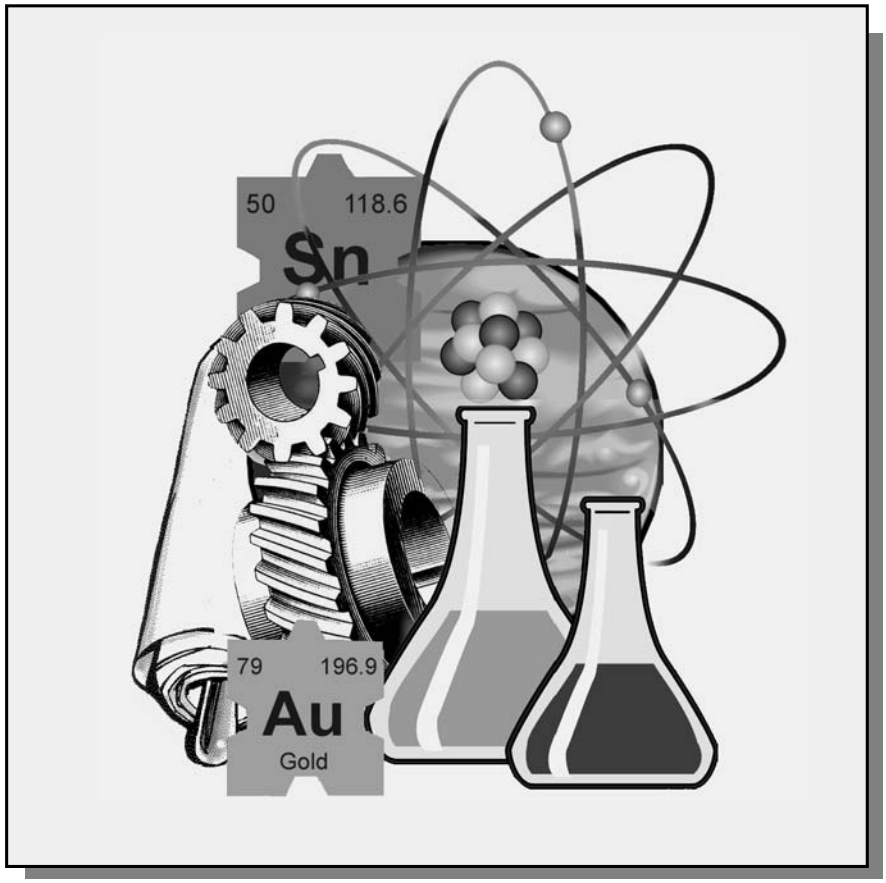
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This chapter requires a companion activity book in which students respond to questions on text content. Answers are found in the *Teacher's Resource Kit*.



Chapter 9

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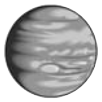
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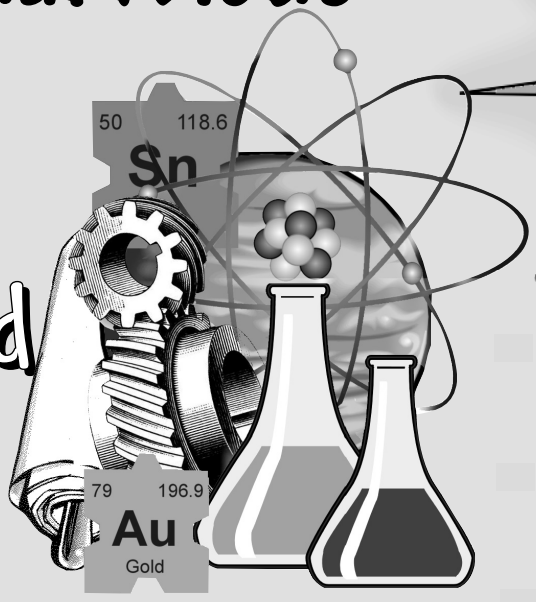
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"The study of science is the chronicle of man's quest to discover the essence of life and how the marvelous laws of creation are applied to human needs."



—Ronald Johnson, Ph.D.

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Integrated Physics & Chemistry



Lesson 1
Planets

Chapter 9

KEEPING TIME— YEARS AND DAYS

Section 1

Lessons 1-5



Few people can go through a day without looking at a clock or watch. Our lives are marked off in seconds, minutes and hours. For most of history, however, when people talked about time, they spoke in terms of days, weeks, months or years. Until the 1500s, the shortest division of time in common usage was the hour. Most clocks had only hour hands. Not until the 1500s could clocks and watches measure minutes and seconds accurately.

For ancient people, knowing the time of the year was more important than knowing the time of the day. Ancient people had to be certain they planted their crops after the last killing frost. They could not wait too long. Grains such as wheat, oats and barley needed time to grow, as do vegetables such as cucumbers and onions. If a farmer planted too late, the crop would be killed by the cold of winter. Ancient people had limited ways to store food from one year to the next. When farmers planted too soon or too late, families faced hardships and starvation.

A calendar is a system of figuring the time of year. Calendars enabled farmers to make wise decisions about seedtime. Experience and observation helped farmers learn the best time in spring to plant crops. By marking the day on a calendar, farmers could repeat their success from one year to the next.

Now



Then



VOCABULARY

Latitude: the distance north or south of the equator, the equator has latitude of 0º and the North Pole has latitude of 90º

Northern Hemisphere: the half of the earth that is north of the equator

Equator: the 0º latitude circle that is equal distance from the North Pole and South Pole

Southern Hemisphere: the half of the earth that is south of the equator

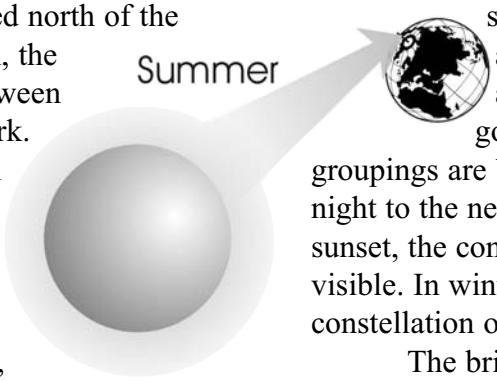
Solstice: either of the two days during the year when the apparent position of the Sun is farthest from the equator

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Genesis 1:14 of the Bible states, "Let there be lights in the expanse of the sky to separate the day from the night, and let them serve as signs to mark seasons and days and years . . . ." From ancient Bible times, men have observed the four seasons.

A year is the time it takes the Earth to orbit once around the Sun. Most people, when they think of a year, do not think in terms of Earth's orbit. Instead, they think in terms of a birthday; from May 5 to the next May 5 is one year. Or, they mark the passage of a year by the weather. One cycle of the four seasons from winter, spring, summer, fall and back to winter is one year.

Ancient peoples made calendars and learned the length of a year, although they did not know Earth orbited the Sun. They did not have telescopes. Yet, they were able to make calendars to mark off the seasons. One clue to this accomplishment is the length of day and night times. The day is longest on the first day of summer, which occurs on/about June 21 each year. The difference between length of light and dark depends on how far a person is located north of the equator. The farther north, the greater the difference between the length of light and dark. In St. Louis, Missouri, on the first day of summer the day is 15 hours and night is only 9 hours. For a person farther north, such as London, England, the effect is greater. On the first day of summer Londoners, have light for 17 hours and dark for only seven hours. At the North Pole (90º ***latitude***), people experience 24 hours of daylight because the Sun does not "set."



In winter, the days are shorter, and the shortest day occurs on the first day of winter, usually December 21. On the first day of winter in St. Louis, Missouri, daylight stays for nine and one-half hours and darkness for 14 ½ hours. In London, England, the shortest day has only eight hours of light and 16 hours of dark. At the North Pole, the daylight is zero hours. Darkness prevails for six months because the Sun does not "come up." From the longest day of the year to the next longest day is one year.

Ancient peoples had no reliable way of measuring hours. They could not easily know which day was the longest. Although they could tell after the passage of a few days that the days were getting longer, knowing exactly the first day of winter was difficult. They had to use some method other than mere visual observation.

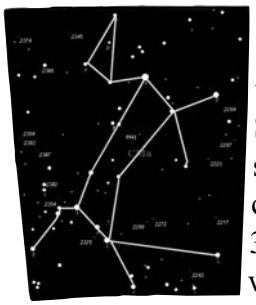
Suppose a person stands in a certain spot and notices the stars that are visible in the east shortly after sunset. Because Earth is going around the Sun, new star groupings are brought into view from one night to the next. In summer shortly after sunset, the constellation of Hercules is visible. In winter shortly after sunset, the constellation of Orion would be visible.

The brightest star in the nighttime sky is *Sirius*. (The brightest star in the daytime sky is the Sun.) Sirius is in the constellation of *Canis Major* (*Big Dog*), which in ancient Egypt became visible in the eastern sky each spring. The Egyptians living along the Nile River observed that and the river flooded at about the same time each year. The spring flooding occurred about the time Sirius became visible shortly after sunset in the

VOCABULARY

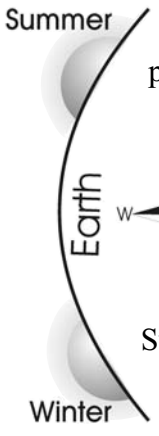
Equinox: either of the two days when the Sun is over the equator and the days and nights are same length

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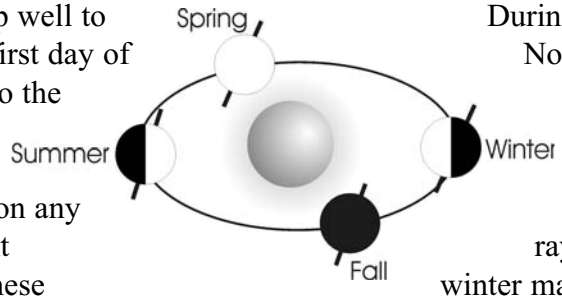
east. By measuring the time from one Sirius rising and the spring flood to the next Sirius rising and the next spring flood, the Egyptians concluded that a year had 360 days. Egyptians worshipped many heavenly bodies, therefore they built temples facing where Sirius comes up in spring. The ancient Egyptians soon learned that 360 days was not right for the length of the year. Each year, their calendar was in error by 5 days because a year of 360 days is too short.

The Sun rises in the east and sets in the west. However, it rises and sets at a slightly different place on the horizon each day. Suppose an Egyptian astronomer were to go outside early on the first day of winter and watch the point on the horizon where the Sun comes up. On the first day of winter the sunrise point was well to the south of directly east. Each day the astronomer continued to track the point on the horizon where the Sun rose. By summer, the Sun came up well to the north of directly east. On the first day of summer the Sun came up farther to the north than on any other day. On the first day of winter, the Sun came up farther to the south than on any other day. The ancient astronomer marked these positions. He put a stone column to mark where the Sun came up on the first day of winter and another stone column to mark where the Sun came up on the first day of summer. When the Sun came up over the summer stone, the Egyptian knew the first day of summer had arrived.



The Sun also casts different shadows depending on the season. At midday, the shadow for that day is at its shortest length. The length of the shortest shadow varies from one day to the next. A tall building or monument casts a shorter shadow in summer than in winter. Suppose an astronomer followed the shadow of a tall monument and put a peg in the ground at the point where the shadow was shortest. A building has its shortest shadow on the first day of summer.

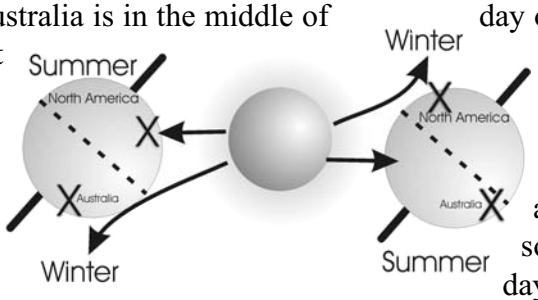
Seasons and the changing position of the Sun are caused because Earth is tilted on its axis. If Earth were not tilted on its axis, the Sun would always shine directly over the equator. Days and nights would be the same length. Earth would not have any seasons. However, Earth tilts about 23.5 degrees. As Earth orbits the Sun, the path of the Sun is north of the equator for six months. This is when the ***Northern Hemisphere*** experiences spring and summer. When the Sun is south of the ***equator***, the Northern Hemisphere experiences fall and winter for the next six months.



During winter, the Northern Hemisphere is tilted away from the Sun. The slanting rays of sunlight in winter make the days cooler. Sunlight is spread over a greater area. The rays hit at an angle and reflect back into space without warming Earth as much as would direct rays. In addition to the slanting rays, days are shorter and nights are longer. Both the angle of the Sun and shorter days cause the temperature in winter to be cooler for people in the Northern Hemisphere. Meanwhile, in the ***Southern Hemisphere***, countries in South America, South Africa and Australia are enjoying summer. Seasons in the Southern Hemisphere are reversed

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compared to seasons in the Northern Hemisphere. While the United States is in the middle of winter, Australia is in the middle of summer. On the first day of spring in the United States, Australia is experiencing the first day of fall.



The Earth's orbit carries the planet around the Sun so that the Northern Hemisphere is tilted toward the Sun in the summer. The more direct rays of sunlight in summer make the days warmer. Sunlight is concentrated over a smaller area, hits more directly and is absorbed better. In addition to direct rays, days are longer and nights are shorter. Both the angle of the Sun and longer days cause the temperature in summer to be warmer for people in the Northern Hemisphere. At this time, the Southern Hemisphere is tilted away from the Sun, causing the season there to be winter.

The first day of summer is the *summer* ***solstice***. On that day, the apparent path of the Sun is as high in the Northern Hemisphere as it will get. The daylight is longer, and the Sun is more directly overhead. The word *solstice* means *sun stands still*, because the Sun pauses in making the days longer and starts making them shorter. The day with the longest daylight and the first day of summer is usually June 21.

The first day of winter is the *winter solstice*. On that day, the apparent path of the Sun is as low in the Northern Hemisphere as it will get. In winter, the solstice marks the change of the days from getting shorter to getting longer. The day with the shortest daylight and the first day of winter is usually December 21.

Halfway between winter solstice and summer solstice is the start of spring. On that day, the tilt of Earth is such that days and nights have the same lengths. The apparent path of the Sun is over the equator. The first day of spring is the *vernal* ***equinox***. *Equinox* means *day equal to night*. *Vernal* means *spring*. Spring usually begins about March 21. Halfway between summer and winter is the *autumnal equinox*. Autumnal is from the word autumn, or fall. On the first day of fall, day and night are the same lengths. Fall usually begins about September 23. Both solstices and equinoxes vary by a day on the calendar from year to year. For example, the summer solstice varies between June 21 and 22; the spring equinox varies between March 21 and 22.

Life Principle



"The future will belong to those who do the most for suffering humanity."

—Louis Pasteur

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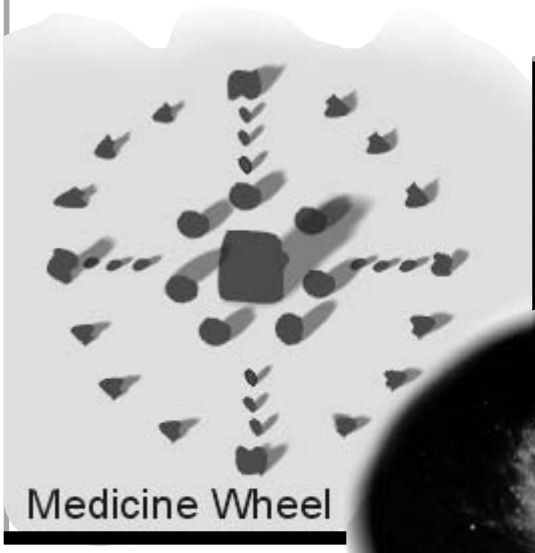
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Inventions and Discoveries

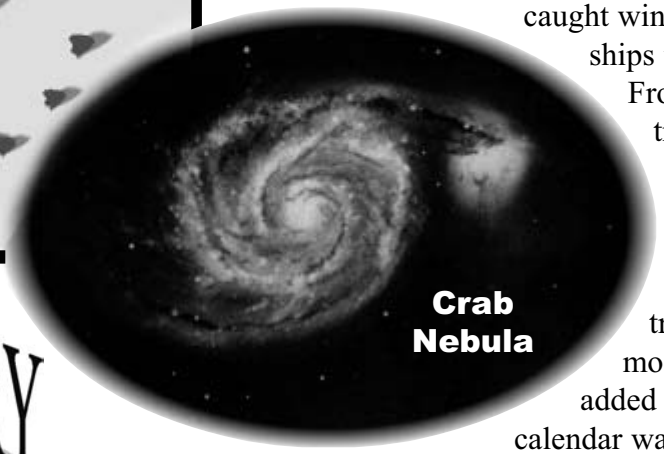
Chapter 9

KEEPING TIME—THE CALENDAR

Section 1

Lessons 1-5





Having an accurate calendar was important to ancient people. Many sea captains wintered at a safe port because of bad weather during winter months. By putting out from port at the right time, sailing ships caught winds that carried the ships to their destination. From experience, travelers on land knew when mountain passes would be free of snow. People also traveled during full moon because of its added light. An accurate calendar was especially important to farmers because they reaped their best harvests by planting at the right times each spring. All religions had special holy days, and faithful followers turned to calendars to know when to observe significant days.

Throughout history, people have worked to make an accurate calendar by observing the Sun, Moon, planets and stars. An *almanac* is a calendar with additional astronomical information. An almanac gives moon phases, rising and setting times for the Sun, the dates for the *equinoxes* and *solstices*, predictions such as ***eclipses*** and ***tide tables***. Often an almanac contains other useful information about the best time to plant crops. Some almanacs also contain weather predictions.

Throughout the world, ***archaeologists*** have found remains of ancient observatories. The pyramids and temples in Egypt were laid out according to the position of the Sun at various times during the year. Native Americans constructed an arrangement of rocks in Wyoming known as *Medicine Wheel*. It is believed to be an observatory. In many ways, their observations

VOCABULARY

Eclipse: the light of one celestial body blocked by another; the Moon passing between the Sun and Earth is a *solar* eclipse; Earth blocking the sunlight falling on the Moon is a *lunar* eclipse
Tide table: a listing of the expected times of high and low tides at a particular location
Archaeologist: a scientist who examines remains of past human occupation, such as buildings, tools and pottery, to determine how the people lived
Petroglyphs: drawings on rocks left by prehistoric people

may have been greater than those of the Europeans at the same time. For instance, Native Americans made rock drawings (***petroglyphs***), leaving clear evidence that early Americans detected an exploding star (*supernova*) in 1054 ***A.D.***, an event that was not reported by any European scientist. The exploded star created the Crab Nebula; an expanding ball of hot gases which is visible today. By projecting backward in measuring the speed of the expanding gas, astronomers can calculate that the star did in fact explode in 1054 as recorded in the petroglyphs.

In Central America and Mexico, the Mayan culture built massive stone pyramids, temples and sculptures. The Mayans were an agricultural society. Their farmers grew corn, beans, squash, avocados, chili peppers, pineapples and papayas. They also harvested cacao beans from which chocolate drink was prepared. Farmers who grew crops such as these were aided by a calendar in planting at the proper time. The Mayan ruins at Chichén Itzá on the Yucatán peninsula in Mexico include an elaborate observatory, built about 1050 A.D. for marking ***celestial*** events.



VOCABULARY

A.D.: abbreviation for the Latin words *Anno Domini* (ăn-nō Dō-mē-nē) meaning *year of our Lord* or *since Christ was born*
Celestial: having to do with the sky or planetary system
Flourished: the time when persons or cultures reached their greatest successes
B.C.: abbreviation for the words *before Christ*

Mound builders of North America who ***flourished*** in the 1200s also constructed observatories. The most extensive ruins of this civilization were near St. Louis, Missouri where the trade city of Cahokia was once inhabited by about 50,000 mound builders. It was the largest city in North America until the 1800s when Philadelphia became larger. Archaeological digs at the site have uncovered the remains of a circle of poles to mark various astronomical events such as the first day of summer, first day of winter and so on.

One well-known ancient observatory is *Stonehenge*, a magnificent circle of stone arches in England. For the past 1,000 years, visitors have examined it and puzzled over its purpose. At first glance, Stonehenge looks like a confusing series of nested stone circles. Two circles of gigantic stone blocks circle two horseshoe shaped sets of blocks eighteen feet high. A massive sandstone table called the Altar is in the center. Despite the name, no one knows the actual use of the Altar. An observer who stands by the Altar and looks through the open ends of the horseshoes sees a great tapering rock called the Heelstone.

A historian who lived in 1130 A.D. described Stonehenge as being ancient even in his time. The Romans visited the site as early as 55 ***B.C.*** Today, some scientists believe construction started on Stonehenge about 2000 B.C. It may be as old as the pyramids.



Although scientists first believed the monument was a temple for barbaric rituals, no conclusive facts about the site have been discovered. The only thing definitely known was that on the first day of summer the Sun rose directly over the Heelstone as seen from

the Altar. Most scholars thought this to be only a coincidence.

Starting in the 1960s, scientists made a scientific study of Stonehenge. They became convinced the arrangement of stones had an astronomical purpose. If the people had wished to mark only summer sunrise, they needed only two stones: one stone to mark where they should stand and another one farther away to show where the Sun would come up. Yet, hundreds of stones weighing thousands of tons were carved and placed in position. Scientists measured the positions of the stones from aerial photographs. The results showed that the structure allowed its builders to predict solstices (first day of summer and winter), equinoxes (first day of spring and autumn) and eclipses.

A trench, 320 feet in diameter and five feet deep circles Stonehenge. In the 1650s, John Aubrey, an English writer, visited the site. Just inside the trench, Aubrey found 56 evenly spaced pits filled with white chalk. Scientists today think the 56 Aubrey holes served as a way to predict eclipses. A cycle of eclipses occurs every 56 years, so placing stones in the Aubrey holes would help mark the passage of the years.



Julius Caesar

By studying the motion of the bodies in the sky, the ancient people saw that the year had 365 1/4 days. The Egyptians had begun with a calendar of 360 days. This was a convenient number because many other numbers can divide 360. One-half of a year is 180 days, 1/4 is 90 days, 1/6 is 60 days, 1/8 is 45 days and so on. Although 360 days in a year makes the math easy, the premise is wrong. The number of days in a year must equal the time required for Earth to go around the Sun once. Otherwise, the calendar will be in error and become unreliable in marking the start of the seasons. From their astronomical observations, the Egyptians changed their calendar from 360 days in a year to 365 days in a year.

By the time of the Romans, cultures clearly understood that 365 days was too short for a year. The year is about 365 1/4 days. In 45 B.C., Julius Caesar authorized adding an extra day to February every four years. This day was the *leap day,* and the year with the extra day is a *leap year*. Without the extra day, the years always start on the next day of the week. If this year starts on Monday, then next year starts on Tuesday. The first day of year 2007 (January 1, 2007) is Monday. The first day of the next year (January 1, 2008) is Tuesday. If there were no leap years, then the next year would start on Wednesday. However, because of the extra day in 2008, the first day of the next year (January 1, 2009) is Thursday. The calendar "leaps" over Wednesday.

The calendar with a leap day was named the *Julian Calendar* in honor of Julius Caesar. The Julian calendar had 12 months with weeks of seven days. In 44 B.C., Julius Caesar changed the name of the month Quintilis to July, after himself. Not to be outdone, the next Roman emperor, Caesar Augustus, renamed the month Sextilis to August.

The Julian calendar, however, was still inaccurate. Earth requires 365 days, 5 hours, 48 minutes and 46 seconds to go around the Sun. The Julian calendar has a year of 365 1/4 days. One-fourth of a day is six hours. The Julian calendar is too long by about 11 minutes 14 seconds each year, so over time, accuracy of the calendar fell behind the seasons.

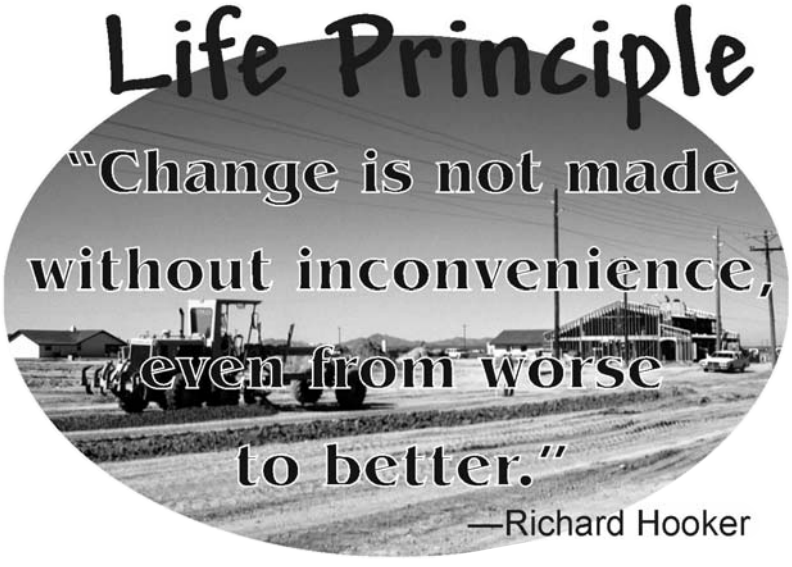
By 1752, the Julian calendar was off by 11 days. In that year, Great Britain and

most of the English speaking countries changed to a new calendar. Officials caught up the calendar with the seasons by skipping September 3 through 13. The day after September 2 became September 14. Many people became upset because eleven days had disappeared overnight. To keep that from happening again, calendar makers made two new rules for leap days: every 100 years take out a leap day, but every 400 years put it back in. Instead of 100 leap days every 400 years, calendars have only 97. The new calendar was named the *Gregorian calendar* after Pope Gregory XIII who first introduced it in 1582.

The Gregorian calendar is the one we use today, but its year does not exactly match the year based on one orbit of Earth around the Sun. A Gregorian calendar has 97 leap days every 400 years, which is an average of 97/400 = 0.2425 days (5 hours, 49 minutes, 12 seconds) extra each year. A year is 365 days 5 hours, 48 minutes, 46 seconds. The Gregorian calendar is too long by 26 seconds. In 3,325 years (about 5325 A.D.), the calendar will be in error by one day.

When the Gregorian calendar began, people also changed how years are numbered. Until then, people counted years based on the king who ruled at the time. For instance, in the Gospel of Luke in the Bible, the year that John the Baptist began preaching is described as "The fifteenth year of the reign of Tiberius Caesar . . . ."

Counting years by different kings can be confusing. The fifteenth year of the reign of the king of one country might be entirely different than the reign of the king of another country. Why not choose one king and measure the years from his birth? Rulers of western Europe believed that Jesus was the Christ. So great was His impact on the world that people began measuring years from the date Jesus was believed to have been born. Years after His birth were identified with the letters *A.D.*, which means *in the year of our Lord.* Years before His birth were given the letters *B.C.,* meaning *before Christ.* By this counting method, Julius Caesar was born in 100 B.C. (100 years before the birth of Christ) and George Washington was born in 1732 A.D. (1,732 years after the birth of Jesus).



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Lesson 3
Inventions and Discoveries

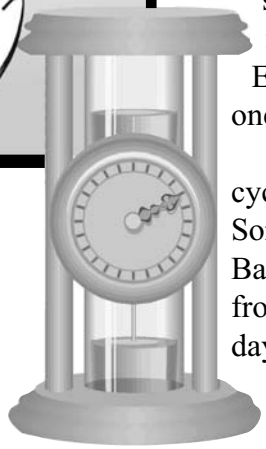
Chapter 9

KEEPING TIME— SUNDIALS AND HOURGLASSES

Section 1

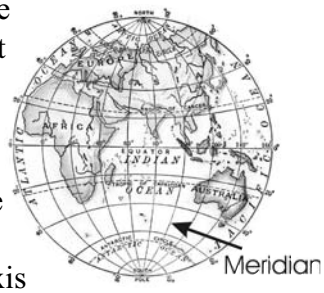
Lessons 1-5





The *year* is one complete orbit of Earth around the Sun. Earth ***revolves*** around the Sun. A person who is 15 years old has gone around the Sun 15 times. The person who has an average life expectancy will travel around the Sun 72 times in his or her lifetime. Ancient people measured the year as the time from the summer solstice, the longest day, to the next summer solstice. The revolution of Earth about the Sun requires a ***period*** of one year.

A twenty-four-hour *day* is a complete cycle of Earth ***rotating*** on its axis once. Some ancient cultures such as the Babylonians and Hebrews measured the day from sunrise to sunrise. Others measured the day from sunset to sunset. Today, the day is measured from the time the Sun passes across any one ***meridian*** until it again crosses the same meridian. A meridian is an imaginary line passing through the North Pole and the South Pole along the surface of Earth. When the Sun is on any given meridian, the time is local noon. The rotation of Earth on its axis has a period of one day.



Because slight variation occurs in the rotation of Earth on its axis and the revolution of Earth about the Sun, astronomers do not use a single observation to time a day. Instead, they calculate an average. The mean (average) solar day is the length of the solar day averaged over a year. It is a solar day because it is based on the apparent motion of the Sun. *Solar* means *related to the Sun.* In general, most measurements for time are taken over several cycles and then averaged.

VOCABULARY

Revolve: to orbit around, Earth revolves around the Sun in a fixed pathway
Period: a complete cycle, the time between two occurrences of an event that reoccurs at regular intervals
Rotating: turning on an axis as Earth rotates on its axis in a routine, fixed manner
Meridian: an imaginary line along Earth's surface extending from the geographic North Pole to the South Pole; any one of 359 meridians dividing Earth into 360 equal sections or degrees of a circle
Lunar: pertaining to the Moon

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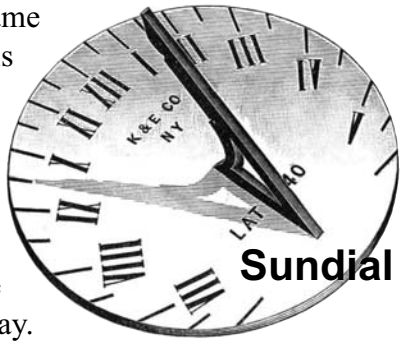
Scientists use the word *mean* to show that the result is an average.

Peoples from ancient to modern times have pondered the design, order and precision evident in the solar system. Concepts of origin ranged from the primitive belief that Earth rested on the shoulders of a mythical strong man, who stood on the back of an elephant, who stood on the back of a giant turtle (but no one knew upon what it stood)—to the Big Bang Theory whereby this orderly universe came into being as the result of a cosmic explosion—to the Hebrew Scriptures of the Book of Job 26:7, 13 which states, "He (God) . . . suspends Earth upon nothing . . . . (and) has garnished the heavens."

Ancient people used the Moon to measure a month. A month by this older definition is the time for the Moon to pass from a particular phase back to the same phase. The ***lunar*** cycle from full moon to full moon is one month. A month based on the Moon has a period of about 29.5 days because in 29.5 days the Moon progresses from full moon back to full moon again. In the Gregorian calendar, the number of days in each month varies. Four months have 30 days (April, June, September, November), seven months have 31 days (January, March, May, July, August, October, December) and one month (February) has either 28 days or 29 days during a leap year. The months that make up the calendar average 30.4 days (divide 365 days in a year by 12 months in a year: 365/12 = 30.4). The month based on the Moon, 29.5 days, and the month used in the calendar, 30.4 days, are not the same lengths. Although the length of a month was based on the regular phases of the Moon, the length has been changed to fit into a year.

For ancient farmers, a simple calendar with days, months and years was needed to tell time. Hours, minutes and seconds were not very important. However, as mankind improved technology, and people lived in cities and engaged in commerce, knowing the time of day became more important. Marking hours, minutes or seconds is more difficult than days, months or years. Days, months and years can be seen by predictable, ***periodic*** events in the heavens: the revolution of Earth about the Sun (year), the rotation of Earth on its axis (day) and the revolution of the Moon around Earth (month).

For keeping time, an event must repeat at a predictable, absolute interval; and the time for each repetition must be definite. The time from the start of the event to the next time the same event reoccurs is the period. A period is a complete cycle.



Sundial

The *hour* is a division of time shorter than a day. The hour is a human invention because no natural events occur every hour. In the earliest systems of timekeeping, people divided the period from sunrise to sunset into 12 equal intervals. Each interval was an hour.

VOCABULARY

Periodic: having repeated cycles usually of the same length
Hourglass: an instrument for measuring time by the flow of sand from an upper globe to a lower globe through a narrow neck between the two globes
Water clock: a device that measured time by the flow of water through a small opening, also known as a clepsydra (to steal water)
Escapement: a gear wheel and anchor that catches and releases the gears of a clock

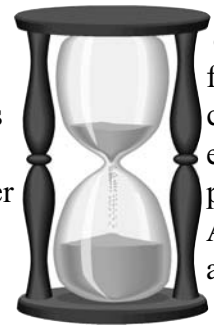
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Because the days are shorter in winter than in summer, hours in winter were shorter than in summer. Hours were not all the same length. The current use of 24 hours in a day and each one of them being of equal length did not begin until the 1600s. The hour as we know it did not come into use until the invention of accurate clocks and watches.

Sundials were invented independently by both the ancient Chinese and Chaldeans about 3500 B.C. and were used to judge time long before clocks and watches became available in the 1600s. The custom of dividing the day into hours began with the Egyptians. The first sundial was probably nothing more than a vertical post. As the Sun traveled across the sky, the shadow moved, and the position of the shadow gave some indication of the time of day. At noon, for instance, the shadow pointed directly north.

Sundials can still be found today as ornaments in gardens. Most consist of two parts. One part is a pointer aimed at the celestial North Pole. Below it is a circular plate marked off in hours. As the Sun crosses the sky, the shadow of the pointer falls on the hour divisions. Most sundials cannot keep time accurately, especially during early morning or late evening. Not until the invention of accurate clocks did people realize that the hours shown by a sundial were not of equal length. Because sundials had been in use for so long, some of the early clock makers tried to modify their clocks so the hours were of different lengths to match the hours shown by a sundial. Today, the circular plate of a sundial has the hours correctly marked. On cloudy days, sundials do not work at all.

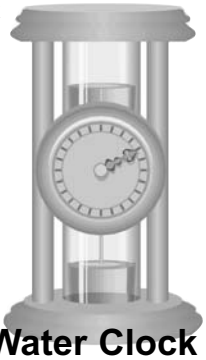
The ***hourglass*** was another ancient device invented about 3500 B.C. and used to measure short intervals of time. The hourglass consisted of two glass bulbs joined by a narrow opening in the middle. The instrument usually was filled with sand, and when upended, the sand trickled from one half into the other half. The hourglass originally had a period of one hour because in one hour all of the sand in the top half dripped through the narrow opening into the bottom half. Hourglasses were used over 2,000 years ago in the Roman government to time how long a senator could speak.



Hourglass

Despite the name, hourglasses later were made to measure other time intervals. For instance, in the 1800s, Queen Victoria of England believed a sermon should not last more than 30 minutes, so she had a 30-minute glass made. During chapel service each Sunday, the preacher turned over the hourglass to start the sand falling and had to finish his sermon by the time all of the sand had fallen into the bottom bulb. As late as the 1950s, three-minute glasses were used to time the cooking of soft-boiled eggs in kitchens.

The ***water clock*** was an Egyptian invention of about 1500 B.C. It was a type of hourglass for measuring time by the gradual flow of water. In the simplest design, water dripped out of one container into another. A gauge was marked with lines to show how much water trickled out. The water clock was not completely accurate. The rate of water flow changed as more water dripped out. The flow was faster when the top container was full than when it was nearly empty. A full container had greater water pressure and forced water out at a faster rate. As the water escaped, pressure was reduced, and the flow slowed.



Water Clock

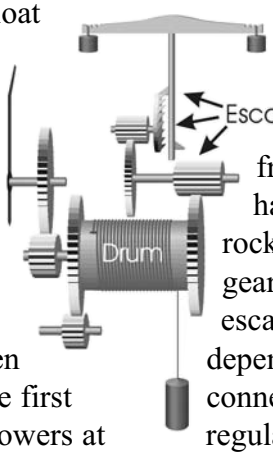
Romans improved on the water clock.

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They put a second container of water above the first one. Water dripped from it into the first container and kept it full. This caused the rate at which the water dripped from the lower container to be uniform. The water dripped into a catch basin that had a wooden stick marked off in hours. As the water in the catch basin rose, the stick began to float and show the hours.

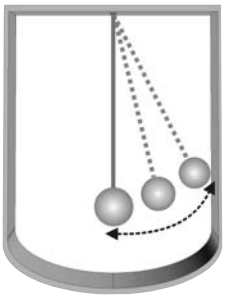
In the 1600s, Galileo used the water clock to time his experiments with falling objects and with round objects rolling down inclines. Water clocks were the most accurate devices for measuring time prior to the 1700s.

Starting in the 1300s, craftsmen made the first mechanical clocks. The first clocks were huge devices that fit in towers at city halls or in the bell towers at monasteries or cathedrals. The internal workings of each clock consisted of a falling weight attached to a cord wrapped around a drum. As the weight fell, it turned the drum. The falling weight had potential energy due to its height above the ground. As it fell toward the ground, the weight gave up potential energy that became kinetic energy and put the gears in motion. The motion of the rotating drum was transferred by a series of gears to the hour hand on the clock face. Early clocks had no minute hands. Gears were made of wood, and clockworks were not protected from dust or changing weather. Even the best of them were in error by as much as half an hour each day.



The ***escapement*** was one of the essential features of an accurate clock. As the weight fell and the drum turned, the escapement caught and then released the gears. Without it, the weight fell faster and faster. The cord unwound faster from the drum and caused the hour hand to spin around. The escapement rocked back and forth, first releasing the gear and then stopping it. The escapement had to be regulated. Some dependable, periodic event had to be connected to the escapement to count off regular time intervals. This was the great failing of the early clocks: although they had an escapement, early clocks were not regulated.

The motion of a pendulum regulated the first accurate clocks. The period of a pendulum is the time required for it to make a complete swing. This interval of time was very regular. A pendulum attached to the escapement of a clock made possible the accurate measurement of hours, minutes and seconds.



Life Principle

"It is the supreme art of the teacher to awaken joy in creative expression and knowledge."



—Albert Einstein

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Integrated Physics & Chemistry



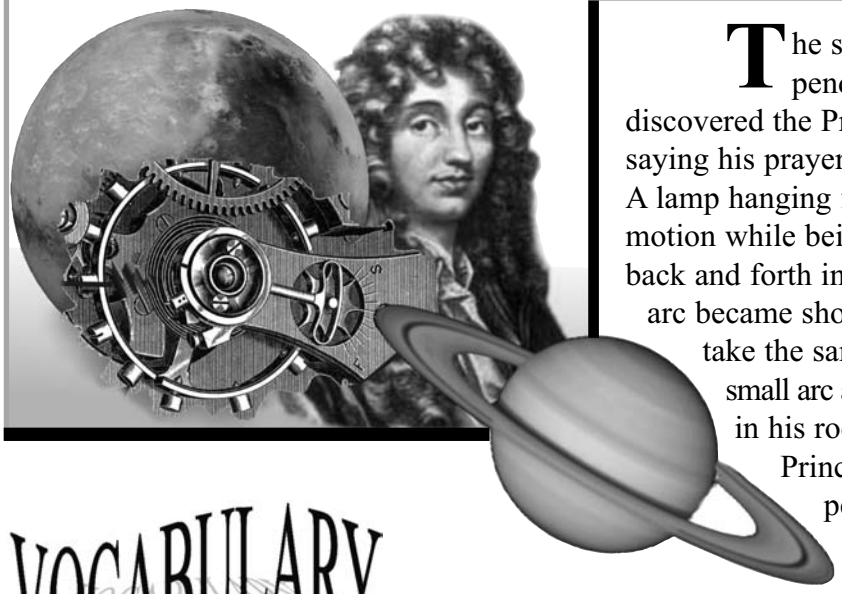
Lesson 4
Inventions & Discoveries

Chapter 9

KEEPING TIME—CLOCKS

Section 1

Lessons 1-5



The scientist Galileo first noted that a pendulum has a constant period. He discovered the Principle of the Pendulum after saying his prayers during a morning chapel time. A lamp hanging from the high ceiling was set in motion while being lighted. The lamp swung back and forth in a wide arc. The length of the arc became shorter, but to Galileo it seemed to take the same amount of time to make a small arc as a large one. After experimenting in his room, Galileo discovered the Principle of the Pendulum: the period of a pendulum depends on the length of a pendulum but is independent of the size of the arc. A pendulum with a wide arc will take the same amount of time as one swinging in a shallow arc.

The *period* is the amount of time to complete a certain event. The period of Earth's revolution around the Sun is an absolute year. The period of Earth's rotation on its axis is an absolute day. The period of a pendulum is the time taken to make a complete arc, to swing from one side to the other and then back again. A pendulum that is almost 25 centimeters long (10 inches) takes one second to make a complete swing in a period of 1 cycle per second.

The discovery of the Principle of the Pendulum led the way to making accurate clocks. The advantage of a pendulum of a fixed length is that it has a constant period. The regular back and forth motion of the pendulum could be used to regulate the *escapement* of a clock mechanism. Christiaan Huygens made the first accurate ***pendulum clock***. Huygens was born in The Hague,



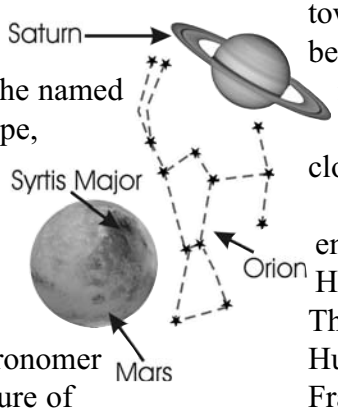
VOCABULARY

Pendulum clock: a clock that uses the regular back and forth swinging of a pendulum to regulate the escapement
Balance wheel: a wheel that swings back and forth under the influence of a hairspring; regulates the escapement
Hairspring: a small spring that by winding and unwinding causes a balance wheel to rotate forward and then in reverse at a regular rate
Fundamental unit: a unit of measure from which other units of measure are derived
Kilogram: the fundamental unit of mass in the metric system

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Netherlands. He received a good education that included instruction at home from his father, private tutors and attendance at the University of Leiden.

Huygens became interested in astronomy while helping his brother construct a telescope. In 1656, Huygens discovered the Orion Nebula. This is a great ball of gas far out in space in the constellation of Orion, the Hunter. Huygens also observed the planet Mars. He was the first man to observe the distinctive V-shaped feature known as Syrtis Major on the surface of that planet. Huygens discovered a large satellite of Saturn, which he named Titan. In Galileo's telescope, Saturn appeared to have two handles. Huygens saw that a ring encircled the planet but did not touch it, which meant Huygens was the first astronomer to understand the true nature of the rings of Saturn.



Huygens realized that astronomers needed accurate clocks. Astronomers could then better predict eclipses of the Sun and Moon, the position of the planets and other celestial events if time could be measured precisely. The best clocks of his day were unreliable. Most kept time very poorly and had only hour hands. They were so large they occupied entire towers at city halls or in churches.

Huygens built a clock capable of keeping time to the minute. He used the regular back and forth motion of a swinging pendulum to control the gears. Falling weights on a chain kept the pendulum in motion. Huygens presented the first working model to the Dutch government and described it in printed form in 1658. Instead of a clock tower, it fit in a much smaller case and could be a piece of furniture in a person's living room. The pendulum clock of Huygen's design became known as the grandfather clock.

For the first time, clocks were accurate enough to have minute hands. Christiaan Huygens' fame spread throughout Europe. The Royal Society of England elected Huygens a member. King Louis XIV of France invited Huygens to France because the king realized that science was important to the development of a modern country. Huygens moved to Paris, France. There, he helped organize the French Academy of Sciences and served as its first president.

Christiaan Huygens had religious beliefs which, by 1681, were in conflict with French Church officials who were intolerant toward Protestants. Huygens could not remain in France and worship God without fear of persecution. Thus, after 15 years in France, Huygens made the difficult decision to leave Paris. He gave up his scientific instruments and said good-bye to his friends. He returned to The Hague, Netherlands, where he could worship God freely.

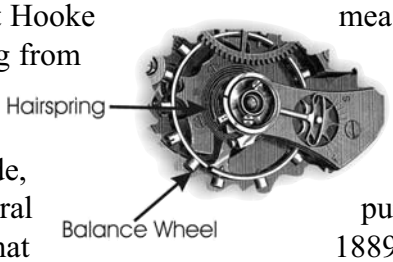
In the Netherlands, Christiaan Huygens continued to make important contributions in mathematics, astronomy, time measurement and the theory of light.

VOCABULARY

Standard: an object or procedure that defines a fundamental unit
Derived unit: a unit of measure that is based on a multiple or fraction of a fundamental unit
Meter: the fundamental unit of distance in the metric system
Second: the fundamental unit of time in the metric system

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The pendulum clock was a great advance that reduced the size of a timekeeper from one that required an entire bell tower to one that fit in a cabinet. The pendulum, however, still required a lot of space. Most pendulum clocks had a pendulum that was about 40 inches long. It made a slow back and forth motion every two seconds. Christiaan Huygens designed a watch that did away with the pendulum. The watch had a ***balance wheel*** that provided a regular back and forth motion. A balance wheel was attached to a small and delicate ***hairspring***. English scientist Robert Hooke made the first hairspring from a tough but flexible coil of hog's hair. In the watch Huygens made, the hairspring was a spiral strip of flexible metal that sprang back when twisted.



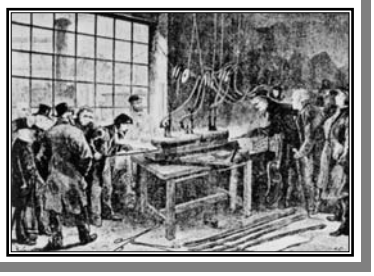
One end of the hairspring was fastened to the frame of the watch. The other end was hooked to the shaft of the wheel. When the wheel was given a push, it turned and tightened the coils of the spring. The spring pushed back and slowed the turning of the wheel until it stopped. Then the coiled hairspring unwound and sent the wheel in the opposite direction. The motion carried it past its starting position. The balance wheel swung back and forth under the continual coiling and uncoiling of the hairspring. A lever with two teeth attached to the balance wheel regulated the escapement. The dependable coiling and uncoiling motion of the hairspring and balance wheel regulated a watch so it kept accurate time.

As time passed, watchmakers learned how to make timepieces more reliable. A watch was found to keep better time if it was in a sealed case that kept out dust and moisture. Some cases had glass coverings so the owners could see the movement of the hands. Others were completely enclosed. A spring latch opened the top of the watch so the hands could be seen. Then it was closed after the owner saw the time. Other improvements included making gears of hardened steel polished smoothly so the gears would move effortlessly against one another. The axles of the gears worked better and lasted longer if they were mounted on small jewels. Watchmakers used diamonds and sapphires for the jeweled movements.

Time, like length and mass, is a fundamental quantity. A ***fundamental unit*** of measure is used to define other units. The fundamental unit of mass is the ***kilogram***. When the metric system first begun, the kilogram was defined as the weight of 1,000 cubic centimeters of pure water at a temperature of 4ºC. In 1889, a cylinder of platinum and iridium was made with exactly the mass of one kilogram and was stored in a vault in Paris, France. Today, that one-kilogram metal cylinder continues to be the international ***standard*** for mass.

Derived units are some combination or divisions of the standard unit. For instance, the milligram (0.000001 kilogram), gram (0.001 kilogram) and metric ton (1,000 kilograms) are derived from the standard kilogram.

The fundamental unit of length is the ***meter***. When the metric system began, the meter was defined as one ten millionth ($^1/_{10,000,000}$) of the distance from the North Pole to the equator. Marks, one meter apart, were engraved on a bar of platinum-iridium that was kept in Paris. Because the bar expanded and contracted with temperature, great care had to be used when marking off a



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copy of the meter. In 1983, the meter was redefined in terms of the speed of light. The meter is the distance light travels in an interval of $^{1}/_{299,792,458}$ of a second. The derived units for length include the millimeter ($^{1}/_{1,000}$ meter) and kilometer (1,000 meters).

The ***second*** is the fundamental, standard unit for time in the metric system. A minute has 60 seconds, an hour has 60 minutes and a day has 24 hours. A day, then, has 86,400 seconds. Originally, the second was defined as $^{1}/_{86,400}$ of a day. A day, in turn, was defined as the average time in which Earth rotates on its axis once in relation to the Sun.

As the need for greater precision increased, scientists realized that a standard unit based on the rotation of Earth was not absolutely accurate. Earth does not rotate uniformly on its axis. When the position of mass on a spinning body moves, the rate of spin changes. For instance, ice skaters can spin faster by pulling in their arms. They also can slow their spins by holding out their arms. Earth's spinning is also slowed by the Moon and Sun which pull up tides of water on Earth. The movement of lava underground and the melting of polar ice caps introduce small irregularities in the period of Earth's rotation. Today, therefore, the second is defined using very short but precise events that take place in atoms.

Life Principle



"It is good to remember that the teakettle, although up to its neck in hot water, continues to sing." —Anonymous

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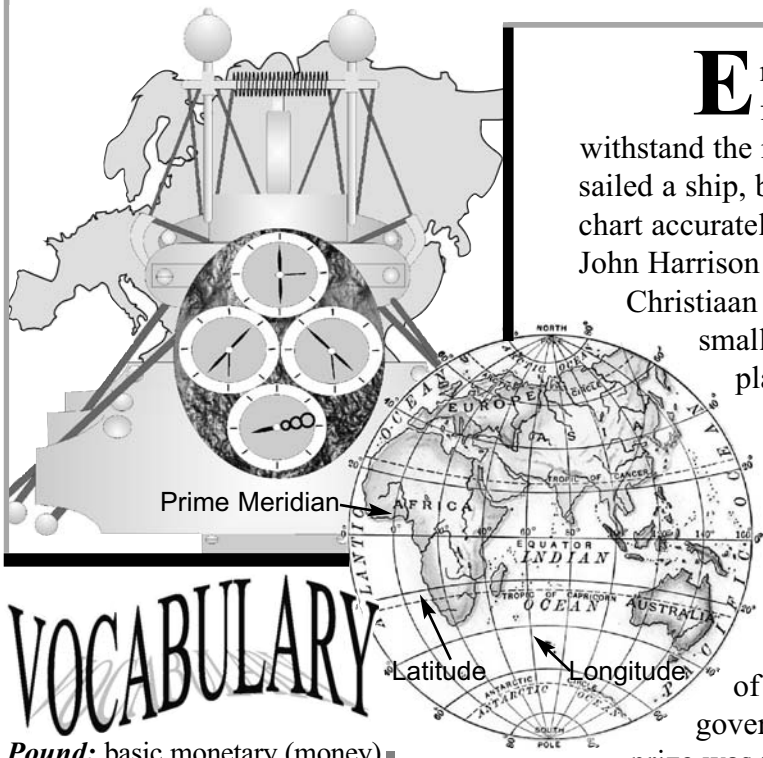
Chapter 9

Lesson 5
Inventions & Discoveries

KEEPING TIME—NAVIGATION

Section 1

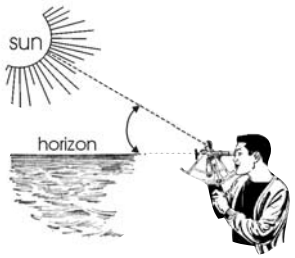
Lessons 1-5



English**man** John Harrison invented the first accurate clock that could withstand the rigors of an ocean voyage. He never sailed a ship, but his skillful hands enabled sailors to chart accurately the most remote locations on Earth. John Harrison was born in 1693, three years before Christiaan Huygens died. As a boy, an attack of smallpox left Harrison in bed. His mother placed a clock nearby to occupy John. He listened to the clock ticking and studied its moving parts. His father trained young Harrison in carpentry, but Harrison took up clockmaking. He also built scientific instruments such as those used by surveyors.

John Harrison learned of a prize of 20,000 ***pounds*** offered by the British government to improve navigation. The prize was to be awarded to the person who could find a way of determining navigation position by longitude. At the start of the 1700s, disasters at sea due to poor navigation had sunk many ships. Accurate navigation would not only improve shipping but also save lives. The prize of 20,000 pounds was more than an average worker earned in a lifetime. The prize required that a ship would sail from England to Jamaica and not miss its port by more than 30 miles.

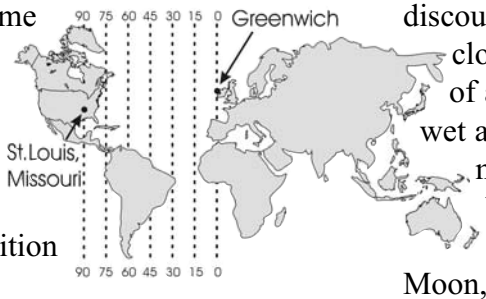
Latitude and ***longitude*** together will locate any position exactly on land or sea. Latitude is the distance north or south of the equator and can be found by measuring the angle formed by one's position to the sun (or the North Star) and the horizon. Longitude is the distance east or west of a reference line. The British used the *Prime Meridian* which passes through *Greenwich, England* as a reference line. A sea captain



VOCABULARY

Pound: basic monetary (money) unit of England and various other countries, symbol is £
Latitude: position north or south of the equator, lines of latitude are parallels
Longitude: position east or west of the Prime Meridian, lines of longitude are meridians
Chronometer: a clock or watch with an accuracy sufficient for navigation, an exceptionally precise timepiece
Synchronous: operating at the same rate
Quartz crystal: a thin slice of quartz that vibrates at a set rate when electricity runs through it

could find the longitude of his location by comparing local time with time in Greenwich, England. Local time could be determined easily enough by the position of the sun or stars.



Most scientists believed that time would have to be revealed by astronomy. For instance, the moon appears in front of stars at predictable times. Astronomers would prepare a table showing the times when particular stars were eclipsed. By observing the time the Moon appeared in front of a certain star, the explorer would know the time by looking at a chart prepared by astronomers. Although this might work for explorers on land, observing a star from the deck of a rolling, pitching sailing ship was no easy task.

Another way to calculate longitude was to carry a clock that had been set to Greenwich time before sailing. Greenwich, England, was the location of the British observatory at longitude 0º. If local time was 12:00 noon in the middle of the Pacific Ocean, but the clock showed the time as midnight in Greenwich, then the ship was exactly halfway around the world from Greenwich.

Because the Earth revolves 360° in 24 hours or 15° per hour, every hour that local time differs from Greenwich time is 15 degrees of longitude from Greenwich. This applies whether the observer is on land or sea. For instance, if the time were 6:00 A.M. in the morning at St. Louis, Missouri, the corresponding Greenwich time would be 12:00 noon. The difference is 6 hours, and 6 * 15 is 90 degrees. St. Louis, Missouri, is at 90º west longitude.

A clock aboard the ship would have to keep Greenwich time faithfully throughout the voyage. The great Isaac Newton discounted the possibility of making such a clock. He said, "By reason of the motion of a ship, the variation of heat and cold, wet and dry, such a watch has not yet been made." The British government believed a scientist who perfected a way to tell local time by looking at the Moon, stars or planets would earn the longitude prize.

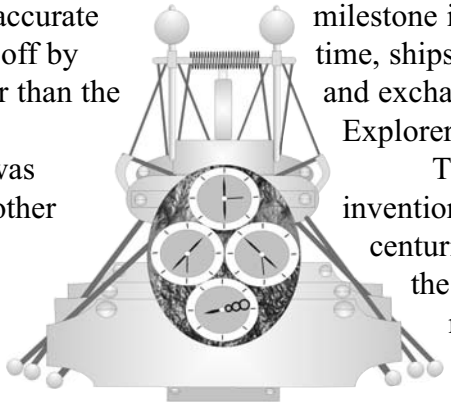
In 1728, John Harrison began building a trustworthy clock. Most people believed that a pendulum clock would not work on a ship. The rolling of the ship would upset the pendulum. John Harrison overcame that problem by designing a system of two large brass balances connected by wires. The weights opposed one another, so the roll of one would counterbalance the roll of the other. Harrison's first clock took seven years to make. He fashioned all the parts by hand. When finished, it weighed 72 pounds and kept good time. In building it, he learned more about clock making. He finished a second clock in 1739 which was even larger and weighed 103 pounds.

Harrison started the next clock even before he completely tested the second one. For seventeen years, John Harrison labored on the third clock. During this time, he received small sums of money from the British government to keep up the work. Harrison completed the third clock in 1757. The first three clocks were big and heavy, and they looked clumsy. He knew he could design a more compact clock. He gave up the idea of pendulum motion for regulating the clock and instead used a coiled hairspring.

In only two years Harrison turned out a fourth clock. It was a triumph of instrument making. The newest clock measured only five inches across and was a mere inch thick. Harrison enclosed it in a brushed metal case and painted the hands in rich colors. The

clock succeeded as a timekeeper of unsurpassed performance and as a work of art. Seldom had a clock looked so beautiful.

In 1761, John Harrison put the fourth clock aboard a ship sailing from England to Jamaica. The clock proved itself in all respects. It helped the captain plot a straight course. The ship arrived three days sooner than another vessel that had a ten-day head start. The contest called for the clock to guide the ship within 30 miles of port. Harrison's latest clock was so accurate that the course of the ship was off by only 1.25 miles, 25 times better than the requirement to win the prize.



John Harrison's clock was more accurate at sea than any other clock at that time on land. His design should have won the longitude prize, but government officials delayed giving him the prize. They repeatedly made demands for more difficult tests. John Harrison's clock passed every trial. Still, they refused to pay him the prize. Finally, Harrison realized that those in charge hoped some of their scientist friends would win the prize. Proud government officials did not want a lowly clock maker to succeed when gentlemen scientists of the Royal Society had failed.

John Harrison boldly asked to meet with King George III, ruler of the British Empire. To King George he described the whole story of his years of work. The King asked about John Harrison's latest clock, his fifth clock. "Has it undergone any official tests?"

"No," Harrison answered. "I am confident to have you prove it in any way you see fit."

"Very well," the King said. "Bring it to my private observatory, and I will examine it." During the next ten weeks, the clock averaged an error of only $^{1}/_{14}$-second per day. At that time, the best pendulum clocks had an error of about 3 seconds per day. The King needed no further proof. With King George in support of his cause, Parliament awarded John Harrison the full prize.

The British Navy would not allow such a precious timepiece to be put aboard a ship for fear it might be lost at sea. Instead, they made carefully crafted copies for maritime use. Harrison's clock was a milestone in navigation. For the first time, ships could meet in mid-ocean and exchange mail and supplies. Explorers could pinpoint tiny islands.

The importance of the invention was illustrated two centuries later. Neil A. Armstrong, the first person to set foot on the moon, visited England. He made a point of giving honor to John Harrison. "His invention enabled people to explore the Earth with precision." John Harrison is a wonderful example of what individuals can accomplish when they work with diligence and determination.

Clocks with a high accuracy such as those made by John Harrison are known as ***chronometers***. The prefix *chrono* means *time,* and *meter* means *measure*. A chronometer is a device to measure time. Early chronometers based on John Harrison's design were 4 to 5 inches in diameter and an inch or more thick. They were about the size of two saucers put together.

As years passed, clocks and watches were improved and made smaller. Most electric clocks that are plugged into a wall outlet have no internal regulator. Instead, the electric current regulates accuracy. In the United States, electric power companies put out alternating current with a frequency of 60 cycles per second. An electric clock has a

synchronous electric motor that runs in step with the frequency of the electricity in the power line. The motor turns at 60 cycles per second, but by gearing it down, the motor drives the hands of the clock at the correct rate.

A modern watch is regulated by a ***quartz crystal***, which responds to electricity by vibrating. Such crystals have a frequency of 100,000 cycles per second, *f = 100,000 cycles/sec*. Watches with quartz timers are extremely accurate. They have an error of about one second every 10 years. Small batteries or solar cells provide electric power. The electric power eliminates the need for a main spring that has to be wound. The display uses liquid crystals or light emitting diodes to show the time as a digital readout. Numbers, rather than hands, show the time. Many watches also include calendars. A watch not much bigger than a U.S. quarter (coin) can indicate years, months, weeks, days, hours, minutes and seconds. The wrist watch is a true marvel because it is a device that contains the efforts of hundreds of individuals over thousands of years.



Life Principle

"The only place where success comes before work is in a dictionary."



–Anonymous

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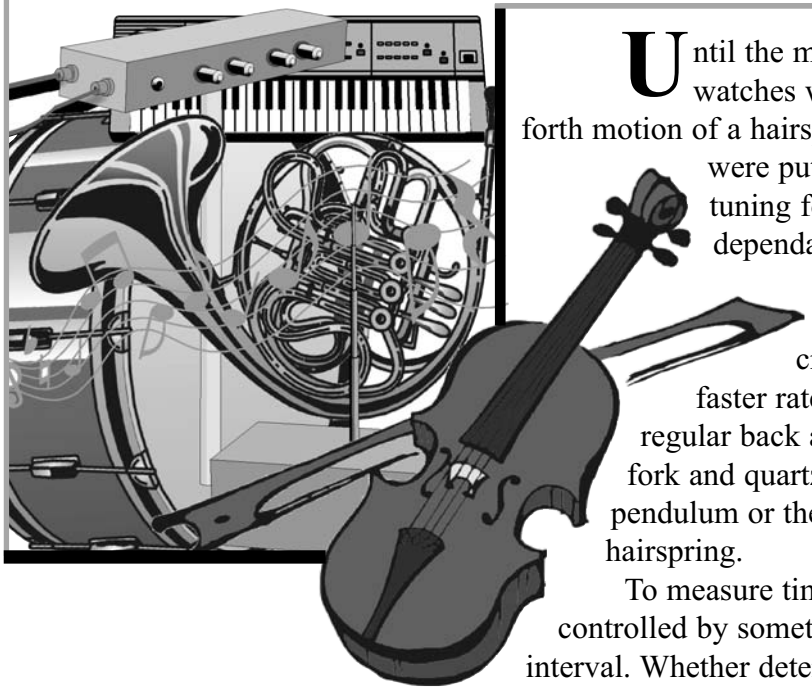
Lesson 6
Energy

Chapter 9

SOUND—PERIOD AND FREQUENCY

Section 2

Lessons 6-10



Until the mid-1950s, most clocks and watches were regulated by the back and forth motion of a hairspring. In 1953, tiny tuning forks were put into watches. The ***period*** of tuning fork vibrations was small and dependable, which improved the accuracy of watches. Later, tuning forks were replaced with quartz crystals that vibrated at an even faster rate and with greater accuracy. The regular back and forth vibration of the tuning fork and quartz crystal replaced the swing of the pendulum or the twisting and untwisting of a hairspring.

To measure time, a clock or watch must be controlled by something that happens at a regular interval. Whether determined by a pendulum, balance wheel, tuning fork, vibrating quartz crystal or some other motion, the time for a complete repetition must be constant.

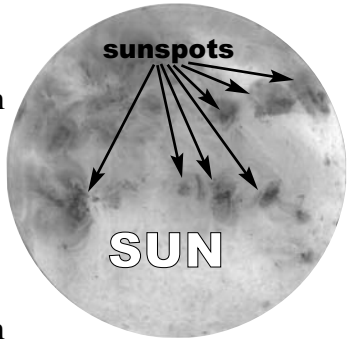
A ***cycle*** is a complete repetition. As an example of a cycle, notice Italian astronomer Galileo, who, early in the 1600s, discovered that the Sun had what appeared to be black spots on its surface. The spots appeared to be dark because they were cooler and dimmer in comparison with the brilliant glare of the rest of the glowing surface of the Sun. Scientists discovered that the number of ***sunspots*** rise and fall in a regular predictable pattern. Sometimes the surface of the Sun is nearly devoid of sunspots or they are at a *minimum*.

As years pass, more sunspots form until their numbers are at a *maximum*. Huge magnetic storms over the sunspots spew out great streams of charged particles which spiral into Earth's atmosphere along the lines of Earth's magnetic field. The charged particles strike molecules in the upper atmosphere, causing a glow. At sunspot maximum, northern lights are common and are most brilliant. The charged particles

VOCABULARY

Period: the time for a complete occurrence of a particular event, symbol is *t*, unit is time/cycle
Cycle: a single complete occurrence of a regularly repeating event
Sunspot: an area on the Sun that appears dark because it is cooler than its surroundings, sunspots are associated with magnetic storms on the Sun

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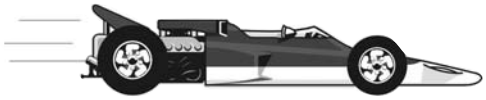


sometimes interfere with communication equipment in space. Then the sunspots fade over the years until they are at a minimum. The complete cycle from sunspot maximum to minimum back to maximum is 11 years.

Galileo and Issac Newton observed a pattern of celestial design that enabled scientists to predict planetary patterns at specific time periods. The period is the time for a single *sunspot cycle*, which is a period of 11 years. The letter *t* is used to symbolize period. The time can be measured in any time unit such as years, days, hours or seconds, *t = time/cycle*. A pendulum that is about 40 inches long makes a complete repetition (cycle) in two seconds. The period of the pendulum is 2 seconds per cycle, *t = 2 sec/cycle*.

To calculate the period, divide the time by the number of cycles. Averaging over several cycles gives a more reliable figure. Suppose that at a particular automobile race, the winning car circles the track 200 times in 167 minutes. Judges can find the average time for a car to make a lap. Solution: divide the total time by the total number of cycles (laps): period = t = time/cycles = (167 minutes) / (200 laps) = 0.835 min/lap or 0.835 min/cycle.

The ***frequency*** is the number of complete repetitions that are made in a given time interval. The letter f is used to symbolize frequency, *f = cycles/time*. To calculate the frequency, divide the number of cycles by the time. The pendulum with a period of 2 sec/cycle has a frequency of 1 cycle per 2 seconds. This can be written as *f = ½ cycle per second* or *f = 0.5 cycles/sec*. In the example of the winning racecar making 200 laps in 167 minutes, the frequency: f = (number of laps)/(total time) = (200 laps) / (167 minutes) = 1.198 laps/min or 1.198 cycles/min.



Period: t = time/cycles
t = 167 (min) / 299 (laps) = 0.835 min/cycle

Frequency: f = cycles/time
f = 200 laps / 167 minutes = 1.198 laps/min

In the United States, household electrical ***alternating current*** has a frequency of 60 cycles per second. The current flows forward, stops and then flows backward. It switches direction 60 times every second. This can be written as *f = 60 cycles/sec*. For alternating current in the United States, the period is 1 second per 60 cycles. This can be written as *t= (1 sec)/(60 cycles) = 1/60 sec/cycle*. As a decimal, the period is *t = 0.0167 sec/cycle*. In England and some European countries, alternating current has a frequency of 50 cycles per second, *f = 50 cycles/sec*. There, the period is one second per 50 cycles or *t = (1 sec) / (50 cycles) = 0.02 sec/cycle*.

VOCABULARY

Frequency: the number of times an event occurs within a given time interval, symbol is *f*, units are cycles/time
Alternating current: an electric current that reverses direction at regular intervals; in the United States alternating current has a frequency of 60 cycles per second
Acoustics: the scientific study of sound
Theremin: one of the first electronic instruments invented by Leon Theremin
Musical synthesizer: an electronic device for creating music

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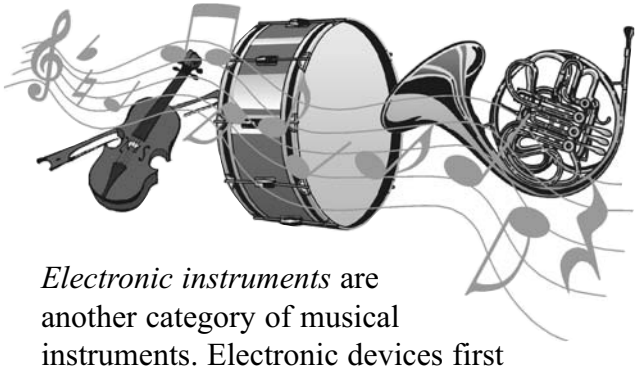
Notice that frequency and period are reciprocals of one another, $f = 1/t$. If the frequency is $f = 2$ *cycles/sec* then the period is $t = ½$ *sec/cycle*. If a regular motion has a high frequency, then the motion has a low period and vice versa. As another example, the frequency of the sunspot cycle is $f = 1$ *cycle / 11 years*. The period of the sunspot cycle is $t = 11$ *years/cycle*.

The terms *frequency*, *period* and *cycle* apply to any motion that regularly repeats. Vibrating matter, for instance, creates sound. As a tuning fork vibrates, it alternately shoves air molecules one way and another. A tuning fork that vibrates 256 times a second has a frequency of $f = 256$ *cycles/sec*. The period is t = (1 sec) / (256 cycles) = 0.00391 sec/cycle. (Divide 1 by 256.)

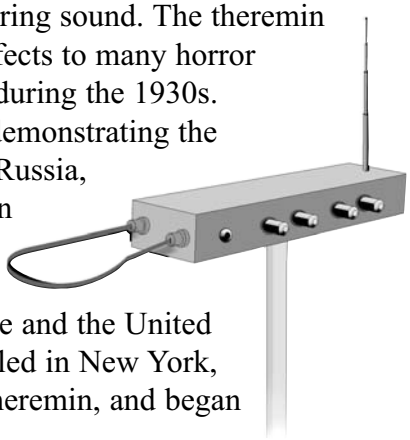
Acoustics is the science of sound. It was one of the first sciences to be developed and the one that has been modified the least over the past 2,500 years. The first person recorded in history to study sound was the Greek scientist *Pythagoras* who was born about 580 B.C. Pythagoras traveled in Egypt and visited Babylon in search of knowledge. He settled in Southern Italy. He believed in simple dress and lived in humble surroundings.

Pythagoras observed the order and design of life and believed that the natural world was mathematical in nature. He therefore applied mathematics to music. He found that the sounds of stringed instruments are related in simple multiples to the lengths of the instruments' strings. His study of the mathematics of music is one branch of physics that has remained unaltered into modern times. Although Pythagoras put the study of music on a firm scientific footing, his most important discovery is the *Pythagorean Theorem*. The Pythagorean Theorem states that *the square of the length of the hypotenuse of a right triangle is equal to the sum of the squares of the lengths of its other two sides*, or $a^2 + b^2 = c^2$.

Music can be made with a variety of instruments. *Percussion instruments* make their sounds by striking one object with another such as the drum, cymbal, xylophone and triangle. *Wind instruments* such as the harmonica, trumpet, clarinet, trombone and organ make their sounds by vibrating streams of air. *Stringed instruments* such as the violin, guitar and cello make their sounds by vibration of the strings.



Electronic instruments are another category of musical instruments. Electronic devices first came into use by musicians in the 1920s. The first successful electronic instrument was the ***theremin***, invented in Russia in 1920 by electronic engineer, Leon Theremin. The player does not touch the instrument. Instead, the pitch (frequency) is determined by how far away the player's right hand is from a vertical antenna. The player's left hand controls the volume by how far it is away from a horizontal antenna. The person makes music by waving his hands around in the air. A skilled user of the instrument can produce an eerie, wavering sound. The theremin gave sound effects to many horror movies made during the 1930s.



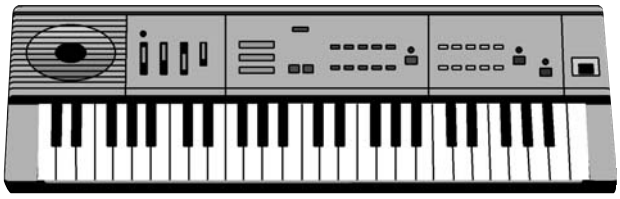
After demonstrating the instrument in Russia, Leon Theremin conducted demonstration tours in Europe and the United States. He settled in New York, patented the theremin, and began

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working on other inventions including the first color television. One day in 1938 Leon Theremin vanished. His apartment was empty. He disappeared from public view and was thought to be dead. The theremin continued to be used and gave the wavering chorus to the Beach Boys hit "Good Vibrations."

In 1987, almost 50 years after he vanished, Leon Theremin was discovered to be alive. In the 1930s, Joseph Stalin, the Russian communist dictator had ordered Soviet secret agents to kidnap Leon Theremin and return him to Russia. Theremin was abducted right off the sidewalks of New York in broad daylight. He was smuggled back into Russia and put to work in a secret scientific research labor camp in Siberia. For 50 years, Theremin was forced to make electronic listening devices and other electronic equipment for Soviet communist spies. In the 1980s, reforms in the Soviet Union resulted in the reappearance of Theremin in Moscow. Finally, Leon Theremin was allowed to travel outside the Soviet Union to attend electronic music festivals in Europe and the United States that were held in his honor. He died in Moscow on November 3, 1993.

Robert Moog, an American inventor who was born in 1934, took the next step in electronic music. Moog studied electrical engineering and physics. He developed a ***musical synthesizer*** that would replicate electronically the sound of any instrument. The instrument was easy to use because of a keyboard, and it was inexpensive to produce. The Moog synthesizer became a popular electronic instrument. In 1969, Robert Moog and American composer Walter Carlos released the record "Switched on Bach," which sold a million copies. Because of Moog's success, other companies began making music synthesizers.



Life Principle

"Out of difficulties grow miracles."

—Jean de la Bruyere

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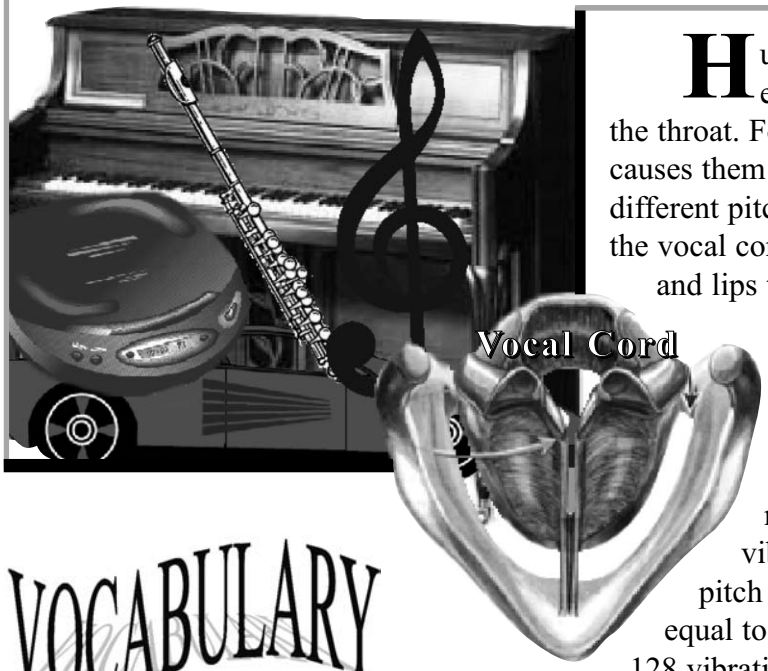
Lesson 7
Light & Sound

Chapter 9

SOUND—PITCH AND QUALITY

Section 2

Lessons 6-10



Human vocal cords are two pieces of elastic connective tissue at the back of the throat. Forcing air through the vocal cords causes them to vibrate. The sound can be given a different pitch by muscles that tighten or loosen the vocal cords. The shape of the throat, tongue and lips then modifies the sound. For most people, speaking at a frequency of between 220 and 440 vibrations per second is most comfortable.

Pitch of a sound is its frequency. A tuning fork vibrating at ***middle C*** makes waves at the rate of 256 vibrations per second. The higher the pitch the greater the frequency. High C is equal to 512 vibrations per second. Low C is 128 vibrations per second. The number 512 and 128 are both multiples of the power of two: 2, 4, 8, 16, 32, 64, 128, 256, 512, 1,024 and so on. Physicists prefer to use that sequence of numbers when dealing with the frequency of sound. Musicians, however, have a different scale. They use 264 vibrations for middle C and 528 vibrations for high C. Notice that high C is twice the frequency of middle C regardless of whether the physicist's scale or the musician's scale is used.

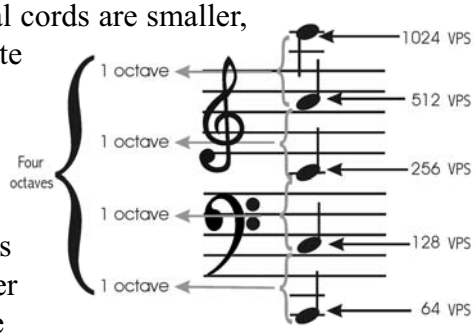
An ***octave*** is a change in pitch by a factor of 2. A note one octave higher has twice the pitch. A note one octave lower has one-half the pitch. The change in pitch from middle C (256 cycles/sec) to high C (512 cycles/sec) is one octave. Any two frequencies in which one is twice the other differ by an octave. A note with a pitch of 440 vibrations per second is one octave higher than a note with a pitch of 220 (220 * 2 = 440). A note with a pitch of 396 is one octave lower than a note with a pitch of 792 (396 * 2 = 792).

VOCABULARY

Pitch: frequency of a sound, the number of vibrations per second
Middle C: the central note in the music scale
Octave: two musical notes in which one has twice as many vibrations per second as the other
Loudness: amplitude of a sound, the maximum movement of an air molecule as a sound wave passes
Decibel: unit for measuring the intensity of a sound, the intensity is the total energy carried by a sound and is perceived as loudness

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The vocal range of the human voice extends about one octave on either side of middle C, 256 vibrations/second. In general, children and women have higher pitched voices. The vocal cords are smaller, lighter and vibrate more quickly. In general, men have lower pitched voices. Their vocal cords are larger, heavier and vibrate more slowly. A deep voice of a man is about 256/2 =128 vibrations per second. A higher pitched voice of a woman is about 256 * 2 = 512 vibrations per second.



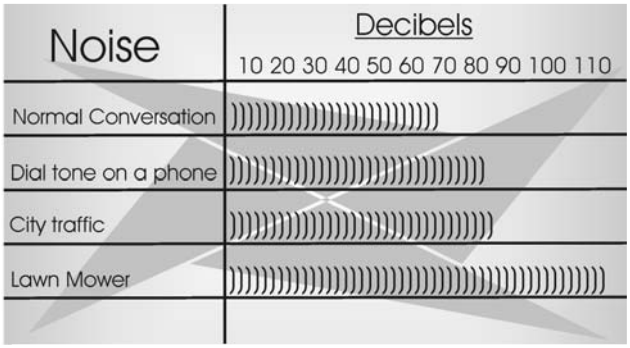
Singers have a greater vocal range than people who do not sing. Some men who sing bass (base) can sing as low as 64 vibrations per second (two octaves—16 notes— below middle C). Some women who sing soprano can sing as high as 1,024 vibrations per second (two octaves above middle C). The total range from the deepest bass to the highest soprano is 4 octaves. The number 64 must be doubled 4 times to give 1,024: 64, 128, 256, 512 and 1,024. Each doubling is an octave. Rarely does a single individual have this range.

The full range of a piano covers seven octaves. The lowest note on the piano has a pitch of 27.5 vibrations/second. The highest note of the piano has a pitch of 4,224 vibrations per second. Starting with 27.5 and doubling it, the series is 27.5→ 55→ 110→ 220→ 440→ 880→ 1,760→ 3,520→ 7,040. Seven doublings and then some are required to go from 27.5 to 4,224. Most other musical instruments do not have this range. A trumpet has about the same four-octave range as the human voice, from about 64 cycles/sec to 1,024 cycles/sec.



Pitch is one of the properties that identifies the sound made by a musical instrument. The human voice, a piano and a trumpet can all sound the middle C note. Distinguishing which instrument makes which note is not difficult, although they have the same pitch. Pitch alone does not determine all of the properties of a sound.

Loudness is another property of sound that the ear detects. Loudness can be represented by the energy of a sound wave, and measured by the amplitude. ***Decibels*** measure the loudness of a sound. A whisper is below 30 decibels. Heavy highway noise is about 90 decibels. A person who cannot hear a sound as loud as 100 decibels is considered



VOCABULARY

Noise pollution: any unwelcome sound, a sound that is annoying, distracting or physically damaging
Abatement: reduction of amount or intensity
Quality: of a sound is the number and amplitude of overtones
Fundamental frequency: the pitch produced by a body that vibrates as a whole
Overtone: a sound with a pitch in a whole multiple of the fundamental frequency

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deaf. At about 120 decibels, a person begins to experience pain because the sound is so loud. At that loudness, the ears can be damaged.

Human senses do not follow a straight-line pattern. Suppose a single buzzer is replaced with ten identical buzzers. Most people will perceive the sound as being only twice as loud, not ten times as loud. A sound that is 10,000 times as loud will be perceived by the human ears to be merely four times as loud as 10 buzzers. The ear can perceive sounds over an enormous range of loudness. The loudest sound that can be tolerated by the human ear is about a trillion (1,000,000,000,000) times louder than the softest sound barely detectable to the human ear.

Human ears have a frequency range of about 15 cycles/sec at the low end to 20,000 cycles/sec at the high end. Human ears are most sensitive in the same range as human speech, an octave on either side of middle C. A person is more likely to hear a whisper at a normal pitch than one that is of the same loudness but at a higher or lower pitch. The ability to hear a sound falls off rapidly beyond 12,000 cycles/sec. The sound must be louder for a person to hear it. Beyond 20,000 cycles per second, the pitch is so high a person cannot hear the sound regardless of how loud it is.

Not all sounds are intentional, and some sounds can be irritating: the persistent barking of a dog, the drip-drip-drip of a leaking faucet, loud talking when others are trying to study or listen to music. Some sounds can be more than irritating. People who are trying to work or do delicate or difficult tasks can be distracted by unwanted noise. Sounds can be so loud that they are physically harmful. Car engines, motor bikes, jet engines, highway noise, construction equipment, rock music concerts, "boom-boxes" (or listening to any sound approaching 110 decimals) can damage a person's hearing.

Noise pollution is any sound that is annoying, distracting or physically damaging. Excessive sounds that do not benefit those who hear the sounds are a serious environmental problem. Even plants can wither and become unhealthy when subjected to heavy metal rock music. In the United States, federal highways that are constructed through residential areas must have a wall built on each side to reduce highway noise reaching adjacent homes. Most airports have noise ***abatement*** plans to reduce the sound of jet aircraft taking off. The Environmental Protection Agency is responsible for protecting the environment for future generations. One of its aims is to reduce and control noise pollution.



The ***quality*** of a sound is the third property of sound that the ear can detect. Secondary vibrations that are simple multiples of the natural frequency produce quality. Suppose a note with a pitch of middle C is played on a trumpet, on a piano and by a singer and all the notes are equally loud. The human ear can tell one instrument from another by the property of quality.

The ***fundamental frequency*** is the natural frequency of an object, and is always the lowest frequency caused when the entire instrument vibrates. When a guitar string is plucked, it vibrates along its whole length. Vibrating at one part gives its natural or fundamental frequency. By touching the string in the middle when it is plucked, the string vibrates in two parts at a frequency twice that of the fundamental frequency. The string vibrates in two parts. In the same way, the string can be made to vibrate in three parts, four parts and so on.

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Overtones are whole number multiples of the fundamental frequency. When a guitar string vibrates in three parts, a pitch is produced that is three times the fundamental frequency. Normally, a musical instrument does not deliver a pure tone of only its fundamental frequency. When a guitar string is plucked in the middle, several of its overtones are also created. The number and loudness of overtones give the quality of a sound.



The number and loudness of overtones produce quality. When a person plays middle C on the piano, a tone is made having a frequency of 256 vibrations per second. At the same time, blended with the fundamental frequency, are overtones having frequencies that are two, three, four and more times the frequency of middle C. The number of overtones and their relative loudness produces the quality of sound that is associated with a piano.

The human ear can detect overtones and enable a person to distinguish one musical instrument from another. A tuning fork produces an almost pure sound wave at its fundamental frequency with practically no overtones. A flute has a quality very similar to a tuning fork because the flute has few overtones. A violin differs in quality because it produces its fundamental frequency with many overtones.

The *three properties of sound* are its pitch (frequency), loudness and quality. The human ear can best detect changes in pitch. Some people can distinguish the difference between two tones, one at 256 vibrations per second and the other at 255 vibrations per second. People with this skill are said to have perfect pitch. Ordinary individuals can detect changes in pitch of about one percent. For instance, an average person can tell the difference between 1,000 cycles per second and 1,010 cycles per second. The difference is 10 (1,010 – 1,000 = 10) and 10/1,000 = 1/100 = 1 percent.

Life Principle

"The person who does not make a mistake does not do anything."

—Anonymous

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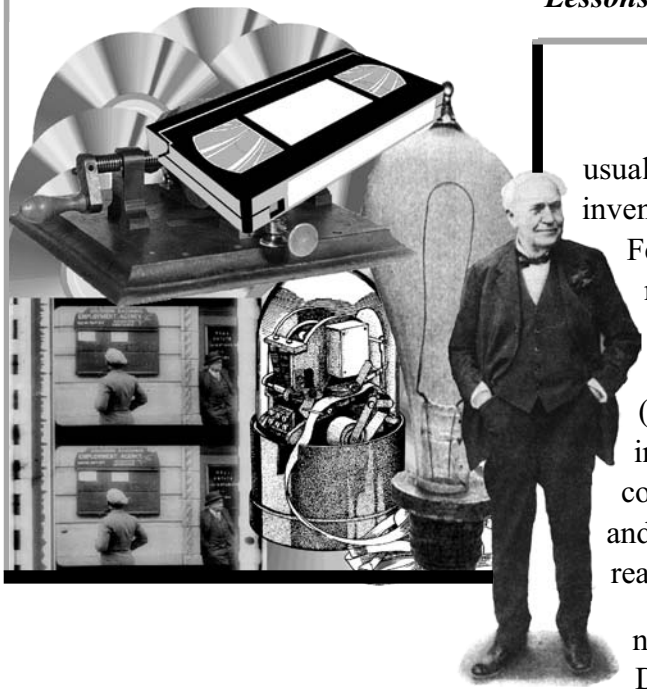
Lesson 8
Light & Sound

Chapter 9

RECORDING SOUND

Section 2

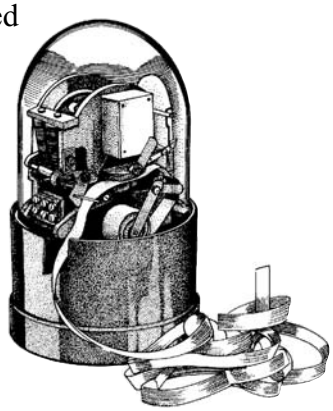
Lessons 6-10



On any list of the world's greatest inventors, Thomas Alva Edison is usually at the top. He patented about 1,100 inventions. Edison was born in Milan, Ohio, on February 11, 1847. He received only three months of education in a public school. His mother educated Thomas at home after his teachers accused Thomas of being addled (confused). Thomas was not like other children in many ways. Stories soon circulated that he could read almost as fast as he could turn pages and could remember practically everything he read.

At age 12, Thomas Edison began selling newspapers aboard a train as it made its run to Detroit. Later, he bought secondhand printing equipment and published the paper he sold on the train. One day, Edison rescued a small boy who had strayed onto the train tracks. As a reward, the boy's grateful father offered to teach Edison to be a telegraph operator. Within a year, Edison became one of the best operators in the United States. With money he earned, he bought the collected writings of the British electrical experimenter and chemist, Michael Faraday.

In 1863, Thomas Edison became a telegraph operator for the railroad. He was 16 years old. He studied the telegraph, one of the first inventions that used electricity for a practical purpose, and began to experiment with electrical devices. In 1869, he made his first important invention, the stock ticker—a strip of paper that came out of a modified telegraph. The paper continuously displayed the price of stock being traded on stock exchanges. Edison sold the stock ticker for $40,000, an incredible sum



VOCABULARY

Megaphone: a funnel shaped device used to direct and amplify sound
Kinetograph: the name Edison gave to his motion picture camera, the word means motion writer
Kinetoscope: the name Edison gave to his motion picture projector, the word means motion viewer
Synchronize: to occur at the same time or to operate together

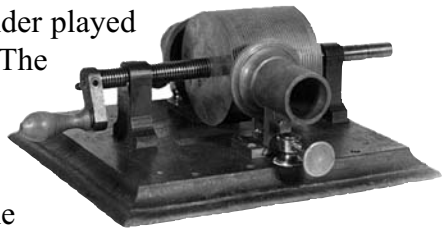
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at that time. The payment was not due to hard bargaining on his part. He had been prepared to sell his invention for $5,000 but did not have the courage to ask for so much. Instead, the buyer suggested $40,000.

Edison invested the money by building a research laboratory at Menlo Park, New Jersey. So many important devices came from his laboratory that he became known as the wizard of Menlo Park. In all, he turned out 1,300 inventions, but did not patent them all. Some of his inventions were as simple as waxed paper. Others included the phonograph, electric light and motion picture projector.

In 1877, Edison demonstrated the phonograph. The word *phonograph* is from the Greek word *phono,* meaning *sound* or *speech,* and *graph,* meaning *to write*. A phonograph is a sound writer. Edison's first model had a needle that touched tin foil wrapped around a cylinder. The cylinder was made to rotate by turning a crank. One spoke into a funnel-shaped ***megaphone***. The sound waves caused the needle to vibrate in time with the sound waves. The needle skimmed over the tinfoil and left wavy grooves on the cylinder that exactly matched the sound waves. Edison recited *Mary Had a Little Lamb*. The cylinder containing the child's rhyme still exists today.

The first phonograph was totally mechanical. No electricity was used. Putting the needle in the groove and turning the cylinder played the sound back. The grooves caused the needle to vibrate, the needle caused the diaphragm to vibrate, and the vibrating diaphragm produced sound waves that were amplified by the megaphone. Problems included the fact that a person had to turn the crank at a steady speed, and the sound was not very loud. A year later Edison added an electric motor to turn the cylinder at a steady rate. Other inventors replaced the cylinder with a flat disc made of vinyl.



As soon as the phonograph was developed, Edison turned to the problem of electric lighting. Until then, people lighted their homes with candles, kerosene, whale oil lamps or gaslights. For bright lights, acetylene torches or arc lights were used. All of these light sources had the risk of explosion or fire. Until the 1800s, the activity of people at night was greatly hindered by the lack of dependable light. Only a few cities had streetlights. Most homes in the city had guestrooms. If a visitor stayed until after dark, the hospitable thing to do was to offer the visitor lodging for the night because walking unlighted city streets at night was not safe.

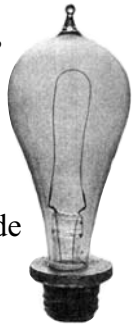
Safe, dependable lighting would improve life dramatically. Factories could work around the clock. Streets would become safer. Even baseball games could be played

VOCABULARY

CD: abbreviation for compact disk
Analog: a process of storing information where a variation in one quantity is at the same ratio as the variation of the quantity being stored, a vinyl record is an analog recording, the wavy grooves in the record vary in the same manner as sound waves, often analog signals are not identical to the original signal
Digital: a process of storing information in which signals are replaced as numbers, a compact disk has information that is digitally recorded, digital signals can be recovered exactly
DVD: abbreviation for digital video (or versatile) disk

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at night. Although other inventors, including Joseph Sawn in England, made electric light bulbs, Edison's version proved to be the most reliable. In 1879, Edison's first carbon filament light bulb burned for 40 hours. Within a year, he made and began marketing bulbs that glowed for 1,500 hours. The first commercial bulb was 16 watts. The filament was of carbon made from a scorched cotton thread.

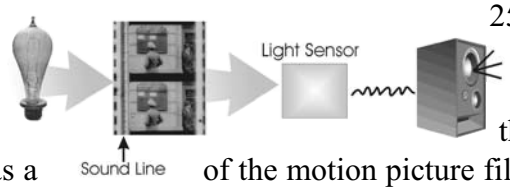


Many inventors contributed to motion pictures. The illusion of motion from still pictures or drawings is due to the *persistence of vision*. An image remains implanted in the mind for a fraction of a second after the image disappears. In 1825, an English physician, John A. Paris, demonstrated this with a rectangle of cardboard on a stick. On one side of a piece of cardboard was a drawing of a birdcage. On the other side, was a drawing of a bird. Paris twirled the stick rapidly; the bird appeared to be in the cage. Movies and television, both live action and animated cartoons, make use of the persistence of vision.

Suppose an activity such as a horse running or a child jumping is photographed as a series of still images with each one differing from the previous one only slightly. If the images were viewed in rapid succession, the viewer would experience an illusion of movement. Motion appears to be continuous to most people if they see 16 or more pictures a second. In the 1800s, several devices were built that caused images to appear to move. Most views were of simple repeating images such as a dog jumping through a hoop. One device had a wheel with slits in it. On the back of the wheel was a paper disk with several drawings of the dog at various stages as it jumped through a hoop. Standing in front of a mirror, the viewer held the wheel by a handle in the middle, and gave the wheel a spin. The slits allowed a reflection of a picture to be seen, and then the lack of a slit blocked the view while the next picture rotated into view. By standing in front of a mirror and rotating the disk, the dog appeared to come alive.

All early motion picture devices featured short scenes and usually displayed flickering images. The images were on opaque media and were intended for only one or two people to view at a time. Edison printed the images on a transparent nitrocellulose film. The sequence of images could be projected on a screen. Edison also invented a camera with the ability to record images continuously. He gave the name ***kinetograph*** for the device to record the images. Kinetic energy is the energy due to motion. *Kine* is a word meaning *motion*. *Graph* means *to write*. The kinetograph was a device to write motion. Edison gave the name ***kinetoscope*** to the device to view the motion picture. *Scope* means *to view*. A kinetoscope was a device to view motion. He filmed the first motion picture that told a story, the *Great Train Robbery.*

Although both sound and motion could be recorded, matching the sound to the speaker was a difficult task that was not solved until the 1920s. The problem was to ***synchronize*** the sound with the image on the screen. Separate devices such as a phonograph and a motion picture projector played at different speeds. The sound and picture did not synchronize. For more than 25 years, movies were silent movies. The solution was to put the sound at the edge of the motion picture film. Rather than physical grooves in the film, the sound was recorded as dark lines that varied in their



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thickness. The motion picture projector shined a beam of light through the lines. A sensor on the other side picked up the light and converted it to electricity, which varied with the thickness of the lines. The electricity then sent the varying electrical impulses to a loudspeaker that produced sound. The sound and picture were synchronized because they came from the same source.

Motion picture cameras and projectors are still used today in the motion picture industry. Most television and home movies are recorded on magnetic media. Rather than light and dark, the information about the scene is recorded as variations in the alignments of small magnetic particles embedded in the tape. Ray Dolby and Charles Ginsberg invented the first videocassette recorder in the 1950s. Ray Dolby also invented the Dolby system of noise reduction in magnetic recording.

Inventions continued to improve the recording of sound and motion. In the 1980s, *compact disks,* ***CD***s, became available. The grooved disk in vinyl had been the most common way to record music up until that time, a period of about 100 years. Within a few years after their introduction, compact disks had almost completely replaced vinyl records.



A compact disk has several advantages over a phonograph record. Disks are smaller but hold more information. A record requires a needle to ride in grooves. With repeated playing, the sound quality deteriorates, and scratches cause the needle to skip from one groove to another. Dirt and other imperfections on the surface of the record cause a hissing sound that some listeners find distracting. A compact disk is not in physical contact with the laser light that reads the information on the disk. The sound reproduction is of higher quality.

The greatest advantage of a CD is the way information is recorded. A vinyl record is an ***analog*** device. The motion of sound is transferred to the record as a series of wavy grooves. The grooves are proportional to the loudness and frequency of the sound. The information may not be exactly repeated during playback. When a CD is recorded, the information is ***digital***. Within the CD, a series of bubbles is created that specifies exactly the loudness and frequency. When the laser reads the CD, the very same sounds that went into recording the CD are returned as a series of binary impulses that are interpreted by a computer to reproduce the original sounds exactly as they were recorded.

For instance, suppose a particular note is exactly middle C, 256 vibrations per second. When the note is recorded on a record by analog means, the needle makes a wavy line on the record. When this is played back, variation in the record player may make the note be 255 vibrations per second or 257 vibrations per second or some other number. On a compact disk, the frequency is recorded not as wavy lines but as the number 256. When the CD is played back, the player reads the number as 256 exactly.



Another advantage of digital recordings is that they can be copied exactly. If a record is played and the music is recorded on another record and that record is played and its sound is recorded on a third record, the sound quality quickly deteriorates. When the contents of a digital device such as a CD are recorded digitally on another CD, no loss of quality occurs. The second CD is an identical copy of the first. The disadvantage of this from the music industry's standpoint is that the illegal copying of copyright songs is made easier.

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Just as CDs replaced phonograph records after 100 years, *digital videodisks*, ***DVD***s, began to replace film and videocassettes as the way of recording and playing back motion pictures in the 2000s. Like CDs, DVDs are digital devices. A CD and DVD have the same physical size and operate in much the same way, but a DVD can store about 10 times as much information as a CD.



Life Principle



"Genius is one-percent inspiration and ninety-nine percent perspiration."

—Thomas Edison

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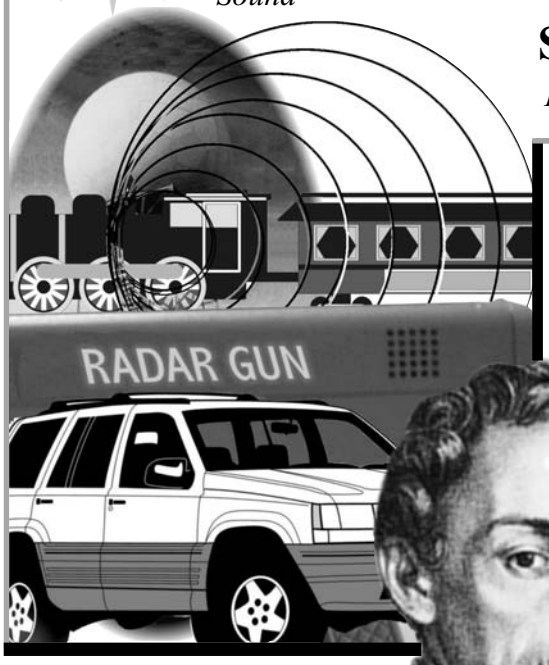
Chapter 9

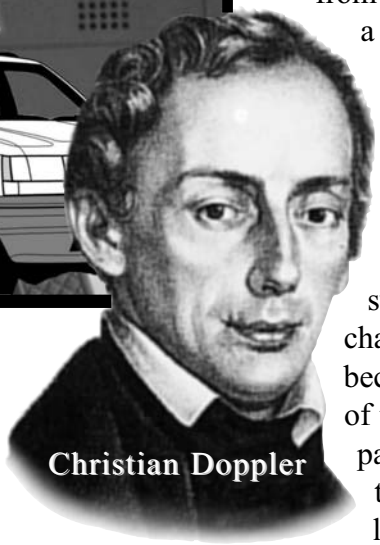
Lesson 9
Light and Sound

Section 2

Lessons 6-10

SOUND—DOPPLER SHIFT




Christian Doppler

Suppose a listener is standing beside a highway as a car passes quickly with its horn sounding. The frequency of the sound from the horn changes in an interesting way. The sound from the horn is higher pitched as it approaches a listener but lower pitched once the car has passed. Although the horn does not change pitch, the frequency of the sound that the listener hears does change. This apparent change in the pitch of a sound because of motion is the ***Doppler effect***.

In the 1800s, methods of transportation such as the train made it possible for the change in frequency from a moving source to become apparent. People noticed the behavior of the sound of a locomotive whistle as a train passed someone at the station. The sound of the whistle dropped from a high pitch to a lower pitch.

Christian Doppler, a physicist who lived in Vienna, figured out what was happening. Normally, two velocities are added together if they are in the same direction. For instance, suppose a person on the front of a train that is going 27 meters per second (about 60 miles per hour) throws a ball forward at 20 meters per second. The ball would travel at 47 m/sec (27 m/sec + 20 m/sec = 47 m/sec). For a moment after it leaves the pitcher's throwing hand, the ball has both the train's speed plus the speed given to it by the pitcher.

The velocity of sound is different. All sound waves travel at the same speed in air regardless of the speed of the instrument causing the sound. In air, sound travels at about 344 meters per second (about 1128 ft/sec). Suppose the source of the sound, such as the whistle on the train, is moving at 27 meters/sec (about 60 mi/hr). The fact that the whistle is moving will not cause the sound waves to travel faster. Once they leave

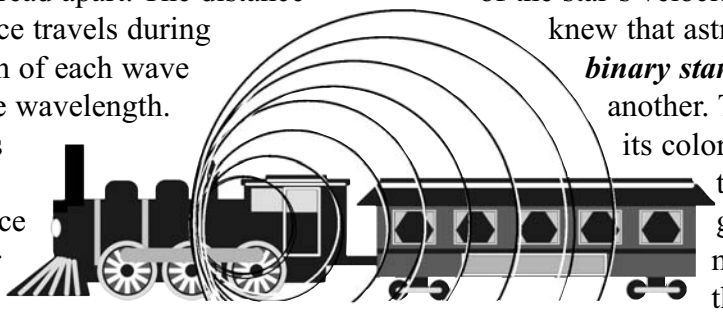
VOCABULARY

Doppler effect: apparent change in frequency of a wave due to motion of the source or receiver
Binary stars: two stars that orbit their common center of mass, often they are so close together they appear as a single star in a telescope, also called double star

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the whistle, they travel at 344 m/sec, the speed of sound in air. Even if the train doubled or tripled its speed, the sound waves would not go faster. They would continue to travel forward at 344 m/sec.

Christian Doppler realized that those sound waves in front of the train would be crowded together. The distance that the source travels during the formation of each wave shortens the wavelength. Those waves in front of the moving source have a higher pitch. Waves behind the moving source of the sound are spread apart. The distance that the source travels during the formation of each wave lengthens the wavelength. Those waves behind the moving source have a lower pitch.



In 1842, Doppler worked out a formula to predict how the pitch of a moving source of sound would change as it approached, then passed by a listener. A locomotive pulling a flatbed car through a crossing at different speeds tested Doppler's formula. On the flatbed car, musicians played trumpets at a fixed note. Musicians who had perfect pitch listened at the crossing. As the train passed, they noted the change in pitch of the trumpets. For two days, the train pulled the flatbed car back and forth at different speeds through the intersection. The experiment showed that Doppler's formula was correct.

The Doppler effect applies to any wave motion. The change in frequency because a body is in motion applies to any wave motion, sound, light or radio. Christian Doppler was aware that the effect should apply to light as well as sound. The color of the light from a star should change because of the star's velocity relative to Earth. He knew that astronomers had found true ***binary stars*** that circled around one another. The frequency of light is its color. As binary stars orbit their common center of gravity, one would be moving toward Earth, and the other would be moving away from Earth. This motion would cause a very slight color shift. One star would be slightly bluer as it approached Earth, and the other one slightly redder as it receded.

Astronomers discovered they could detect the slight color shift with a spectroscope. The spectroscopic lines did shift slightly. Some stars that astronomers previously thought were single stars proved to be binary stars. The stars orbited so closely together that a telescope could see but one star. However, the spectroscope revealed their secret. As the stars orbited one another, their lines in the spectrum split. One star shifted toward the blue, and the other shifted toward the red. This Doppler effect is also known as the ***Doppler shift***.

The stars do not have to be double for a spectroscope to detect their speed. Suppose a star is approaching Earth. The extra speed causes a change in frequency (color) of the light. When its light is examined in a spectroscope, the lines will all be shifted

VOCABULARY

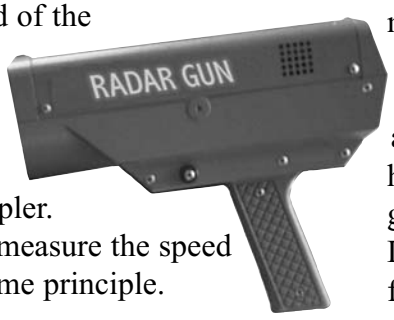
Doppler shift: other name for the Doppler effect based on the fact that lines in a spectroscope appear to shift toward the red for a source of light that is going away from Earth and shift toward the blue for a source of light that is approaching Earth

Doppler radar: radar that uses the Doppler effect to calculate the speed of the target

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slightly toward the blue. The speed of the star relative to Earth can be calculated by the amount of the shift. If the star is moving away from Earth, then its light is shifted slightly toward the red. The amount of shift gives the speed.

Doppler radar was invented in the 1960s as an improvement to regular radar. Radar was developed in the 1940s during World War II. Its primary purpose was to detect approaching enemy aircraft and to show their direction and distance. The distance was calculated by how long it took for radar waves to echo back. Doppler radar makes use of the changes in frequency of the reflected radar waves to measure the speed of the target. Doppler radar became important in a number of applications. Doppler radar is used in weather forecasting to measure the speed of winds in thunderstorms. Radar guns that measure the speed of a thrown baseball use Doppler radar. The radar gun emits radio waves of a precisely known frequency. They reflect from the baseball and return to the radar gun. Because they are reflecting from a moving object, the pitch changes due to the motion of the baseball. If the radar gun is stationary, the change in frequency is due entirely to the speed of the baseball. The speed of the ball can be calculated by the formula worked out by Doppler. Police use radar to measure the speed of cars using the same principle.



The shift in frequency occurs whenever the source or the listener is in motion. For instance, suppose a person is in a fast moving car and hears the sound of a horn from a parked car. As the person approaches the horn, the sound will be of higher pitch. As the person passes the parked car, the sound of the horn will drop to a lower pitch.

Doppler's formula for the change in pitch of sound because of a moving source multiplies the original frequency, f_o, by a number that involves both the velocity of sound in air, v, and the velocity of the source of the sound, v_s. The new frequency, the one that the listener hears, is f. The symbol $\pm$ is read plus or minus.

Doppler Formula

$$f = f_o * \frac{V}{(V \pm V_s)}$$

The key ratio in the formula is an expression that divides the velocity of sound, V, by either of two expressions: $v + v_s$ or $v - v_s$. Which expression to use depends on whether the sound is higher pitched or lower pitched. If the sound is approaching, then the pitch will be higher and the ratio $v/(v - vs)$ will be greater than one. If the sound is receding, then the pitch will be lower and the ratio $v/(v + vs)$ will be less than one. The choice to add or subtract depends upon whether the source of the sound is approaching or going away.

As an example, suppose a horn makes a sound that has a frequency (pitch) of middle C, 256 cycles per second. The speed of sound in air is 334 m/sec, and the car is going 60 miles per hour (26.8 m/sec). As it approaches a person, the sound will be higher pitched, so the final pitch will be greater than 256 cycles per second. In the Doppler formula, f is what we want to find, $f_o = 256$ cycles per second and v = 334 m/sec.

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If we add the two velocities, we have 334 m/sec + 26.8 m/sec = 370.8, and if we subtract, we have 334 m/sec – 26.8 m/sec = 307.2. Because the sounding horn is approaching, the final frequency, *f*, must be greater than the original frequency, f_o. To make *f* greater, it must be multiplied by a number greater than 1.0. Dividing the velocity, 334, by the subtracted velocities, 307.2 gives a number greater than one. For an approaching sound, the velocity of the source, v_s, is subtracted from the velocity of sound in air:

Approaching Sound



$$f = f_o * \frac{V}{(v - v_s)}$$

$$f = 256 \text{ hz} * \frac{334 \text{ m/sec}}{307.2 \text{ m/sec}} = 256 \text{ hz} * 1.087 = 278 \text{ hz.}$$

Because the horn is approaching the listener, the pitch increases from 256 cycles/sec to 278 cycles/sec. This is a very noticeable difference in pitch.

After the car passes, the pitch is lower, and 256 cycles/sec must be multiplied by a number less than one. For a receding sound, the velocity of the source, v_s, is added to the velocity of sound in air:

Receding Sound



$$f = f_o * \frac{V}{(v + v_s)}$$

$$f = 256 \text{ hz} * \frac{334 \text{ m/sec}}{307.2 \text{ m/sec}} = 256 \text{ hz} * 1.087 = 278 \text{ hz.}$$

The Doppler effect applies to all wave motion including sound, water waves and light waves. The effect depends upon both the motion of the observer and the source of the waves. Either or both may be in motion. When their combined motion brings them closer, frequency increases. When motion separates the source and the observer, frequency decreases. Astronomers must take into account the motion of Earth when they calculate the motion of distant stars. Police radar must take into account the motion of the police car.

Life Principle

"Provision for others is a fundamental responsibility of human life."

–Woodrow Wilson

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Integrated Physics & Chemistry



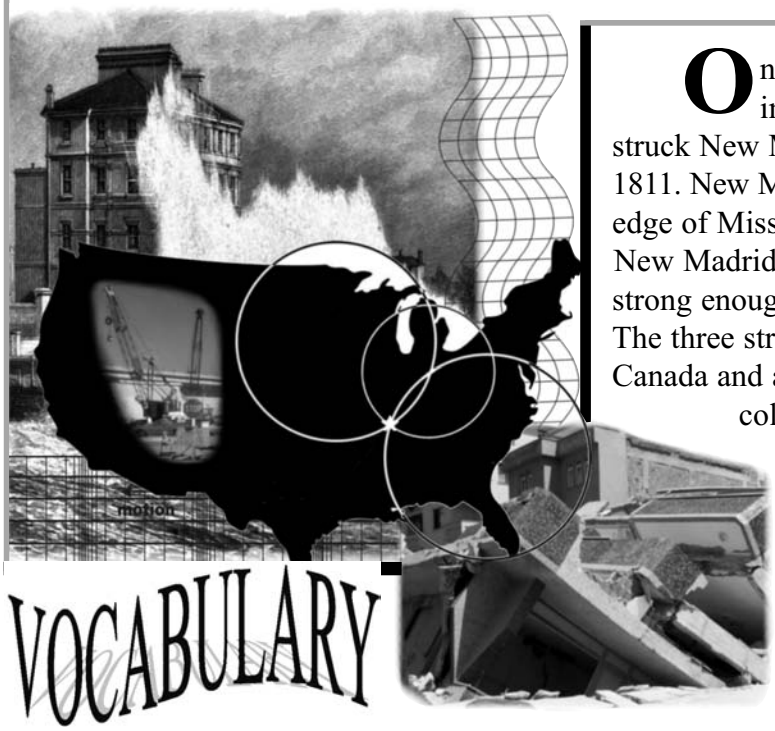
Lesson 10
Geology

Chapter 9

EARTHQUAKE WAVES

Section 2

Lessons 6-10



One of the most powerful ***earthquakes*** in the history of the United States struck New Madrid, Missouri, in the winter of 1811. New Madrid was a town on the southeastern edge of Missouri along the Mississippi River. The New Madrid event produced 1,800 earthquakes strong enough to be felt two hundred miles away. The three strongest quakes shook buildings in Canada and along the Gulf of Mexico. Chimneys collapsed in Cincinnati, Ohio, about 400 miles from the quake. The American explorer Daniel Boone was living in a home that he had built 200 miles away at Defiance, Missouri. The shaking moved the building four inches on its foundation, but Daniel Boone had constructed the home with such thick foundations that the house remained standing. In some places around New Madrid, the ground fell three meters (almost 10 feet). The Mississippi River ran backwards. Across the Mississippi River, the earthquake formed Reelfoot Lake, the largest natural lake in Tennessee.

An earthquake is any disturbance within the Earth felt on the surface as a shaking of the ground. Motion felt on the surface of the Earth during an earthquake comes from energy released deep in the Earth. Energy released from the earthquake radiates to the surface as waves.



VOCABULARY

Earthquake: a sudden movement of Earth's crust caused by stress accumulated along geologic faults or due to volcanic activity

Pressure wave: an earthquake wave traveling through solids faster than the secondary wave, and causing rocks to vibrate parallel with the wave; also known as primary wave or *P wave*

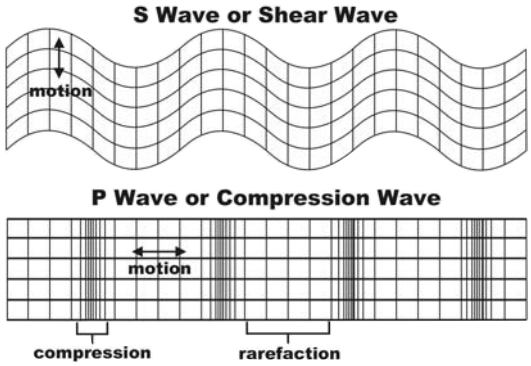
Shear wave: an earthquake wave in which soil and rocks vibrate at right angles to the wave direction of travel; also known as secondary wave or *S wave*

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A ***pressure wave,*** or *P wave*, is one type of wave from an earthquake. It travels between 4 and 7 kilometers per second (2.49 to 4.35 miles per second). It has the same form as a sound wave or a compression wave in a spring. A particle of earth is pushed in the same direction as the wave is traveling and then pulled back along the path of the wave. The material in the Earth is first compressed and then released. The *P wave* of an earthquake causes rocks to compress and expand alternately.

VOCABULARY

Seismograph: an instrument for recording information about the direction, intensity, and duration of earthquakes or other movements of Earth's crust
Seismologist: a scientist who studies earthquakes
Triangulation: location of an unknown point by means of combining observations from widely separated points, observations from two locations are required if the distance and direction are known, observations from three locations are required if only the distance is known
Focus: the point within Earth's surface where an earthquake originates
Epicenter: the point on the surface of Earth directly above where an earthquake begins, usually the epicenter feels the greatest effect from the earthquake
Seismic waves: waves from an earthquake
Fault: a line where the stress in a rocky layer has caused the rocks to break, often the site of earthquakes
Liquefaction: the process of changing a solid into a liquid, some soils that contain moisture change to mud when an earthquake strikes
Tsunami: a large and destructive ocean wave caused by an earthquake beneath the sea floor



A ***shear wave,*** or *S wave*, is another type of earthquake wave. It travels at about 3.5 kilometers per second (2.17 miles per second). The *S wave* is similar to a wave made when a rope is shaken. The disturbance is at right angles to the direction the wave travels. Portions of earth are pushed at right angles to the direction of travel. *S waves* cause rocky material to move either side to side or up and down, perpendicular to the direction the waves are traveling, thus shearing the rocks. S*hearing stress* is a force that causes rocks to slide along one another in opposite directions.

Once the disturbance reaches the surface, soil and rock particles move in a circular motion—forward, up, backward and down in a path that is similar to a cork on a water wave. At the same time, the rock moves side to side at right angles to the direction of the traveling wave. The motion of these waves causes the destruction associated with an earthquake.

A ***seismograph*** is a scientific instrument to record data about an earthquake. *Seismo* is from a Greek word meaning *to shake*. *Graph* means *to write*. When an earthquake strikes, seismographs record information about the waves as they pass. English geologist John Milne invented the seismograph in 1880. The seismograph consists of a massive weight hanging from a spring. Below the weight, a rotating drum is firmly anchored to the earth. The weight carries a pen that makes a straight mark on a

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cylinder of paper wrapped around the slowly turning drum. Should Earth move, the drum moves with the earth, but the massive weight on a spring tends to remain stationary because of its inertia. The pen marks a wavy line as the drum jiggles during the earthquake.

Another type of seismograph uses a ray of light that reflects from a mirror that is anchored to the earth. When Earth moves, the mirror vibrates causing the ray of light to trace out the motion of Earth's surface.

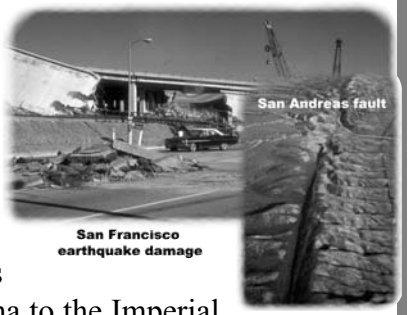
Because of their greater speed, *P waves* are the first to reach any point on Earth's surface. They are sometimes called *primary waves* because they arrive first. *S waves* are sometimes called *secondary waves* because they arrive second. The farther the *P* and *S* waves travel the farther behind *S waves* get. By measuring the time between their arrival, a ***seismologist*** (earthquake scientist) can calculate how far away the waves originated. Distance alone does not identify where the earthquake began. The seismologist must also know the direction.

The source of the earthquake is pinpointed when information from several seismographs in different parts of the country is combined. Seismologists draw a circle on a map around each seismograph station. The radius of each circle is the distance of the earthquake from that station. The point of intersection of the three circles locates the earthquake. Finding distance by using the intersection of observations is ***triangulation***. The ***focus*** is the point below the surface of Earth where the earthquake originates. *Focus* means *the source of radiating waves*. The ***epicenter*** is the point on the surface of Earth directly above the focus. The word *epicenter* means *near the center*.



Rocks, like all solids, are elastic. They can be bent or deformed under pressure. Should their elastic limit be reached, then the potential energy from being twisted, pressed or pulled is released as kinetic energy. When the rock breaks, there is movement along the line of the break. ***Seismic waves*** (earthquake waves) are produced when strain in layers of rock is suddenly released, usually by the rocks breaking.

A ***fault*** is a break in Earth's rocky layers caused by too much stress. Earthquakes usually occur along faults. One of the best-known fault lines is the San Andreas Fault which runs through California for about 600 miles from Point Arena to the Imperial Valley. A slippage of the San Andreas Fault in 1906 resulted in the disastrous San Francisco earthquake. Rock along 267 miles of the fault slipped by about 20 feet. Roads that crossed the fault were shifted sideways. Pavement on one side completely missed connecting to the lanes on the other side. The earthquake destroyed the central part of the city of San Francisco.



Earthquake waves vary greatly in the number of vibrations that they produce each second. They can have a frequency higher than 20 waves per second, which makes them audible to the human ear as a low, bass-sounding rumble. People compare the sound to a train passing through an underground tunnel. Most

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earthquake waves vibrate more slowly. Some are powerful enough to cause the entire Earth to vibrate at its *fundamental frequency*, which is one vibration every 54 minutes. The frequency of the waves affects how destructive they can be. High frequency waves can cause water-saturated soil to change into mud, an effect called ***liquefaction***.

Measuring the intensity of earthquakes is not easy. One earthquake may have weak vibrations that last for several minutes. Another may have a massive jolt that is over almost as soon as it occurs. Comparing the strength of one earthquake to another is difficult because they can vary considerably in magnitude (how much the Earth moves from its position of rest), frequency (the number of waves generated each second), extent (the amount of area covered) and duration (length of time the earth shakes).

Measuring the total energy released by an earthquake may not correctly reflect the destruction. Destruction depends on other factors such as the number and type of buildings and the type of soil. The New Madrid earthquake of 1811 is believed to have been more powerful than the San Francisco earthquake of 1906. However, the New Madrid earthquake was not particularly destructive or deadly because the affected area was sparsely settled with few buildings. The San Francisco earthquake of 1906 was more deadly because of the greater population density and more destructive because the buildings had not been designed to withstand an earthquake. The earthquake in Alaska in 1964 caused much destruction because of the type of soil in that region. The ground in the far north was permanently frozen except for a layer near the surface. The earthquake shook so violently that the top soil layers slid down the hills, destroying trees and buildings.

Most news media report the strength of an earthquake measured on a magnitude scale developed by the American seismologist Charles F. Richter in 1935. The *Richter scale* measures the amplitude or displacement of seismic surface waves. From experience, scientists have learned that an earthquake of 2.0 on the Richter scale is just noticeable by a few people. One of 3.0 is generally felt. At 5.0 light, damage occurs. At 6.0, weak structures suffer major damage. At 7.0, strong structures suffer major damage. At 8.0, total destruction results. The scale is not linear. Each increase from 2 to 8 represents an earthquake 10 times more powerful than a quake which registered at the previous scale. An earthquake of 6.0 is ten times more powerful than one of 5.0. On the Richter scale, the San Francisco earthquake of 1906 was estimated to be 8.3. The New Madrid earthquake is believed to have been greater than 8.3 on the Richter scale.

The strongest earthquake in the last 100 years in the United States was the Alaskan earthquake of 1964, measuring 8.6 on the Richter scale. The earthquake caused lakes and ponds as far away as Texas to move back and forth. In some places, the land was thrust up 80 feet. Extensive damage in coastal areas resulted from landslides and water waves. Wave damage occurred as far

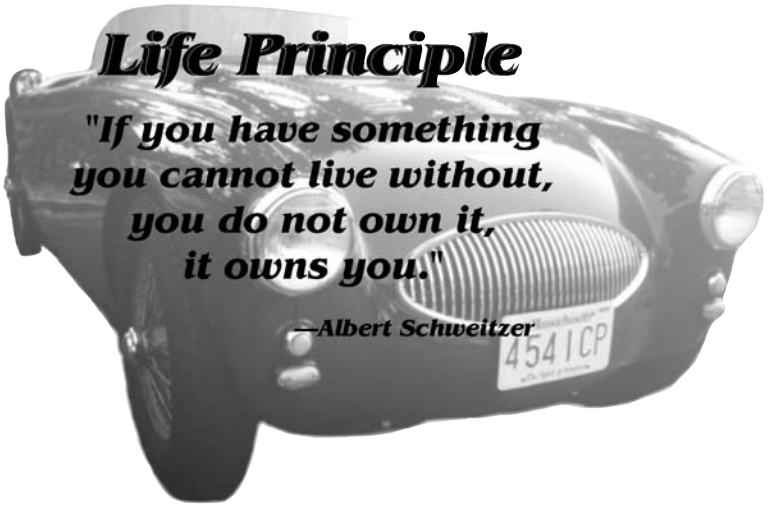
Richter Magnitudes	Earthquake Effects
Less than 3.5	Generally not felt, but recorded
3.5-5.4	Often felt, but rarely causes damage.
Under 6.0	At most slight damage to well-designed buildings. Can cause major damage to poorly constructed buildings over small regions.
6.1-6.9	Can be destructive in areas up to about 100 kilometers across where people live.
7.0-7.9	Major earthquake. Can cause serious damage over larger areas.
8 or greater	Great earthquake. Can cause serious damage in areas several hundred kilometers across.

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away as Crescent City, California, a distance of 2,000 miles.

A ***tsunami*** is a wave caused by an earthquake. A tsunami is sometimes incorrectly called a tidal wave. A tsunami is not caused by tides. The action of the earthquake beneath the sea floor causes the water to rise and then lower. The wave can travel approximately 224 miles per hour. As a wave approaches shallow coastal water, it piles up. If the wave enters a harbor or funnel-shaped inlet, the water becomes even higher. The indicator that a tsunami is coming ashore is that several minutes before it strikes, the water drains out of a bay. What was once a huge bay becomes a mud flat with the ships lying on their sides. As the water suddenly reverses direction, the tsunami comes ashore as a wall of water up to 90 feet high.





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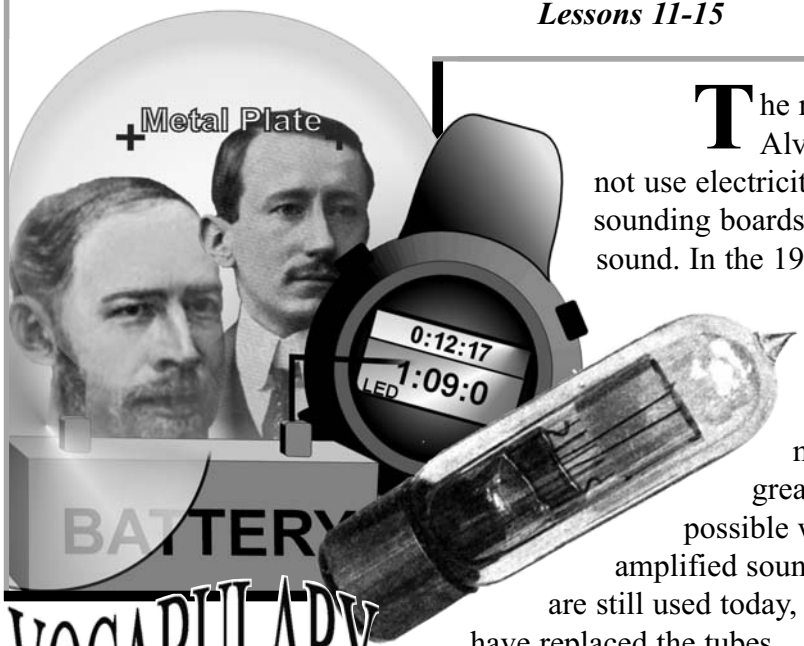
Chapter 9

Lesson 11
Inventions & Discoveries

RADIO

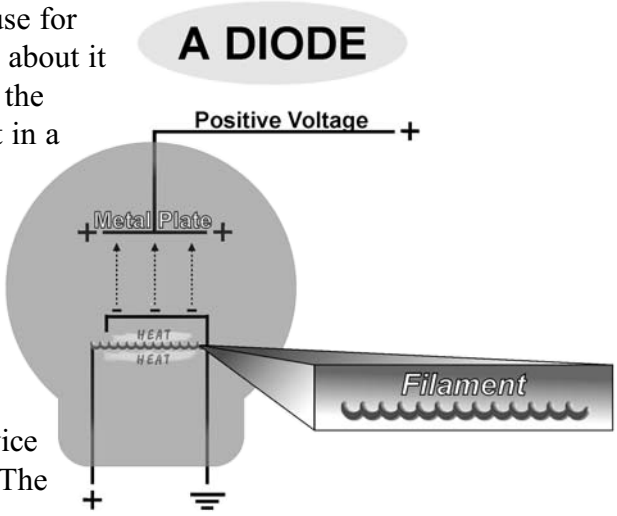
Section 3

Lessons 11-15



The record player invented by Thomas Alva Edison was mechanical. It did not use electricity. ***Acoustic*** engineers designed sounding boards and megaphones to amplify the sound. In the 1920s, record players produced sound loud enough to be heard by a room full of people at a party, despite the fact that the sound was amplified by mechanical means. However, greater volume (loudness) became possible with electronic vacuum tubes that amplified sound. The principles of ***vacuum tubes*** are still used today, although solid semiconductors have replaced the tubes.

The first step toward inventing an amplifier actually was made by Thomas Edison in one of his experiments to improve the electric light bulb. He sealed an unheated (cool, unconnected) wire near the hot filament of the light bulb. Upon testing the unheated wire, Edison was surprised to see that a small current flowed. Further tests showed that electrons boiled off the heated wire and jumped the gap to the cool wire. Edison saw no particular use for this observation. He wrote about it in his notebooks, patented the discovery, and described it in a technical journal so others could benefit from his discovery.



The English scientist John Ambrose Fleming invented the ***diode*** based on Edison's discovery. A diode is a device containing two electrodes. The

VOCABULARY

Acoustic: having to do with sound or the science of sound
Vacuum tube: early electrical devices that had electrodes inside a gas vacuum tube similar in shape to a light bulb
Diode: a device with two electrodes that allows electricity to pass in one direction but not the other
Plate: the part of a diode that has a positive charge and is a collector of electrons
Semiconductor: a crystalline substance, such as germanium or silicon that conducts electricity with an efficiency between that of metals and insulators

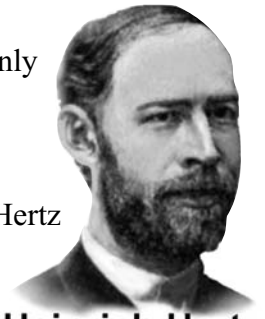
word *diode* is made from *di* meaning *two* and *ode* from electrodes. Fleming's diode was shaped like an electric light bulb. It had a hot (connected) metal wire called the filament, connected to a source of electrons. The wire had a negative charge. Some of the electrons in the heated metal reached speeds high enough to escape from the metal's surface. Fleming put a cool flat piece of metal, the ***plate***, near the hot filament giving the metal plate a positive charge. The positively charged metal attracted the electrons, and they flowed from the hot filament to the plate.



A diode was a one-way path for electricity. Electrons traveled from the hot filament with its negative charge to the cold plate with its positive charge, but not the other way. If the metal plate were given a negative charge, electrons would not jump to the filament because the plate was not hot enough to emit electrons. A diode was primarily used as a one way valve to filter out the backward flow of *alternating current*. A *rectified current* is an alternating current that has been made to flow in only one direction.

The diodes in electronic circuits today are ***semiconductor*** diodes. Germanium and silicon have some nonmetallic and some metallic properties. They do not conduct electricity as well as metals, but they conduct electricity better than nonmetals. They are semiconductors. In an early model of a semiconductor diode, a fine, pointed wire rested on the surface of a tiny piece of germanium or silicon crystal. Electrons could flow one way but not the other. Whether by a vacuum tube or a semiconductor, a diode rectifies electric current, allowing electricity to flow in only one direction.

In addition to rectification, diodes can be made to glow when electricity flows but are dark when the electricity does not flow. Some watches and calculators use ***light emitting diodes*** to produce a glowing display of the numerals. The abbreviation for a *light emitting diode* is *LED*.

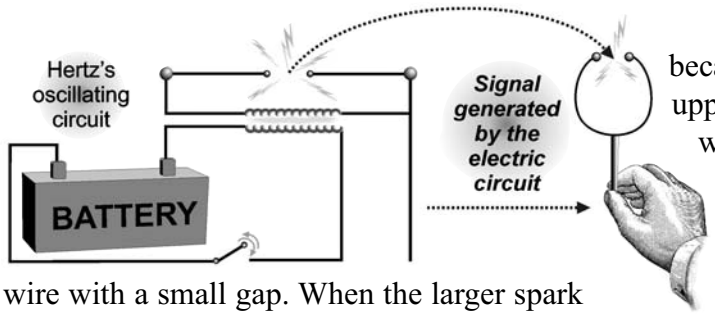

Heinrich Hertz

In the 1880s, the knowledge that light was only a small part of the total electromagnetic spectrum became clear. The German physicist Heinrich Rudolf Hertz believed waves of lower frequency and greater wavelength existed below the visible light spectrum. Hertz developed equipment to generate, broadcast and receive radio waves. In 1889, after ten years of trying, he succeeded in generating radio waves and sending them to the other side of his laboratory.

Hertz's device generated the signal by an ***oscillating circuit***. Oscillate means to swing back and forth. The circuit was connected to two metal balls separated by an air gap. When the current built to its greatest voltage in one direction, a spark jumped between the two balls. Then the amount fell and built up to its greatest voltage in the other direction, and a spark jumped between the two balls. Across the laboratory, Hertz set up a receiver wire made of a simple coil of

VOCABULARY

Light emitting diode: a diode that emits light when electricity flows
Oscillating circuit: a circuit in which electricity flows first one way and then the other



wire with a small gap. When the larger spark jumped between the balls of the broadcast circuit, a tiny spark jumped across the gap in the receiver.

Heinrich Hertz investigated farther and found that the waves traveled at the speed of light and had properties similar to visible light. These waves could be reflected, refracted and polarized. The unit of frequency, *hertz*, is named in his honor. One hertz (Hz) is one cycle per second. One cycle per second is written as 1.0 Hz. A thousand cycles per second is 1000 Hz or 1.0 kHz. The *k* means 1,000. A million cycles per second is 1,000,000 Hz or 1.0 MHz. The *M* stands for Mega which means million. You have probably heard the term, "mega hertz" in reference to sound systems. Heinrich Hertz died at age 36 in 1894 before he could develop the radio further.


Guglielmo Marconi

The next year, Italian physicist and inventor Guglielmo Marconi read an article about the electromagnetic waves discovered by Hertz. Marconi realized that radio waves would make possible a wireless telegraph. He succeeded in sending wireless signals a short distance in 1895. Marconi found support for his work in Britain and preferred the protection offered by their patent system. Thus, he moved from Italy to England and continued his experiments. In 1899, he sent a signal between England and France.

Through experimentation, Marconi became convinced that a layer in Earth's upper atmosphere reflected long radio waves. In 1901, he communicated across the Atlantic Ocean between England and St. John's, Newfoundland. Marconi used balloons to lift his antenna as high as possible. By 1907, commercial use of his wireless system began. Ships were outfitted with radios. Ship to shore radios and radio signals among ships eventually led to improved oceanic safety and rescue after disasters at sea. Marconi received the Nobel Prize in physics in 1909.

The wireless radio of Marconi transmitted signals by dits (dots) and dahs (dashes) like the telegraph. An operator keyed in the information, which was sent out as short and long blasts of electromagnetic waves. The current flowed to produce a dit or dah of *Morse code*. A dit was a short electric signal. A dah was an electric signal about three times as long as a dit. The signal was made by making and breaking the circuit. During transmission, the frequency and amplitude (strength) of the radio wave did not vary. The reception at a great distance required powerful transmitters and delicate receivers.

The Marconi radio was not able to carry sounds such as speech or music. To send sound by radio required three improvements to Marconi's radio. First, the sound waves had to be converted to electrical impulses. The device that does this is a *microphone*. The microphone had been invented earlier by Alexander Graham Bell for use with his telephone. Thomas A. Edison had improved the microphone greatly. Next, the radio waves had to be modified to carry the electrical impulses generated by the microphone. *Modulation* is the process of changing some part of an electric signal so it carries

information. *Modulate* means to *modify*. Then, the receiver had to be capable of amplifying the weak radio signals. Amplification is the process of making a weak signal stronger. Although a diode could control the direction that electricity traveled, it could not increase the strength of the signal. At the beginning of the 1900s, electrical engineers experimented with ways to modulate and amplify electric currents.

Life Principle



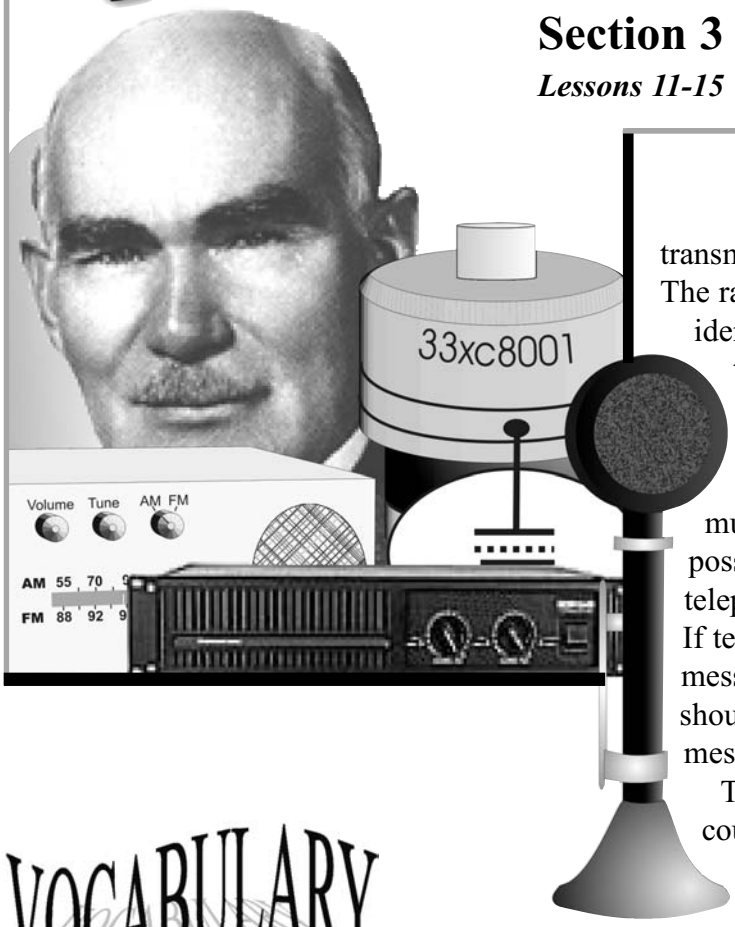
Chapter 9

Lesson 12
Inventions & Discoveries

Section 3

Lessons 11-15

AMPLIFYING ELECTRIC SIGNALS



The first radios were wireless telegraphs. Signals were transmitted in dits and dahs of Morse code. The radio operator sent signals with a key identical to a telegraph key. Operators tapped the key to transmit the signal. Scientists speculated that a wireless telegraph radio could be modified to carry sound waves such as voice and music. The concept certainly seemed possible. Alexander Graham Bell tested his telephone by using existing telegraph wires. If telegraph wires could carry telephone messages, then wireless telegraph radio should be capable of carrying voice messages.

The first step in making a radio that could transmit speech or music was to convert the sounds to electric impulses. This was done with a microphone. A *microphone* is a device that changes sound energy into electrical energy.

VOCABULARY

Amplitude modulation: modulation of a radio signal by varying the amplitude of the waves, abbreviated AM

Frequency modulation: modulation of a radio signal by varying the frequency of the waves, abbreviated FM

Bandwidth: the amount of space, measured in frequency, that is required by a radio broadcast; FM radio stations require more bandwidth than AM stations

Alexander Graham Bell invented the first microphone. He had built one for his telephone almost twenty-five years before the invention of the radio. Thomas Edison greatly improved on it. His *carbon microphone* consisted of a metal cup filled with carbon particles. The particles conducted more electricity when they were pressed together and less electricity when the pressure was released. A thin, flexible metal disk covered the cup. Sound waves vibrated the disk, which pressed in

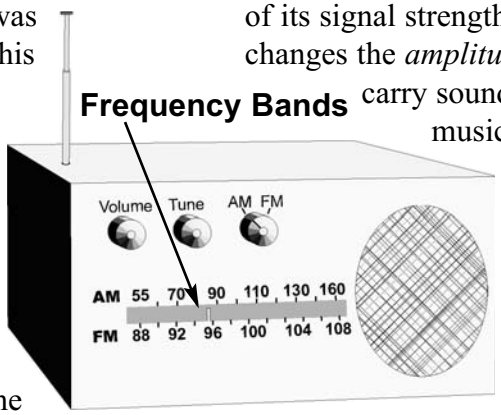


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and out on the carbon particles. This varying pressure created an electric current that varied in the same way as did the sound waves.

A *crystal microphone* was another type of microphone. This microphone used a crystal that generated an electric current when placed under pressure. A quartz crystal, for instance, generated a slight electric current when placed in a vise and squeezed. French chemist Pierre Curie discovered this in 1880 when he applied pressure either to a quartz crystal or salt crystal, generating a small electric current. The size of the current was directly proportional to the pressure. A greater pressure produced a greater voltage. In the crystal microphone, sound waves vibrated a metal disk that, in turn, varied the pressure on the crystal. The crystal generated a small electric current that varied in step with the sound waves.

Signals from the microphone go to the radio transmitter. One way to transmit voice or other sound signals is to modulate the amplitude of the waves. *Amplitude* is the size of the disturbance of a wave. For an ocean wave, the amplitude is the distance from the point at rest to the crest of the wave. For a radio wave, the amplitude is a measure of its signal strength. ***Amplitude modulation*** changes the *amplitude* of the radio wave to carry sound such as speech or music. The AM radio stations use amplitude modulation. The AM broadcast band has a frequency from 535 kilohertz (535 kHz) to 1,605 kilohertz (1,605 kHz). Any particular station broadcasts at a set frequency along that band. The strength (amplitude) of an AM radio signal is varied at a rate that corresponds to the frequency of a sound wave. The first radio stations using amplitude modulation began broadcasting in the 1920s.



Another way for radio waves to carry information is to modulate the frequency. ***Frequency modulation*** changes the *frequency* of the radio waves to carry speech or music. The FM radio band uses frequency modulation. The FM broadcast band extends from a frequency of 88 million Hertz (88 MHz) to 108 million Hertz (108 MHz). Any particular FM station maintains its signal at its greatest amplitude during transmission. The amplitude is not modified. Instead, the frequency of the radio wave is varied slightly within a fixed range at a rate that corresponds to the frequency of a sound signal. Frequency modulation radio stations began broadcasting in the 1930s.

FM stations broadcast at a frequency in millions of cycles per second (MHz), while AM stations broadcast at a frequency in the thousands of cycles per second (kHz). A radio station that broadcasts at 100 MHz on the FM band sends out waves at the rate of 100 MHz = 100 * 1,000,000 Hz =

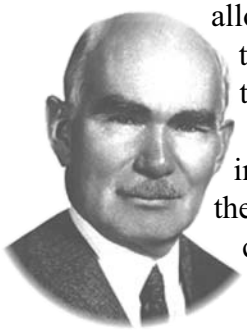
VOCABULARY

Range: the maximum distance a radio signal is carried; AM stations have greater range than FM stations
Triode: a three-electrode device that amplifies radio signals
Grid: a wire mesh in the triode that controls the flow of electricity from the filament to the plate
Mail fraud: the use of the United States Postal Service to conduct business in a deceitful manner or to make unlawful gain

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100,000,000 Hz = 100,000,000 cycles per second. A radio station that broadcasts at 1,000 kHz on the AM band broadcasts waves at the rate of 1,000 kHz = 1,000 * 1,000 Hz = 1,000,000 Hz = 1,000,000 cycles per second. A typical FM station broadcasts at a frequency 100 times greater than the frequency of an AM station. (100 million Hz for FM compared to 1 million Hz for AM.) Signals of FM stations vary about 200 kHz (200,000 Hz) on either side of their assigned frequency. For that reason, FM stations need more room or ***bandwidth***. Because their signals take up so much room, if FM stations were to broadcast on the AM band, only five FM stations could be accommodated. Putting the FM band at the higher frequency allows more FM stations to broadcast.

Frequency modulation radio stations send out a signal at its greatest amplitude. By so doing, FM stations are less likely to experience interference from lightning or other sources of electromagnetic waves such as those emitted by electric motors or spark plugs in automobiles. The FM stations broadcast at a higher frequency and shorter wavelength. The ionosphere does not reflect the shorter waves, therefore FM stations have a limited ***range***. However, because of their shorter range, several FM stations in different cities across the United States can broadcast at the same frequency. AM waves are so long that the ionosphere reflects them, allowing AM broadcasts to transmit greater distances than FM stations.

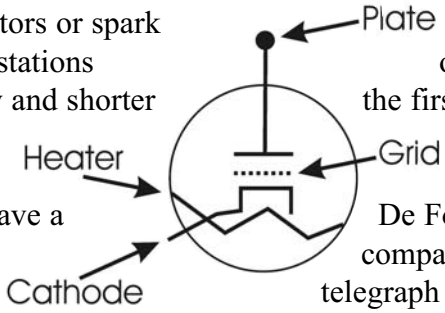


Lee De Forest

The American inventor, Lee De Forest, was the first person to recognize commercial uses of radio for broadcasting music, sports and news. He invented the ***triode***, a modification of the diode. The triode amplified weak signals. The triode became the key component in radios, televisions and other devices such as radar, record players and the first electronic computers.

Lee De Forest was born in Council Bluffs, Iowa. However, he grew up in Alabama where his father was a Gospel minister and served as principal of the Talladega College for Negroes only 14 years after the end of the American Civil War. White people who taught previous slaves were not respected in Alabama. Young Lee's friends were his brother, sister and black children of the town. Lee's father wanted Lee to enter the Gospel ministry, too. However, Lee was fascinated with electrical machinery. As a child, he made a device to plate silver onto other metals.

Lee De Forest attended Yale University to gain a scientific education. He earned an advanced degree in physics in 1899. As part of his degree, he wrote one of the first scientific papers about radio waves produced by an American. A few years later, De Forest started his own company and demonstrated wireless telegraph to anyone who would listen – businessmen, newspaper reporters and military leaders. Unfortunately, Lee De Forest was not a very good businessman, nor was he a good judge of character. His own business partners stole from him, causing his company to go out of business in 1905.

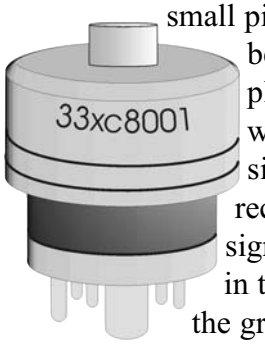


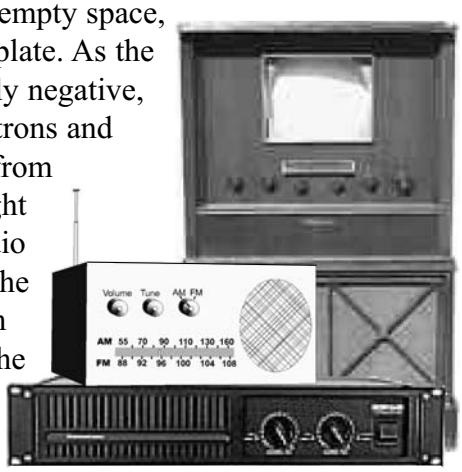
In 1906, Lee De Forest made his most important invention, the triode. A triode has three parts. De Forest made it by inserting a third element called a ***grid*** between the filament and plate of a diode. The filament and plate were attached to a strong electric circuit. The filament was connected to the

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negative side of the electric circuit and was supplied with electrons. The plate was connected to the positive side of the electric circuit and collected electrons emitted by the filament.

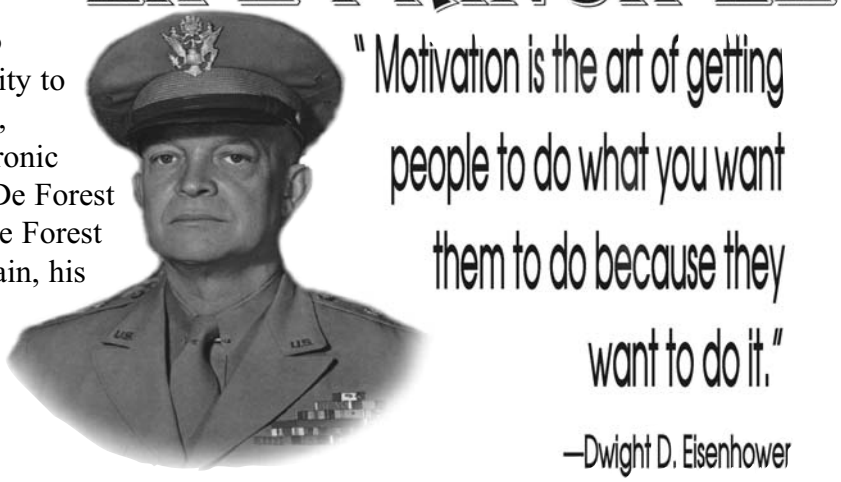
The grid was a fine mesh wire, like a small piece of window screen, between the filament and plate. The wire mesh grid was attached to the weak signal coming from a radio receiver. The weak radio signal caused slight changes in the electrical charge on the grid. As the grid became more positive, it attracted electrons from the filament. The electrons flew through the grid, which was mostly empty space, and landed on the plate. As the grid became slightly negative, it repelled the electrons and slowed their flow from the filament. A slight variation in the radio signal attached to the grid caused a much greater change in the number of electrons that flowed between the filament and plate. The grid amplified the electric current that flowed through the triode.





The grid amplified radio signals. The triode, with its ability to amplify weak electronic signals, became the heart of every electronic device for the next fifty years. De Forest began a second company, the De Forest Radio Telephone Company. Again, his partners lacked integrity and looted the company which began to collapse in 1909. The triode had not yet proven itself, and Lee De Forest was placed under arrest for ***mail fraud***. He had mailed letters in an attempt to raise cash to finance the manufacture of triodes. The government claimed De Forest was trying to promote a worthless device. The charges were dropped, but he had to spend large amounts of money for his legal defense.

In 1910, De Forest transmitted a live performance by famous tenor singer Enrico Caruso at the Metropolitan Opera. In 1916, De Forest began a radio station to broadcast news. He was the first to announce the results of a presidential election by radio. As De Forest gained experience, he realized that he did not have the skills necessary for business matters. Instead of attempting to manage a company, De Forest concentrated on making inventions and selling them to other companies to manufacture. He sold the triode to American Telephone & Telegraph Company (AT&T) for $390,000, a very small sum considering its importance.



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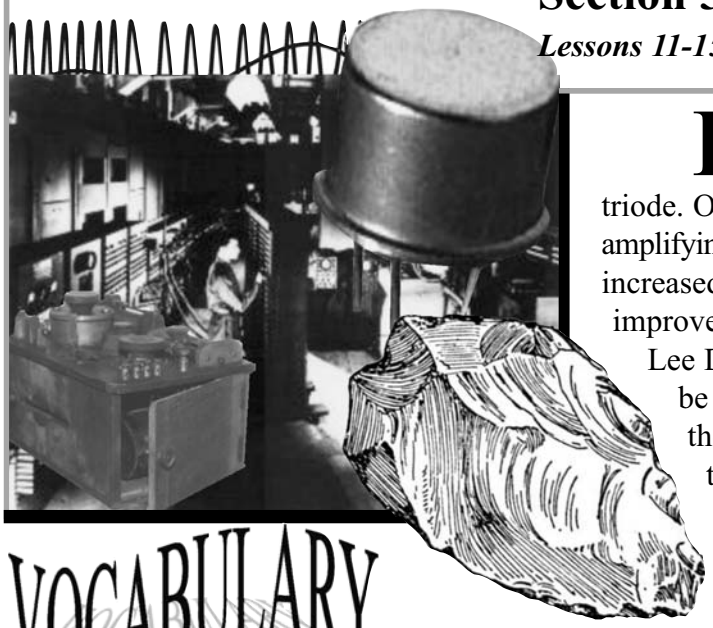
Chapter 9

SEMICONDUCTORS

Lesson 13
Inventions & Discoveries

Section 3

Lessons 11-15



Lee De Forest's work with electricity did not end with the invention of the triode. Other experimenters tried to improve the amplifying power of the triode. The first enhancement increased a signal by about 10 times. Later improvements increased the signal by 50 times.

Lee De Forest found that several triodes could be combined to provide an amplification of thousands of times. Suppose six identical tubes were connected together in ***series*** so that the amplified signal of the first one was sent to the second one for additional amplification and so on through all six. If each step amplified the signal 10 times, then all six together would amplify the signal 10 * 10 * 10 * 10 *10 * 10, or 1,000,000 times.

In the 1920s, Lee De Forest developed the first sound-on-film system used by motion pictures. His procedure was to send the varying electrical current from a microphone to a light bulb. The light bulb grew brighter and dimmer in direct relationship with the sound striking the microphone. The edges of motion picture film were exposed to the light and then developed. On the edge of the film was a line of light and dark that matched the original sound. This procedure made the sound synchronize with the action on the screen.

Unlike Edison, who had a staff of fifty or more scientists working in his laboratory, Lee De Forest preferred to work alone. He still managed to earn more than 300 patents for his inventions. He received his last patent in 1957 at the age of 84. De Forest died in Hollywood, California four years later. For fifty years, the triode served as the main amplifier in radios and other devices. Lee De Forest is sometimes called the Father of Radio.

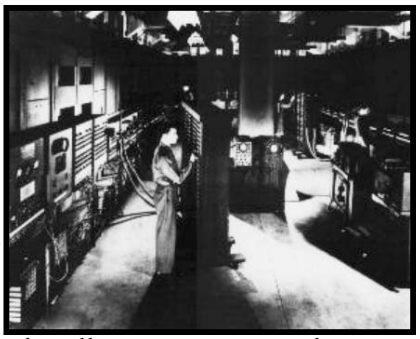
During World War II, radar sites used thousands of vacuum tubes. *Vacuum tubes* were devices such as the diode and triode that had electrodes enclosed in a vacuum. Vacuum

VOCABULARY

Series: an electric circuit with but one path, electrons must flow through all of the devices that are connected in series
Frequency: the number of waves per unit of time, the units of frequency are cycles per second, waves per second or *hertz* (*Hz*).
Velocity: distance divided by time, *d/t*, for wave motion the velocity is also given by the product of frequency and wavelength, $v = f * \lambda$
Miniaturize: to shrink or make smaller
Carrier wave: radio waves that have been modified to carry information
Silica: silicon dioxide (SiO_2)

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tubes failed when they were jarred and burned out with prolonged use. Circuits were made with redundant vacuum tubes so that if one failed, the circuit would switch to another to keep operating. One of the first electronic computers, ENIAC, was completed in 1945. *ENIAC* stands for ***E***lectronic ***N***umerical ***I***ntegrator ***A***nd ***C***omputer —the first large-scale, general purpose, digital computer. ENIAC contained more than 18,000 vacuum tubes. About 65 of the computer's tubes burned out every day. A full time technician was assigned to replace vacuum tubes. On his daily rounds, the technician carried a basket of spare vacuum tubes to replace those that burned out.



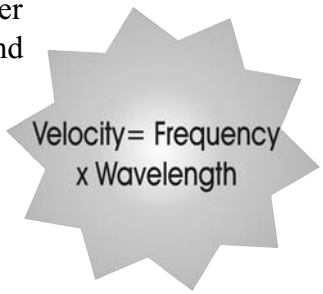
Still used for some applications, vacuum tubes can handle greater power than microchips. Because vacuum tubes operate at high temperatures, they can be used in high temperature applications that would fry transistors. The microwave oven that is used in the home for cooking has a vacuum tube to generate microwave radiation.

Microwaves are members of the electromagnetic spectrum. The *electromagnetic spectrum* is made of the entire range of electromagnetic waves, which extends from radio waves through the visible spectrum to X-rays. Radio waves have low frequency and long wavelength. X-rays have a high frequency and short wavelength. All electromagnetic waves travel at the speed of light.

Frequency is the number of waves that pass a fixed point in a given time. The symbol is *f*. Frequency is measured in cycles per second or vibrations per second. The metric unit for frequency is the *hertz*, abbreviated *Hz*. The hertz is named after Heinrich Rudolf Hertz, who produced the first radio waves. 1.0 Hz is 1.0 cycle/sec.

The *wavelength* of any wave motion, whether it is sound or light, is the length of a complete wave. Wavelength is represented by the Greek letter *lambda* (λ). For instance, if a radio wave is 20 feet long, then the wavelength is $\lambda = 20$ ft.

Velocity of a wave motion is stated in the same units as any other velocity, meters per second or miles per hour. The symbol for velocity is *v*. One way to find velocity is to divide distance by time: $v = distance/time$.



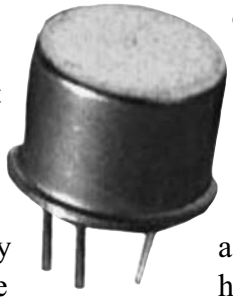
Another way to calculate velocity is to multiply frequency times wavelength. If ten waves are made in a second and each wave is 20 feet long, then the velocity of the wave is: velocity = frequency * wavelength = 10 wave/sec * 20 feet/wave = 200 feet/second.

The formula $v = f * \lambda$ and a microwave oven can be used to find the speed of light. Most microwave ovens have a turntable enabling the food to cook evenly; because, when the microwave is in operation, hot spots develop one wavelength apart. Suppose the turntable is taken out and marshmallows are heated in a microwave oven. Hot spots develop on the marshmallows 12 centimeters apart. The wavelength is $\lambda = 12$ centimeters or 0.12 meters. A tag on the side of the microwave oven shows that it operates at a frequency of 2,450 MHz. It produces 2,450 million waves per second. The speed of light is calculated by the formula $c = f * \lambda$ = 2,450 MHz * 0.12 m/wave = 2,450,000,000 waves/sec * 0.12 m/wave = 294,000,000 m/sec. The accepted speed of light is 300,000,000 m/sec (or about 186,000 miles/sec). The difference between the

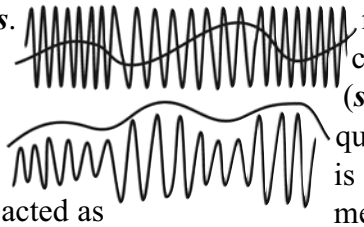
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calculated value and the accepted value is not too far off, especially when you consider that melted marshmallows are being used to measure the speed of light!

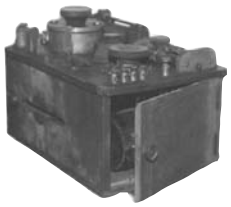
Although development of vacuum tube amplifiers led to manufacture of microwave ovens, radio, television and electronic computers, the tubes had some undesirable properties. They required excessive power to heat the filament and needed time to warm up when turned on. They generated a lot of heat, and like light bulbs, they burned out. Rough jarring easily damaged the tubes. Vacuum tubes could not be ***miniaturized***. The elements of a triode had to be separated by a vacuum. If made too small, the electrons would jump from the electrodes to the glass or to other nearby components.



During the 1950s, transistors began to replace vacuum tubes. The first clue that crystals could replace vacuum tubes came from the early days of radio. Scientists learned that crystals would conduct electricity in one direction better than in the other direction. The crystals acted as a diode (rectifier). More surprisingly, crystals also demodulated radio signals. *Demodulation* is the process of changing high frequency radio waves back into the lower frequency of sound waves. A radio station modulates (modifies) radio waves to carry sound waves. The sound waves are impressed on radio frequency ***carrier waves***. A radio receiver demodulates the radio waves to convert them back to sound waves.



Natural crystals acted as radio receivers and demodulated the radio signals. Radio hobbyists made inexpensive radio receivers from crystals. A crystal radio had a fine wire that just brushed against a natural crystal such as silicon or galena (lead sulfide). The advantages were that a crystal radio was cheap, had no moving parts and required no electricity to operate. The radio signal itself provided power to the headphones. The devices were not very sensitive, fine wires had to be constantly adjusted, and a person had to wear headphones to hear the signal. After invention of the triode, crystal radio sets fell into disuse.



Scientists, however, were still fascinated by crystal radios. Crystal receivers used a semiconductor such as silicon. A *semiconductor* is a material with electrical conductivity between that of metal and nonmetals. Metals such as gold, silver and copper are good conductors and have low resistance. They are good conductors of electricity but poor insulators of electricity. Sulfur is a poor conductor of electricity but a good insulator of electricity. Silicon, however, is between silver and sulfur in its electrical properties, making it a semiconductor.

Silicon is one of the most common elements in rocks and minerals and is second only to oxygen in abundance. Silicon is found in practically all rocks as well as in sand, clays and other soils. Earth's surface is a little more than 25 percent silicon by weight. Silicon does not occur uncombined in nature. Usually, silicon is found in combination with oxygen as silicon dioxide (***silica***, SiO_2). Silicas include quartz and flint. The name *silicon* is from *silex* a Latin word meaning *flint*. Flint creates a spark when struck. From 1570-1846, sparks from flint ignited the black powder of flintlock



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rifles. Many fireplace or stove lighters still use flint as the spark that ignites the gas. A silicon crystal has the silicon atoms arranged in the same strong pyramid shape as carbon atoms in diamond. Each silicon atom is bonded to four nearby atoms.

Pure silicon is a hard, dark gray solid. It has a metallic luster and forms crystals in which each silicon atom is bonded with four surrounding silicon atoms. This is the same structure found among the carbon atoms in diamond. Silicon has the same valence as carbon (4) and shares many chemical and physical properties with carbon. Silicon and carbon are in the same chemical family (vertical column) in the periodic table. The other members of that family are germanium (Ge), tin (Sn) and lead (Pb). Carbon is a nonmetal, while tin and lead are well-known metals. Silicon and germanium are between carbon and tin. Chemists classify them as nonmetals, but they do have some metallic properties. Silicon and germanium are semiconductors.

Carbon forms organic compounds and is often called the element of life. Silicon could be called the element of non-life. It is found in rocks and minerals and is the primary element in computer chips, transistors and other semiconductor devices. You have probably heard or read about Silicon Valley, California—the most populated region of companies involved with research and production of computer chips, transistors and semiconductors.

Life Principle



"The first requisite for success is the ability to apply your physical and mental energies to one problem incessantly without growing weary."

—Thomas A. Edison

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Integrated Physics & Chemistry

Chapter 9

Lesson 14
Inventions & Discoveries

TRANSISTORS

Section 3
Lessons 11-15



28.0
Si
Silicon

Silicon (Si) is located below carbon on the periodic table and has similar chemical properties. Like carbon, silicon has four electrons in its valence shell but needs eight to fill the valence shell. In a crystal of pure silicon, the silicon atoms share electrons with each other. The electrons in a crystal of pure silicon are held in place by the neighboring silicon atoms.

Crystals of pure silicon are rare. Usually, there are impurities. Suppose a few atoms of arsenic (As) take the place of some of the silicon atoms. Arsenic is below nitrogen and phosphorus on the periodic table. Rather than having four electrons in its outer shell, arsenic has five electrons. When arsenic replaces a silicon atom, four of the electrons of arsenic are bonded with the surrounding silicon atoms. The fifth electron is not needed, so it is left "hanging loose" and is free to roam about the crystal. In the diagrams below, the lines (— and |) represent pairs of shared electrons. The extra electron in the silicon crystal contaminated with arsenic is shown by e^-

```
|   |   |   |
— S – S – S – S —
|   |   |   |
— S – S – S – S —
|   |   |   |
— S – S – S – S —
|   |   |   |
— S – S – S – S —
|   |   |   |
```

silicon crystal

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|   |   |   |
— S – S – S – S —
|   | e⁻ |   |
— S – As–S – S —
|   |   |   |
— S – S – S – S —
|   |   |   |
— S – S – S – S —
|   |   |   |
```

silicon crystal with arsenic and free electron

VOCABULARY

Negative type: a semiconductor that has impurities which give it an excess of electrons, abbreviated *N-type*

Positive type: a semiconductor with impurities that give it too few electrons, abbreviated *P-type*

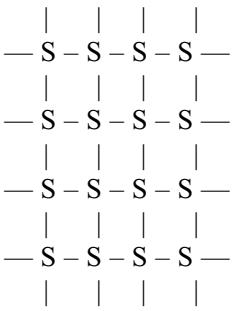
Semiconductor: a device that is used to make transistors, microchips and integrated circuits

Emitter: a semiconductor that acts as a source of electrons, equivalent to the filament of a vacuum tube

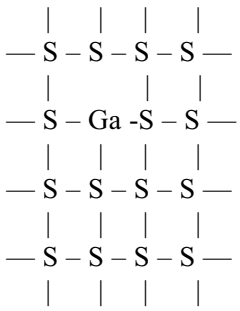
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A silicon crystal with arsenic impurities acts as if it had extra electrons with a negative electrical charge. The silicon with arsenic crystal acts as a supplier of electrons. Scientists call it a ***negative type*** or *n-type semiconductor* because of the extra electrons.

Suppose that a silicon crystal is contaminated with atoms of gallium (Ga). Gallium is located below boron and aluminum on the periodic table. Rather than having four electrons in its outer shell, gallium has three electrons. When a gallium atom replaces a silicon atom, the missing electron produces a hole in the regular electron grid among the atoms. The silicon crystal with the missing electron acts as if it had a positive charge. In the diagrams at the left, the lines (— and |) represent pairs of electrons. The hole in the regular electron structure is shown by the gap above the gallium atom. The hole moves about as if it were a positive charge.



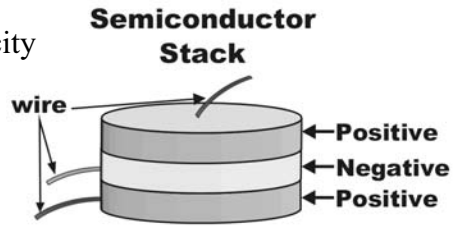
Silicon Crystal



Silicon Crystal with gallium the hole is the gap above the gallium atom

The silicon crystal with the gallium impurities attracts electrons to fill in the hole. A body that attracts electrons carries a positive charge. Scientists call it a ***positive type*** or *p-type* semiconductor.

By the start of the 1960s, ***semiconductor*** devices replaced vacuum tubes for most applications. Semiconductor devices are smaller, cheaper and more reliable. They do not burn out as often and can withstand shocks and rough treatment. The simplest semiconductor device is a diode, a one-way valve that lets electrons flow one way but not the other. A semiconductor diode has a layer of p-type semiconductor joined to a layer of n-type semiconductor. The p-type side has electron holes, and the n-type side has extra electrons. If electrons enter on the n-type side, they naturally flow from the electron rich n-type side to the electron poor p-type side. The diode conducts electricity in the direction from *n* to *p*. If electrons enter on the p-type side, they tend to stay there. The holes of the p-type side attract them, and the electrons of the n-type side repel them. The diode does not conduct electricity in the direction from *p* to *n*.



Recall that a triode is made of three parts, the filament, the grid and the plate. The *filament* is a source of electrons and acts as a negative electrode. The *plate* receives the electrons and acts as a positive electrode. How well electrons flow between filament

VOCABULARY

Base: a semiconductor that controls the flow of electricity and amplifies it; equivalent to the grid of a vacuum tube
Collector: a semiconductor that receives electrons; equivalent of the plate in a vacuum tube
Microchip: a piece of silicon that has several diodes, transistors and other devices on it
Limiting factor: a circumstance that restricts the full use of a device's capabilities

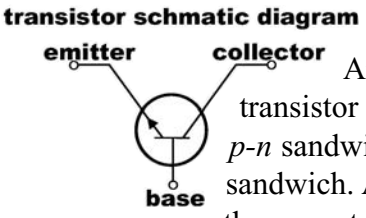
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and plate depends on the grid. A *grid* with a positive charge encourages electron flow. A positively charged grid amplifies the flow of electricity between filament and plate. The same action can be done with semiconductors.

In 1947, three physicists working at Bell Telephone Laboratories in Murray Hill, New Jersey, invented the transistor, which did the work of a triode. The three scientists were John Bardeen, Walter Brattain and William Shockley. The transistor was quickly recognized as an important invention. The three scientists were awarded the Nobel Prize in physics in 1956. John Bardeen continued to study electrical conductivity at very low temperatures and became one of the few people to win two Nobel prizes.

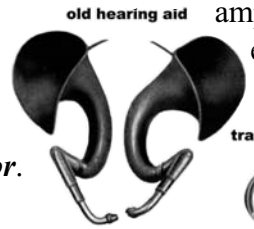


The *transistor* was given that name by combining the word *transfer* with the word *resistor*. A transistor carries (transfers) an electric current across a semiconductor resistor. The transistor that worked like a triode contained three layers. Rather than being called the filament, grid and plate, the three parts were the ***emitter***, ***base*** and ***collector***. An amplifying transistor can be made as an *n-p-n* sandwich or as a *p-n-p* sandwich. As a specific example, the *n-p-n* transistor has a small layer of p-type semiconductors (the base) between two layers of n-type semiconductors (the emitter and collector). The emitter corresponds to the filament of a vacuum tube. The emitter is connected to the negative side of the circuit and is supplied with electrons. The collector corresponds to the plate of the vacuum tube. The collector is connected to the positive side of the circuit and collects electrons released by the emitter.



The base controls how well electricity flows between emitter and collector. The base has a slight positive charge which attracts electrons from the emitter just as the grid attracts electrons from the hot filament of a vacuum tube. In the vacuum tube, the electrons fly toward the grid but pass on through because the grid of wire mesh is mostly empty space. In the transistor, the electrons flow onto the base but do not find a home. The base is made extremely thin, and it does not have enough holes for all the electrons. Electrons pass through the base and flow on over to the collector. A slight change in the voltage on the base produces a much more dramatic change in the current that flows between the emitter and the collector. The base corresponds to the grid of a vacuum tube. The transistor amplifies the current.

One of the first uses of transistors was in hearing aids. Until the 1950s, hearing aids were large bulky devices. The electronics were in a case carried in a pocket or by a cord around the neck. A wire carried the amplified sound from the case to an earphone. In 1953, hearing aids that used transistors were made so small the entire device could be fitted inside the ear.





Transistors had advantages over vacuum tubes. Transistors could be made very small; they used little power, generated far less heat, required no warm-up time, and could withstand jolts and other rough treatment. Transistors found many applications. Portable radios became possible, as did hand held calculators. Most electronic devices today use transistors: radios, televisions, calculators and computers.

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Manufacturing silicon crystals with the right amount of impurities was difficult at first. The silicon crystal was made as a bar and then sliced into thin wafers. To make better use of the crystals, transistors were made a small as possible. Several devices were manufactured from a single silicon wafer and then cut into individual ***microchips***. To increase savings still more, several transistors and other semiconductor devices were built into a single microchip. The smaller size led to other savings. Transistors required only a small amount of energy, and they operated at great speed.

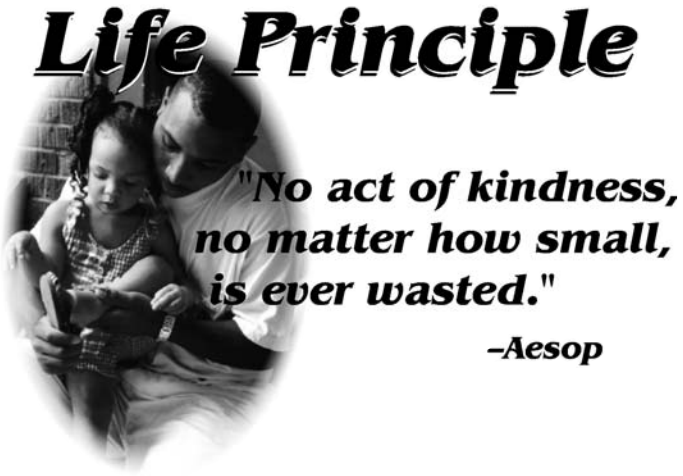


In the 1970s, microchips were replaced with integrated circuits. An *integrated circuit* is a thin semiconductor wafer that has a multitude of transistors and other components such as diodes, resistors, capacitors and electronic switches. Making an integrated circuit small served a practical purpose. Less energy was required to operate devices packed on the same silicon chip.



The first vacuum tube computers were so large they occupied entire floors of buildings. By the late 1960s, the use of transistors reduced computers to the size of cabinets that occupied one wall of a room. By the end of the 1970s, the cabinet sized calculating machines had become desktop computers. In 1985, an integrated circuit contained about 50,000 devices. Today, integrated circuits contain 100 million devices. The functions common in a desktop personal computer of 1985 now fit into a device that will slip into a shirt pocket or purse.

In addition to reducing the size of computers, small integrated circuits allow devices to operate faster. Packing semiconductor devices closely together on an integrated circuit improves processing speed. As computers became faster, the speed of light became a ***limiting factor***. The speed of light and electric signals is 300,000,000 meters per second (300 million m/sec or about 186,000 miles/sec). Some computers operate so fast they are delayed by the time required for electricity to go from one component to another. By the beginning of the 21st century, the fastest computers could process an instruction in 3 billionths of a second. During the time a computer processes an instruction, an electric signal travels only 1/10 meter, about four inches. Should the components in the main part of the computer, the central processing unit, be farther apart than four inches, the computer will run slower while it waits for the electric signal to go from one device to the other.



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Integrated Physics & Chemistry

Chapter 9

Lesson 15
Inventions & Discoveries

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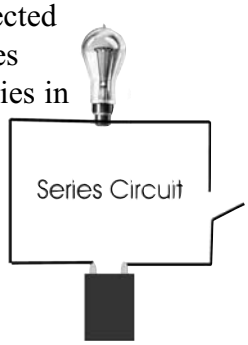
SERIES AND PARALLEL CIRCUITS



When a person opens a CD player to replace batteries, a diagram shows the correct placement for fresh batteries. Some battery-powered devices require four batteries which must be inserted correctly. The diagram may show two batteries facing one way with the flat end of one fitting against the raised end of the other, and then the other two positioned in the opposite direction. Sometimes all four are in a row.

Many electric powered devices use AA or AAA. The AAA batteries, are smaller. The flat end is the negative end of the battery. The slightly raised end (the nubbin) is the positive end of the battery. An AA or AAA battery supplies 1.5 volts of electricity. The larger AA battery can provide electricity for a longer time to a CD player, radio or flashlight. However, the voltage supplied by a AA battery is the same as the voltage from the smaller AAA battery, 1.5 volts.

A ***series circuit*** has all devices connected in a single path. Flashlights with long handles hold as many as five batteries inserted in series in the handle. The batteries are put in one after the other so that the negative end of one touches the positive end of the other, forming a single circuit. The electricity goes through all five batteries and then to the flashlight bulb.

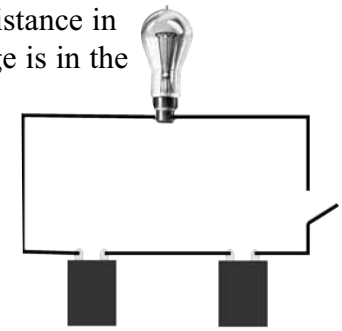


VOCABULARY

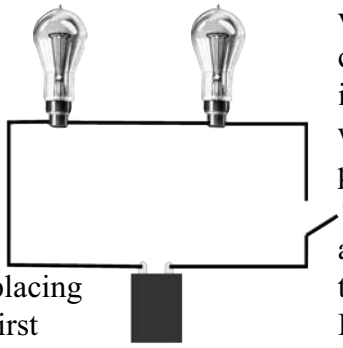
Series circuit: a circuit in which the electricity can follow but one path
Current: the number of electrons that pass a given point along a circuit during a given period
Voltage: electromotive force, puts electrons in motion
Resistance: device in a circuit that opposes the motion of electrons
Parallel circuit: a circuit in which the electricity can follow more than one path

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Ohm's Law relates ***current***, ***voltage*** and ***resistance***. According to Ohm's Law, the current that flows through an electric circuit is directly proportional to the voltage and inversely proportional to the resistance. If the voltage increases, then the current increases. If the resistance increases, the current decreases. Ohm's Law is written as $I = V/R$ with I the current in amperes, V the voltage in volts and R the resistance in ohms. Because voltage is in the numerator of the fraction, voltage and current are directly related. If voltage doubles, so does current. Because resistance is in the denominator of the fraction, resistance and current are inversely related. If resistance doubles, current is cut in half.



A series circuit has all components in a single path. Most flashlights are series circuits. When the flashlight is switched on, electricity flows from the negative base of the battery through a wire to the light bulb, through the filament to the base of the bulb and to the positive top of the battery. The electricity has but one path. Every electron follows exactly the same route. Suppose two batteries are put in series with the bulb. The positive end of one battery is connected to the negative end of the other battery. Electrons still follow a single path. They travel through the bulb and both batteries. Replacing one battery with two batteries in series changes the voltage. Voltage is electromotive force. Batteries put the electrons in motion around the circuit. By placing batteries in series, the first battery gives a certain amount of force to the electrons, and the second battery adds to that force. The increased voltage from the two batteries will push more electrons through the circuit, so the current changes, too. According to Ohm's Law, doubling the voltage will send twice as much current flowing through the flashlight bulb. The bulb will burn brighter.



Replacing one battery with two batteries in a series does not change the resistance. The batteries are a source of current and voltage but not resistance. The light bulb is the source of resistance to the flow of electricity. Because the number of light bulbs has not changed, the resistance of the circuit is the same whether the flashlight holds one or two batteries. (The internal resistance of the copper wires and batteries is usually too slight to make a difference in total resistence.)

Suppose a flashlight is modified with two light bulbs in series that draw power from a single battery. The electricity leaves the battery, goes through one bulb, then goes through the other bulb and back to the battery. The battery will still produce 1.5 volts. However, according to Ohm's Law, if the resistance increases, the current decreases. By doubling the number of bulbs, only half as much current flows and each bulb burns less brightly.

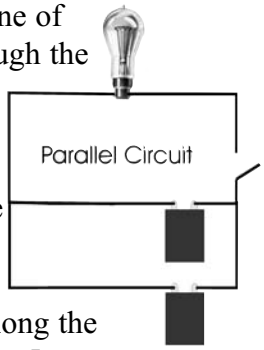
Voltage is sometimes called *voltage drop*. From one side of a battery to another, the voltage drop is 1.5 volts. The idea of voltage drop can be explained by thinking of current as a river. Imagine a river that flows in a single stream and falls down two waterfalls one after another. Each waterfall puts the molecules of the river in motion. If the first one causes the water to fall 150 feet and the second one is another 150 feet, then the total fall is 150 feet + 150 feet = 300 feet. In the same way, if one battery gives a circuit

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1.5 volts and the second one gives it another 1.5 volts, then the total voltage is 1.5 volts + 1.5 volts = 3.0 volts.

The *total voltage* in a series circuit is equal to the sum of the individual voltages: $V_T = V_1 + V_2$. If two batteries each are 1.5 volts and are connected in series, then the total voltage is V_T = 1.5 volts + 1.5 volts = 3.0 volts. A device that needs 6.0 volts can get that voltage with four batteries connected in series. Four batteries with a voltage of 1.5 volts that are connected in series (positive pole of one to the negative pole of the next) will deliver 6.0 volts: V_T = 1.5 volts + 1.5 volts + 1.5 volts + 1.5 volts = 6.0 volts.

The current throughout a series circuit is constant. Any electron that goes through one battery must go through the others. Any electron that goes through one of the light bulbs must go through the others. Using the river that has but one course as an example, the total amount of water flowing is the same above a waterfall as below it. The total current is equal to the current at any point along the circuit. This can be written as I_T = *constant*. The current is the same everywhere in a series circuit.



Light bulbs are the resistance of the circuit. Doubling the number of light bulbs doubles the resistance. By placing resistance in series, the *total resistance* is equal to the sum of the individual resistances: $R_T = R_1 + R_2$, with R_T, the total resistance, R_1, the resistance of the first device, and R_2, the resistance of the second device.

A ***parallel circuit*** is one in which the electrons have a choice of two or more paths to complete the circuit. When people have a choice as to the route they walk, the greater number will take the easy way. If the crowd is large, the easy way becomes clogged with people so some people choose to take a different and more difficult route. In the same way, electricity flow is proportional to the resistance. In places of little resistance, a greater amount of electricity flows. In places of a lot of resistance, only a small amount of electricity flows.

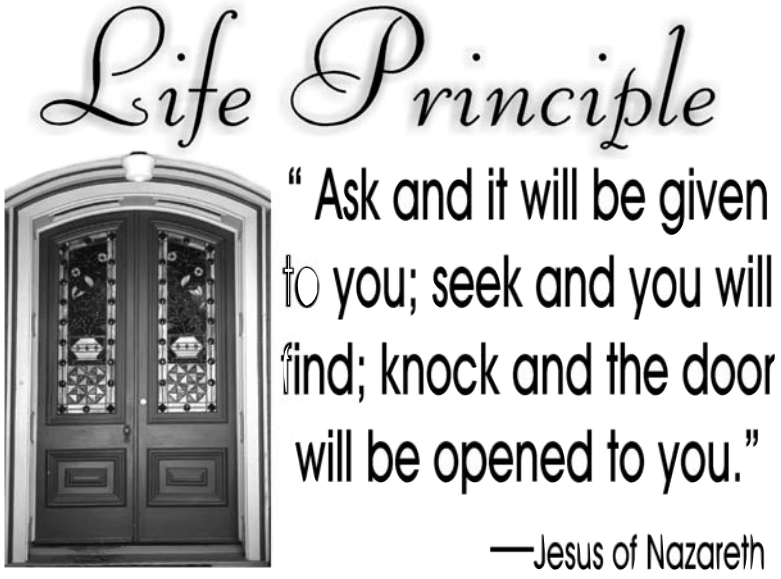
Replacing one battery with two batteries in parallel does not change the voltage. Batteries are in parallel by having the negative terminals connected to one side of the circuit and having positive terminals connected to the other side of the circuit. The voltage drop is not changed. It is still 1.5 volts. Using the river and waterfall example, should a river split into two branches and go over a cliff as two waterfalls, the distance the water falls is still the same. In a parallel circuit, voltage drop is the same along either path: V_T = *constant*. The total voltage drop is the same as the voltage drop across the first battery or across the second battery.

Replacing one battery with two batteries in parallel changes the total current supplied by each battery. Each battery contributes to the total current that flows. Placing batteries in parallel means that each battery provides some of the current to the circuit: $I_T = I_1 + I_2$ where I_T is the total current, I_1 is the current supplied by one of the batteries and I_2 is the current supplied by the other battery. Because two batteries are supplying current, the flashlight bulb draws energy from two sources, and it will stay lighted longer.

Use a river as an example. A river comes to a cliff and branches into two flows before going over the edge. At the bottom of the cliff, the two streams flow back together. This is an example of a parallel circuit. The water has more than one path to follow. The total amount of water (current) is equal to the sum of the amounts that go over each path (fall). The distance the water falls (voltage) is the same for both paths (falls).

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A parallel circuit has two or more devices, such as light bulbs, that provide resistance. Suppose two light bulbs with identical resistance are connected in parallel. Electricity in the circuit has two choices. The electrons can go through either bulb. Half of the electrons will go through the first bulb, and half of the electrons will go through the second bulb. Because they have two choices, the overall resistance is reduced. Electricity flow is proportional to the resistance. If one of the bulbs has more resistance than the other, then the bulb with the least resistance will receive the greater current.



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