remember all the facts about the many new elements; students had an even more difficult time. Scientists have found that simple principles govern nature. Like other scientists, Mendeleev believed that the most confusing observations could be summarized with simple laws. Mendeleev believed the elements should have a logical order that would summarize information into a compact and easily understood form. Other chemists tried to arrange the elements into a logical order. The other chemists had failed in their quest. Dmitri Mendeleev became a chemical detective, trying to solve the mystery of how elements should be arranged.

Dmitri Ivanovich Mendeleev was the youngest of fourteen children. He grew up in Tobolsk, Siberia. His father had been a schoolteacher. Shortly after Dmitri's birth, his father became blind. Dmitri's mother supported the family by managing a glass factory. When Dmitri was fourteen years old, his father died, and a few months later, the glass factory burned.

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Mendeleev's mother realized she could not afford to send all of her children to college. She picked Dmitri as the most promising student. She enrolled him in a technical school at St. Petersburg, hundreds of miles from home. Mendeleev finished college at the top of his class. He went to Germany for further studies; then he returned to Russia to teach chemistry.

Mendeleev began his project to organize the elements in the late 1860s. He wrote each of the then known 60 elements on note cards. Mendeleev described each element as a metal, nonmetal or gas. He entered the atomic weight and other properties of each element and its compounds. He also listed the element's color, melting temperature, boiling temperature and density. Mendeleev wrote whether the element formed acids, bases, salts or combined with oxygen.

Mendeleev cleared one wall of his laboratory. He hammered rows of small nails partway into the wall. Then he attached the cards on the wall in front of the desk where the data could be studied. He arranged and rearranged the cards, looking for a predictable pattern to emerge.

One of the important properties of an element is its atomic weight. Each element had an atomic weight that differed slightly from the one next to it. The lightest element was hydrogen with an atomic weight of 1.0. The next six lightest elements were lithium (Li), beryllium (Be), boron (B), carbon (C), nitrogen (N), oxygen (O) and fluorine (F). Their atomic weights, rounded to one decimal place, are:

Element	Li	Be	B	C	N	O	F
Atomic Weight	6.9	9.0	10.8	12.0	14.0	16.0	19.0

Another important property is valence. Hydrogen will form many compounds, and study of its compounds helped establish the valence of various elements. For example, one atom of hydrogen (H), combines with one atom of chlorine (Cl), to give hydrochloric acid (HCl). Chlorine has the same combining power as hydrogen. Chemists gave both hydrogen and chlorine a valence of 1. (They did not use + or – signs at that time.)

Comparing *HCl* with H_2O shows that oxygen has the greater valence. Oxygen has a valence twice as great as the valence of hydrogen. The water molecule requires two hydrogen atoms for each oxygen atom. Oxygen's valence is 2. The chemical formula for ammonia is NH_3 and methane is CH_4. From these formulas, chemists concluded that the valence of nitrogen is 3, and carbon is 4. Nitrogen, with a valence of 3, requires three hydrogen atoms; and carbon, with a valence of 4, requires four hydrogen atoms. After chemists established the valence of a few elements, chemists could predict and find the valence of other elements. For instance, sodium forms sodium chloride (NaCl) and sodium oxide (Na_2O). Knowing that chlorine's valence is 1 and oxygen's valence is 2 means that sodium must have a valence of 1, the same as hydrogen. Sodium and all the other elements of that family, including lithium, have a valence of 1.

VOCABULARY

Inert gases: inactive elements discovered after Mendeleev completed the periodic table, the first three inert gases are helium, neon and argon, the inert gases have a valence of zero

Periodic table: an arrangement of the elements based on the Periodic Law, elements with similar chemical properties are in the same vertical column

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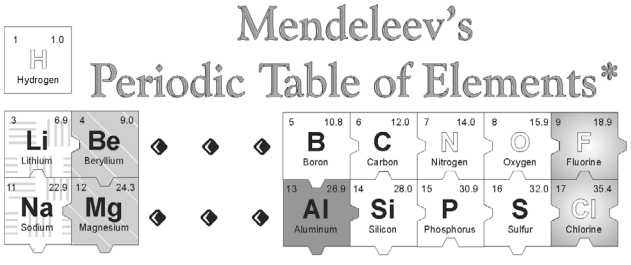
Mendeleev recorded the valence for the elements from lithium through fluorine.

Element	Li	Be	B	C	N	O	F
Valence	1	2	3	4	3	2	1

Valence rose and fell. It began as one for lithium, rose to four for carbon and fell again to one for fluorine. Chemists noticed variation among the range of chemical properties from lithium to fluorine. Lithium (Li) is a highly active metal. Beryllium (Be) is a metal less active than lithium. Boron (B) is a relatively inactive nonmetal. Nitrogen (N) is a nonmetal and relatively inactive, too. Oxygen (O) is a more active nonmetal. Fluorine (F) is the most active nonmetal.

To begin his table of the elements, Mendeleev put hydrogen (H) at the top in a row by itself. It was the lightest element and had a valence of one. However, hydrogen had unusual properties which no other element shared. In the second row, Mendeleev pinned up the seven elements from lithium (Li) to fluorine (F).

A predictable pattern began to form. The next element by atomic weight was sodium (Na). Mendeleev realized sodium should fall below lithium because they both have similar properties and the same valence. He began the third row. He pinned up seven more elements: sodium (Na), magnesium (Mg), aluminum (Al), silicon (Si), phosphorus (P), sulfur (S) and chlorine (Cl). Elements with similar chemical properties fell one below the other across the table.



The first element in the third row of Mendeleev's table is sodium (Na), a metal like lithium. Again, the properties repeat themselves. The row begins with sodium (Na), an active metal. Then, the row goes through to silicon (Si), an inactive nonmetal. Finally, the row ends with chlorine (Cl), a highly active nonmetal like fluorine.

Mendeleev discovered that the properties of the elements repeat on a regular basis. This is the ***Periodic Law***. Chemists call the horizontal rows ***periods***. Chemical properties change along the period, from highly active metals on the left to less active nonmetals in the middle to highly active nonmetals on the right. Valence rises and falls, too. Within the vertical columns, called ***families***, the elements share similar properties, especially valence. For instance, elements in the first column, lithium and sodium, are highly active metals. They both have a valence of one. Two of their atoms combine with one oxygen atom, Li_2O and Na_2O. Elements in the second column or family, beryllium and magnesium, are metals. They are not quite as active as lithium and sodium. In addition, they each have valence of 2. One atom of beryllium or magnesium combines with one atom of oxygen, *BeO* and *MgO*.

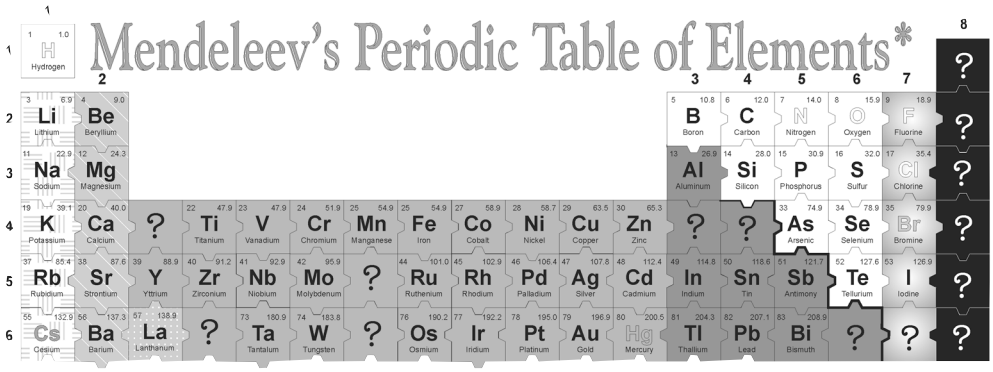
Mendeleev began the next row. He put the elements in order by atomic weight. The active metal potassium fell into its proper place below sodium and lithium. Calcium fell below magnesium and beryllium. Over on the other side, selenium fell below sulfur and oxygen. Bromine fell below chlorine and fluorine. Here and there, an element fell in a family to which it did not belong. Mendeleev moved the element over to leave a gap. He predicted that new elements would be discovered to fill the blanks.

In a couple of places, Mendeleev found that atomic weight put an element in

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the wrong place. Iodine (I) had an atomic weight less than that of tellurium (Te). Using atomic weight alone would put iodine in the wrong family based on its valence. Iodine would be in the oxygen family rather than in the same family as fluorine, chlorine and bromine. Mendeleev used valence as the deciding factor and put iodine after tellurium.

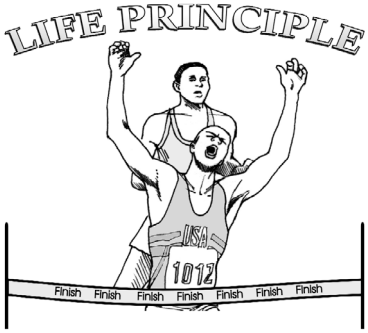
The table looked something like this. The question marks (?) show the location of elements not known in Mendeleev's time.



The row of question marks along the right side of the table is for the family of ***inert gases***. This entire family of elements was unknown to chemists of Mendeleev's day. Later, chemists discovered the inert gases: helium (He), neon (Ne), argon (Ar), and three others. The new discoveries did not destroy Mendeleev's table; they completed it. The inert gases are inactive, and only the best efforts of chemists can force these gases into reactions with other elements. For that reason, chemists give the inert gases a valence of zero.

The modern form of Mendeleev's ***periodic table*** is not the same as the original one he published. It has undergone considerable changes. Chemists made some of the changes to update information. They added newly discovered elements and the family of inert gases. Chemists made other changes so the chart would fit on a sheet of paper.

The present Periodic Table of the Elements is a tool used by all contemporary chemists. It is a compilation of many different types of data and information including atomic number, atomic weight, valence, symbol, name, family and period of each of the elements with which chemists work every day. The Periodic Table of the Elements combines all the above mentioned items into a concise and manageable reference that saves the chemist many hours of research and calculations for experiments. The periodic table is a useful map of the main properties of the elements. Although many different forms for the periodic table can exist, they are all based on the Periodic Law. The Periodic Law states that the properties of chemical elements repeat on a regular basis. The Periodic Law is true regardless of whether it is shown as a table.



"The most important thing of all, as one approaches the end, is to be able to say, 'I have done what I could.'"

—Louis Pasteur

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