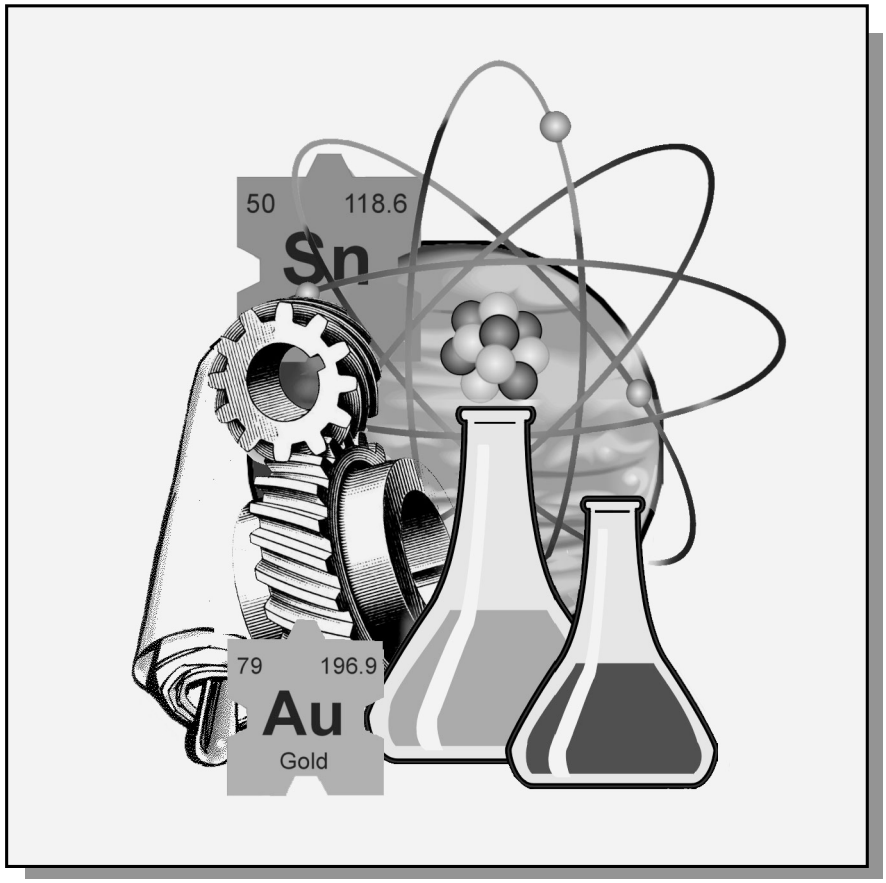
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This chapter requires a companion activity book in which students respond to questions on text content. Answers are found in the *Teacher's Resource Kit*.



Chapter 4

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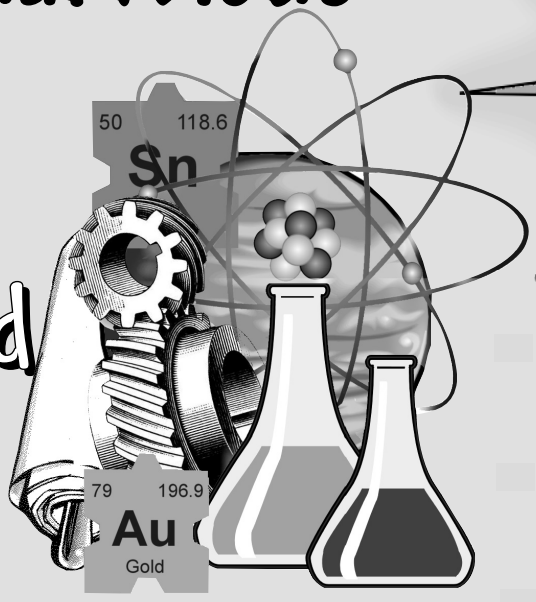
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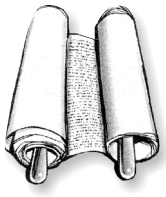
"The study of science is the chronicle of man's quest to discover the essence of life and how the marvelous laws of creation are applied to human needs."



—Ronald Johnson, Ph.D.

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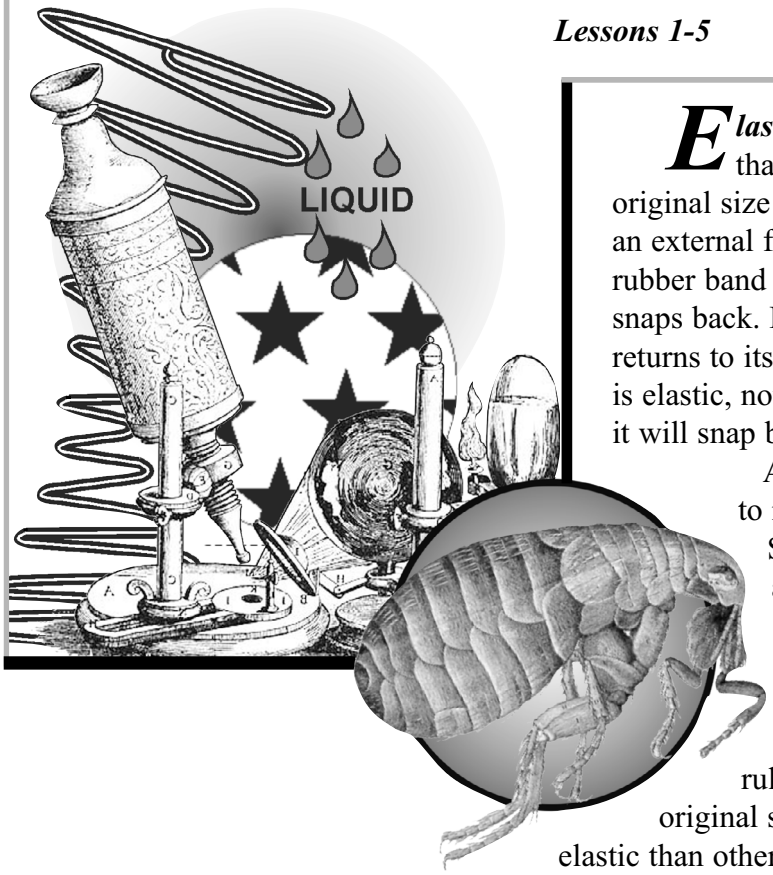
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Scientific Laws

Chapter 4

PROPERTIES OF SOLIDS: ELASTICITY

Section 1

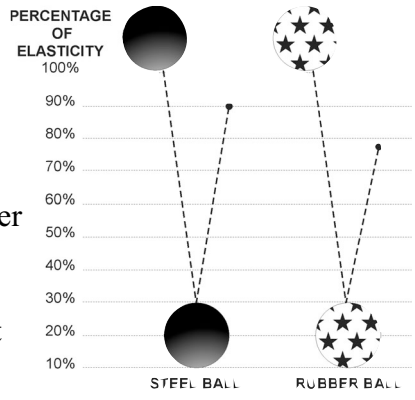
Lessons 1-5



***E**lasticity* is the property of a material that causes the material to return to its original size and shape after being acted upon by an external force. When a person pulls on a rubber band and then lets go, the rubber band snaps back. In physics, an object is elastic if it returns to its original condition. The rubber band is elastic, not because it will stretch, but because it will snap back to its original shape.

An elastic solid is one that will return to its original form after being deformed. Suppose a person clamps one end of a wooden ruler to the edge of a table and presses down on the free end. The wooden ruler will bend. When the pressure is released, the ruler will pop back straight. The wooden ruler is elastic because it returns to its original straight shape. Some solids are more elastic than others. Glass marbles, for example, are highly elastic. When a glass marble strikes another object, the glass becomes deformed and rebounds, regaining its original shape. On the other hand, a ball made of lead would strike another object with a thud and be deformed. The ball would not bounce back after the collision. Glass is more elastic than lead.

One rough measure of the elasticity of a body is to drop a ball made of the substance to be measured on a hard floor. The higher the ball bounces, the greater its elasticity. At the moment of impact with the floor, the ball is deformed. If it is highly elastic, it will spring back to its original



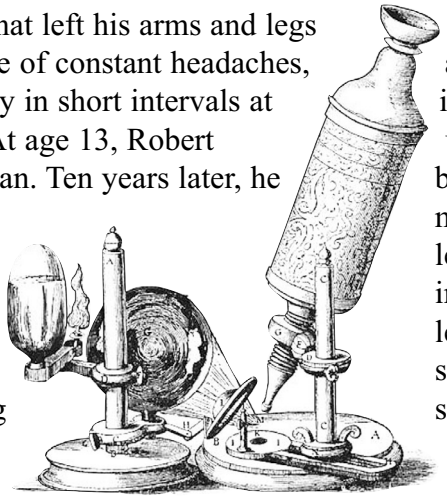
VOCABULARY

Elasticity: the property of solids that returns them to their original shape after having been deformed by an applied force
Plastic: capable of being shaped or formed

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shape, causing it to bounce into the air again. A ball that bounces back to the same height from which it is dropped is one hundred percent elastic. Glass and steel are highly elastic. A glass marble or a steel ball will bounce back to nearly 90 percent of the height from which it is dropped. A ball made of rubber does not bounce as high as glass or steel. Lead hardly bounces at all. A ball made of putty would strike the floor and stay there. Putty possesses nearly zero elasticity.

A ***plastic*** object is one which shape is easy to change. Putty, clay and dough are easy to shape and retain the new shape that is given them. Rather than being elastic, they are plastic. Robert Hooke was the first person to make a scientific investigation of elasticity. Robert Hooke was an English scientist who lived in the 1600s, about the same time as Isaac Newton. Robert Hooke was frail and very small in stature as a child who battled with a disease that left his arms and legs twisted. Because of constant headaches, Hooke slept only in short intervals at odd moments. At age 13, Robert became an orphan. Ten years later, he enrolled in Oxford University and earned a living by waiting tables and doing other chores.



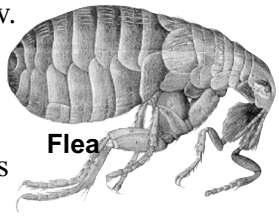
At Oxford, Robert Hooke became Robert Boyle's assistant. Together they made an improved air pump that pumped all the air out of tubes to produce vacuums. Together, Robert Hooke and Robert Boyle proved that sound would not carry in a vacuum. The two scientists also discovered that without air resistance, a feather and lump of lead fell at the same speed.

To many people, Robert Hooke appeared unkempt and ill tempered. His friends, Robert Boyle and Christopher Wren, appreciated Hooke's exceptional talents and broad knowledge of science. Boyle and Wren also understood that Hooke fought the constant pain that wracked his body. Hooke could only sleep when exhaustion overcame the feverish activity of his mind. Those who knew his situation marveled at Robert Hooke's ability to defeat such trying conditions.

The Royal Society employed Robert Hooke to demonstrate three or four interesting new ideas each week. As the years passed, Robert Hooke performed thousands of experiments. He became an expert in many fields.

Robert Hooke was one of the first scientists to use a microscope to study nature. A *microscope* is an optical instrument for viewing objects too small to be seen by the unaided eye. The microscope had been around for fifty years, but naturalists ignored it for scientific purposes. Robert improved upon the first crude microscope and built a better one. His design was a compound microscope, which is made of more than one lens. Robert Hooke used one lens to form an image of the object being viewed and another lens to magnify the image. He looked at snow crystals, insect wings, feathers, fish scales and tiny living things such as molds and mosses.

In 1665, Robert Hooke published a book about what he saw. His book, *Micrographia*, contains some of the most beautiful drawings ever made of tiny subjects. *Micrographia* means *drawings of small objects*. His drawings of snowflakes, feathers and fleas are both accurate and attractive. His portrait of a flea is a classic.

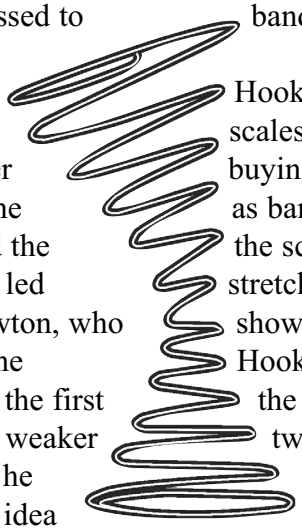


Flea

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Shortly after Hooke published his book, a disastrous fire nearly destroyed the city of London. City leaders put Christopher Wren, a member of the Royal Society, in charge of rebuilding the city. Christopher Wren called for Robert Hooke to be his chief assistant.

Robert took care of the thousands of details to build a new city from the ashes. He became a familiar figure around London as he hurried from one construction site to the next. The frail orphan had progressed to become one of England's best known and most respected scientists.



Robert Hooke, Christopher Wren and Edmund Halley were the great men who met and discussed the nature of gravity. That discussion led Edmund Halley to visit Isaac Newton, who provided a complete solution to the problem. Robert Hooke had been the first person to state that gravity grows weaker by the square of the distance, but he had been unable to prove that his idea was correct.

Robert Hooke is remembered as an all-around scientist who made many exciting discoveries. In spite of his physical handicaps, he won admiration for his dedication and enthusiasm.

One of Robert Hooke's best-known discoveries is *Hooke's Law* that states that the amount a solid is deformed is directly proportional to the force being applied. Forces can deform solids in many different ways. A solid can be stretched, bent, compressed or twisted. The force can act on wood, glass, metal, rubber or a host of other substances. Yet, they all follow Hooke's Law.

As an equation, Hooke's Law is written as $F = k * s$, with F the force, k the proportionality constant and s the amount of deformation. This is a direct linear relationship. If the force increases, so does the deformation. If the force doubles, so does the deformation. If the force becomes three times as great, the deformation becomes three times as great.

Suppose a rubber band stretches one inch when a weight of four ounces is suspended from the rubber band. With eight ounces suspended from the rubber band, Hooke's Law predicts the rubber band will stretch by two inches. If three times as much weight is used (12 ounces), then the rubber band will stretch three inches.

Most spring scales make use of Hooke's Law. Many grocery stores have scales for customers to weigh what they are buying. The customer puts the produce such as bananas, apples or grapes in the pan of the scale. The weight of the produce stretches a spring attached to a pointer to show the weight. The spring follows Hooke's Law. A one-pound weight causes the spring to stretch a certain amount. A two-pound weight will stretch the spring twice as far.

An elastic object is limited as to how far it can be deformed. Forces that bend a solid cause stress in the molecules that make up the solid. The molecules have to move from their normal positions. When the deforming forces are removed, the molecules return to their normal positions. If the molecules are pulled too far out of alignment, the forces that normally cause them to return are broken. The solid does not return to its original size and shape. The solid's *elastic limit* has been exceeded. When an object is deformed beyond its elastic limit, the object is permanently changed. For instance, when a rubber band is stretched too far, it breaks. Steel springs may become sprung. A glass marble may shatter. In each case, the elastic limit has been exceeded. Hooke's Law applies only within the elastic limit of the substance.

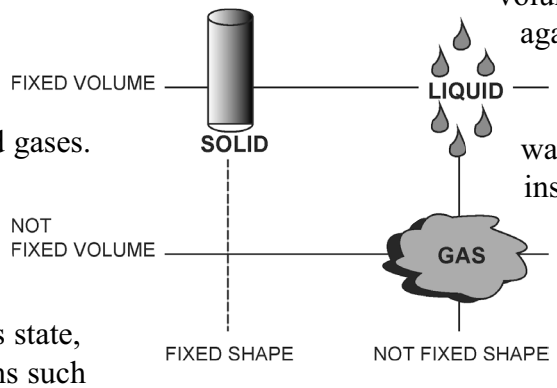
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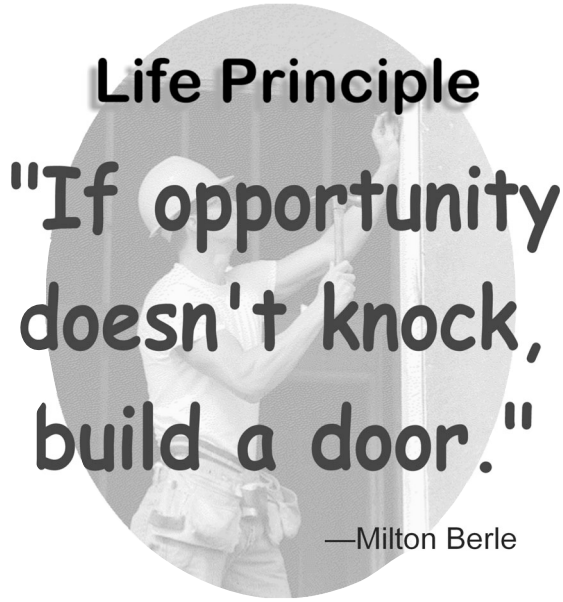
Suppose experiments show that a rubber band will stretch an additional inch for each weight of four ounces that is suspended from the rubber band. With 12 ounces, the rubber band stretches three inches. Hooke's Law predicts that with 16 ounces it should stretch four inches. Suppose the rubber band stretches only three and a half inches. This is an indication that the rubber band has reached its elastic limit. The rubber band no longer follows Hooke's Law. If any more weight is added, the rubber band is likely to break.

Properties of Solids

Solids differ from other states of matter such as liquids and gases. Many properties are the same. Whether solid, liquid or gas, all matter has inertia and exerts a gravitational attraction for other objects. When a substance changes state, other properties are different. Terms such as hardness and elasticity apply to solids but not to liquids. Solids such as metals can be described as ductile or malleable. Nonmetals can be described as brittle. The same terms do not apply to liquids or gases. Liquids and gases very easily change their shapes. Solids are more or less rigid and have definite shapes. Solids resist forces that intend to deform the shapes of solids.

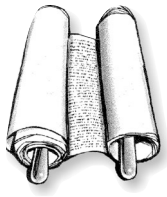
A solid has a fixed volume and a fixed shape. A liquid also has a fixed volume but not a fixed shape. A gas has neither a fixed volume nor a fixed shape. A column of solid marble that is put in the middle of a room stands freely. The column keeps its volume and shape against the force of gravity. A column of water, however, instantly collapses. The water collects on the floor. The water has the same volume after it falls but not the original shape. A column of gas scatters until it fills the entire room. After it is released, the gas changes both volume and shape.





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Integrated Physics & Chemistry



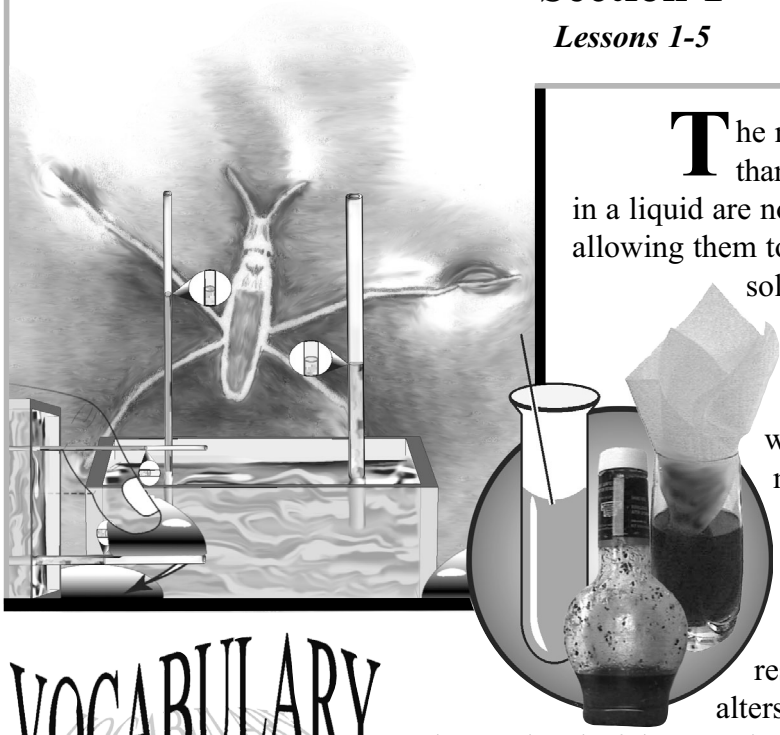
Lesson 2
Scientific Laws

Chapter 4

COHESION AND ADHESION

Section 1

Lessons 1-5



The molecules in a liquid are farther apart than molecules in a solid. The molecules in a liquid are not held as strongly by one another, allowing them to move about more freely. Like a solid, a liquid has a definite volume. A liquid does not have a definite shape. A liquid takes the shape of its container. A liquid is a *fluid*, a word that means *to flow*. The molecules of a fluid can move freely past one another, causing the fluid to assume the shape of its container. All liquids and gases are fluids.

Because a liquid can flow, it responds to the force of gravity and alters its shape. Molecules move to the lowest level of the container. The liquid flattens as much as possible. The top surface of the liquid becomes flat and level. Should the container have a hole in the bottom, the liquid will pour out under the attraction of gravity.

The molecules of a solid firmly cling to one another. When a person picks up a baseball bat by the handle, the entire bat comes along. If a bicycle rider presses down on a bicycle pedal, the entire bicycle begins moving. The property that binds molecules of the same substance together is ***cohesion***. The word means *to cling together*.

Cohesion is not the result of gravitational attraction among molecules. Gravity is far too weak to explain the strong cohesion forces. Chemists have proven that electrical attractions have a role in holding atoms together to form molecules. The electrical charges are not spread out evenly throughout the molecule. The molecules themselves have regions of slight electric charge. These static electric charges cause one molecule to cling to another.

VOCABULARY

Cohesion: a force of attraction between molecules of the same substance, to cling together
Electron: a subatomic particle with a negative electric charge of 1
Lead shot: a small pellet of lead, dozens of which are loaded into cartridges to produce shotgun ammunition
Bonds: links that hold two objects together
Adhesion: attraction that holds two different substances together
Capillary action: the rise or fall of a liquid in a tube of small diameter

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The ***electron***, a subatomic particle, carries the smallest electric charge. Although the electron is small, its role in chemical ***bonds*** is vast. In addition to the static charge they carry, the motion of the electrons generates tiny magnetic fields. These magnetic fields also have a role in holding the molecules together.

The cohesion of liquids is far less than that of solids. You expect to lift a whole baseball bat by grasping it by the handle. If you dip your hand in a container of water, you are not surprised that only a small part of the water clings to your hand.

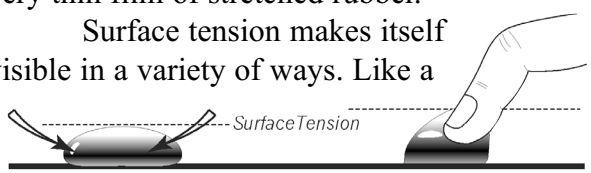
Although the cohesion of water is much less than the cohesion of solids, it does exist. The cohesion of liquids is best seen at the surface of the liquid.

Imagine a molecule of water below the surface. It is attracted in all directions by the other water molecules—up, down, left, right, forward and back. The forces of cohesion acting on the molecule are well distributed and tend to cancel one another. The molecule is free to move in any direction.

Consider a water molecule at the surface of the water. Cohesion forces attract the water molecule in every direction except upward because no molecules are above it. The directions of the cohesive forces are inward toward the liquid and not outward. The molecule experiences attractive forces that prevent it from moving outward. This imbalance of cohesive forces produces *surface tension*.

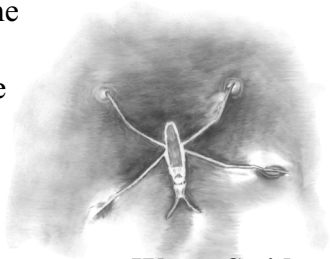
Surface tension causes the surface of liquid to have properties like those of an elastic skin under tension. Although rubber is not involved, surface tension is similar to a very thin film of stretched rubber.

Surface tension makes itself visible in a variety of ways. Like a stretched sheet of rubber, the surface membrane tries to contract. Surface tension accounts for the shape of raindrops. If a small quantity of water is dropped into the air, the surface tension forces each drop into the shape having the least surface area. The water changes shape and becomes a sphere or ball shape. A sphere has the property of containing the greatest volume with the least surface area.



Surface tension is what prevents water from penetrating into tiny air pockets. The pores of dirty clothes cannot be reached by pure water. Using hot water and soap reduces the surface tension. Molecules of hot water move more vigorously than cold water molecules. The faster action disrupts the force of cohesion. Hot water has a much weaker surface tension than cold water. Soap molecules interfere with the cohesion of water molecules. Hot, soapy water is used to clean clothes. The water then mixes better with the fibers of the clothes.

Some insects make use of surface tension. An insect known as the water strider lives on the surface of water. Its legs and feet are covered with fine, dense hairs. These hairs keep the insect from breaking the water's surface. The water strider uses its middle pair of legs as paddles and the hind pair for steering. The front pair of legs grasps the prey. The water strider lives on other insects and can move quickly across water.



Water Strider

Most liquids display surface tension. When the metal mercury is dropped, it also forms spherical drops as do molten metals such as iron and lead. Passing molten lead through a screen at the top of a tower makes ***lead shot***. The screen separates the lead into drops. As the lead falls, it cools and becomes

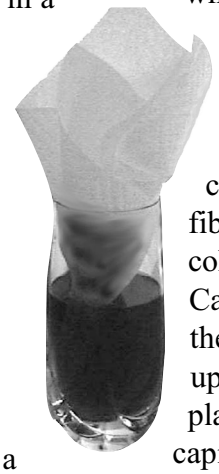
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a solid. By the time it hits the bottom of the tower, the lead has formed into a solid spherical shot.

ADHESION

When you dip your hand in water and bring it away, some water clings to your hand. The attraction between two different surfaces is ***adhesion***. When you dip your hand into water, cohesion causes most of the water to be pulled back into the main body of water. Adhesion is the attraction between water and your skin.

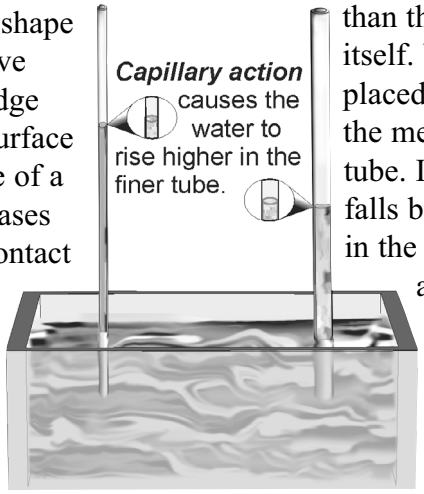
Adhesion can be stronger than cohesion. For instance, water molecules are attracted more strongly to the surface of clean glass than they are to each other. This affects the shape of the surface of water in a glass container. At the very edge of the surface of water where it touches the glass, the adhesive force pulls up the water. The surface of the water becomes slightly raised.



Two forces act against the adhesive force between water and glass. One is cohesion. The other is gravity. When the combined forces of cohesion and gravity equal the force of adhesion, the water rises no further.

When you look from the side of a glass at the upper level of water, you see that the edge is curved upward. This shape, which looks like a crescent moon, is a *meniscus*. In the case of water and glass, the shape is a concave meniscus. A concave surface curves up more at the edge than at the middle. A concave surface has the same shape as the inside of a sphere. A concave surface increases the amount of water that is in contact with the glass.

Capillary action causes water to rise in a glass tube. The word *capillary* is from a Latin word meaning *hair-like*.



Suppose a glass tube with a very fine hole down the middle is placed in water. The water in the tube will rise higher than the surface of the water. The finer the tube, the higher the water rises.

The effect of capillary action is inversely proportional to the diameter of the tube. The smaller the inside diameter of the tube, the greater will be the height to which adhesion lifts the liquid.

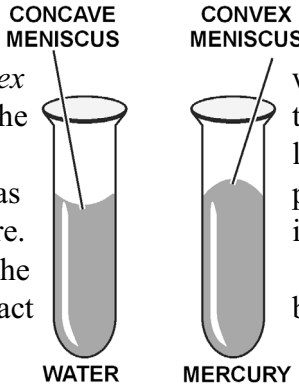
Touch a corner of a paper towel to spilled water. The water wets the towel and soaks into it. Place a strip of paper towel in a glass of water and let one end extend over the side. Water will wick up the paper and drip off the other side. Capillary action is what causes the water to rise against the force of gravity. The paper towel is made of fibers with small spaces along them. The narrow spaces act as capillary tubes. The water rises by capillary action. The adhesion of the fibers for the water is greater than the cohesion of the water with itself. Capillary action transports moisture in the soil to the roots of plants. The upward flow of water in soil and sap in plants and trees is partially caused by capillary action.

Adhesive forces are not always stronger than cohesive ones. For instance, forces attracting mercury to glass are weaker than the forces attracting mercury to itself. When a long glass tube is placed upright in a dish of mercury, the mercury does not rise in the tube. Instead, mercury in the tube falls below the level of the mercury in the dish. Mercury atoms are attracted more strongly to each other than to glass.

If you could see the mercury in a fine tube from the side, you would see that the

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edge is curved down. The meniscus is convex. A *convex* surface bows up more in the middle than it does at the edge. It is the same shape as the outer surface of a sphere. A convex surface reduces the amount of mercury in contact with the glass.



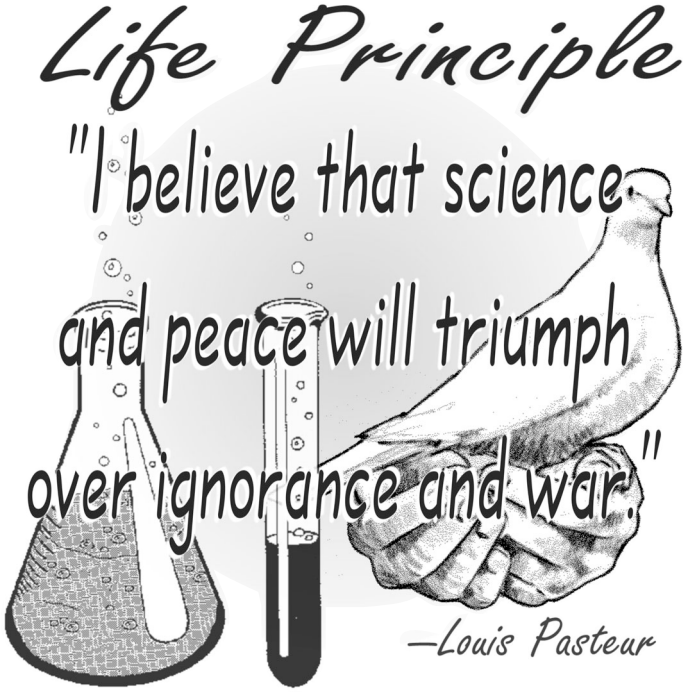
Adhesive attraction varies from one substance to another. What is true of water and glass may not be true of water and some other solid. For instance, water and oil have very little adhesion. When a drop of water falls on an oily sheet of glass, the water forms a bead. Water and oil do not mix.

Water does not rise in a tiny tube coated with paraffin. *Paraffin* is a waxy solid used to make candles, wax paper and some lubricants. Water in a tube coated with paraffin falls below the surface of the water in a container, forming a convex meniscus.

Adhesive forces also act between liquids. If two liquids mix completely, then the adhesion is strong. On the other hand, if the liquids separate, or if one liquid forms globules within the second liquid, then the force of adhesion is weak. Water and oil do not mix. This shows that the adhesive forces between the molecules of water and oil are weak.

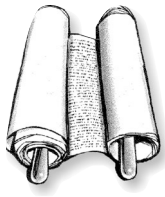


Weak adhesion (water and oil)



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Integrated Physics & Chemistry



Lesson 3
Scientific Laws

Chapter 4

DENSITY AND PRESSURE

Section 1

Lessons 1-5



A pound of lead weighs the same as a pound of feathers. People often speak of weight when they mean density. For instance, to say that lead is heavier than feathers is not correct. The size of each sample decides the weight. A truckload of feathers is heavier than a small lump of lead. The correct statement is "lead is heavier than an equal volume of feathers." Another way of expressing this concept is to state that lead is denser than feathers. The density of feathers is very slight, only about 0.01 g/cm^3. The density of lead is 11.4 g/cm^3. Lead is 1,140 times as dense as feathers. Gold has a density of 19.3 g/cm^3, which makes it denser than lead. Other dense metals include platinum at 21.5 g/cm^3 and osmium at 22.5 g/cm^3.





VOCABULARY

Density: the mass of an object compared to its volume, density = mass/volume
G/cm^3: grams per cubic centimeter, the metric unit for density
Lbs/ft^3: pounds per cubic foot, the English unit for density
Specific gravity: the density of a substance compared to the density of water
Pressure: the force exerted per unit area, pressure = force/area, pressure = weight/area, for liquid pressure a more useful equation is pressure = density * depth

Density is mass divided by the volume: grams per cubic centimeter (***g/cm^3***) pounds per cubic foot (***lbs/ft^3***) or some other unit that compares mass with volume. Density = mass/volume.

Osmium (Os) is a hard, bluish-white metallic element. It is the densest substance found on earth. Each of its atoms is lighter than a gold atom, but the osmium atoms are packed together more closely. This gives osmium a greater mass than gold for the same volume. Osmium is denser than gold or platinum.

A solid expands as it is heated. The increased volume results in a reduced density. Therefore, as a solid is heated, its density decreases. When chemists are interested in extremely accurate values for density, the chemists measure the density at a set temperature such as 0ºC.

When a solid changes into a liquid, the expansion

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increases even more. The molecules of a liquid are freer to move about. Usually they become separated more widely. Because of the greater distance between molecules, most substances are less dense as a liquid than as a solid.

Water is an exception to the rule that the liquid state is less dense than the solid state. The density of ice is 0.91 g/cm^3. Water is most dense as a liquid at about 4ºC. At that temperature, water has a density of 1.00 g/cm^3.

Specific gravity compares the density of a substance to water. Specific gravity has no units and is the same in the metric and English measuring systems. The specific gravity of lead is 11.4, which means a block of lead weighs 11.4 times as much as the same volume of water. The specific gravity of ice is 0.91, of water is 1.00, and of gold is 19.3.

PRESSURE

Pressure is the force per unit area. Pressure = force/area. In the metric system, the units of pressure are newtons per square meter (***N/m^2***).

In the English system, pounds per square inch, *PSI* or ***lbs/in^2***, is often used. Suppose a car weighs 3,200 pounds, and each tire supports an equal share of the weight. Each tire has 25 square inches resting against the pavement. The 3,200 pounds is distributed equally among four tires, so each tire supports 800 pounds. The 800 pounds is spread across 25 square inches. Recall that weight is the force exerted by gravity. Pressure = force/area = weight/area = 800 pounds / 25 in^2 = 32 lbs/in^2.



Consider a person who weighs 100 pounds. The person is standing still with an equal amount of his weight on each foot. Each shoe has a surface area of 12 square inches. Pressure = force/area = weight/area = 100 lbs / (2 * 12 in^2) = 100 lbs / 24 in^2 = 4.17 lbs/in^2. The person exerts a pressure of 4.17 pounds per square inch.

Assume each shoe heel has an area of three square inches, 3 in^2, and the person can balance his entire weight on the heel of one foot. Pressure = force/area = weight/area = 100 lbs / 3 in^2 = 33.3 lbs/in^2. This pressure is actually more than the pressure exerted by the tires of the car in the previous example. This illustrates the fact that pressure depends upon both weight and area. When the same weight is concentrated in a smaller area, the pressure increases. Pressure changes depending upon the surface area in contact with the floor. Pressure and total force are different. If the same weight is concentrated in a smaller area, the pressure increases. Needles, nails, chisels and other such instruments perform their functions because the instruments concentrate force in smaller areas. For instance, if the person in the previous example rested his weight on a single nail, the pressure would be far greater. If the nail has an area of 1/16 of a square inch, then the pressure = weight/area = 100 lbs / (1/16 in^2) = 1,600 lbs/in^2.

Liquids also exert pressure. When you dive under water, you feel pressure against

VOCABULARY

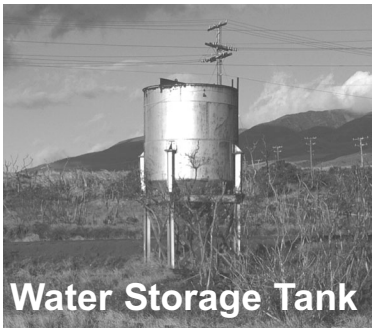
N/m^2: Newtons per square meter, a metric unit for pressure
Lbs/in^2: pounds per square inch, an English unit for pressure, also written as PSI
Perpendicular: a line that intersects another line or surface at a right angle

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your eardrums. If you swim even deeper, the pressure increases and you can feel it against your chest, too. Pressure of water is simply the weight of the water above the diver pressing against the ears and other parts of the body. Pressure is related directly to the distance to the surface of the liquid.



If you swim twice as deep, the weight of the water above you doubles. You feel twice the pressure. Pressure of a liquid follows the same formula as for a solid: pressure = force/area. However, this formula can be changed by suitable substitutions to give a more useful equation for liquid pressure: pressure = density * depth. Here, density represents the density of the liquid, and depth is the distance to the top surface of the liquid. The equation for liquid pressure shows that pressure is directly proportional to depth. The pressure at the bottom of a tank of water is directly proportional to the distance to the surface of the water. Water towers not only store water but also provide water pressure to cities. A water tower, twice as high, provides twice as much water pressure. Neither the volume nor shape of the water tower matters. The only factor that determines pressure is the height of the water in the tower.


Water Storage Tank

A person who dives six feet into a swimming pool feels the same pressure as diving six feet into a lake. The depth the person dives, not the volume of the water, determines pressure.

Consider two lakes. One is vast and covers several thousand acres. The lake is large but shallow, and the water is only 10 feet deep. The other lake is small and covers only two hundred acres. Although the lake is small, it is 30 feet deep. The dam at the first lake is holding back a greater volume of water, but pressure on it is much less. The dam at the second lake, which is deeper, is holding back a smaller volume of water, but the pressure is three times as great. The second dam must be built to withstand a greater pressure. Most dams are constructed with a top that is relatively thin. The bottom of the dam is much thicker. The greater thickness is needed to resist the greater pressure at the bottom of the lake. Pressure is directly proportional to the depth below the surface.



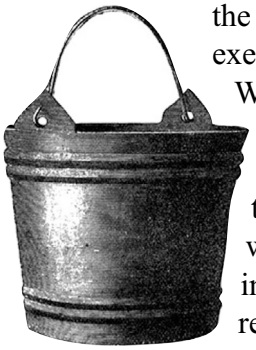
Pressure is also directly proportional to the density of the liquid. Kerosene, a hydrocarbon fuel, has a density of 0.69 g/cm^3. Water has a density of 1.00 gm/cm^3. Assume two containers have the same height, but one contains kerosene and the other contains water. At the bottom of the kerosene container, the pressure will be 69 percent of the pressure at the bottom of the container of water. Water is denser and exerts the greater pressure.

Mercury is a dramatic example of how density changes pressure. Mercury has a density of 13.6 g/cm^3. A column of mercury has 13.6 times as much pressure as a column of water the same height.

Pressure is exerted differently in liquids than in solids. A stack of bricks exerts pressure in only one direction – directly

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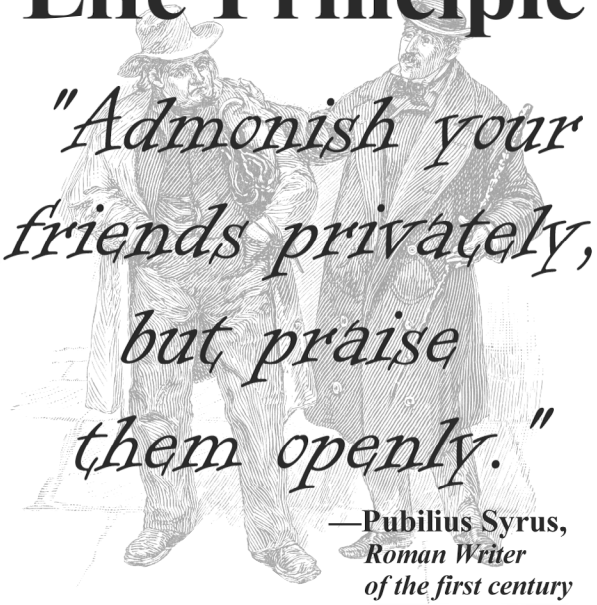
down toward the center of the earth. A liquid exerts pressure against its container. The force of liquid pressure is perpendicular to any surface against which the liquid presses. ***Perpendicular*** describes a line that forms a right (90°) angle to another line, like the corner of this page.



A person is aware of this by the simple observation that if a bucket of water springs a leak along the side, water will stream out. The pressure of the water acts against the side of the bucket. Pressure in a liquid at any point is exerted in equal amounts in all directions.

Water pushes on the sides as well as on the bottom of its container. A liquid presses upward on anything placed in it. If you try to force an empty bucket into a tank of water by pressing the bucket bottom first into the water, you will feel the water resisting the bucket.

Life Principle



"Admonish your friends privately, but praise them openly."

—Pubilius Syrus,
Roman Writer of the first century

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Integrated Physics & Chemistry

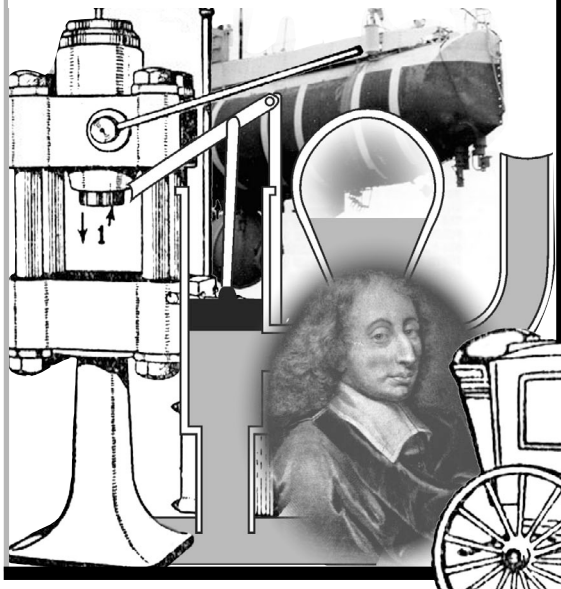
Lesson 4
Energy

Chapter 4

HYDROSTATICS

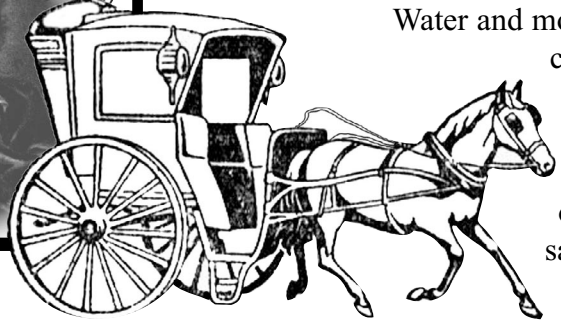
Section 1

Lessons 1-5



Blaise Pascal was a French scientist who showed that atmospheric pressure is greater at the surface of the earth and grows less at higher elevations. Gases, such as the atmosphere, will compress when put under pressure. The atmosphere at the surface of the earth is denser because the weight of the air above the earth is compressing air into a smaller volume.

Water and most liquids do not compress when put under pressure. A sample of water taken at the surface of the ocean has the same density as one taken at the bottom of the ocean.



Although the density of water in the ocean does not increase with depth, the pressure certainly does. The pressure increases steadily as one dives deeper into the water. Divers use an ***atmosphere*** to measure pressure. One atmosphere is the average pressure exerted by the atmosphere at sea level. The pressure is equal to 14.7 pounds per square inch, 14.7 lbs/in^2. Every 33.9 feet down in water increases the pressure by one atmosphere. The average ocean depth is 12,400 feet, a little over two miles. The maximum ocean depth is 36,198 feet in the Mariana Trench southwest of Guam in the Pacific Ocean. The water pressure at the bottom of the Trench reaches 1,067 atmospheres, about eight tons per square inch. Exploring the lowest point in the ocean is far more difficult than exploring the highest point on earth.

The highest point on the earth's surface is Mt. Everest at 29,028 feet. At that elevation, the conditions are harsh—bitterly cold temperatures and an atmosphere too thin to sustain life.

VOCABULARY

Atmosphere: a measure of pressure equal to the average atmospheric pressure at sea level, about 14.7 pounds per square inch

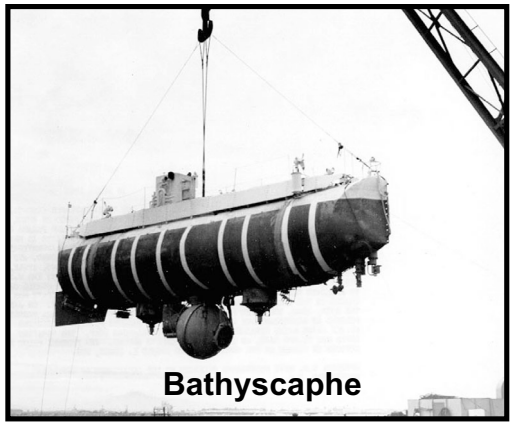
Bathyscaphe: a free diving, deep sea exploration craft that reached the deepest point in the ocean

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Edmund Hillary and an experienced native guide, Tenzing Norgay from Nepal, reached the summit in 1953. This was only 16 years before man walked on the moon. Although Mt. Everest had been conquered, the deepest point in the ocean remained unvisited by mankind. Because of the crushing pressure, exploring such a depth appeared to be impossible.

Divers can descend about 200 feet at most. Submarines can do a little better, about 600 feet. To go even deeper, William Beebe, an American naturalist, developed the *bathysphere*. It was a sphere of steel with portholes of thick quartz. The inside crew compartment was only 4.5 feet in diameter. A ship on the surface lowered the steel sphere into the sea by a cable. Because the ship could carry a limited amount of cable, the bathysphere's greatest depth was 3,000 feet. That is far short of the 36,198 feet in the Mariana Trench. Beebe's dives were made in the 1930s.

August Piccard, a Swiss scientist, next took up the challenge of deep diving. His goal was to design a submarine that could move about freely and resist the crushing pressure at the bottom of the ocean. He used his experience as a balloonist to aid in designing a ship. August Piccard had set a record for a balloon ascent. He also built a ship to explore the bottom of the ocean. August Piccard's ship, a ***bathyscaphe***, was in many ways like a balloon. A balloon gains lift by using light gases. In the bathyscaphe, a tank contained a liquid lighter than water to give the vessel lift. Piccard used gasoline, which floats in water and is unaffected by pressure. No matter how great the pressure became, the gasoline would retain its volume and keep the ship from being crushed. A load of metal shot caused the bathyscaphe to sink. By releasing the metal shot, the bathyscaphe rose to the surface. Below the tank of gasoline was a steel sphere, which contained the brave human explorers. The bathyscaphe was not connected by a cable to a ship on the surface. Instead, it had propellers and could be steered. In 1960, Jacques Piccard, August's son and Lt. Don Walsh of the United States Navy, descended to the bottom of the Mariana Trench. They reached the deepest point on the earth's surface. This was only six years before the first manned landing on the moon.


Bathyscaphe

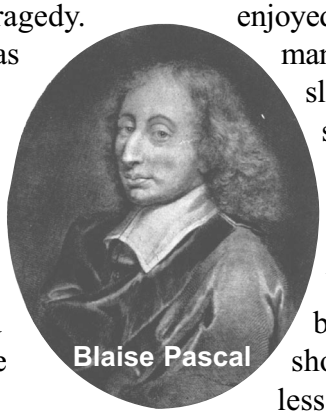
In 1999, the son of Jacques and the grandson of August set a world record for balloon flight. The first balloon to fly around the world nonstop was piloted by Bertrand Piccard, along with Brian Jones of England. As a Swiss doctor, Bertrand Piccard did not appear to follow in the exploring footsteps of his father and grandfather. However, in 1994, he decided to engage in the race to be the first to circle the earth in a balloon. On the third attempt, Piccard and Jones caught the jet stream over Egypt and set off on a 26,000-mile voyage that took almost 20 days. Jacques Piccard welcomed the return of his son from the incredible journey.

The principles that helped August Piccard design his ship had first been stated more than 300 years earlier by Blaise Pascal. This great French scientist had established the science of *hydrostatics*, the study of fluids under pressure. *Hydro* means *water* and *static* means *still* or *at rest*. Hydrostatics is the study of

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fluids at rest. *Hydrodynamics* is the study of fluids in motion.

Blaise Pascal was one of the most remarkable people of the 1600s. He grew up in wealthy circumstances. His father was a member of the nobility and a rich merchant; but riches do not guarantee against tragedy. Pascal's mother died when Pascal was three. His father took charge of raising Blaise and his two sisters. Pascal's father saw to his son's education and hired tutors. When Blaise was seven years old, his family moved to Paris. His father was interested in science and wanted to ensure that his son would meet the great French scientists.


Blaise Pascal

Pascal's father locked up books about mathematics and geometry because he wanted his son to concentrate on other studies. He believed the boy should be 15 years old before studying geometry. Blaise Pascal asked a tutor about geometry. The young Pascal found the subject fascinating. At the age of 12, Pascal began using his playtime to study geometry secretly. In a few weeks, he had discovered many properties of figures. Blaise Pascal proved that the sum of the angles in a triangle is always 180 degrees. When his father found out that Blaise had progressed so far on his own, he gave the boy a copy of Euclid's *Elements of Geometry.* Euclid was a Greek scientist who wrote a textbook on geometry. The *Elements of Geometry* is still the best-known and most successful book about geometry. It is still used in classrooms today.

Blaise Pascal attended scientific gatherings with his father. Pascal presented papers about his own discoveries. The scientists were astonished that a person so young could be so knowledgeable about science. Late in 1639, Blaise's father was appointed tax collector for Upper Normandy and had to move. The Pascal family left Paris. To aid in his father's mission, Blaise Pascal built a mechanical calculator, the first of its kind. He constructed the machine when he was 18 years old.

Pascal had been frail at birth and never enjoyed good health. He suffered from many ailments. Pascal was a man of slight build, and a perfectionist of stubborn persistence. By enlisting the aid of the husband of one of his sisters, Pascal carried out a full schedule of experiments. The brother-in-law carried a barometer up a mountainside to show that the atmosphere grows less dense at higher elevations.

With a French mathematician, Pierre de Fermat, Pascal developed the Laws of Probability. This became a very useful study because scientists often must deal with a multitude of particles that cannot be tracked individually. Instead, scientists predict what the particles will do based on probability. James Clerk Maxwell proved the kinetic theory of gases by applying probability to the motion of gas molecules.

Pascal was a firm believer in experiments rather than reasoning alone. Pascal's other important scientific contributions include the research paper, *Treatise on the Equilibrium of Liquids*. A treatise is a thorough study of a particular subject, written so that it develops from the simple and known into the complex and unknown. The treatise contained *Pascal's Principle*, which stated that fluids in a container transmit pressure equally in all directions. Unlike a solid, which transmits pressure only directly down, liquids in a container press equally in all directions against the container.

Throughout his life, Blaise Pascal had been interested in pursuing a better

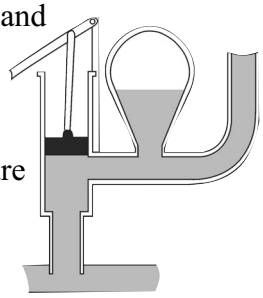
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understanding of the Christian faith. At age 32, he had a frightening accident. While riding in a carriage, the horses bolted. The carriage was left hanging over a bridge. Pascal was rescued, but the accident changed the direction of his life.

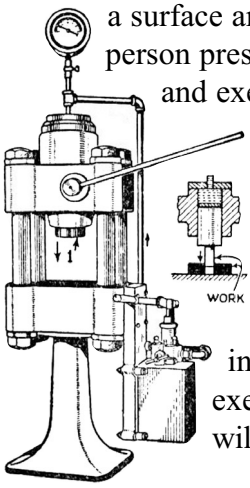


During the last years of his life, he devoted himself full time to religious matters. He became one of the most important writers in Christian literature. His writings are noted for their logic and the passion with which he expressed his beliefs.

Pascal's most famous work in philosophy, entitled *Penses,* is a collection of personal thoughts on human suffering and faith. He wrote with authority about pain because he constantly suffered migraine headaches and painful stomach ulcers. He died at the age of 39. Despite his short life, he left his mark in a variety of fields including mathematics, geometry, philosophy and physics. He is often listed as one of the most influential scientists and philosophers of all time. Blaise Pascal was the first to explain the science of a hydraulic press. A hydraulic press has two cylinders with a liquid between the two pistons. By applying a small force to the smaller piston, a larger force is exerted on the larger piston. Suppose a small piston has a surface area of one square inch. A person presses down on the piston and exerts a force of 10 lbs upon that one square inch, 10 lbs/in^2. A fluid conducts the pressure to the other side to a much larger piston. It has an area of 350 square inches, 350 in^2. The force exerted by the larger piston will be 10 lbs/in^2 * 350 in^2 = 3,500 lbs. This appears to be something for nothing—press down with a force of 10 pounds and move a weight of 3,500 pounds. As with a simple machine, one does not get something for nothing. To realize the greater force, the smaller force must travel through a greater distance. Although the effort is much less in the smaller cylinder, it must be applied through a greater distance. The mechanical advantage of the hydraulic press is equal to the ratio of the area of load piston to area of effort piston. M.A. = (area of load piston)/(area of effort piston). In the example above, the mechanical advantage is 350: M.A. = 350 in^2 / 1 in^2 = 350. The hydraulic press in some automobile service stations makes use of this principle. An electric motor pumps hydraulic fluid into a small cylinder, and the pressure is transmitted to a much larger cylinder that lifts a car.

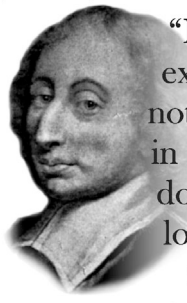


The fact that pressure on the small cylinder is transmitted to the entire surface of the larger cylinder is a direct application of Pascal's Principle. This principle states: "pressure exerted anywhere on a confined liquid is transmitted unchanged to every portion of the interior and to all the walls of the containing vessel." It is always exerted at right angles to the walls of the container.



Hydraulic Press

Life Principle

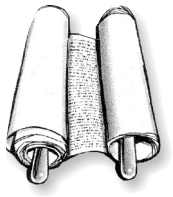


"If God does not exist, one will lose nothing by believing in Him, while if He does exist, one will lose everything by not believing."

—Blaise Pascal

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Integrated Physics & Chemistry



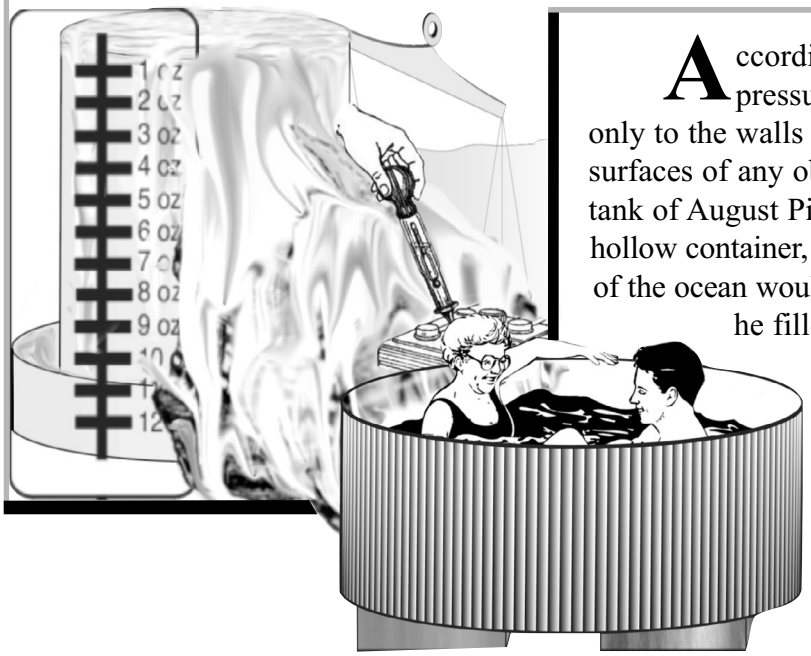
Lesson 5
Scientific Laws

Chapter 4

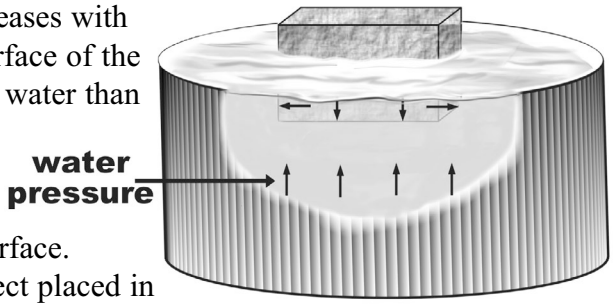
BUOYANCY

Section 1

Lessons 1-5



According to Pascal's Principle, the pressure of a liquid is transmitted not only to the walls of a container but also to the surfaces of any object in the liquid. If the flotation tank of August Piccard's bathyscaphe had been a hollow container, as the ship descended, the pressure of the ocean would have crushed the tank. However, he filled the tank with gasoline. Like most liquids, gasoline cannot be compressed. As the ship descended, the liquid gasoline resisted the pressure of the water. The walls of the container did not collapse. Only the diving sphere needed thick steel walls to protect the crew from the pressure. The divers released steel shot to rise to the surface. When an object rises in water, two factors are at work. First, pressure increases with depth. Secondly, the pressure of liquid acts on all surfaces of a solid in water, including the top and bottom surfaces. Suppose a block of concrete is immersed in water. The top and the bottom of the solid block will not experience the same pressure because pressure increases with depth. The bottom surface of the block is deeper in the water than the top surface. The pressure is greater on the bottom surface and less on the top surface.



Any solid object placed in water will have a greater pressure pushing up on it than pressing down on it. If you take a heavy rock and lower it into water, the rock will seem to become lighter. The water pressure on the

VOCABULARY

Net: final values after reductions have been taken
Therapy: a treatment to reduce or eliminate the effects of an illness or injury
Buoyancy: the upward force a fluid exerts on an object
Displace: to move or shove aside
Hydrometer: an instrument used to measure density or specific gravity of a liquid

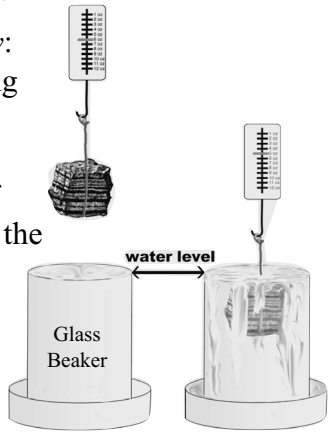
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bottom of the rock is greater than the water pressure on the top of the rock. Because the two pressures are unequal, the water exerts a ***net*** upward force on the submerged rock. A person entering a swimming pool feels the same effect. The swimmer's body feels lighter and nearly floats. People who have injuries and cannot walk find that their weak legs can support their body in a pool of water. Physical ***therapy*** takes advantage of the ***buoyancy*** of water to help a person use muscles that are not strong enough to perform activities out of the water. Buoyancy is the upward force of liquids against a submerged object. A block of concrete is lighter when in water than in the air. Any solid object of any shape immersed in any liquid or gas will appear to lose weight. Buoyancy is the name given to the lifting force. A stone appears to be lighter in water, yet it still sinks. A human body is barely able to float. A block of wood bobbles on the top of the water with nearly 35 percent of its volume above the water. Archimedes found the answers to what explains these three different observations.



Archimedes lived about two thousand years ago in Syracuse, a port city on the island of Sicily, a Greek city. Archimedes had a practical mind quite unlike the other Greek philosophers. One day, King Hieron II received a new, golden crown. The king ordered Archimedes to test the crown for purity without damaging it. Archimedes was not allowed to bore into it or file off a sample to test it.

Archimedes did his best thinking while soaking in his bath. When he stepped into the water, he noticed that the level of water rose. He also noticed that he felt lighter. He seemed to float. Archimedes experimented with the apparent loss in weight of an object immersed in water. He stated what became known as Archimedes' *Principle of Buoyancy*: "the lifting force acting on a solid object immersed in a fluid is equal to the weight of the fluid displaced by the object." Archimedes' Principle can be illustrated by hanging a solid object, such as a stone, from a spring scale. The object is first weighed in the air and then lowered into a beaker that is filled to the brim with water. The stone will ***displace*** or shove aside some of the water which then overflows the beaker. Once the stone is completely under water, the spring scale shows that the stone weighs less. If a person catches the water that overflows from the beaker and weighs it, the weight of the water equals the weight the stone lost.

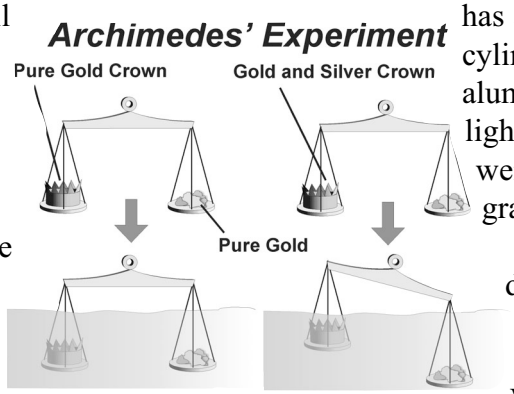


The buoyant force depends on the volume of the liquid displaced. Water weighs about 62 pounds per cubic foot. A cubic foot of lead weighs about 712 pounds. When it is immersed in water, it displaces one cubic foot of water. The lead weighs 62 pounds less: 712 – 62 = 650 pounds. A cubic foot of aluminum weighs 169 pounds. When under water, it too weighs 62 pounds less: 169 – 62 = 107 pounds. A cubic foot of steel, lead, concrete or any other solid will weigh 62 pounds less when dropped into water. The buoyant force depends on the volume of water displaced. An average adult human has a weight of about 180 pounds and a volume of about three cubic feet. The volume of water displaced will determine if the person sinks or floats in the water. Three cubic feet of water weighs 186 pounds (62 lbs/ft^3 * 3 ft^3 = 186 lbs). The person weighs six pounds

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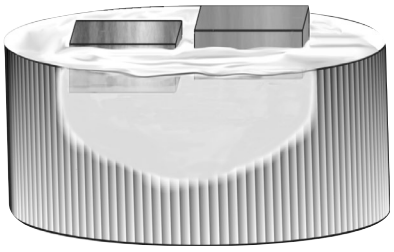
less than an equal volume of water, so the person will float, but very slightly.

Archimedes devised a way to test the crown of gold using the Principle of Buoyancy. In his day, merchants weighed objects with a balance scale that had pans on either end of a beam with a pivot in the middle. A balance scale works on the same principle as a teeter-totter. If the weights on either side are the same, then the two pans stay level. Merchants put an object to be weighed in one pan of the scale. On the other side, they added test weights of known value until the two pans balanced. Archimedes put the gold crown in one pan and added pure gold to the other pan until they balanced. Next, he lowered the scale under water. Suppose the crown was made of pure gold. The crown in one pan and the gold weight in the other pan would both lose weight under water by exactly the same amount. The pans would stay in balance under water. The crown might have contained some silver, which is less dense than gold. Silver takes up more space than an equal weight of gold. A crown made of silver mixed with gold would tend to float more than one made of pure gold. It would weigh less than pure gold when put under water. The pans would no longer balance. Archimedes worked out all of this while in his bath. When he realized he had the solution he shouted, "I have found it!" Of course, he spoke Greek. What he actually shouted was "Eureka!" According to the story, his test showed that the dishonest goldsmith had mixed in silver to make the gold crown.



Another way of understanding Archimedes' Principle is to consider an aluminum cylinder with a volume of 10 cm^3. The cylinder is hung from a spring scale. The scale shows that the aluminum weighs 27 grams. Still hanging from the spring scale, the aluminum cylinder is dipped into water. A total of 10 cm^3 of water is displaced. Water weighs one gram for each cubic centimeter, so the cylinder's weight is reduced by 10 grams. The spring scale now shows that the cylinder weighs 17 grams: 27 grams – 10 grams = 17 grams. The same aluminum cylinder dropped into kerosene will lose weight but not as much. Kerosene is not as dense as water. Kerosene has a density of 0.69 g/cm^3. Because the cylinder displaces 10 cm^3 of kerosene, the aluminum will appear to be 6.9 grams lighter: 10 cm^3 * 0.69 g/cm^3 = 6.9 g. Its weight in the kerosene would be 20.1 grams: 27 g – 6.9 g = 20.1 g.

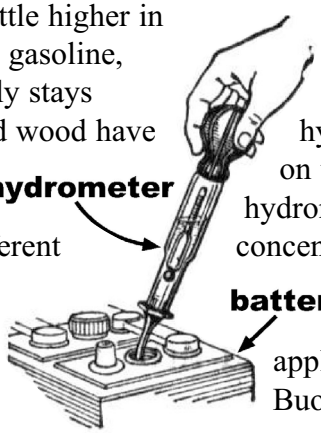
Solid objects sink in water if the density of the solid is greater than the density of water. Any object with density less than the density of water will float. Wood has a density of about 0.65 g/cm^3, so it will float. When a block of wood is placed in water, the wood sinks until the amount of water the wood displaces is equal to the weight of the wood. A cubic foot of wood weighs about 40 pounds. It will sink in water until it displaces 40 pounds of water. About two-thirds of the block of wood is below water and about one-third is above water. The height that a solid piece of wood floats in a liquid is a measure of the liquid's density. Seawater has salt and other chemicals dissolved in it. Because of the additional



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chemicals, seawater is slightly denser than pure water. Wood will float a little higher in seawater than in fresh water. In gasoline, however, a block of wood barely stays above the surface. Gasoline and wood have about the same density.

The fact that liquids support a floating object at different heights depending on their density is used to measure density of the liquid. A ***hydrometer*** measures density of a liquid. A hydrometer is usually made of a thin glass tube with a scale along the side. A weight in one end keeps the hydrometer upright in the liquid. How high or low the hydrometer floats in the liquid depends on the density of the liquid. The hydrometer is used to measure the concentration of battery acid or the amount of coolant in an automobile radiator. The hydrometer is an application of Archimedes' Principle of Buoyancy.



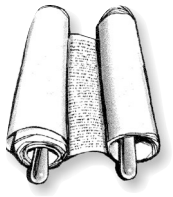
Life Principle

"Everyone has limits. You just have to learn what your own limits are and deal with them accordingly."

—Nolan Ryan

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Integrated Physics & Chemistry



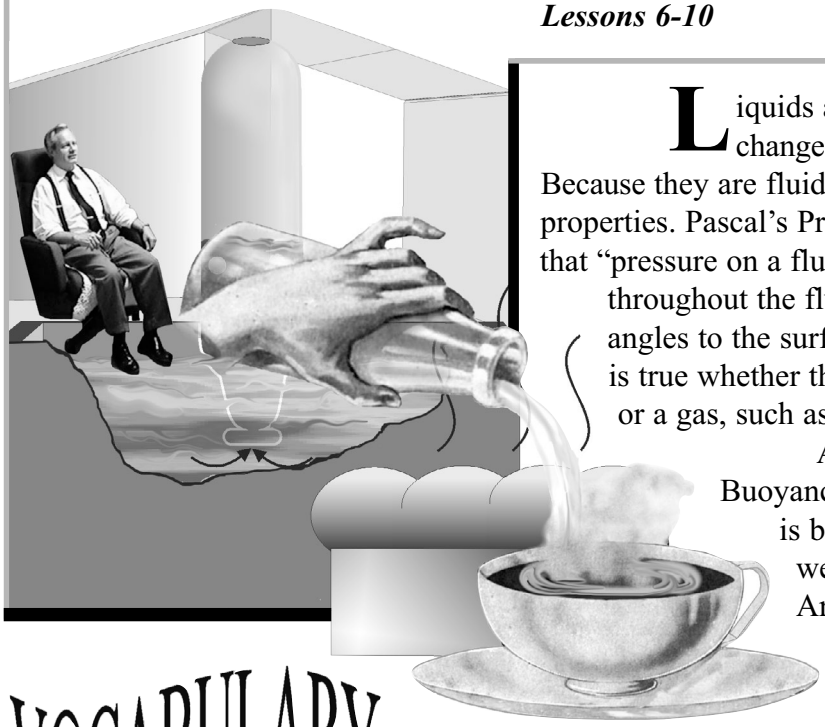
Lesson 6
Scientific Laws

Chapter 4

GASES AND DIFFUSION

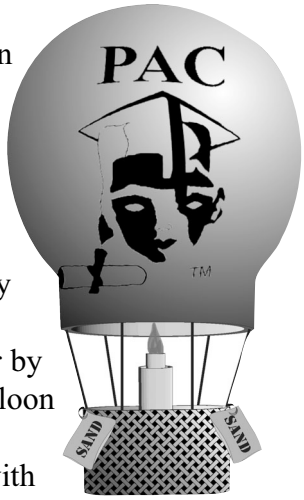
Section 2

Lessons 6-10



Liquids and gases are fluids. They readily change their shapes and can flow. Because they are fluids, liquids and gases share some properties. Pascal's Principle of Fluid Pressure states that "pressure on a fluid confined in a container acts throughout the fluid in all directions and at right angles to the surfaces it contacts." This principle is true whether the fluid is a liquid, such as water, or a gas, such as the atmosphere.

Archimedes' Principle of Buoyancy states that "an immersed body is buoyed up by a force equal to the weight of the fluid it displaces." Archimedes' Principle of Buoyancy applies to all fluids, both liquids and gases. A balloon rises in the air because the total weight of the air it displaces is greater than the weight of the balloon. As the balloon rises, the density of the air becomes less. When a balloon reaches an altitude at which the balloons weight and the weight of the air the balloon displaces are equal, it stops rising. To rise higher, the balloonist can increase the volume of the air bag to give it greater lift. A hot air balloon gains lift by heating the air in the bag and making it expand. The balloon can also rise higher by dropping ***ballast*** over the side so the balloon is lighter.



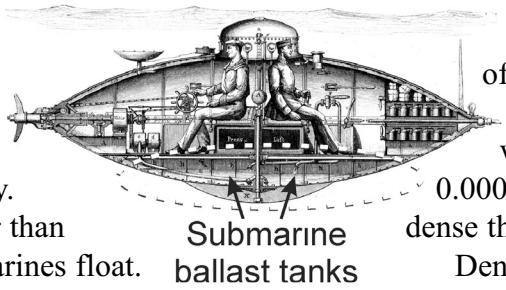
A submarine controls its depth with ballast tanks. By letting water flood the tanks, the submarine will sink. By forcing the water from the ballast tanks with compressed air, the ship becomes lighter and will rise.

VOCABULARY

Ballast: usually bags of sand, weight to hold down the balloon
Displacement: the amount of a fluid shoved aside by a body in a fluid, the displacement of a ship is the amount of water shoved aside as the ship floats
Liter: the metric unit of volume measured, equal to 1,000 cubic centimeters, a little more than a quart
Absolute temperature: the temperature measured from absolute zero, $^{-}273^{o}C$
Diffusion: mixing two substances by random molecular motion

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The submarine and balloon both rise or fall according to Archimedes' Principle of Buoyancy.



Steel is denser than water, yet steel submarines float. It is not the steel alone that counts, but the density of the entire ship. The hull is made of steel, but the rest of the ship is more or less hollow, giving it a larger volume and lower density than a tube of solid steel. The total weight of a submarine or surface ship is its ***displacement***. The displacement is the number of tons of water shoved aside. For a ship to float, it must displace as much water as it weighs. The displacement is equal to the weight of the ship. Suppose that a submarine began sinking. It would never reach a depth where it ceases to sink. Water and air are different in this regard. Air can be compressed, but water cannot be compressed. As an object sinks in water, the density of the water stays the same. The object never reaches a point where it becomes as light as the water displaced. It continues to sink until it reaches the bottom of the water. The statement that water and most other liquids cannot be compressed is a simplification. Under ordinary conditions, water cannot be compressed. Ordinary conditions are those conditions likely to be achieved in a well-equipped physics laboratory or found in nature in everyday life. Under exceptional conditions of extremely high pressures, water can be compressed by approximately three percent. Under ordinary conditions, water cannot be compressed.

Gases also differ from liquids and solids in their density. For most substances, the liquid state is slightly less dense than the solid state. When the substance changes to a gas, the density changes dramatically. The density of gases is much less than that of either liquids or solids. A sample of air has a density of 0.0013 g/cm^3. Air is 770 times less dense than water. The density of steam is 0.00061 g/cm^3, about 1,700 times less dense than water.

Density is found by dividing the total mass by the total volume (density = mass/volume). The density of solids and liquids is usually stated as grams per cubic centimeter (g/cm^3). When the densities of gases are stated in this unit, the numbers come out to be very small. For instance, the density of the lightest gas, hydrogen, is 0.00009 g/cm^3. Scientists prefer to state the densities of gases in grams per liter, g/l. A ***liter*** is a metric unit of volume equal to one thousand cubic centimeters, liter = 1,000 cm^3. Using liters rather than cubic centimeters makes the values for the densities of gases a thousand times larger. Nitrogen gas, for instance, has a density of 0.00125 g/cm^3. Stated as grams per liter, its density is 1.25 g/l.

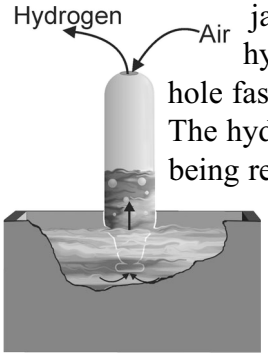
The reduced density of a gas compared to the same substance as a liquid is a result of the distance between the molecules. The mass and size of each individual molecule remains the same. However, when a substance becomes a gas, the molecules move further apart. On average, molecules of a substance as a gas occupy about one thousand times as much space as the same molecules as a liquid. Because of the extra space between molecules, gases are easy to compress. The fact that gases readily compress is one way they differ from liquids and solids. As a sample of air is compressed, its volume decreases. Robert Boyle investigated air under pressure and found that the volume of a gas is inversely proportional to the pressure. If the pressure upon a sample of air is doubled, then its volume is compressed to only one half as much. Boyle's Law states

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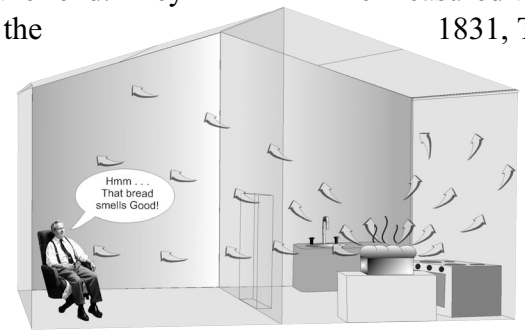
that the volume of a gas is inversely related to the pressure acting on it. The law assumes that temperature is kept constant. Both temperature and pressure can change the volume of a gas. Most solids and liquids expand when they are heated. The effect of temperature on gases is even more pronounced. The volume of a gas is directly proportional to the ***absolute temperature***. Absolute temperature is measured in Kelvin (K). The Absolute or Kelvin scale starts at absolute zero which is -273º Celsius (C). If a gas is heated so its absolute temperature doubles from 273ºK (or 0ºC) to 546ºK (or 273ºC), the volume of the gas will double, provided the pressure remains the same. Hydrogen, oxygen and nitrogen all follow Boyle's Law and the law relating volume to temperature. If a change in temperature causes nitrogen gas to expand by a certain amount, the same change in temperature will cause oxygen gas to expand by the same amount. Mixtures of gases such as the atmosphere also follow these laws.

The smell of freshly baked bread can be detected from a great distance. As the bread is in the oven, the vapors rise into the air of the kitchen. The molecules released by the bread can travel far from the kitchen and spread throughout the entire house. ***Diffusion*** is the mixing of two substances by the ceaseless motion of their molecules. Suppose oxygen gas is released at one end of a tube and hydrogen gas at the other end. They will expand until they fill the container. Diffusion causes the two gases in a container to mix thoroughly.

In the 1820s, Thomas Graham experimented with the diffusion of gases. Thomas Graham was born in Glasgow and educated at the university there. He came to London where he eventually became Master of the Mint, an important government post. It was the same position held by Isaac Newton when he moved from Cambridge to London. Thomas Graham proved that gases diffuse based on their density. Less dense gases diffuse most rapidly. He drilled a small hole into the bottom of a jar of hydrogen. Then he removed the cap and upended the jar into water. From the hole in the bottom of the jar, which is now on top, hydrogen can escape from the jar. Air from the atmosphere can enter the jar through the same small hole. During his experiment, Thomas Graham noticed that water was drawn up into the jar. This proved that hydrogen escaped from the hole faster than air entered the hole. The hydrogen escaped without being replaced. This reduced pressure as the jar drew up the water. As time passed, air entered the jar and equalized the pressure, and the water level fell.



Although all gases diffuse, some diffuse more quickly than others do. In this experiment, hydrogen diffused more quickly than the gases of the atmosphere. Thomas Graham continued to experiment. He let various gases diffuse through very fine tubes. He measured their rates of diffusion. In 1831, Thomas Graham announced that the rate of diffusion of a gas is inversely proportional to the square root of its molecular weight. This became known as *Graham's Law of Gas Diffusion*. Oxygen gas is 16 times as heavy as the same volume of hydrogen gas.



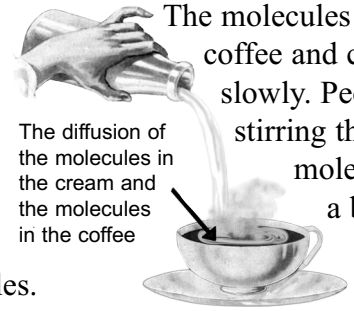
Diffusion
(the vapors from the bread mixing with the atmosphere of the house).

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Oxygen gas diffuses 1/4 as fast as hydrogen gas. (Four is the square root of sixteen.)

Later, physicists understood why this was true. At the same temperature, hydrogen and oxygen molecules have the same kinetic energy. However, the hydrogen molecule is less massive than the oxygen molecule. The kinetic energy equation states that $K.E. = 1/2mv^2$. For a smaller mass to have the same kinetic energy, its velocity must be greater. Diffusion is proportional to the velocity of the molecules. Faster moving molecules diffuse more quickly than slower moving molecules.

Of the three states of matter (gases, solids and liquids), gases diffuse most quickly. Their molecules move around more freely than the molecules of liquids or solids. The molecules of two liquids such as coffee and cream will diffuse, but slowly. People speed the process by stirring the coffee and cream. The molecules of solids diffuse at a barely discernable rate.



Life Principle



"Although we are not responsible for all of the things that happen to us, we are responsible for the way we react to them."

—Anonymous

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Integrated Physics & Chemistry

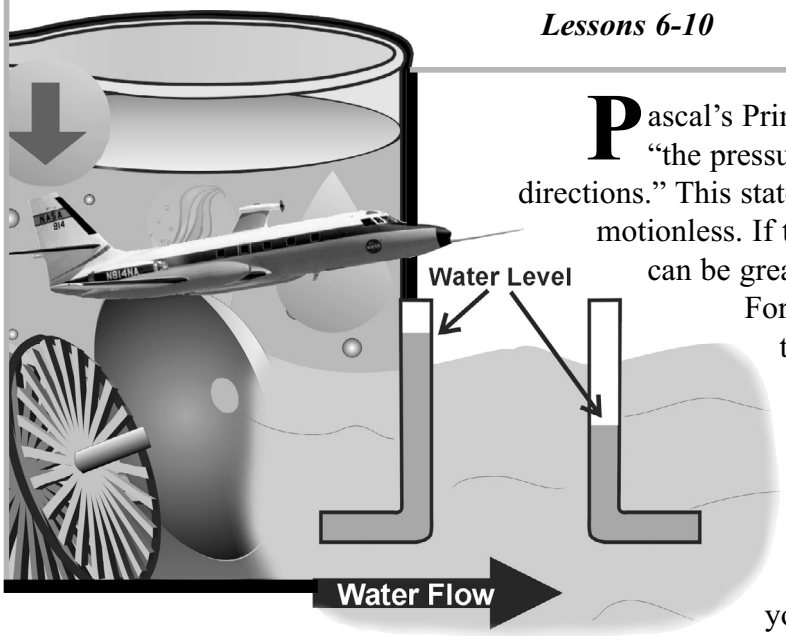
Lesson 7
Energy

Chapter 4

FLUID FLOW

Section 2

Lessons 6-10



Pascal's Principle of Fluid Pressure states that "the pressure of a fluid acts equally in all directions." This statement is true only for fluids that are motionless. If they are in motion, then the pressure can be greater in one direction than in another. For instance, a fast flowing stream can turn a waterwheel. The water produces a greater pressure in the downstream direction than in the upstream direction. The extra energy is due to motion.

Normally, a liquid at rest has a surface that is flat and level. If you were to put a straw in a water glass, the water in the straw would be the same level as the water in the glass. Except for slight capillary action, water could not rise in the straw. Suppose, however, the straw were in the shape of the letter J, with a bend at the bottom. If the straw were put in a stream, with the *J* facing upstream, water would rise higher in the straw than the level of the stream. If the water flowed fast enough, or if the straw were short enough, the water would stream up the straw and come out the top. If the J-shaped straw were turned downstream, the water level in the straw would be lower than the level of the water in the stream.

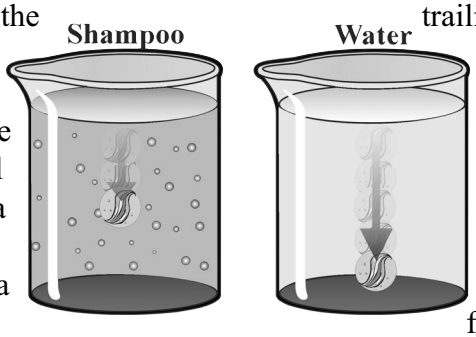
Hydrostatics is the study of fluids at rest. *Hydrodynamics* is the study of fluids in motion. The natural laws that are true for fluids at rest may not be true for fluids in motion. Even if a fluid is at rest, but an object is moving through it, this motion will change how the properties of the fluid act upon the object. Normally, still water would rise in the J-shaped straw to the same level as the surface of the water. However, if the J-shaped straw were moved rapidly through the still water, the effect would be the same as if the fluid were moving.

VOCABULARY

Friction: a force that resists the motion of two objects rubbing against one another
Viscous drag: a force that acts against motion through a fluid
Vortex: a spiral motion in a fluid
Laminar: flow in layers; laminar flow has less energy loss than turbulent flow
Terminal velocity: the maximum speed at which an object of a fixed size and weight can fall under the force of gravity

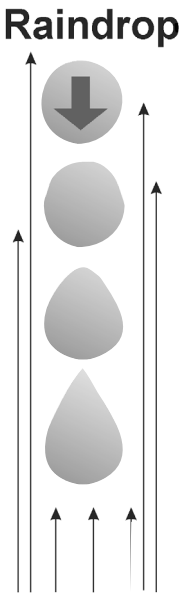
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When a solid, such as a box, is pushed across the floor, ***friction*** opposes the motion of the box. Friction acts in the opposite direction as the motion. Friction causes an object in motion to slow and stop unless a force continually pushes it along. Friction is a force that resists the motion of two bodies in contact. Friction can be external, like the tires of a car against the highway. Friction can be internal. When a guitar string is plucked, it begins vibrating and makes a sound. The sound slowly dies as the string comes to rest. One of the reasons it stops vibrating is because of internal friction in the guitar string. Fluids such as water and air also have internal friction. *Viscosity* is the internal friction of fluids. It is visible as a resistance to flow. Some fluids are more viscous than other fluids. A measure of viscosity for liquids can be found by tipping over a container of the liquid and watching how fast it pours. Compared to a stream of water, a stream of syrup pours more slowly. The syrup is more viscous than water. Another way to test the viscosity of a liquid is to drop marbles into containers of the fluids. A marble will fall slower through a beaker of shampoo than it will through a beaker of water. The shampoo has a higher viscosity.



Molecules of a liquid have *cohesion*. They resist being forced apart. Viscosity arises from this internal friction. The engines of a ship must continually turn the propellers to overcome the viscosity of ocean water. The energy the ship exerts depends on its speed and its shape. A ship that passes through still water leaves behind it a foaming wake and a series of waves and eddies, or small whirlpools. The waves and eddies contain energy that is taken from the ship as it passes through the water. Ships that sail cleanly through the water use less energy than those that cause waves and eddies. The friction a solid encounters in passing through a fluid depends on the shape of the object. Reducing the surface of the ship that contacts the water also reduces the friction between ship and water. To reduce ***viscous drag***, most ships have a pointed bow and are wider at the top, which is out of the water, than at the bottom, which meets the water.

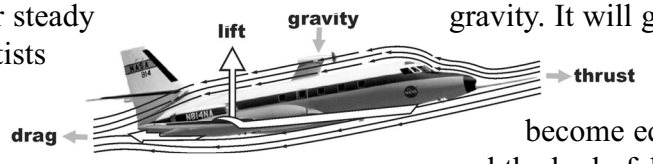
A *streamlined* shape reduces *turbulence*. Turbulence is motion in a fluid that carries away energy without doing useful work. A streamlined shape is one that offers reduced resistance to flow and turbulence. Not only must the streamlined shape reduce the area that meets the fluid, but the streamlined shape must also prevent turbulence in the body's wake. In the 1930s, aircraft engineers experimented with the shape of high-speed aircraft. Experiments showed that both the leading edge and trailing edge of the aircraft had to work together to reduce turbulence. The best-known streamlined shape is the teardrop shape of a falling water droplet. When a drop of water first begins falling, it has a spherical shape. As it falls and gains speed, friction of the air changes the sphere into a teardrop shape. It is blunt in front and gently tapers to a point in the back. A solid object in the shape of a teardrop shoves aside the fluid and lets it come back together in the rear with a minimum of turbulence. Automobiles and some airplanes have that shape, as do many aquatic animals such as penguins and whales.



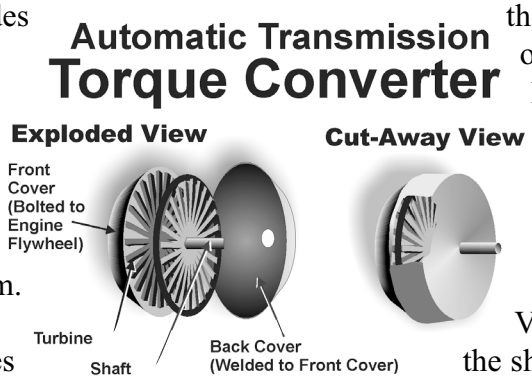
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The tips of some aircraft wings are turned up into small vertical fins. The tip of an aircraft wing normally produces a ***vortex*** in the air that is similar to an eddy in water. This vortex is a rapidly spinning funnel of air. The airplane loses energy to the air as it creates the vortex. The small vertical fins on the tips of the wings reduce the vortex. Although the fins add another surface that must push aside the air on the leading edge, it reduces the amount of turbulence behind the aircraft. Overall, the viscous drag is less. The teardrop shape is not the best for aircraft such as jets or rockets that travel faster than the speed of sound. For those vehicles, a sharper nose gives them a better streamline.

Scientists who studied turbulence coined the word *streamline*. They found that a fluid that flowed without turbulence ran in layers or steady streams. Scientists gave the name ***laminar*** flow to the smooth layers. Viscous drag is greatest when the flow is turbulent. The drag is least when the flow is laminar. A line that runs along the laminar stream is smooth. It is a streamline.



Sometimes the viscous effect of a fluid is desirable, as in a fluid clutch in an automobile. The power of a car is transferred through the transmission to the drive axle. The transmission, whether manual or automatic, allows the automobile to shift gears. A fluid clutch provides a smooth transfer of the engine power to the transmission. In the fluid clutch, two metal disks are close to one another, but they do not touch; a viscous fluid separates them. The engine drives one of the disks, which has a series of fans. The engine spins the disk, which sets the fluid in motion. The viscous effect of the fluid rotates the second disk. Power is transferred from the engine to the transmission.



The friction between a moving solid and a surrounding fluid increases with velocity. An automobile traveling at 75 miles per hour uses considerably more fuel than one going at 55 miles per hour. The extra gasoline overcomes the viscosity of the air. In the 1970s, the United States faced a fuel shortage. The federal government ordered the maximum highway speeds to be lowered to 55 miles per hour in an effort to conserve fuel.

Air resistance slows a falling body. The faster a body falls, the greater the air resistance. An object accelerates because of gravity. It will gain speed until the force of air resistance equals the force of gravity. When they become equal, the acceleration ceases and the body falls at a constant velocity. ***Terminal velocity*** is the speed at which the resisting force of friction balances the force of gravity. Terminal velocity depends upon the viscosity of the fluid and the size and weight of the body that is falling. Human beings in free fall, such as skydivers who jump from airplanes, reach terminal velocity at about 120 miles per hour. Once they jump from the airplane, skydivers will gain speed until they reach terminal velocity. After that, they fall at a constant speed of about 120 miles per hour. As the ground nears, the skydiver is interested in increasing his viscous drag and making his terminal velocity far less than 120 miles per hour. Viscous drag depends upon the shape of the object. The

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skydiver changes his shape with a parachute. An open parachute reduces the terminal velocity to less than 15 miles per hour. Terminal velocity is another way to measure viscosity. An object of fixed size and weight, such as a steel ball, is dropped in different fluids. It accelerates at first, but then it falls at a constant speed. The terminal velocity depends upon the viscosity of the fluid. The terminal velocity of a steel ball in air is about 55 times greater than its terminal velocity in water. Water is 55 times more viscous than air.

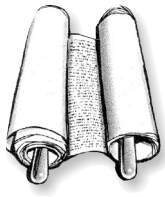
LIFE PRINCIPLE



"I have always found, when I was worrying, that the best thing to do was to put my mind upon something, work hard and forget what was troubling me."

—Thomas Edison

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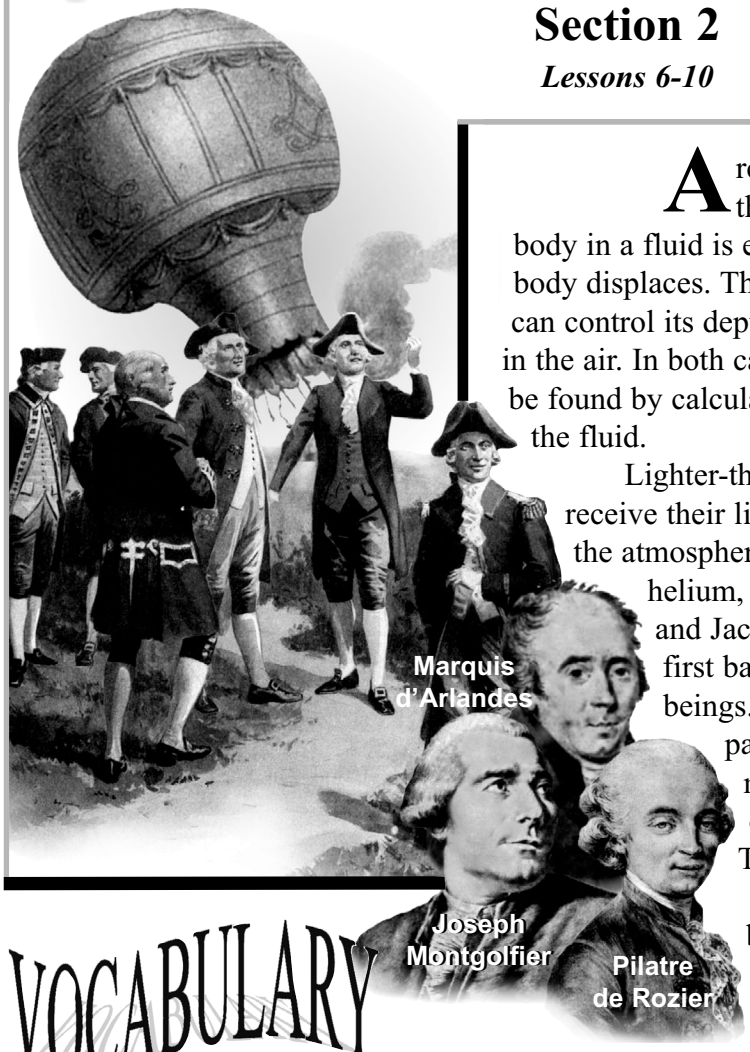


Lesson 8
Scientific Laws

Chapter 4

BERNOULLI'S PRINCIPLE

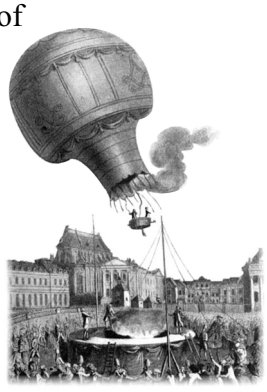
Section 2
Lessons 6-10



Archimedes' Principle of Buoyancy states that the apparent loss in weight of a body in a fluid is equal to the weight of the fluid that the body displaces. This principle explains how a submarine can control its depth in the ocean and how a balloon rises in the air. In both cases, the loss in weight of the craft can be found by calculating the weight of an equal volume of the fluid.

Lighter-than-air craft such as hot air balloons receive their lift from gases that are less dense than the atmosphere. Such gases include hydrogen, helium, and air that have been heated. Joseph and Jacques Montgolfier of France made the first balloons capable of carrying human beings. Joseph and Jacques' father operated a paper factory. The Montgolfier brothers made large paper bags and held them open over a fire to heat the air inside. The first balloons carried no humans.

In November 1783, the Montgolfiers built a balloon to be flown at a public demonstration in Paris. The balloon was 54 feet in diameter and contained 55,000 cubic feet of air. When heated, the hot air would lift about 1/2 ounce for each cubic foot. The balloon and its cargo could weigh a total of about 1,700 pounds. A young French nobleman, Pilatre de Rozier, and his friend, Marquis d'Arlandes, volunteered to test the balloon. More than 300,000 people turned out to see their flight. They rose to a height of 500 feet and came down safely five miles from their takeoff point. After their successful flight, scientists realized the reason the balloon



VOCABULARY

Constricted: made smaller or narrower
Venturi tube: a tube with a constriction in the middle that causes reduced air pressure, an automobile carburetor and an airplane air-speed indicator use venturi tubes
Wind tunnel: chamber through which wind is forced at controlled speed

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rose. It made use of Archimedes' Principle of Buoyancy, which had been known for almost two thousand years. A light gas such as hydrogen could be used instead of hot air. Scientists began to use hydrogen-filled balloons to explore the atmosphere. The French scientist, Jacques Charles, made the first flight in a hydrogen-filled balloon. Later, he established the relationship that the volume of a gas is proportional to its absolute temperature. The rise of the Montgolfier's balloon can be explained by Archimedes' Principle of Buoyancy.

Balloons are lighter-than-air crafts. Birds are heavier-than-air crafts. The weight of the fluid that birds displace is less than their weight. Birds must receive lift in some other way. More than 100 years passed before the first successful heavier-than-air craft was constructed. Two brothers, Otto and Gustave Lilienthal of Germany, built human carrying gliders that could soar when launched into the wind. Otto Lilienthal, the pilot, made almost 2,500 successful flights before a gust of wind overturned his craft. He died in the crash.



Orville and Wilbur Wright read about the Lilienthals' work and began their own experiments. The Wright brothers built the first powered heavier-than-air craft, the Wright Flyer. The airplane weighed 750 pounds including engine and pilot. The first successful flight was on December 17, 1903. Only five people witnessed the first flight. The brothers traded off as pilot, and both made flights on that day.

When an airplane is in flight, the air pressure on top of the wing is less than the air pressure on the bottom of the wing. The difference in the pressure, applied over the entire wing, gives enough lift to support the airplane. The difference in pressure is a direct result of *Bernoulli's Principle*, which states that the velocity of a fluid and its pressure are inversely related. As speed increases, the pressure decreases. This principle applies to both liquids and gases. The principle is named after Daniel Bernoulli. He came from a large and successful family in Switzerland. From the 1650s to 1800, members of the Bernoulli family made significant achievements in science. Many of the members of the family began in other professions but ended up as scientists or mathematicians. Daniel studied medicine and became a doctor. As part of his thesis to receive an advanced degree, he wrote about the action of the lungs. In studying the lungs, Daniel became interested in airflow. His most important work was in hydrodynamics, dealing with the motion of fluids.

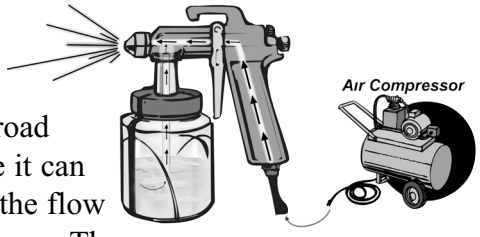


The simplest demonstration of Bernoulli's Principle is to place a small strip of paper below your lower lip and blow. The paper will rise. The fast flowing air reduces the pressure on the upper surface of the paper. On the lower surface, the pressure is unaffected. The paper rises because of the greater pressure pushing up from below. A spray gun uses the Bernoulli Principle. A tube leads down into a liquid to be sprayed. Compressed air passes across the mouth of the tube. This reduces the pressure in the tube and draws up the liquid. Once the liquid hits the stream of air, the liquid is broken into fine particles and sprayed along with the air.

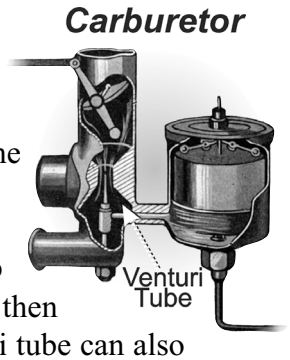
A moving fluid speeds up when its passageway becomes narrower. For instance, when a river is forced between two narrow rocky bluffs on each side, the water flow

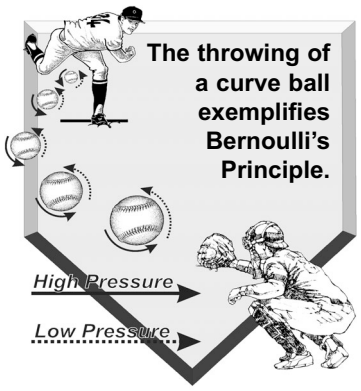
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increases. When the river reaches a broad plane where it can spread out, the flow becomes slower. The same thing happens when air flows through a pipe that becomes narrower. The air speeds up. This reduces the pressure. Giovanni Battista Venturi, an Italian physicist, experimented with a pipe that is ***constricted*** or made narrower in the middle. The device became known as a ***venturi tube***.



The venturi tube has many applications. For instance, the carburetor of an automobile mixes gasoline and air. A constricted throat in the carburetor causes a reduction in pressure. The reduction in pressure results in fuel being drawn from a small bulb of fuel where the fuel is then mixed with air. A venturi tube can also be used as a pump with no moving parts except for the fluid itself. As a liquid, such as water, passes through the tube, the liquid generates a lower pressure that can be used to pull air from a container and make a vacuum. The venturi tube makes use of the Bernoulli Principle as does a baseball pitcher who throws a curve ball. The pitcher can give a baseball a spin. On one side, the surface of the ball spins with the direction of travel of the ball. On the other side, the surface of the ball spins opposite the direction of travel. One side has a higher speed relative to the air. That side experiences a low pressure. The other side has a lower speed relative to the air. That side experiences a higher pressure. The air is pushed in the direction of lower pressure. Depending upon which axis the pitcher spins the ball about, the pitcher can throw a curve ball or sinker. From the pitcher's point of view, Bernoulli's Principle is helpful. Although the lacing on the ball has an effect on the ball's travel, a perfectly smooth ball will curve if it is given a spin.





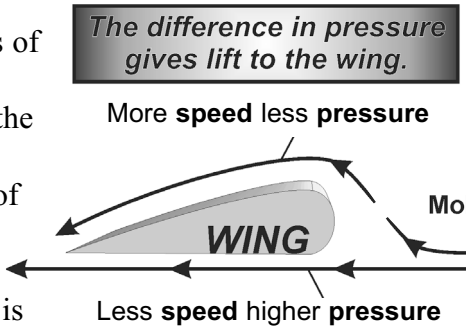
A golf ball can experience a sudden change in direction due to an unintentional spin. Such a spin can cause a *hook* or *slice* depending on the direction of the spin. From the golfer's point of view, Bernoulli's Principle is undesirable. Another example of an unwelcome side effect of Bernoulli's Principle would be that of a strong gale, which may leave a house relatively undamaged except for the roof, which is blown off. A roof has a shape similar to an airplane wing. The wind that blows across a peaked roof is capable of lifting the roof from the house.

The most dramatic use of the Bernoulli's Principle is in the shape of an airplane wing to give lift to the aircraft. The bottom surface of the wing is relatively flat and the upper surface bows up. The wing is designed for smooth laminar flow without turbulence. Imagine two streams of air molecules separated by the leading edge of the wing. One stream goes over the top of the wing. The other stream goes along the bottom edge. Both streams of molecules meet at the trailing edge of the wing at about the same time. Because the molecules going over the top of the wing had to travel a greater distance, their speed is greater than the molecules on the bottom of the wing. The faster moving air along the top of the wing

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has less pressure than the slower moving air along the lower surface. This difference in pressure gives lift to the wing.

Daniel Bernoulli was one of the first scientists to understand the idea of conservation of energy. A moving fluid has two forms of energy. One is the kinetic energy from the motion of the fluid. The other is potential energy due to the pressure of the fluid. Air under pressure is like a compressed spring. Energy is stored in pressurized air. A higher pressure has a higher potential energy. An increase in speed of the fluid gives it greater kinetic energy. To keep the total energy constant, some potential energy must be released. The pressure of the fluid drops. Bernoulli's Principle states that increased speed of a fluid results in lower pressure. This principle applies only to laminar flow. Should the flow become turbulent, the principle no longer holds. Predicting the effect of turbulent flow is much more difficult than predicting laminar flow. Even the best aircraft still produce some vortices and turbulence. ***Wind tunnel*** tests are usually necessary to predict fully what will occur around all of the surfaces of an aircraft. A scale model is made of the aircraft and placed in a fast flowing stream of air. One of the reasons the Wright brothers succeeded in making a successful aircraft is because they first tested their design in a wind tunnel.



Life Principle

"As I grow older, I pay less attention to what people say. I just watch what they do."



—Andrew Carnegie

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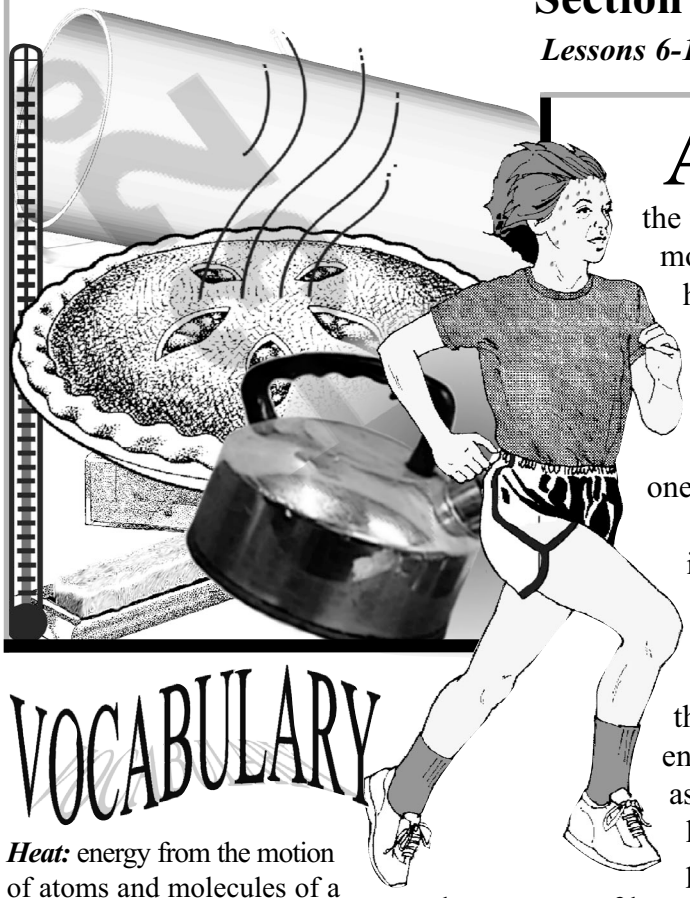
Chapter 4

Lesson 9
Energy

CHANGES OF STATE

Section 2

Lessons 6-10



A solid, liquid or gas can change state by the addition or removal of heat. ***Heat*** is the total energy of motion of the atoms and molecules that make a substance. Because heat is a form of energy, it can do work. ***Work*** is the application of a force through a distance. The ***calorie*** is the metric unit of heat energy. One calorie is the amount of heat that will raise the temperature of one gram of water by one degree Celsius.

The calorie listed in the nutritional information on the side of food packages is sometimes called a *big calorie*. Dieticians find the regular calorie used by physicists too small for diet purposes. Dieticians use the *kilocalorie*, 1,000 calories, to specify the energy content of foods. A bagel that is listed as containing 150 calories actually has 150 kilocalories or 150,000 calories. In the process of digestion, the bagel furnishes that amount of heat energy to the body.

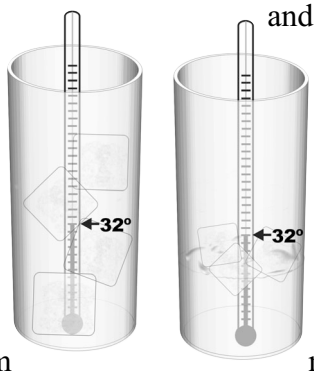
Heat capacity of a substance is the amount of heat required to raise the temperature of one gram of the substance by one degree Celsius. The units of heat capacity are calories/gram. Each substance has a different heat capacity. For instance, when a pie is removed from the oven, the crust of a pie and the filling are at the same temperature. The crust feels cool enough to eat while the filling burns like molten lava. The difference is due to heat capacity. The crust has a far lower heat capacity than the pie filling. As another example, the heat capacity of water is 1.00 cal/g, but the heat capacity of ethyl alcohol is 0.60 cal/g. Heat capacity assumes the substance does not change state, from solid to liquid or liquid to gas.

VOCABULARY

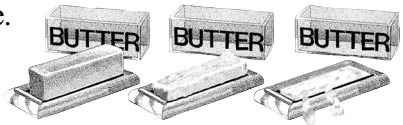
Heat: energy from the motion of atoms and molecules of a substance, equal to the total kinetic energy of the atoms and molecules of a substance
Work: the transfer of energy from one system to another
Calorie: the heat required to raise the temperature of one gram of water by one degree Celsius
Evaporate: to change a liquid into a gas at a temperature below its normal boiling temperature

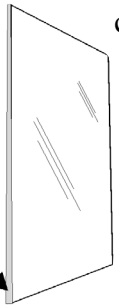
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Specific heat is sometimes used instead of heat capacity. Specific heat compares the heat capacity of a substance to the heat capacity of water. The specific heat of water is set equal to 1.00, and other substances are compared to it. The specific heat of lead as a solid is 0.031 that of water. The heat content of water is 32 times greater than the same mass of lead at the same time. If specific heat is used, it has no units. The specific heat of lead is 0.031, and the specific heat of water is 1.00. The heat capacity of a substance is usually different for each phase of the same substance. The specific heat of water is 1.00 cal/g; but the specific heat of ice is 0.49 cal/g, and the specific heat of steam is 0.50 cal/g.



The change of state or phase, from a solid to liquid is fusion. *Fusion* means *to melt*. Ice, metals and solids with a crystalline structure have definite melting temperatures. Some substances such as butter, glass and wax do not have definite melting temperatures. These are amorphous solids. They have no definite crystalline structure. Rather than changing to liquids at a set temperature, amorphous solids become softer and softer until eventually they flow freely. Some scientists classify all amorphous solids as liquids, no matter how solid they appear. They consider glass a liquid rather than a solid. Glass does flow at room temperature, but at a very slow rate. Panes of glass from windows that are hundreds of years old are thicker at the bottom than at the top. During the centuries, the glass has flowed toward the bottom under the pull of gravity.





Joseph Black was the Scottish chemist who helped James Watt understand how a steam engine works. Joseph Black experimented with ice and other solids that have definite melting temperatures. As he heated a solid, it slowly gained temperature at a predictable rate until it reached its melting point. Then the temperature ceased to rise. The temperature remained constant as the substance melted. Energy entered the solid and disappeared without a corresponding rise in temperature. Only after all of the solid melted did the temperature rise again. Joseph Black measured the temperature of a mixture of water and ice as he heated it. Heat went into the ice water mixture but the temperature did not rise. The temperature remained at 32ºF, until all of the ice melted. Then the temperature began to rise. Joseph Black proved that the heat still existed by performing the reverse experiment. He cooled water to change it back into a solid. The water lost heat energy and the temperature fell at a regular rate until the water began to freeze. Then the temperature did not fall, although heat energy continued to be drawn from the liquid as it froze. The heat was given up as the liquid changed to a solid. Then, after all of the water froze, the temperature fell again. These experiments showed that the Law of Conservation of Energy was not being violated. Joseph Black called the disappearing heat the *latent heat of fusion*. *Latent* means *hidden* and *fusion* means *to melt*. The latent heat of fusion is heat energy in a substance that is hidden from detection by the thermometer.

The latent heat of fusion is the amount of heat required to melt one gram of a substance. The substance does not gain or lose temperature. Instead, it merely

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changes from a solid to a liquid. Using the metric system, a single gram of ice at 0ºC must absorb 80 calories before it melts and becomes water at the same temperature. The latent heat of fusion is not the same for all substances. For water, latent heat is 80 calories, but the latent heat of fusion for alcohol is 26 calories. The latent heat of fusion for mercury is less than one calorie.

Water as a liquid stores heat especially well and gives up heat when converted to ice. When citrus crops are in danger of freezing, farmers sometimes spray their trees with water. The liquid water releases heat to the spring buds and helps keep them warm as the water changes to ice. Ice itself acts as an insulating layer and diminishes further damage from cold weather.

Joseph Black also discovered that a liquid absorbs a large quantity of heat as the liquid becomes a gas. The change in state from liquid to gas requires the addition of considerable heat. As in the case of fusion, the heat appears hidden because it does not reveal its presence by a rise in temperature. The *latent heat of vaporization* is the amount of heat required to change one gram of a substance into a vapor. The temperature of the substance does not change. Instead, the substance merely changes phase from a liquid to a gas.

For water, the latent heat of vaporization is large. To change one gram of liquid water at 100ºC to steam at 100ºC requires 540 calories. Compare that to 100 calories required to heat one gram of water from 0ºC to 100ºC. More than five times as much heat energy is required to change a set amount of water at the boiling point into steam at the same temperature as is required to heat the same amount of water from its freezing point to its boiling point. Water has a very high latent heat of vaporization compared to other liquids such as ethyl alcohol (202 calories) and ammonia (324 calories). When steam cools and changes to liquid water, it releases a tremendous amount of heat. Exposure to steam can result in a very serious burn because steam carries so much heat.



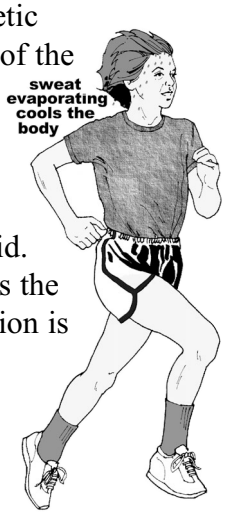
Molecules of a solid can change directly into a gas. *Sublimation* is the changing from a solid to a gas without going through the liquid phase. The best known substance that displays sublimation is solid carbon dioxide or dry ice. Dry ice is a solid at -78.5°C (-110°F). When a block is left out at room temperature, it slowly disappears as its molecules form a gas because it sublimates.

Under certain conditions, water ice will sublimate. When exposed to ultraviolet rays of the sun while in a cold climate, an irregularly shaped chunk of ice slowly becomes smoother. Jagged edges disappear and the ice itself grows smaller. Ultraviolet rays are especially energetic. An ultraviolet ray of light striking a water molecule, transfers energy to the molecule. Molecules near the surface escape from the ice. The water sublimates.

A liquid can also become a gas at a temperature below the boiling point. A puddle of water left by a passing rain shower will dry as wind blows and sunlight shines on the water. The temperature stays well below 100ºC (212ºF), the boiling point of water. ***Evaporation*** is the conversion of liquid water to water vapor at a temperature below the boiling point of the water. Molecules of a liquid are in motion, and not all molecules have the same velocity. As they bounce around and collide with one another, some molecules gain speed at the expense of

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others. Those that gain enough kinetic energy break free from the surface of the water. They enter the atmosphere as water vapor. The most energetic molecules escape and the less energetic ones are left behind. This reduces the temperature of the liquid. Evaporation is a process that lowers the temperature of the liquid. Evaporation is a cooling process.



LIFE PRINCIPLE

"ANGER is one letter short of DANGER."

—Anonymous

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Integrated Physics & Chemistry

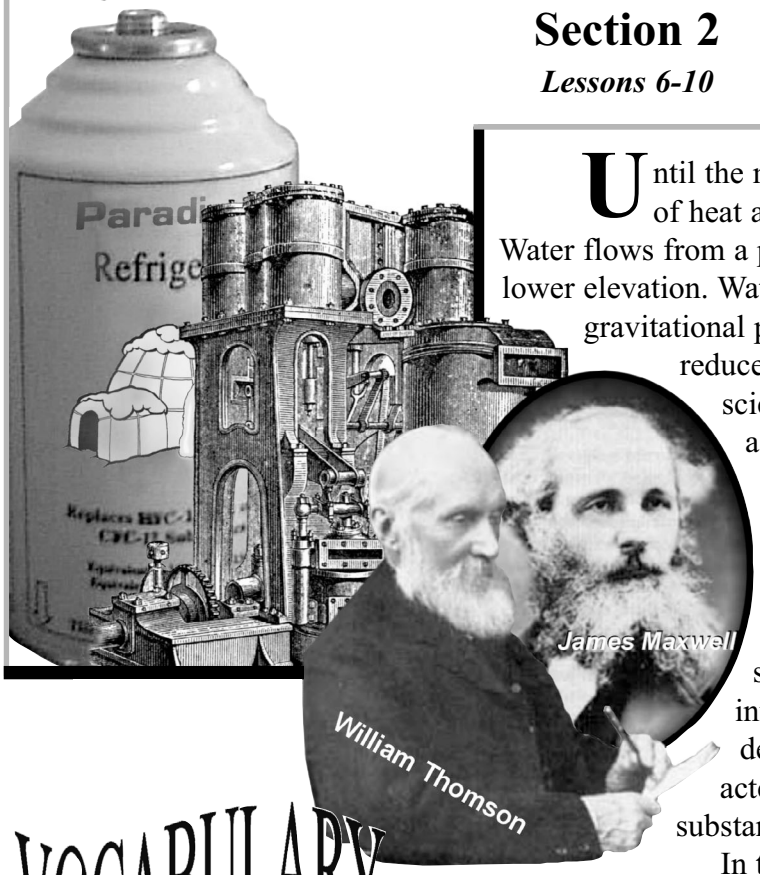
Lesson 10
Energy

Chapter 4

HEAT

Section 2

Lessons 6-10



Until the middle of the 1800s, scientists thought of heat as a substance that flowed like water. Water flows from a place of higher elevation to one of lower elevation. Water flows from a region of greater gravitational potential energy to a position of reduced potential energy. In the same way, scientists imagined that heat flowed from a region of high temperature to a region of lower temperature. When a hot steel bar is placed in water, the heat will leave the bar and go into the water. The bar becomes cooler, and the water becomes warmer. Heat seems to flow from the hot steel bar into the cooler water. Scientists developed laws that described how heat acted based upon the idea that heat was a substance that flowed.

In the 1800s, physicists such as James Clerk Maxwell and William Thomson showed that heat is actually the kinetic energy from the motion of atoms and molecules. When the hot steel bar is thrust into cool water, rapidly vibrating iron molecules at the surface of the steel collide with the water molecules. The vibrations of the iron molecules are dampened, and their energy is transferred to the water. Iron molecules deeper in the steel set those near the surface vibrating again, and in this way the heat moves out of the steel and into the water. Although heat is not a substance that flows like water, many of the principles earlier scientists discovered could still be used with suitable modification.

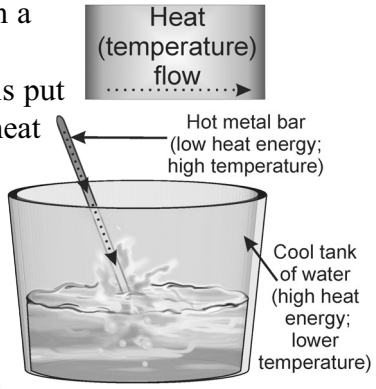
Heat is a measure of the total kinetic energy of the molecules of a substance. ***Temperature*** is a measure of the average kinetic energy of the molecules of a substance. Temperature describes how fast an average molecule is moving.

VOCABULARY

Temperature: the average kinetic energy of an atom or molecule in a substance
Efficiency: the ratio of work done compared to the work expended
Entropy: a measure of disorganization; in any closed system the entropy is always on the increase
Heat pump: a machine that moves heat from a region of cooler temperature to a region of warmer temperature

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Temperature indicates which direction heat will flow. Heat travels of its own accord from a body of high temperature to a body of low temperature. Suppose one body has a vast amount of heat, and another body has a small quantity of heat. When they are in contact with one another, to say which way the heat will travel is impossible. The direction heat moves depends on temperature, not heat content. If one object is small but hot, and the other object is large but cooler, then heat will flow from the small, hot body into the large, cool one. The total amount of heat energy in a large tank of water is greater than the heat energy in a small, hot bar of metal. If the bar is put in the water the heat flows from the bar into the water. The metal has a higher temperature than the water. Temperature, and not heat content, shows the direction heat will travel.

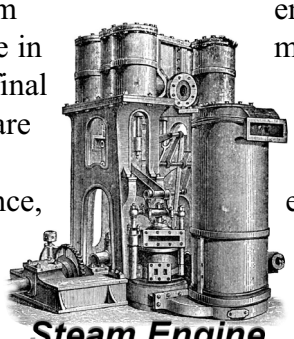


Nicolas Carnot, a French physicist, was the first person to make a detailed study of heat flow. Nicolas Carnot asked the question, "Can a steam engine utilize all of the energy in steam?" He approached the subject by the analogy of a waterfall. An *analogy* is a comparison between two things that otherwise appear to be different. The amount of energy that a waterfall can provide to a waterwheel depends on the height of the waterfall and the amount of water that goes over the fall. By analogy, the amount of work that steam can provide in a steam engine is equal to the change in temperature (how far the heat falls) and the amount of steam. Suppose in one steam engine, the steam enters at 400ºF and leaves at 300ºF. In a second steam engine, the same amount of steam enters at 600ºF and leaves at 300ºF. The change in temperature is greater in the second steam engine, and it can do more work than the first. Of course, steam engines may not be equally efficient. The engineer of the second steam engine possibly made one that has a lot of friction and loose fittings. Steam may be wasted in the second engine so that it does not perform as well as the first. The second engine may not be as efficient as the first because of its construction. However, if both are equally well built, then the second is capable of better performance. The engine with the greater temperature change will do more work. The ***efficiency*** of a steam engine or any other machine that does work is equal to the work output divided by the work input. Efficiency = (energy out)/(energy in). If only half of the energy in the steam is changed into work, then the engine's efficiency is 50 percent. If all of the energy from the steam comes out as work, then the efficiency is 100 percent.

Nicolas Carnot found that for steam engines to have 100 percent efficiency is impossible. A steam engine can never utilize all of the energy in steam. Despite the engineer's best efforts, the maximum efficiency of a steam engine is especially low. In every steam engine in use in the early 1800s, the amount of heat energy lost was greater than the useful work obtained from the machine. The maximum efficiency was less than 50 percent. Most steam engines had an actual efficiency of 12 percent or less. Nicolas Carnot investigated further. He found that measuring efficiency for any machine is possible. Carnot developed an equation that showed the greatest efficiency that could be expected from a steam engine. His equation is best stated in terms of *absolute temperature*. Remember that 0ºC is 273ºK. Liquid water changes to steam at 373ºK

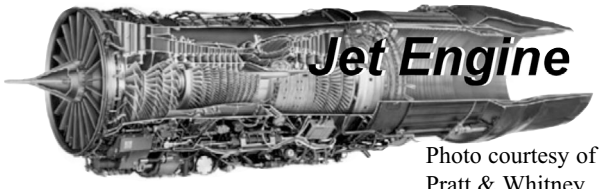
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(100ºC). Carnot showed that the greatest possible efficiency of a steam engine is equal to the change in temperature divided by the final temperature, provided both are stated in the absolute temperature scale. For instance, steam enters an engine at 600ºK and leaves the chamber at 400ºK.



Steam Engine

Maximum efficiency = (change in temperature)/(starting temperature) = (600ºK – 400ºK) / (600ºK) = 200ºK / 600ºK = 1/3 = 33.3 percent. One way to increase the efficiency is by increasing the temperature difference. Using hotter steam and letting it cool down more will increase the efficiency. If the steam changes from 1,200ºK to 400ºK, then the efficiency is 66.6 percent. Efficiency = (change in temperature)/(starting temperature) = (1,200ºK – 400ºK) / (1,200ºK) = 800ºK / (1,200ºK) = 2/3 = 66.6 percent. Most steam engines in Nicolas Carnot's day worked at temperatures in the 600ºK range, about 620ºF. If the steam in the boiler got any hotter, the boiler might explode. Using the temperatures available, no matter how skillful an engineer designed a steam engine, a perfect machine could provide useful work from only 33 percent of the total energy that is given up by the heat. Most worked at far less than 33 percent efficiency because of friction and faulty fittings in the engine. Engines that use heat as the force of movement are called *heat engines*. Steam engines are heat engines as are *internal combustion engines* used in automobiles, diesel engines in trucks and jet engines in airplanes. The Efficiency Law developed by Nicolas Carnot applies equally well to engines that use heat as the force of movement.



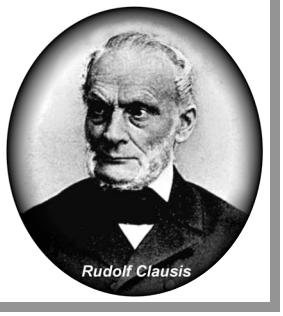
Jet Engine

Photo courtesy of Pratt & Whitney

For a steam engine to be 100 percent efficient, steam would have to be supplied at an infinitely high temperature. The engine would have to extract all of the heat and release the steam as ice at absolute zero, 0ºK. Of course, this is not possible.

If an engine makes use of only 33 percent of the heat energy, the 67 percent remaining is not lost; that would violate the Law of Conservation of Energy. Although the heat is not lost, it becomes unavailable and can do no useful work. Energy cannot be created or destroyed, but it can change form. Scientists have found that whenever energy changes form or is transferred from one place to another, some heat is generated. For instance, when electricity flows through a wire, the wire becomes warm. When electrical energy turns a motor, the shaft becomes warm because of friction. Useful work cannot be recovered from this heat because the temperature difference is too slight. An electric wire may be only a degree or two warmer than the rest of the room. Even if a heat engine could be designed to operate on such a small temperature difference, the efficiency would be very low. For instance, if the wire were three degrees above room temperature, a perfectly efficient heat engine could extract only one percent of the available energy.

Nicolas Carnot died at the age of 36. Shortly after his death, a German physicist, Rudolf Clausis, coined the word ***entropy*** to serve as a measure of unavailable energy. He and other physicists showed that entropy is always on the increase. Heat energy is due to the random motion of atoms



Rudolf Clausis

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and molecules. These motions are disorganized and unpredictable. Entropy is a measure of the amount of disorganization in the universe. Entropy, or disorganization, is always on the increase in the universe as a whole. In local areas, however, organization can be increased. For example, when a freezer converts water to ice, the organization increases. Ice, like most solids, has a regular crystalline structure. How does a refrigerator reverse entropy? Reversing entropy is the same as reversing the direction that heat normally flows. Just as work must be done to pump water uphill, so work must be done to move heat energy in a direction contrary to its normal flow. The refrigerator and other devices such as air conditioners, must expend energy to pump heat against its natural flow. Work must be done to decrease entropy in a local area.



A heat pump moves the hot air from within the cooler and releases it throught the vent into the atmosphere.

A ***heat pump*** is any device, such as a refrigerator or air conditioner, that reverses the normal flow of heat. Heat normally flows from hot to cold. A heat pump moves heat from cold to hot. A heat pump can remove heat from water in a freezer and change the water to ice. The heat does not disappear. It is taken from the inside of the freezer and released outside the freezer. Most heat pumps use a chemical that readily changes state depending upon whether or not the chemical is under pressure. Two common gases used are freon and ammonia. Ammonia, like freon, is a liquid when under pressure. Releasing the pressure changes ammonia from a liquid to a gas. All gases become cooler when allowed to expand. Ammonia is no exception. Changing ammonia from a liquid to an expanding gas causes ammonia to become cooler. The heat pump transports liquid ammonia under pressure to the area to be cooled. Releasing the pressure and changing the ammonia to a gas decreases its temperature. The ammonia becomes cooler than the freezer compartment. Heat flows from the freezer compartment into the ammonia. This cools the freezer compartment, but warms the ammonia. The ammonia gas is then transported outside the freezer where it is compressed. Compressing ammonia and changing the ammonia to a liquid increases its temperature so that it becomes greater than the outside surroundings. Heat energy leaves the ammonia. The heat flows into the surroundings through cooling vanes on the back of the refrigerator or through a cooling tower outside the building. The liquid ammonia is transported to the freezer compartment and the cycle repeats. Heat is moved from one place to another, but energy is expended in compressing the ammonia and transporting it.



Pressurized gas (freon) used in heat pumps

LIFE PRINCIPLE

"Our patience will achieve more than our force."



—Edmund Burke

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Integrated Physics & Chemistry

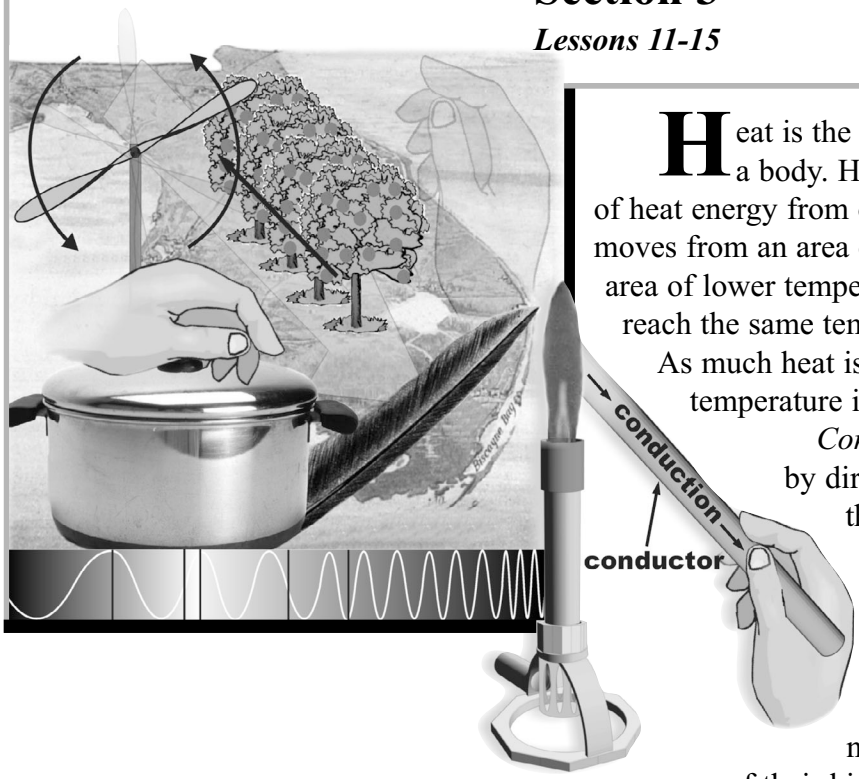
Lesson 11
Energy

Chapter 4

HEAT FLOW

Section 3

Lessons 11-15



Heat is the kinetic energy of molecules of a body. Heat transfer is the movement of heat energy from one place to another. Heat moves from an area of higher temperature to an area of lower temperature. When the two areas reach the same temperature, heat flow equalizes. As much heat is gained as is lost; so the temperature is constant.

Conduction is the transfer of heat by direct contact. The object with the greater temperature has molecules with more kinetic energy than the molecules of the cooler object. Molecules of the hotter body move more vigorously. They strike neighboring molecules, and some of their kinetic energy is transferred to the molecules of the cooler body.

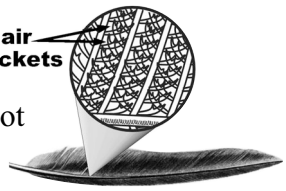
Solids, especially metals, are better ***conductors*** than liquids or gases. Conduction takes place more readily in substances whose atoms and molecules are close together. The molecules of a metal are in an interlocking crystalline structure. A disturbance at one end is quickly passed along throughout the crystal. As one end of a long metal rod is heated, the heat eventually makes itself felt at the other end of the rod. The molecules that gain kinetic energy jostle other molecules nearby and give some energy to them. Metals are better conductors than nonmetals. A person who sits in an indoor chair with a metal seat feels cold because the metal is a good conductor of heat. Heat is removed from the person's body, and the sensation is that the desk seat is cold. A chair with a wooden seat does not feel as cool because the heat does not leave the person's body as quickly. Wood does not conduct heat as readily as metal. Iron conducts heat about 320 times better than wood.

VOCABULARY

Conductor: substance that is effective at transferring heat by conduction
Insulator: substance that prevents the passage of heat by conduction
Convection: transfer of heat by currents, convection occurs only in fluids
Radiation: the transfer of heat by electromagnetic radiation

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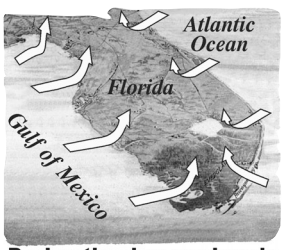
A heat ***insulator*** is a material that is a poor conductor of heat. Heat does not flow into or out of an insulator as readily because the motion of one molecule is not passed along as readily to nearby molecules. Because the molecules of a gas are far apart, gases do not conduct heat well. Air is a poor conductor. Feathers, fur and wool are good insulators. The insulation is caused by the tiny air pockets trapped by the feathers, fur and wool. The body heat of the animal does not cross the air pockets and is not conducted away.



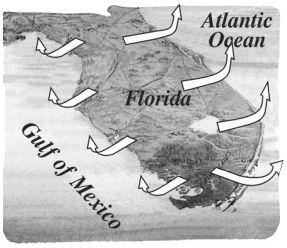
Snow is a poor conductor of heat. This is primarily because snowflakes trap air. A snow crystal has an open structure, and as snowflakes accumulate, they leave air spaces between them. Because snow conducts heat poorly, some animals take shelter under blankets of snow. Sometimes when a blizzard hits, sheep are trapped in snowdrifts. If the rancher is successful in rescuing the sheep when the storm clears, the animals may survive despite the harsh conditions. The snow does not provide heat itself, but it does prevent the escape of body heat.

Convection is the transfer of heat by currents. Convection can take place in fluids, but not in solids. Most liquids and gases decrease in density when they are heated. The warm liquid or gas rises to be replaced by cooler liquid or gas. This circulation is an example of convection.

In coastal areas, sea breezes are generally very predictable. During the day, sunlight strikes both land and sea. The heat capacities of land and water are not equal. Sunlight causes a greater increase in temperature over land than over water. The land becomes warmer and hot air rises. Cooler air from the ocean flows in to replace the rising hot air. This causes a breeze from sea to land. At night, the situation reverses. Land cools more quickly than the sea. Air over the sea is warmer and rises. A breeze blows from the land to the sea to replace the rising air over the ocean.

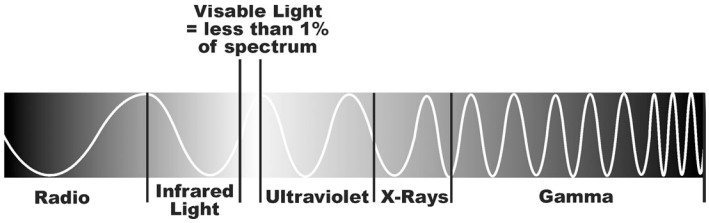


During the day, cooler air from the ocean flows in to replace rising hot air.



At night, a breeze blows from land to the sea to replace rising air over the ocean.

Water changes temperature primarily by convection. When a pan of water is heated on a stove, the water at the bottom gets hot first and rises. Convection currents distribute heat throughout the water. The temperature of the water is uniform throughout the container. Suppose that instead of being heated from below, a pan of water is positioned so the heating coil is above the water. With this arrangement, convection currents are slight because the hot water is already on top of the pan. Heat reaches the bottom of the pan only by conduction. Water is a poor conductor, so the water at the bottom of the pan remains cool. Conduction and convection require a substance to be present to act as a medium through which the heat energy is transferred. The sun warms the earth, but between the sun and the earth is a vacuum. Energy is transferred through a vacuum by electromagnetic waves. Infrared light, visible light and ultraviolet light are examples of electromagnetic waves. Light is a type of electromagnetic radiation.

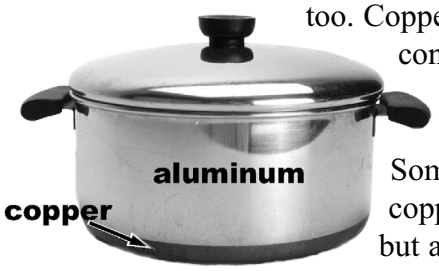


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Radiation is heat transfer by electromagnetic waves. Radiation is the only way heat can be transferred across a vacuum. The sun is the primary source of energy for the earth. Heat energy is transferred across the vacuum of space by radiation.

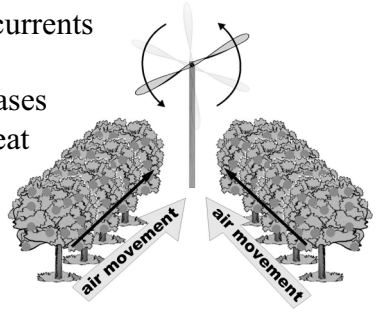
How readily a body emits radiation depends on its temperature, whether the body has a rough surface or a smooth one, and its color. Dark, rough surfaces are good radiators of heat. Radiator fins placed on sockets holding microprocessors are black to help cool the tiny electronic chips. The cooling fins of an engine are painted black to radiate heat more quickly. A surface that is a good radiator is also a good absorber of heat. A building with a black roof becomes far hotter during the day than a building with a silver roof. Black absorbs heat better than silver. However, at night, the black roof radiates heat better than a silver roof. Painting the roof of a building black in winter does not result in the building being warmer. Although the roof gains heat in the day, it loses heat just as readily at night. In winter, the nights are longer than the days; so heat loss is greater at night than heat gain during the day.

A pot that is black on bottom will absorb heat more easily than a pot that is silvery. The sides of the pot should be silver or shiny because this will reduce heat loss by radiation. The type of substance is important, too. Copper is a better conductor of heat than aluminum. Some pots have copper bottoms but aluminum sides. These two metals make an efficient use of heat energy. The copper conducts heat to the contents of the pan, and the aluminum slows the heat loss along the sides.



Conduction, convection and radiation do not take place at the same rate. A body may gain more heat by one method than it emits by the others. For instance, a greenhouse has a glass roof that admits sunlight. The radiant energy strikes the plants and soil inside the building where the radiant energy changes into heat energy. Warm convection currents rise, but the glass blocks their escape. The glass is also a poor conductor. Radiant energy enters the greenhouse, but once it is converted to heat, it cannot escape by conduction or convection. Overall, the greenhouse becomes warmer. The opposite effect explains why frost forms on blades of grass. A body that loses more heat energy than it gains becomes cooler. At night, bodies open to the black sky radiate energy. Poor conductors, such as blades of grass, radiate energy faster than conduction and convection can replace the energy. Blades of grass can become cooler than the air itself. On a chilly morning, frost will form first on the cooler blades of grass. Because of radiation, frost may form on blades of grass although the air temperature itself stays above freezing.

Farmers who grow citrus crops in Florida, Texas and California sometimes are faced with cool, still nights. Even if the weather does not drop below freezing, the citrus trees can radiate away so much heat that the buds will be damaged. One way farmers prevent damage is to use huge motors with propellers to keep the air flowing through the citrus groves. The air currents passing over the vegetation increases the amount of heat the vegetation absorbs and prevents it from freezing.



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James Dewar realized the role of radiation in transferring heat when he designed the Dewar flask for keeping liquids cold. The Dewar flask is also known as a vacuum bottle and is marketed under the brand name of Thermos bottle. It is a double-walled glass container with a vacuum between the walls. Because of the vacuum, heat cannot enter the liquid in the bottle by conduction or convection. However, heat can enter by radiation. James Dewar overcame this problem by putting a silver coating on the walls of the glass container. The silver reflects radiant heat.

LIFE PRINCIPLE



"Let us devote our life to worthwhile actions and feelings, to great thoughts, real affections, and enduring undertakings."

—Andre Maurois

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Integrated Physics & Chemistry



Lesson 12
Motion

Chapter 4

WAVES IN FLUIDS

Section 3

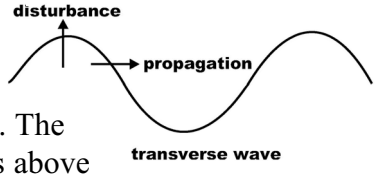
Lessons 11-15



Waves can be produced in solids, liquids and gases. The waves with which we are most familiar are water waves. Observe a pebble dropped into the middle of a quiet pond of water. Waves form and travel outward in ever widening circles. If a piece of cork is floating in the water, the cork will rise and fall as the wave passes. At first, the cork is resting in still water. As the wave approaches, the cork rises a certain distance above the water's usual level, then the cork falls about the same distance below normal water level. If no additional waves are made, the disturbance on the surface of the water dies. The cork then floats on still water.



A line that runs in the direction the wave travels and lies along the plane of the undisturbed water is the ***axis*** of the wave. The axis shows the line along which the wave travels. The direction a wave moves is its direction of ***propagation***. As a wave goes forward across a pond, the water rises and falls at right angles to the axis. The wave moves in a horizontal direction across the pond. Yet, the disturbance is up and down. A wave like the *water wave*, with the disturbance at right angles to the propagation, is a *transverse wave*. *Transverse* is from a Latin word meaning *to turn across*. The part of the wave where the cork rises above the axis is the ***crest*** of the wave. The part of the wave where the cork sinks below the axis is the ***trough***. Between the crest and trough are points where the water is at the same level as still water. These points at the surface of undisturbed water are the ***nodes***. They are found along the axis. Usually, the top of a crest will be as high above the undisturbed water as the bottom of



VOCABULARY

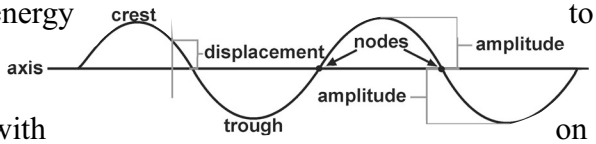
Axis: line in the direction of travel along the undisturbed surface of a wave
Propagation: the motion of waves through a medium
Crest: that part of a transverse wave above the axis
Trough: that part of a transverse wave below the axis
Nodes: points that separate the crest and trough of a wave; nodes are at the same level as the undisturbed surface
Displacement: the straight-line distance from a point on the axis to a point on the wave
Period: the time interval between two successive occurrences of the same event; for waves, the period is time per wave

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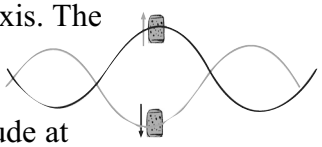


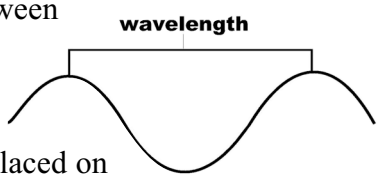
the trough is below the undisturbed water.

The ***displacement*** is the vertical distance from the axis to a point on the wave. At a node the displacement is zero. The displacement is greatest for a point at the top of the crest or at the bottom of the trough. The *amplitude* of a wave is the maximum displacement from the position of rest. The amplitude is the vertical distance from the undisturbed surface of the water to the highest point of the crest. This distance is also the same as the vertical distance from the undisturbed surface of the water to the lowest point of the trough. The amplitude is a measure of the energy carried by a single wave. A single wave with large amplitude carries more energy than a single wave with small amplitude.



A cork on the water bobbles up and down as the wave passes. Once the wave passes, the cork is still in about the same place it was before the wave came along. The molecules of the water move much as the cork does. If an individual molecule could be seen, it would trace out a small loop path, moving forward slightly and up, then back down. After the wave passed, the molecule would be more or less in its original position. Although the disturbance of the wave moves across the pond, the molecules of the water do not move far from their original positions. As a wave passes, the cork rests on the undisturbed surface of the water. The cork is on a node on the axis. The next wave causes the cork to rise to its greatest amplitude at the top of the crest of the wave. Then the cork falls back to the middle position, a node on the axis, which marks the end of the crest portion of the wave. The cork continues to fall to the lowest point in the trough. The distance the cork falls from the axis is the amplitude. Then as the wave continues to move beyond the cork, it rises again to the undisturbed level of the water. This marks the end of the trough portion of the wave. From one node to the next node, where the wave is above the axis, is the crest. From one node to the next node, where the wave is below the axis, is the trough. The crest portion of the wave is one half of the wave, and the trough portion of the wave is the other half. A crest and trough are equal in length. Together they make a complete wave. Follow the cork floating on the water as a complete wave passes. The cork goes from node on the axis to the crest, back down through a node on the axis and continues down to the trough. Then the cork rises back to node on the axis at the same height as it started. A complete wave is measured as the horizontal distance from one point on a wave to the same point on the next wave. The *wavelength* is the distance between any successive identical points of a wave. Suppose a line of corks is placed on the pond along the axis and that instead of a single wave, a series of identical waves follow along behind one another. At any one moment, the corks will be in various stages of their rise and fall. When the first cork is on a crest, the next one is in a trough, and a third one is on a crest. The distance from the top of one crest to the top of the next one is the wavelength. The distance from the first cork to the third one is a full wavelength. The wavelength can be measured from a variety of starting points. The distance from the node where the wave begins ascending to the next node where the wave begins ascending is one





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wavelength, as is the distance from the bottom of one trough to the bottom of the next trough. A wavelength is the distance along the axis between two points in the same relative position on the wave.

Two points that are in the same relative position in a series of waves are in phase. A cork on the crest of one wave is in phase with a cork on the crest of the next wave. Their positions differ by one full wavelength. Should they differ by two full wavelengths or three full wavelengths, they would still be in phase because they would be in the same relative position. Points on waves are in phase if their location differs by a whole number of wavelengths. As the crest passes the first cork and it begins to fall, the crest of the next wave will pass the second one and it will start to fall, too. The corks will remain in phase as the waves pass. As one goes up, so will the others. As one falls, so will the others.

Two points that occupy different positions on a wave are out of phase. A cork on the crest of one wave is out of phase with a cork in the trough of the same wave. Their positions do not differ by a full wavelength.



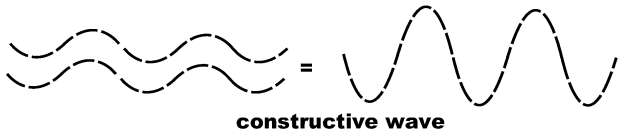
out of phase waves

The horizontal distance along the axis from the first cork at the top of the crest to the second cork at the bottom of the trough is one half of a wavelength. As the wave passes, the first cork at the crest will fall. The second cork in the trough will rise. Both will be on a node at the same time, but one will be falling and the other will be rising. Not only must the two corks be in the same position to be in phase, they must be moving in the same vertical direction.

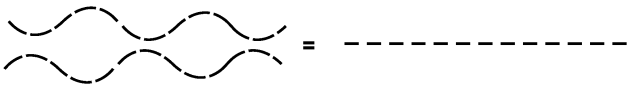
Any time the distance between two points on a series of waves is a whole number of wavelengths, the points are in phase. Any time the distance between two points on a series of waves is a fractional number of wavelengths, the points are out of phase.

Suppose that two pebbles are tossed into the pond, and each one sets up a series of identical waves expanding outward in concentric circles. When the waves meet, they will interfere with one another. When two waves that are alike or nearly alike meet, they can interact with one another. This interaction is *interference*. If the crest of one wave meets the crest of the other wave, the result is a larger crest than normal. This is *constructive interference.* The greatest constructive interference occurs when the waves are exactly in phase. Crest meets crest, and trough meets trough. In that case, the resulting wave has amplitude twice as great as either one of the identical waves. Should the two identical waves meet but are out of phase, then *destructive interference* occurs. Suppose the crest of one meets the trough of the other. They interfere with one another and the amplitude of both is reduced. The greatest destructive interference occurs when the two waves are out of phase by one half of a wavelength. The top of the crest of one meets the bottom of the trough of the other. The water becomes still.

The ***period*** of a wave is the length of time required for any point to go through one



constructive wave



destructive wave

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full cycle, first up, then back down and then to its original position again. The period is given in time per wave: second/wave or minutes/wave. For instance, a person stands by the beach counting waves and keeps track of the time. In one minute, 11 waves crash against the shore. The period = time/wave = 1 min / 11 waves = 0.09 min/wave or about 5.45 seconds per wave. Each ocean wave travels one wavelength in 5.45 seconds.

LIFE PRINCIPLE

"Laziness travels so slowly that poverty soon overtakes him."



—Benjamin Franklin

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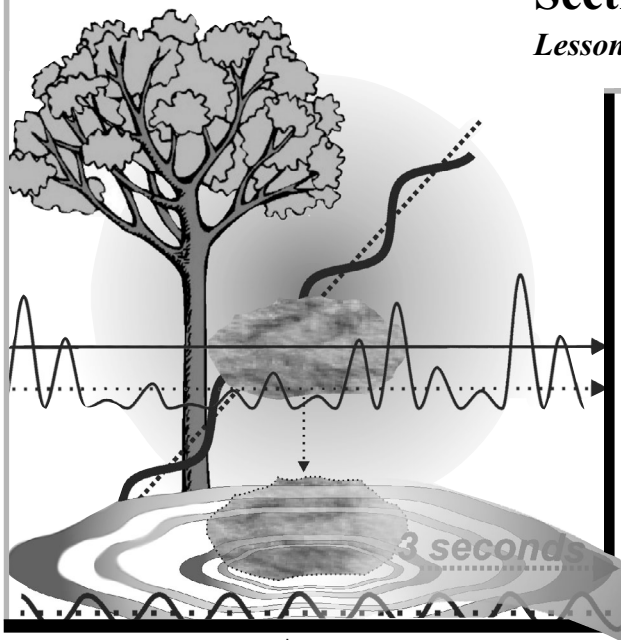


Lesson 13
Motion

Chapter 4

TRANSVERSE AND LONGITUDINAL WAVES

Section 3
Lessons 11-15



Another common way to understand waves is to tie a rope to one end of a post, and then hold the other end of the rope, and shake it to create waves along the rope. Raising and lowering the rope quickly at a constant rhythm will send an identical series of waves along the rope. The waves travel horizontally along the length of the rope. The rope raises up and down. Or, the rope can be given brisk swings left and right. This time the rope is disturbed to the right and left. Either method forms ***transverse*** waves. The disturbance goes crossways while the wave travels lengthways. The rope illustrates the fact that a wave does not carry the ***medium*** with it. Although the wave travels along the rope, the rope itself returns to its original position after the wave has passed. Although the medium is momentarily disturbed, the particles of the medium are left near the original positions after the wave passes. The rope acts merely as a medium through which the wave energy passes. Sound waves, water waves and waves along the rope all transfer energy from one point to another. Wave motion is one way of transferring energy from one point to another. Radiant energy is a transverse wave of electric and magnetic fields that transfers energy from the sun to the earth. The fact that water waves contain energy is illustrated by the fact that beach erosion is a problem along some seacoasts.

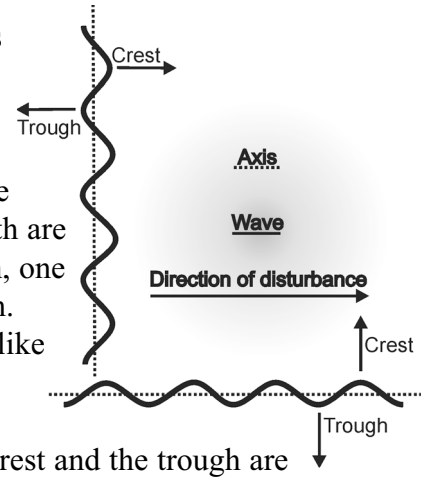
Suppose the rope is stretched tight and straight before the person shakes it. The rope represents the axis of the wave. Once the rope is shaken, either up, down, left or right, the disturbance in one direction is the crest, while the disturbance in the other direction is the trough. Usually, the part of the wave that is above the rope is called the crest, while the part of

VOCABULARY

Transverse: running crossways, transverse waves have the disturbance at right angles to the direction of wave motion
Medium: substance through which waves are carried
Frequency: the number of complete cycles in a specific time interval, cycles/sec
Cycle: a complete repetition
Reciprocal: inverse; 1.00 divided by a number; the reciprocal of 10 is $1/10^{th}$
Longitudinal: running lengthwise, longitudinal waves have the disturbance in the same direction as the motion of the wave

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the wave that is below is the trough.



A crest and a trough are alike in that both are the same length, one half wavelength. They are also alike in that the amplitudes are identical. The crest and the trough are identical in size. Physicists agree to call the upper part the crest and the lower part the trough. This is a naming convention or custom. If the rope is shaken left and right, then the convention is to label the part on the right the crest and the part on the left the trough.

The displacement is the distance from the position of rest to a point on the wave. At a node, the displacement is zero. The maximum displacement, or amplitude, is the distance from the axis to the crest or from the axis to the trough. A strong shake of the rope produces large crests and troughs. The wave has a large amplitude. A weak shake produces small crests and troughs. The wave has a small amplitude. The distance along the wave from crest to crest is the wavelength. The distance from trough to trough or from any point on the wave to the next point in the same relative position is also a wavelength.

VOCABULARY

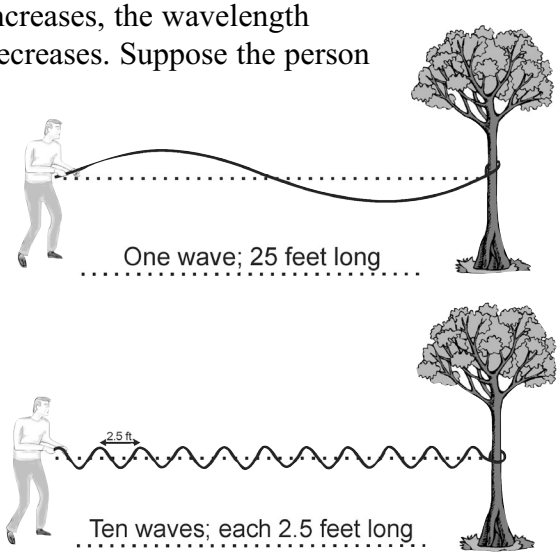
Compression: the area of a longitudinal wave with the particles of the medium closer together

Rarefaction: the region of a longitudinal wave with the particles of the medium farther apart

Tines: long, slender portion of a fork

Frequency is the number of waves made each second. A complete wave is a ***cycle***. Frequency is given in waves per second or cycles per second. In an example from a previous lesson, a person counted 11 ocean waves crashing against the shore in one minute. The ocean waves have a frequency of 0.183 cycles/sec: frequency = cycles/time = waves/time = 11 waves / 60 seconds = 0.183 waves/sec = 0.183 cycles/sec.

Frequency and period are reciprocals of one another. The word ***reciprocal*** means *inverse*; 3 and 1/3 are reciprocals. A wave with a frequency of 2.00 waves/second has a period of 1/2 second per wave. As the period decreases, the frequency increases. A shorter period means more waves can be made each second. Suppose the person holding the rope goes from making 2 waves per second to 10 waves per second. The frequency has increased from 2.00 waves/sec to 10.0 waves per second. The period has decreased from 0.50 sec/wave to 0.10 sec/wave. The fraction 0.10 (1/10) is smaller than the fraction 0.50 (1/2). As frequency increases, the period decreases. Frequency and wavelength are inversely related. If ten times as many waves are made in a second, then each wave must be only $1/10^{th}$ as long. As the frequency increases, the wavelength decreases. Suppose the person

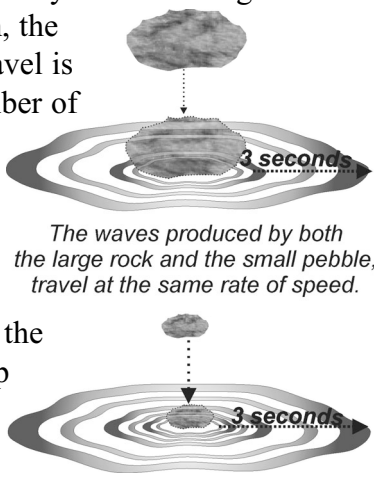


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shaking the rope makes 1.00 waves a second and each one is 25.0 feet long. If he shakes the rope more quickly to make 10 waves each second, then the new waves will be 2.5 feet long.

The velocity of a wave depends primarily on the nature of the medium. All transverse water waves on the surface of the water travel at the same speed, regardless of their amplitude. Speed of a wave is independent of amplitude. If a person heaves a very heavy stone at great speed into a pond, the waves will be larger than if a small pebble is lightly tossed into the pond. However, both big waves and little waves will travel at the same speed. The speed depends on the medium, not on the amplitude. The speed of waves can be calculated in the same way as the speed of any other moving object is calculated, by dividing distance by time: speed = distance/time. If you time a water wave as it travels the length of a pier that runs 183 feet into the ocean, the wave takes 25 seconds to travel that length. Then the speed = distance/time = 183 ft / 25 sec = 7.32 ft/sec. In the rope example, if the rope is 40 feet long, and a wave travels its length in 5 seconds, then the speed of the wave is distance/time = 40 ft / 5 sec = 8 ft/sec.

Another way to calculate the speed of a wave is with frequency and wavelength. In a particular medium, the speed that waves travel is constant. If the number of waves made per second increases, then each wave has to be shorter by a corresponding amount. Otherwise, the waves would pile up against one another. The speed of a wave is equal to the product of frequency and wavelength: speed = frequency * wavelength. The frequency gives the number of waves made in a set amount of time, and the wavelength gives the distance along the waves. The two numbers multiplied together give the total distance the waves travel in that amount of time. For instance, if 10 complete waves are made each second, and each wave is 25.0 centimeters long, then the speed = frequency * wavelength = 10.0 wave/sec * 25.0 cm/wave = 250.0 cm/sec. The expression speed = frequency * wavelength is the *wave equation*. It applies equally well to any wave motion — water waves, waves in ropes, sound waves in air or liquid or solids, light waves and any other waves. To use the wave equation to calculate the velocity of the waves in the rope, the frequency and wavelength must be known. In the rope example, 4 waves were made each second, and each wave was 2 feet long. The velocity of the waves in the rope is: speed = frequency * wavelength = 4 waves/sec * 2 feet/wave = 8 ft/sec. As another example, sound waves in air at a frequency of 256 waves per second have a wavelength of about 4.4 feet per wave. Speed = frequency * wavelength = 256 waves/sec * 4.4 feet/wave = 1,126.4 ft/sec. Rounded off, that is about 1,130 ft/sec. The two equations, speed = distance/time and speed = frequency * wavelength will arrive at the same answer. In the ocean wave example, the waves are made at the frequency of 0.183 waves per second. Each wave is 40 feet long. Speed = frequency * wavelength = 0.183 waves/sec * 40 feet/wave = 7.32 ft/sec. This is the same speed that was found using the equation, speed = distance/time.



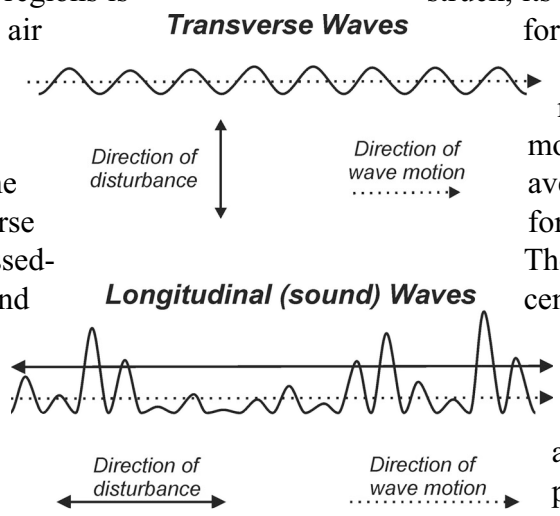
The waves produced by both the large rock and the small pebble, travel at the same rate of speed.

Not all waves are transverse. Sound waves are ***longitudinal***. The disturbance in the air is in the same direction that the sound moves. *Longitudinal* means *along the same*

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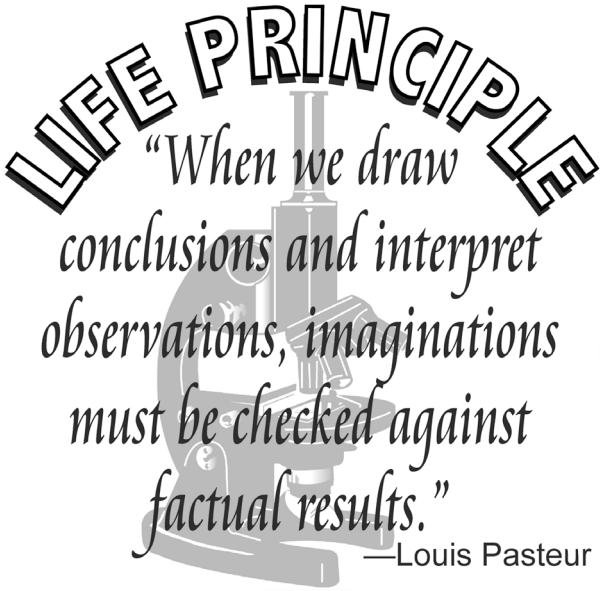
line. As a sound wave passes through air, the molecules of the air move back and forth. In a transverse wave, the disturbance is perpendicular to the direction of motion. In a longitudinal wave, the disturbance is along the same line as the direction of motion.

A longitudinal sound wave is made of two regions of air that differ in pressure. In the first part, the molecules of the air are pressed together. The air pressure is higher than normal. In the next part of the wave, the molecules of the air are pulled further apart. The air pressure is lower than normal. Between the two regions is a node where the air pressure is normal. Just as a crest and trough together make one complete transverse wave, so the pressed-together region and the pulled-apart region make one complete longitudinal wave.



The pressed together part of the sound wave, corresponding to the crest of a transverse wave, is the ***compression***. The air has a higher pressure in the compression. The region where the molecules are more widely separated, corresponding to the trough, is the ***rarefaction***. *Rare* means *scarce* or *not common*. In the rarefaction part of the sound wave, the molecules are not as common as in the compression. The air pressure is less in the rarefaction.

A vibrating object makes sound waves. For instance, when a tuning fork is struck, its ***tines*** vibrate rapidly back and forth. The vibrating fork causes regions of compression and rarefaction in the air. The air molecules are disturbed from their average position, first being shoved forward and then being drawn back. The distance they move from their central position is the displacement. The maximum distance they move is the amplitude. After the sound wave passes, the air molecules are more or less in the same position they were before the sound came through.



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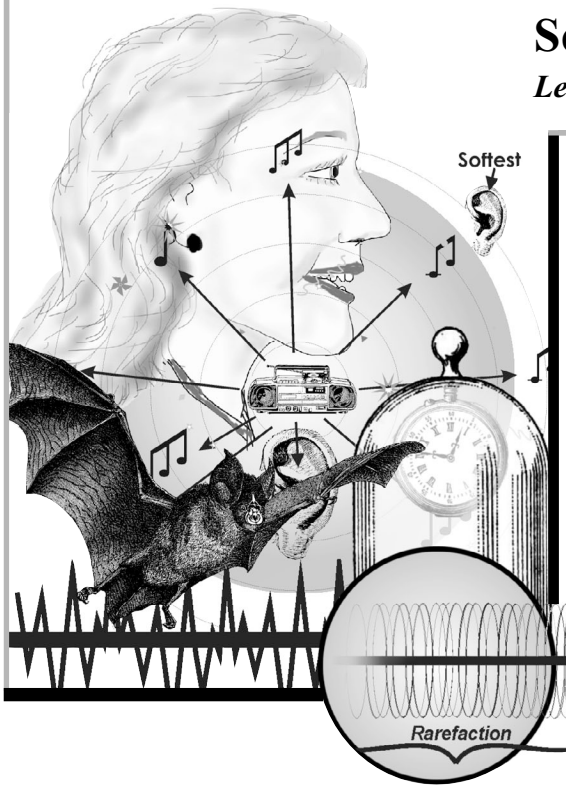
Lesson 14
Motion

Chapter 4

SOUND WAVES: AMPLITUDE AND PITCH

Section 3

Lessons 11-15



Longitudinal waves create a disturbance along the same line as the wave motion. One way to visualize this is in a spring, such as the spring toy with the brand name of Slinky. Hold one end of the spring at rest and give the other end a quick motion toward the other end and then away from the other end. This will send a compression wave along the Slinky. The coils will be close together in one place, and pulled apart in another.

The area where the coils are close together is compression. The area where they are spread apart is rarefaction.

Longitudinal waves are also known as *compression waves*.

Because sound waves are longitudinal, visualizing the different parts is sometimes more difficult. One solution is to draw a longitudinal wave as a transverse one. This can be done by letting the source of the sound trace out its motion on a strip of paper. If a pen is attached to a tuning fork and a strip of paper moved as the tuning fork vibrates, the pen traces out a curve very much the shape of a water wave. This curve with axis, nodes, crest, trough, displacement and amplitude is a *sine curve*. It is a mathematical expression of wave motion and displays the essential features of both transverse and longitudinal waves.

The ***loudness*** of a sound wave corresponds to its amplitude. If a person strikes a tuning fork harder, sound is louder, and the amplitude is greater. For a loud sound, the pen drawing the sine curve makes higher crests and deeper troughs. If one could see the air molecules, a loud sound causes the molecules to move farther from their average position of rest. After a tuning fork is struck, its sound slowly dies. The air waves carry away some of its energy. The loudness grows less.

VOCABULARY

Loudness: the amplitude of a sound wave
Damping: a decrease in amplitude
Reflect: to bounce back from a surface
Pitch: the frequency of a sound, measured in waves per second, vibrations per second or cycles per second

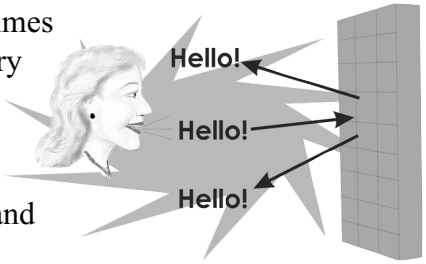
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Eventually, the tuning fork comes to rest. This slow loss of amplitude is ***damping***. When a bell is damped, it will become silent.

Sound in air expands as a spherical shell. The source of the sound is at the center of the sphere. As the sphere enlarges, its surface area increases. The sound energy is spread across a larger surface. The sound is not as loud to a person farther away from the source. If expansion alone accounted for weakening the sound wave, it would follow the Inverse Square Law. The loudness would fall off by the square of the distance from the source. However, the Inverse Square Law does not hold for sound.

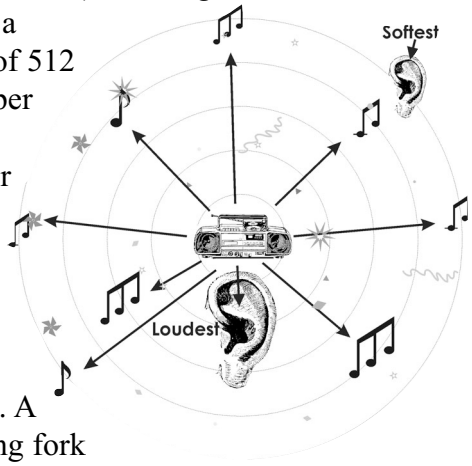
The brightness of light in a vacuum does follow the Inverse Square Law. The intensity or amount of brightness of light at a point twice as far away from the source is only one fourth as great. The intensity of light at a point three times as far away is only one ninth as great. Unlike light in a vacuum, sound must travel through air or some other medium. Air has a damping effect on sound waves and absorbs some of sound's energy. The amplitude, or loudness of sound waves falls off even faster than by the square of the distance. Loudness of sound does not follow the Inverse Square Law.

Sound waves can be ***reflected***. A person who shouts into an empty building or honks an automobile horn while in a tunnel hears an echo. An *echo* is a reflected sound. Sometimes the echo is very distinct. The word a person shouts reflects back and can be clearly understood. Sometimes it is less distinct. When lightning causes thunder, the sound of the thunder is reflected back from the clouds and since the clouds have no definite surface, the sound takes on a long rolling *reverberation*. A reverberation is a series of echoes of the same sound from different surfaces.



An object that reflects a wave must be as big or bigger than the wave. Waves will bend around an obstruction that is smaller than the wavelength. For instance, water waves which come to a small obstruction will wash around and reform behind the object. Ordinary sound waves have a wavelength of about 1 to 20 feet. An object such as a wall 20 feet high, will reflect the sound of a voice. If the wall is smaller, then some of the sound will refract around the obstruction and keep on going. *Refract* means *to bend*.

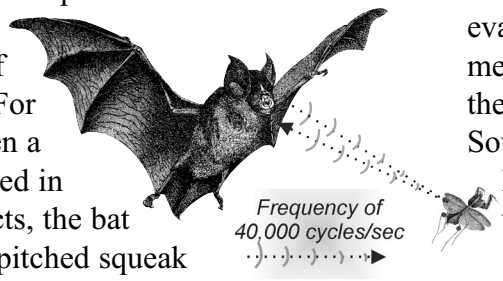
The ***pitch*** of a sound wave is its frequency. Because most sounds are made by vibrating objects, pitch is often stated as vibrations per second. High-pitched sounds are those made by objects vibrating at a high frequency. A tuning fork that makes middle C has a frequency of 256 vibrations per second. (Musicians use 264 vibrations/sec as middle C. However, physicists prefer 256 because it is a multiple of 2.) A tuning fork that makes high C has a frequency of 512 vibrations per second. It has a higher pitch and greater frequency than the middle C tuning fork. A low C tuning fork has a frequency of 128 vibrations per second. It has a lower pitch and lower frequency than either the middle C or high C tuning forks. The human ear can respond to vibrations in the range of 15 to 20,000 cycles per second. A sound at 15 cycles per second is an



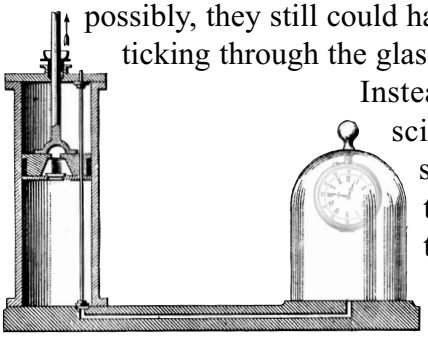
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extremely low pitch and low frequency sound. A sound at 20,000 cycles per second is an extremely high-pitched and high frequency sound. Older people or youth exposed to extremely loud noises lose their ability to hear sounds at either end of the normal range.

Frequency and wavelength are inversely related. As frequency increases, the wavelength decreases. A sound at middle C, 256 vibrations/sec, generates 256 waves per second, and each one has a wavelength of about 4.4 feet. A sound with a frequency of 1,056 vibrations/sec has a wavelength of about one foot. The highest pitched sound a person can hear, 20,000 vibrations/sec, has a wavelength of only 17 millimeters, less than an inch. The lowest pitched sound that a human being can detect, 15 vibrations/sec, has a wavelength of 75 feet. Higher pitched sounds are more easily reflected because they have shorter wavelengths. This explains why you have difficulty locating a cricket in the house. The cricket makes high-pitched sounds, and the waves are easily reflected. The sound reflects many times from other objects. The listener cannot pinpoint the location of the original source of the sound. Some animals can hear sounds well above the 20,000 cycles per second that is above the upper limit of human ears. For instance, when a bat is interested in locating insects, the bat emits a high-pitched squeak with a frequency of 40,000 cycles per second or higher. This extremely high-pitched sound has a wavelength of about 1/4 of an inch. The wave is so small it will reflect from an insect's body. The bat detects the faint echo and homes in on the insect. Submarines detect objects in their vicinity by echolocation. A high-pitched ping is sent out from the submarine, strikes an obstruction and reflects back. The receiver aboard the submarine calculates the distance and direction from the object that reflects the echo. The process is called *SONAR*, Sound Navigation And Ranging. The range of an object is its distance.



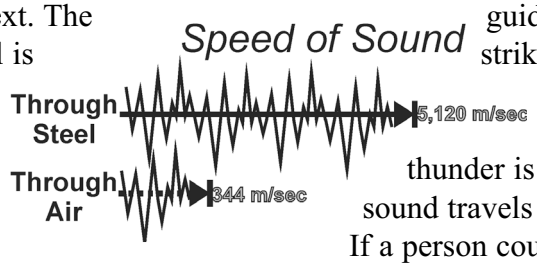
Most sound comes to human ears through the air. The air is put in motion by vibration: vibrating strings as in pianos and guitars, vibrating reeds in wind instruments, vibrating columns of air in pipes such as organs, vibrating surfaces such as drums. Vibrating vocal cords make the spoken word. Speech is in the range of about 50 cycles/sec to 1,000 cycles/sec. The piano keyboard goes from 32 cycles/sec to 4,096 cycles/sec. Human hearing is in the range of 15 cycles/sec to 20,000 cycles/sec. Although different objects vibrate to make sound, air carries the sound waves to our ears. During the time of Aristotle, scientists realized that sound must travel through a medium. They speculated that sound would not travel in a vacuum. The scientists were correct, as proven in the mid 1600s by Robert Boyle and Robert Hooke. They hung a loudly ticking watch in a glass container. Mr. Boyle and Mr. Hooke used their newly invented air pump to evacuate the air. They could see the watch mechanism moving, but once they removed the air, they could no longer hear the ticking. Sound does conduct through solids, so if Boyle and Hooke had merely laid the watch on the bottom of the glass jar, possibly, they still could have heard the ticking through the glass itself. Instead, the scientists suspended the watch in the middle of the



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container by a slender thread to prevent contact with the jar.

The speed of sound is faster in liquids and solids than in gases. The molecules in solids and liquids are closer together and transmit the disturbance more quickly from one molecule to the next. The speed of sound in steel is 5,120 m/sec, but is 344 m/sec in air. Sound is about 15 times faster in steel. Because the steel has a crystalline structure, the damping effect is less. Steel does not dampen sound as much as does air. The same amount of sound energy will travel farther in steel than in air. Knowing that sound travels about 1,128 ft/sec in air can be used as a rough guide to how far away lightning strikes. Begin counting by seconds when the flash of lightning is seen. Stop counting when the thunder is heard. A mile is 5,280 feet, so sound travels about a mile in five seconds. If a person counts to 10 before the thunder is heard, then the lightning strike was two miles away.





—Anonymous

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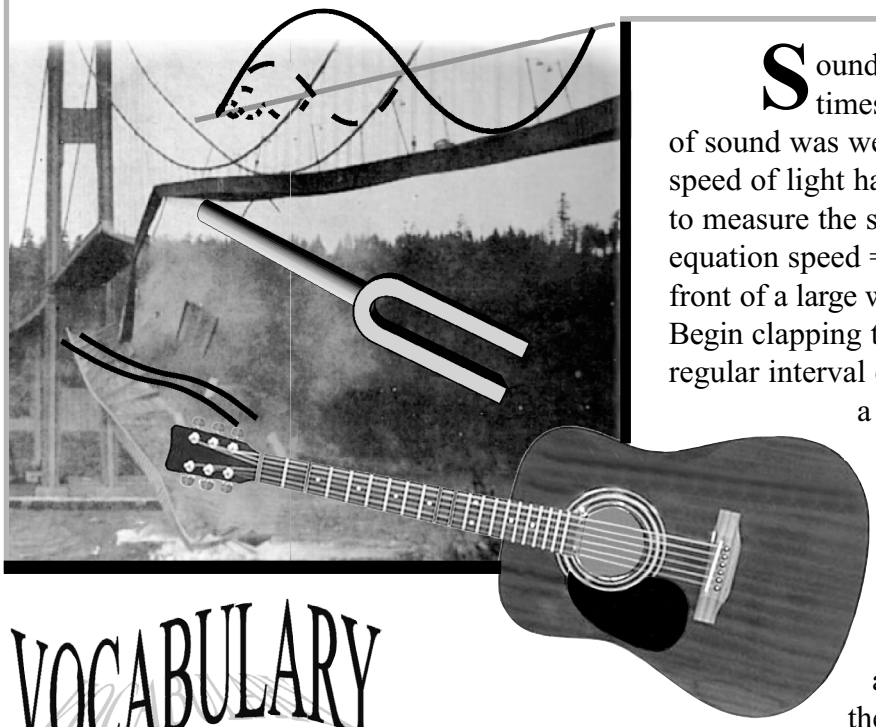
Lesson 15
Motion

Chapter 4

PROPERTIES AND SOUNDS

Section 3

Lessons 11-15



Sound in air travels about 870,000 times slower than light. The speed of sound was well known long before the speed of light had been measured. One way to measure the speed of sound is to use the equation speed = distance/time. Stand in front of a large wall that will produce an echo. Begin clapping two boards together at a regular interval of twice per second, to cause a ½ second interval between each clap. If you are close to the wall, an echo will arrive back so quickly it cannot be distinguished from the original sound. As you back away from the wall, an echo will arrive in between the sound of the boards hitting together. Eventually, an echo will arrive at the same time the boards bang against one another. The sound that bounces back is an echo of the previous sound. It has taken ½ second to travel to the wall and back. Measure the distance to the wall and back. The formula speed = distance/time gives the velocity of sound.

Another way to measure the velocity of sound is by the wave equation speed = frequency * wavelength. Many musical instruments, such as organs, make sound by waves in pipes. In the laboratory, the pipes can be put on their sides, and a small dusting of cork can be put into the pipes. Where a node is, the cork will be still. Where a crest or trough is, the cork bounces around. The distance from one node to the next is half of a wavelength. Knowing the frequency of the pipe and the wavelength gives the velocity. Either calculation shows that the speed of sound in air at room temperature is 344 m/sec or about 1,128 ft/sec. Room temperature is specified because the speed

VOCABULARY

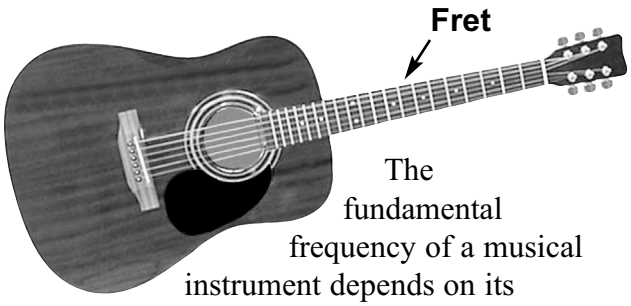
Natural frequency: the frequency at which an object vibrates
Fret: ridges of wood or metal across the finger board of a stringed instrument
Tension: a stretching force
Overtone: a secondary pitch, usually a whole number multiple of the fundamental frequency
Resonance: increase in amplitude by a periodic force acting on a system at or near the system's natural frequency
Beats: the pulsating, throbbing sound caused by the interference of two sounds with slightly different frequencies

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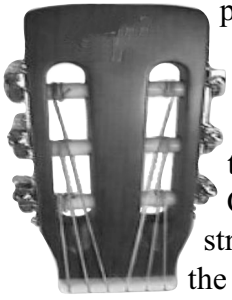
of sound in air does vary slightly because of changes in temperature. The hotter the temperature, the faster the speed. A higher temperature means the molecules move faster, so as one is disturbed it carries that disturbance to its neighbor more quickly.

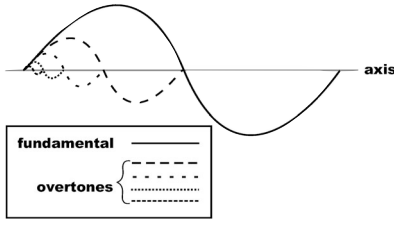
FUNDAMENTAL FREQUENCY AND OVERTONES

Frequency of a sound is its pitch. Most objects vibrate at a ***natural frequency***. A metal spoon that is dropped on a floor has a different sound than a wooden spoon that strikes the same floor. The natural frequency of an object depends on several factors such as size, shape, mass, tension and elasticity. Although musical instruments have a natural frequency, a musician can change the natural frequency. Depending on the instrument, the musician may open valves, shorten strings or strike the surface in a certain way. A guitar makes a sound by vibrating strings under tension. Each of the six strings of a guitar is held at each end. When one string is plucked and allowed to vibrate its whole length, the string makes the lowest pitch possible for that string. This is its *fundamental frequency.*



The fundamental frequency of a musical instrument depends on its length, mass and tension. A guitar string pressed to a ***fret*** becomes shorter and vibrates at a higher pitch. Smaller objects usually vibrate at a higher pitch than larger objects. The smaller an object, the higher pitched is its natural frequency. Of the six strings on a guitar, the top three strings are usually made of wrapped metal. The other three are bare steel and smaller in diameter. The heavier, more massive metal strings vibrate at a lower pitch than the lighter steel strings. A guitar is tuned by tightening or loosening the strings. The greater the tension, the higher the pitch. Changing the ***tension*** on the strings causes them to vibrate at the correct frequency. A guitar string can vibrate in two parts. One part moves out and produces compression, while the other part moves in and produces rarefaction. The string has a crest and a trough with a node between them. The frequency is twice the fundamental frequency. The string may also vibrate in three parts, four parts and so on. Each produces a higher tone that is a multiple of the fundamental frequency. These higher frequencies are called ***overtones***.





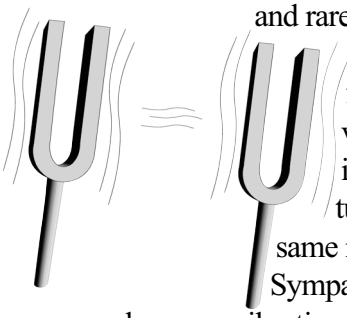
The quality of musical instruments refers to their distinctive sound because of the number and prominence of their overtones. Overtones are tones of higher frequency than the fundamental frequency. Usually, they are simple multiples of the fundamental frequency. For instance, if the fundamental frequency is 256 vibrations per second, the first overtone would be 512 vibrations per second (256 * 2 = 512), and the second overtone would be 768 vibrations per second (256 * 3 = 768). A body can vibrate at its fundamental frequency and produce overtones at the same time. Overtones distinguish instruments. The fundamental pitch of a kettledrum is 128 vibrations per second. Other instruments can produce that pitch, but one made by a piano is easy to distinguish because the piano has more

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overtones. Although musical instruments can produce sounds of the same pitch, they can still be distinguished by their quality.

RESONANCE

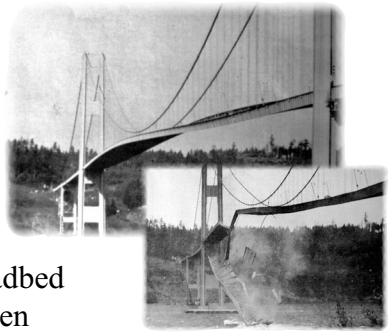
Suppose two middle C tuning forks are placed near one another, but only the first one is struck. It will vibrate and send sound waves to the second fork. As the compressions and rarefactions impinge against the second fork, it begins vibrating in time with its neighbor. Both tuning forks have the same rate of vibration. Sympathetic vibration occurs when one vibrating body sets another one vibrating either at the same frequency or at a multiple of the original frequency. *Sympathetic vibration* is a type of resonance.



Resonance occurs when energy is applied at a body's natural frequency to increase its amplitude. A child learns to put a swing in motion by pumping the swing. Strength is not as important a factor as timing. A small arc of a swing can be made larger and larger by small pushes at the right moment. The swing has a natural frequency. By adding energy in time with the natural frequency, the amplitude increases.

The engines of airplanes have a natural frequency. The frame of the airplane should not have the same frequency as the engines. If it does, vibration and unnecessary noise can occur. Engineers test the engine throughout its range of speeds and then change the airframe so it does not have the same natural frequency. The engineer can modify the airframe by changing the length, tension or mass of its members. The airplane flies quieter and smoother.

One of the most dramatic examples of resonance was the Tacoma Narrows Bridge collapse in the state of Washington. In 1940, only four months after the bridge was completed, a strong wind began blowing across the suspension bridge. The bridge had been built to withstand much stronger gales. The wind set up a force in resonance with the natural frequency of the bridge. The bridge rocked in a *torsional* wave. A torsional wave twists in a clockwise then counterclockwise motion around a center axis. Eventually, the wind caused the bridge to rock back and forth so violently the roadbed broke apart. When engineers rebuilt the bridge, they added mass to the roadbed to give it a different natural frequency.



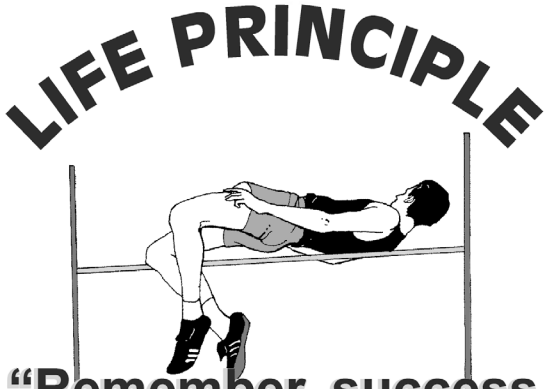
All types of waves can set up resonance. For instance, if a person sings and holds a note near a piano, the strings of the piano with the same frequency will begin vibrating. Electromagnetic waves at one place can cause resonance in an electric circuit provided the circuit has the same frequency.

Suppose two musical instruments are to be tuned to the same frequency, but one is a little off tune. As both instruments are played, they will send out sounds that differ slightly in pitch. Sometimes the sound waves will meet compression to rarefaction and cancel one another. Sometimes, the compression will meet compression, rarefaction will meet rarefaction, and the two waves will reinforce one another. The combined sound will grow louder, then softer, then louder again. ***Beats*** are a series of alternate reinforcements and cancellations caused by interference of sound waves. To understand beats, suppose a father and a

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young son are walking together. The father takes larger steps, and the small boy takes shorter ones but walks faster. They start out on the same stride, but after a few steps, they are out of step with one another. However, they eventually get back in step again for a moment.

Consider two middle C tuning forks vibrating at 256 vibrations per second. If both are struck, both generate sound at the same frequency. The total sound is louder because they are in phase. As their sound waves meet, the amplitude doubles. Suppose the second middle C tuning fork vibrates at 255 vibrations per second. Both forks start out in phase. After one half of a second, one has produced 128 waves, and the other has produced 127 ½ waves. They are ½ wave out of phase. Compression meets rarefaction, and the volume of the sound is reduced. The sound begins loud at the start, but at the end of ½ second, a noticeable reduction in volume can be noticed. After a second of time has passed, the first tuning fork has made 256 waves and the other has made 255 waves. They differ by a full wavelength. Compression meets compression and rarefaction meets rarefaction. Although the tuning forks are not at the same frequency, the sound waves they make are momentarily in phase. The sound is noticeably louder. The two tuning forks make a throbbing sound known as beats. The number of beats per second is the difference in the two frequencies. Two tuning forks that differ by one vibration per second generate one beat per second. Beats are the variation in the loudness of a sound caused by constructive and destructive interference. Musicians tune their instruments by listening for beats. They play their instruments at the same pitch at the same time. If they are in tune, the sound level will be constant. If they are out of tune, they will hear a wavering sound caused by beats. If they hear four beats per second, then the pitch of the two instruments is different by 4 vibrations per second.



"Remember, success is not measured by heights attained but by obstacles overcome."

—Bruce Jenner

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