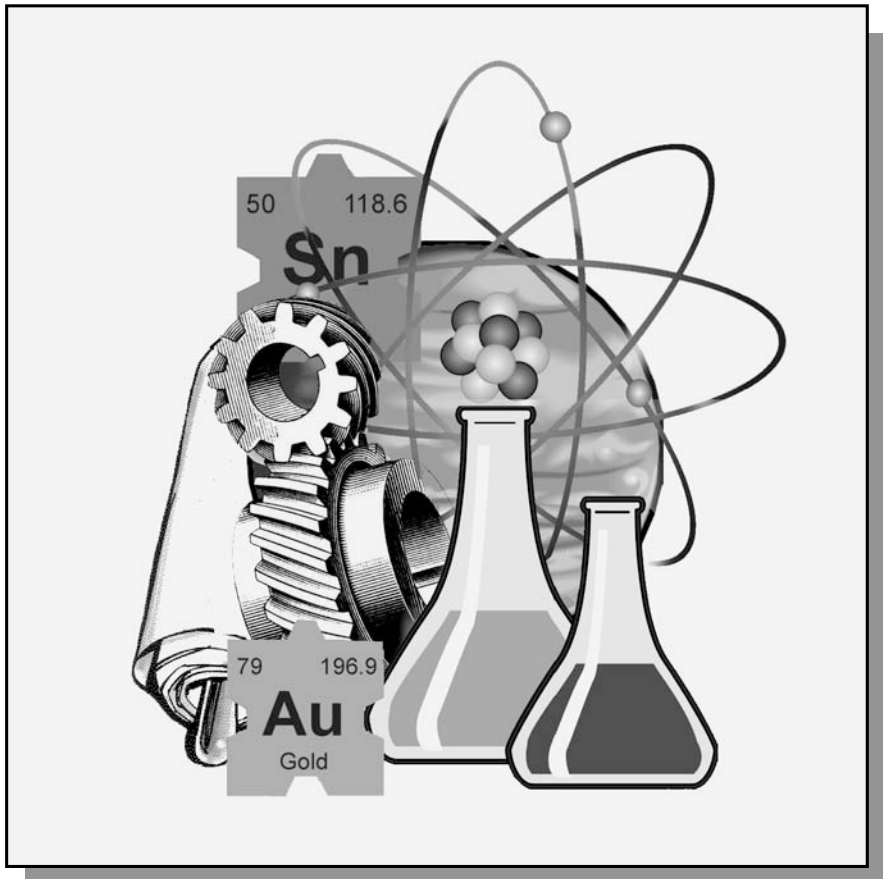
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This chapter requires a companion activity book in which students respond to questions on text content. Answers are found in the *Teacher's Resource Kit*.



Chapter 2

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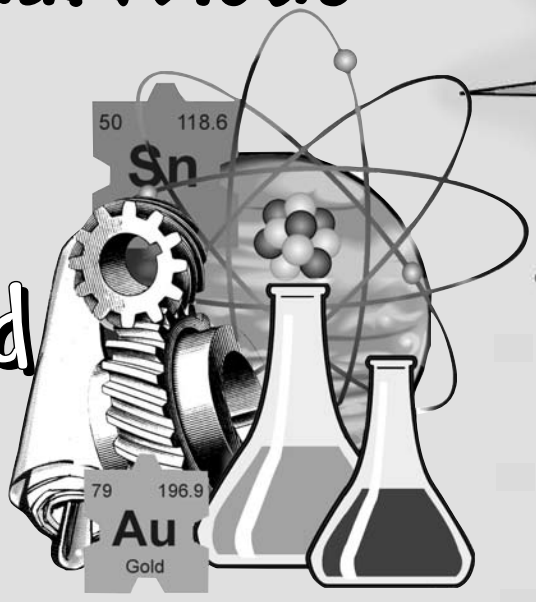
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"The study of science is the chronicle of man's quest to discover the essence of life and how the marvelous laws of creation are applied to human needs."



—Ronald Johnson, Ph.D.

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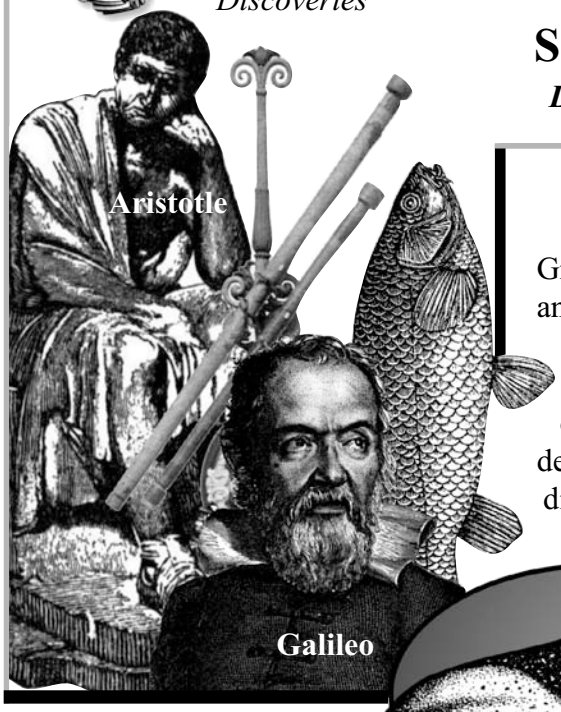
Chapter 2

Lesson 1
Inventions & Discoveries

Section 1

Lessons 1-5

GALILEO AND THE PENDULUM



Physics began during the time of the Greeks more than 2,000 years ago. The Greeks attempted to gain knowledge through reasoning and observation. Greeks who studied the natural world were known as natural philosophers. ***Philosophy*** is a Greek word that means *love of learning.* A "Doctor of Philosophy"(Ph.D.) is an advanced university degree. The Greeks did not separate science into different areas of study. Greek philosophers studied natural science and called it physics. An individual could not be an expert in all areas of science. Scientists specialized in various areas of science, such as biology, geology, chemistry and others. Biology is the study of life and living organisms. Geology is the study of the Earth. Chemistry involves the study of composition and structure of matter.



After biology, geology, chemistry and others are removed from physics, much remains. Physics includes the study of motion, sound, heat, light, electricity, magnetism and nuclear energy. Physics is the study of matter and energy and their interaction. ***Matter*** has weight and occupies space. ***Energy*** can put matter into motion or bring about a physical change.

Aristotle is one of the earliest known scientists. He was born in Macedonia in 384 B.C. At the age of 17, Aristotle's father sent Aristotle to the best school in the world, Plato's Academy, in Athens, Greece. At Plato's Academy, Aristotle learned to observe, pose questions and use reason to arrive at conclusions.

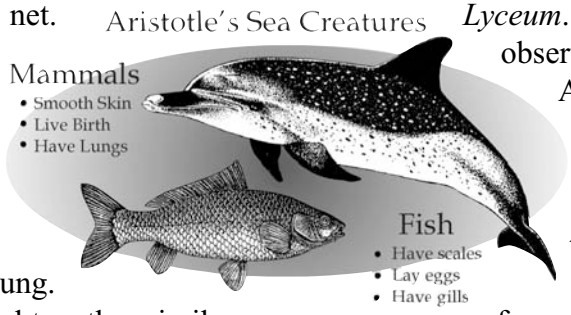
Aristotle stayed in Athens for twenty years and taught at Plato's Academy. After Plato died, Aristotle returned to Macedonia.

VOCABULARY

Philosophy: love and pursuit of wisdom or learning
Matter: anything that occupies space and has weight
Energy: capacity to make a change in matter, to heat, to move, or to change its physical form
Arc: part of a circle
Period: interval of time between two occurrences of a repeating event
Experiment: an observation under controlled conditions

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Aristotle especially enjoyed studying animals that lived in the sea. The Greeks gave the name "fish" to all sea life. Greeks believed that all creatures in the sea differed slightly from one another. Aristotle could see differences among the things he caught in his net. For instance, some sea creatures had scales, and others did not. Some gave live birth to their young. Aristotle grouped together similar creatures.



An essential step in science is to summarize information so it is easier to understand. A scientist can summarize information by using a table or by an equation. Alternatively, the scientists can group items into categories based on how the items are alike and how they are different. Facts that apply to one member of a category are likely to apply to other members in the same category. Aristotle organized sea life into categories. He noticed that dolphins gave birth to live young and came to the surface for air. Because of this, Aristotle placed dolphins with the animals of the field like horses and cattle.

When Aristotle returned home, he became a tutor for the king of Macedonia's son, Alexander. A *tutor* is a personal teacher. The boy was thirteen years old and quite inquisitive. Alexander and Aristotle became friends.

In 336 B.C., following the death of his father, Alexander became king of Macedonia at age 20. He determined to conquer the world quickly. He conducted military campaigns all the way to India and became known as Alexander the Great. Military historians named him the greatest military general who ever lived.

Alexander the Great provided money for Aristotle to start his own school in Athens. Aristotle called his school *The Lyceum*. He encouraged his students to observe and ponder what they saw. Aristotle wrote about 170 books. Approximately, 50 of his books are still available today. Aristotle believed education was essential to the survival of a nation. He said, "All who have meditated on the art of governing mankind are convinced that the fate of empires depends on the education of youth."

The Greeks made remarkable gains in understanding the natural world. After the Greeks became weak within their military, the Romans became powerful. The Romans made fewer scientific discoveries but applied science and technology to practical problems. The Romans built roads and ships, improved mining and made useful inventions.



In mid 400 A.D., the Roman Empire began to collapse. For almost a thousand years, from the 400s to the 1400s, learning declined worldwide. People forgot most of the wonderful scientific gains made by the Greeks. Education became of little importance, and, as a result, the leaders of most countries were not capable of reading or writing. Books were few in number and became very precious. Europe fell into a period known as the Middle Ages, which was sometimes called the Dark Ages.

Starting in the late 1400s, learning began to revive. Books by Aristotle and the

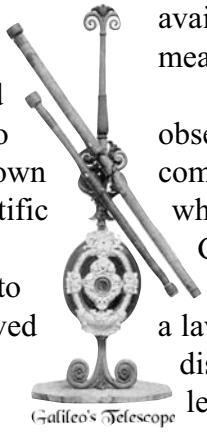
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other Greek natural philosophers began to circulate. Johann Gutenberg's printing press, invented circa 1450, made possible the inexpensive production of books. This helped revive learning. Some of the first books printed were those of the ancient Greek writers. Compared to the scholars of the Middle Ages, the ancient Greek scientists seemed incredibly informed. For that reason, people of the 1500s began to think of the ancient books as the final authority on scientific matters.

Aristotle had instructed his students to observe and think. Aristotle insisted that his students test ideas with observation and clear thinking. Yet, many of the readers of his books did exactly the opposite. Aristotle had written most confidently about so many subjects, students began to view Aristotle's writings as incapable of having errors. Teachers taught their students to refer to the ancient Greek texts for answers on scientific matters. Suppose a teacher of the 1500s posed a scientific question. His students did not solve it by experimentation. Instead, they hurried to find the answer in a book by Aristotle or one of the other Greek writers.

Changing this attitude and establishing modern science required exceptional skill and personal courage. One of the founders of modern science who accepted the challenge was Galileo.

Galileo Galilei, an Italian physicist, was born in Pisa, Italy, in 1564. This was the year that the great painter Michaelangelo died and the year Isaac Newton was born. Galileo lived for 78 years and died in 1642. Galileo lived in exciting times. He is best known for his use of the telescope as a scientific instrument. Although Galileo did not invent the telescope, he was the first to use it to study the heavens. He observed the night sky and made a number of remarkable discoveries. He saw mountains and valleys on the Moon, four large satellites orbiting Jupiter and a multitude of new stars in the Milky Way. None of these sights were previously mentioned by the ancient Greeks. Although Galileo's observations of celestial bodies are important and well known, his research into the motions of bodies on Earth was as important to science.


Galileo's Telescope

Galileo's first major discovery of motion was made in 1581 while he was a young student in Pisa, Italy. He began each day by going to chapel. Early one morning, Galileo knelt and whispered his prayers in the dark chapel. He arose to watch the lamplighter at work. The lamp hung thirty feet from the high ceiling. The lamplighter pulled on a cord to bring the lamp over the balcony. After lighting it, the lamplighter released the lamp. The lamp swung back and forth in a wide ***arc***. As its motion decreased, the lamp seemed to take as long to make a small arc as a large one.

Galileo returned to his room and experimented with pendulums of various lengths. A pendulum can be made by tying a weight to one end of a length of string. The top is fixed in place, leaving the weight at the other end free to move. Galileo pulled the weight back a short distance and released it. He measured the time required for the pendulum to swing from one side to the other and back again. Accurate clocks were not available, so Galileo used his pulse to measure the rate of the pendulum.

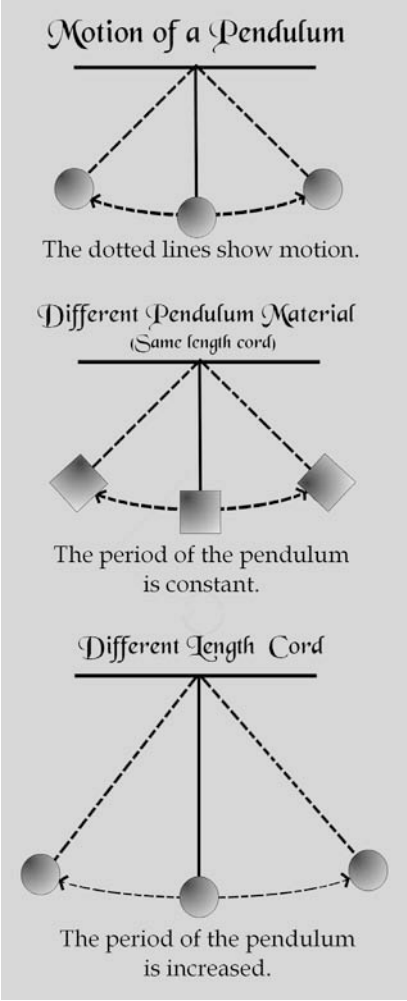
Galileo confirmed what he had observed in the chapel. The time for a complete back and forth swing is the same whether the arc is a small arc or a large one. Galileo's discovery is known as the *Principle of the Pendulum*. A *principle* is a law of science. In this case, Galileo had discovered that two pendulums of the same length would swing at the same rate

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regardless of how wide or shallow their arcs.

The ***period*** of a pendulum is the time required to swing from one side to the other and then back again. This is a complete arc. A pendulum that is almost 25 centimeters long (10 inches) requires one second to make a complete arc. Its period is one second.

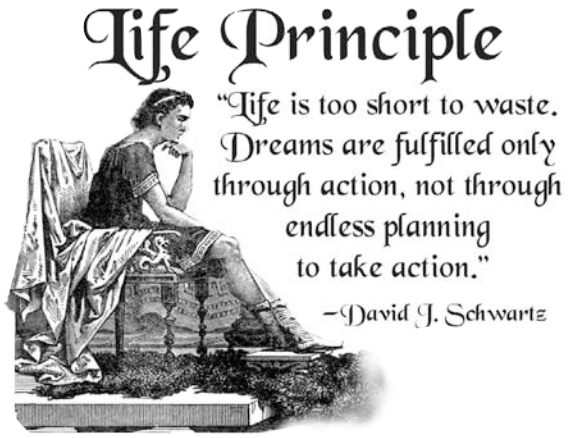
Galileo then experimented to see what would cause the period of the pendulum to change. He used different materials such as wood, glass and lead for the weight at the end of the pendulum. This change made no difference. A pendulum with a glass weight had the same period as one with a lead weight, provided the pendulums were of the same length.



The length of the cord did make a difference. When Galileo made the length of the pendulum longer, the pendulum slowed. The time for a complete arc was greater. The period increased. For instance, if the length of the pendulum was about 100 centimeters, a complete arc took two seconds. When Galileo made the string shorter, the pendulum swung more briskly. The period became shorter.

The period and the length of the pendulum are directly related because as one increases, so does the other. As one decreases, so does the other. A longer string causes the pendulum to take more time to make a swing across its arc. A shorter string causes the pendulum to take less time to swing across its arc.

Galileo's discovery of the Principle of the Pendulum was new. The Greeks had not mentioned it in any of their books. Galileo was willing to observe, think and experiment. Although the Greeks did think and observe, they seldom experimented. ***Experiments*** are better ways to reveal and test new scientific discoveries and theories.



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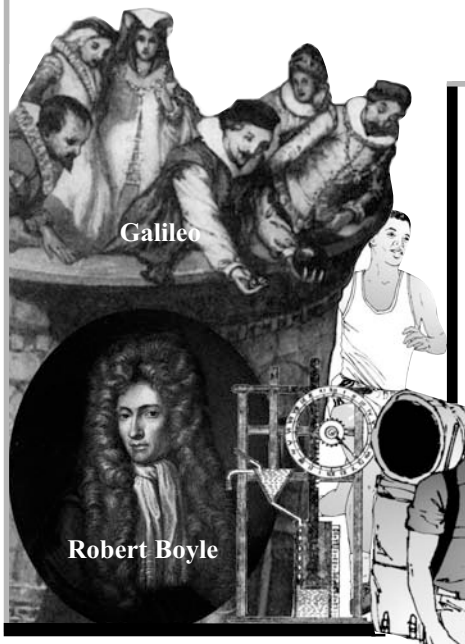
Lesson 2
Motion

Chapter 2

GALILEO AND MOTION: SPEED

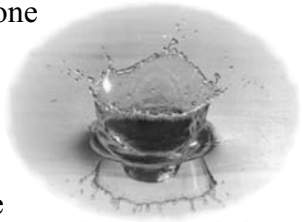
Section 1

Topics 1-5



Galileo's experiments with the pendulum started his thinking about other forms of motion. Almost everything taught about motion came from books by Aristotle. Because of the vast number of books that Aristotle wrote, he became a leading expert in nearly every field of science and other fields as well. Aristotle constantly called for thinkers to use careful observations, common sense and reasoning. He made a thorough study of reasoning or ***logic***. His ideas about logic are still accepted today without major change. Aristotle made mistakes in other areas, but the number of errors was minor considering the vast number of subjects about which he wrote.

Aristotle's influence upon the scholars of the late Middle Ages was immense. For some reason, they consistently promoted Aristotle's most spectacular errors. One of those areas where Aristotle was incorrect concerned motions of bodies on Earth. Aristotle taught that bodies go into motion to reach their natural place. Raindrops fall to Earth and flow into the sea because that was their natural place. Other objects, such as clouds, drifted into the air because that was their natural place. The reason a stone fell to Earth or smoke rose in the air was because they sought their natural place. Objects came to rest once they found their natural place. For that reason, Aristotle believed a state of rest or no motion was the natural state.


Raindrop's natural place

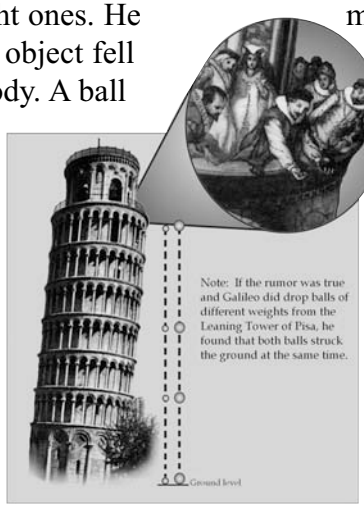
Scholars still taught Aristotle's contention that any ball-shaped solid object would sink in water. The natural place for solid objects is not water but Earth itself. Galileo tested this statement. Galileo made spherical objects from wood, wax and lead. Some spherical objects floated in water while others sank.

VOCABULARY

Logic: study of the principles of reasoning
Speed: distance traveled divided by time
Independent: not determined or influenced by something else
Inclined plane: a ramp; a flat surface tilted from the horizontal
Average speed: speed measured over a period of time
Instantaneous speed: speed at a particular moment of time

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Aristotle had also written that heavy objects fell more rapidly than light ones. He taught that the ***speed*** at which an object fell depended on the weight of the body. A ball that is ten times heavier than another would fall ten times faster. Galileo's teachers in Italy at Pisa repeated this claim.

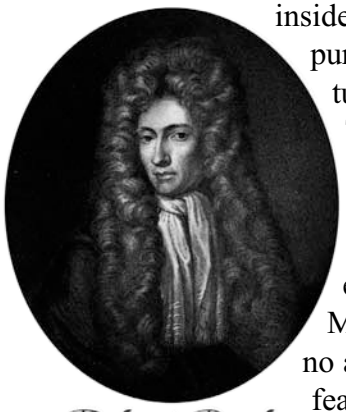


Galileo often argued with teachers and students and earned the nickname "The Wrangler." A rumor sprang up that Galileo dropped balls of different weights from the Leaning Tower of Pisa. Galileo observed that both light and heavy balls struck the ground at the same time.

Galileo concluded that all objects fall at the same speed. The speed of falling bodies was ***independent*** of their weight. Two quantities are independent of one another if changing one has no effect on the other. In his experiments with the pendulum, Galileo found that a swing of the pendulum in a wide arc or in a shallow arc did not change the period. The period of the pendulum and the distance the pendulum is pulled to one side before being released are independent quantities. The amount of weight at the end of the pendulum did not change the period. The material used to make the weight did not matter. The weight could be made of glass, lead or any other substance. Provided the string was the same length, pendulums with different weights took equal times to make a complete swing. The period of the pendulum and the amount of weight at the end of the pendulum are independent of one another.

In the same way, the speed of a falling body is independent of its composition. A lead ball will fall as fast as a glass ball. Galileo believed that the slight exception was due to air friction. To prove his point, Galileo beat a ball of lead into a thin sheet. When he dropped the sheet, it fluttered to the ground more slowly than a lead ball of the same weight. Objects with large surface areas, like feathers, fell more slowly. Galileo suggested an interesting experiment: drop a feather and a lead shot in a vacuum. Without air resistance, they would fall together.

The professors pointed out that Aristotle said a vacuum was impossible. University professors claimed Galileo's experiment could not be done. However, about 50 years later, an English scientist named Robert Boyle built an air pump. He put a lump of lead and a feather inside a glass tube. He pumped out the air and turned the tube over. The feather and lead fell side by side. (The Apollo astronauts later repeated the experiment on the Moon. The Moon has no atmosphere, so the feather and lead fell beside one another.)


Robert Boyle

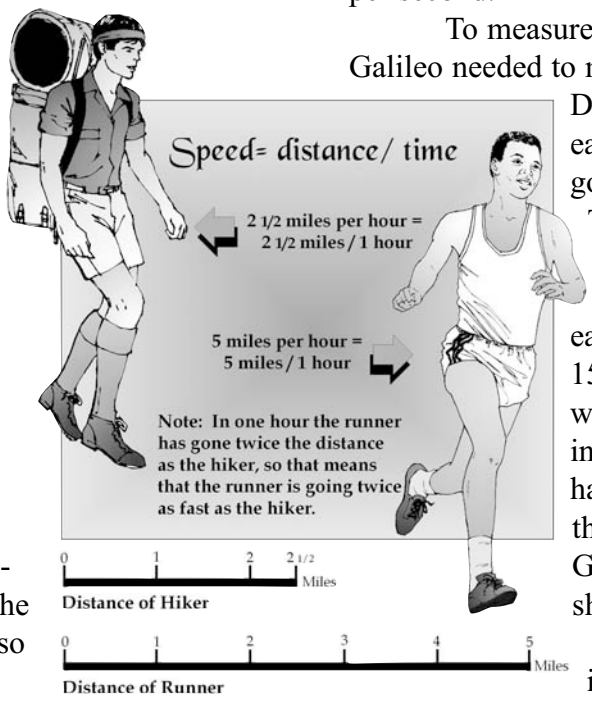
Galileo became a professor at the University of Padua. Students enjoyed his classes so much that he had to move his classes outside for more room. Professors who lectured from ancient books found empty seats.

Until the time of Galileo, people believed that a moving object would naturally tend to slow. To keep it moving, a force constantly had to act on it. Galileo believed just the opposite. A body in motion would stay moving in a straight line at the same speed. It would slow, speed up or change direction only when a force acted on it. A ball rolling on a flat surface eventually slows down and

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stops. The force of friction slows the ball's forward motion.

Galileo wanted to experiment with the speed of falling objects. The speed of a body is the rate at which it covers distance. Speed is stated as distance per time interval: centimeters per second, feet per second or miles per hour. Centimeters, feet and miles are measures of distance. Seconds and hours are measures of time. The equation is: *speed = distance/time*. The slash mark, /, is read "divided by."



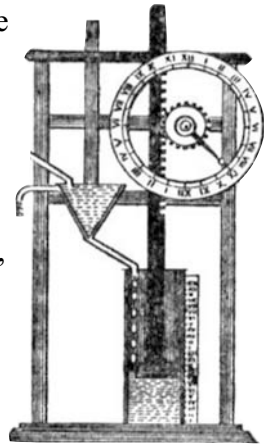
As Galileo worked with distance, speed and other quantities related to motion, he gave them definitions so other scientists would understand his meaning. The equation, *speed = distance/time*, is actually a definition. It defines speed to be the total distance traveled divided by the time of travel.

To calculate speed, scientists divide the distance by the time. If a runner covers 220 yards in 28 seconds, the runner's speed = change in distance/change in time = 220 yards / 28 seconds = 7.86 yards/second. As another example, suppose a hiker takes 90 days to walk the entire length of the Appalachian Trail, a distance of 2,140 miles. His speed = distance/time = 2,140 miles / 90 days = 23.8 miles per day. Distance is measured in miles, and time is measured in days. Speed is always measured as distance divided by time.

The "miles per day" or "yards per second" are the units of the speed. Units are an important part of the overall quantity, and should always be stated. For instance, to describe a car's speed as 100 is a meaningless quantity. The speed could be 100 kilometers per hour, 100 miles per hour or 100 feet per second.

To measure speed of a falling body, Galileo needed to measure distance and time. Distance could be measured easily. Merchants sold goods by the foot and yard. They had accurate ways to measure distance. Time, however, could not be easily measured. In the 1500s and 1600s, clocks were large, clumsy and inaccurate. Most clocks only had hour hands. To measure the speed of falling objects, Galileo needed to measure short intervals of time.

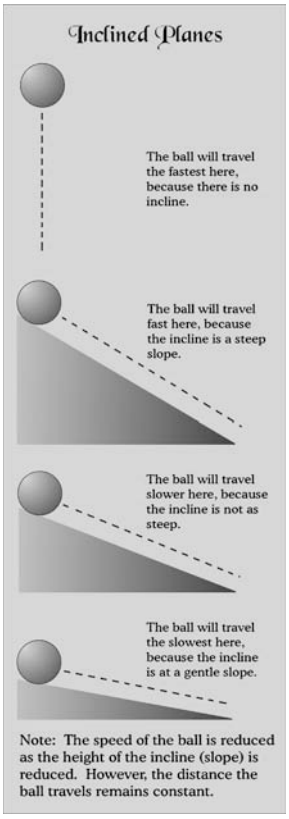
Galileo developed an inventive solution to measuring time. Merchants sold many products by weight because accurate scales did exist. Galileo allowed water to escape from a hole in the bottom of a container during his experiments. Then, he weighed the water. Time could be related to the weight of the water.


Galileo's Water Clock

The objects still fell much too quickly for Galileo to make accurate measurements. Again, Galileo found a solution. Rather than dropping the objects, he let them roll down an ***inclined plane***. By lowering the incline to a gentle slope, he could reduce or lessen the force of gravity.

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Objects rolled down the incline slowly enough for Galileo to measure the speed. Galileo found that the speed was not constant throughout the entire trip down the incline plane. At the top, the object barely moved. The object continued to gain speed until it came to the bottom. The objects fastest speed was at the very bottom of the ramp.



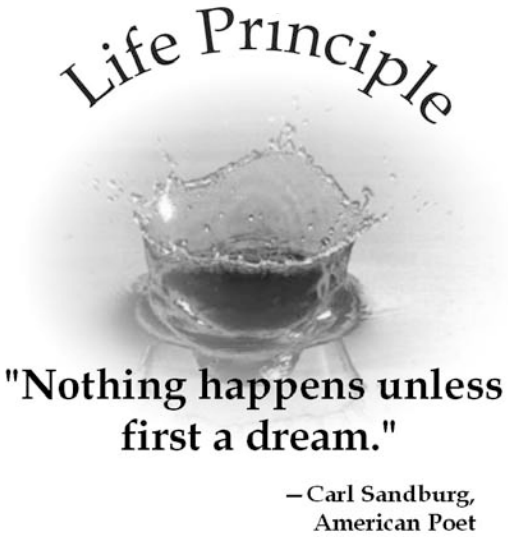
Because the speed changed, Galileo had to distinguish between ***average speed*** and ***instantaneous speed***. In the examples given of the hiker and runner, the speeds are averages.

The runner may gain speed right after he leaves the starting block, sprint at a constant rate for most of the 220 yards, and then put on a burst of speed in the last few yards near the finish line. The runner's average speed was 7.86 yards per second. At any one instance, the actual speed may be more or less than the average. It was slower at the starting block and may have been faster at the finish line. The hiker's speed for the 90 days is an average, too. It includes the time the hiker was on the trail as well as time in camp.

Instantaneous speed is the actual speed at a particular moment. For an automobile, the speedometer gives the instantaneous speed. The speedometer is geared to the wheels, and the speed at any moment can be directly read.

A radar gun gives the instantaneous speed of an automobile or another moving object such as a baseball thrown from a pitcher's hand. When a pitcher tosses a fastball at 97 miles per hour, that speed is the instantaneous speed as seen by the radar gun.

Finding the instantaneous speed is more difficult than the average speed. Instantaneous speed must either be calculated or estimated from the average speed.



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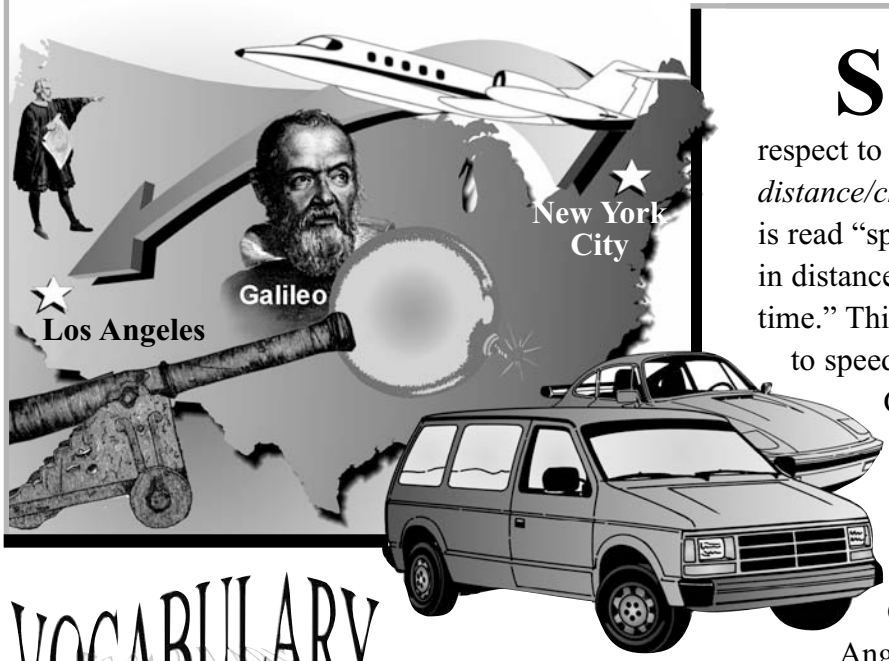
Lesson 3
Motion

Chapter 2

GALILEO AND MOTION: ACCELERATION

Section 1

Lessons 1-5



Speed is defined as the change in distance with respect to time: *speed = change in distance/change in time*. This equation is read "speed is equal to the change in distance divided by the change in time." This equation is often shortened to speed = distance/time.

Common units for speed are meters per second, m/sec, feet per second, ft/sec, and miles per hour, mi/hr. The distance from New York City on the east coast to Los Angeles, California on the west coast is 2,928 miles. A jet aircraft makes the flight from New York City to Los Angeles in 4.75 hours. The speed of the jet is: speed = distance/time = 2,928 mi / 4.75 hr = 616 mi/hr.



Often speed and ***velocity*** are used as though they had the same meaning. Physicists prefer to use velocity to refer to both the speed and direction of motion. In the example above, the jet has a velocity of 616 mi/hr west. Like speed, velocity may be an average, or it may be instantaneous. Average velocity is measured over time. Instantaneous velocity is measured at a particular moment in time.

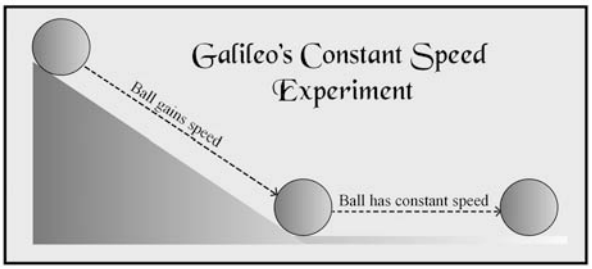
VOCABULARY

Velocity: speed and direction of an object's motion
Force: capable of putting an object in motion
Gravity: force of attraction between two bodies; the force of attraction between a freely falling object and the earth gives the body an acceleration of 32 ft/sec^2
Free fall: falling motion of an object that is subject only to the force of gravity
Parabola: path followed by a projectile

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Galileo measured the average speed of the ball rolling down the inclined plane. In addition, he wanted to measure the instantaneous speed at any point along the ramp. This was more difficult because he had no radar gun or other way to identify the speed at any particular instant. Galileo found a solution.

Galileo used a highly polished, level track and smooth bronze balls. The surfaces were so smooth he believed friction could be ignored. His experiments showed that a ball would roll at a constant speed in a straight line over a horizontal table. The ball would not lose speed, gain speed or change direction unless a ***force*** acted on it. A ball at rest would stay at rest, unless a force put it in motion.



Galileo put a horizontal, level track against the ramp at the point where he wanted to measure the instantaneous speed. The ball would gain speed as it rolled down the ramp. Then it would roll onto the level track. While rolling horizontally, it would neither gain nor lose speed. Knowing the distance along the horizontal track and the time for the ball to roll along it, Galileo could calculate the horizontal speed. Its average horizontal speed along the track equaled its instantaneous speed at the point where it left the ramp.

In the case of falling bodies, the force that acted on them was the force of ***gravity***. Objects that are in ***free fall*** have only the force of gravity acting on them. Galileo's goal was to learn the laws governing falling bodies. Galileo found that with suitable modification, the information from his inclined plane experiments could be applied to falling bodies.

Galileo noticed that the ball gained speed throughout its trip down the inclined plane. His careful study of falling objects convinced him that objects also gained speed as they fell. The speed increased with time. Galileo gave the name *acceleration* to the change in speed with respect to time.

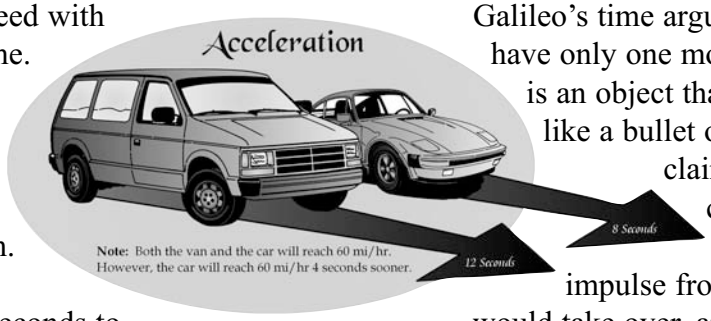
Acceleration involves a change in velocity. When a car makes an emergency stop with the brakes fully applied, passengers feel the sudden change in velocity. Passengers are thrown forward against the seat belts. The car is going from a faster speed to a slower speed. Once the car comes to rest the velocity is no longer changing and acceleration ceases. Velocity must change for acceleration to take place. The passengers in an elevator feel the acceleration as the elevator moves. Once the elevator reaches a constant and unchanging speed, acceleration ceases.

To calculate a value for acceleration, the change in speed and the change in time must be known. Suppose a ball started at the top of Galileo's ramp at 0 ft/sec and came off the bottom of his ramp at 12 ft/sec. The time for the ball to roll along the ramp was 3 seconds. Acceleration is change in speed divided by change in time = 12 ft/sec divided by 3 sec = 4 ft/sec per sec. The expression "4 ft/sec per sec" can also be written as 4 ft/sec^2. It is read as "four feet per second squared." The superscript *2* means *squared.*

As another example of acceleration, suppose a car accelerates from 0 ft/sec to 88 ft/sec in 8 seconds. (A speed of 88 ft/sec is the same as 60 mi/hr.) The car's acceleration is the change in velocity (88 ft/sec) divided by the time (8 sec). The acceleration is 11 ft/sec. If the car accelerates smoothly, at the end of the first second the car is traveling 11 ft/sec.

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The car gains 11 ft/sec in speed every second until at the end of the 8th second, the car is traveling 88 ft/sec. Acceleration is not merely the change in speed. Acceleration is the change in speed with respect to time. To say a car accelerates from 0 mi/hr to 60 mi/hr is not enough. A car that requires 12 seconds to reach 60 mi/hr does not have the same acceleration as a car that requires 8 seconds to reach 60 mi/hr. Both the change in speed and the elapsed time must be known to calculate acceleration.



Galileo wanted to find the acceleration due to gravity of a freely falling body. From his experiments with the inclined plane, Galileo determined the distance, speed and acceleration of a freely falling body for each second of travel. Notice that the acceleration due to gravity is a uniform 32 ft/sec^2. Each second a falling object gains an additional 32 ft/sec of speed. The acceleration is the same in or out of vacuum regardless of the type of object, whether it is a brick, bowling ball or steel safe. If each one is dropped from the same height at the same instant, they will fall together and each will gain speed at the same rate. A heavy object does not fall more quickly than a light one. A heavy object and a light one will each accelerate at 32 ft/sec^2. Their distance traveled and final velocity will be the same. In the metric system, the acceleration due to gravity is 9.80 m/sec^2.

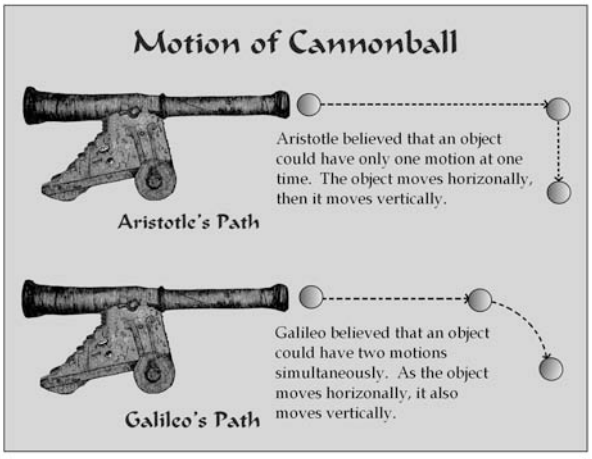
Acceleration due to Gravity

Time in seconds	Distant in feet	Final Velocity in ft/sec	Acceleration of Gravity in ft/sec^2
1	16	32	32
2	64	64	32
3	144	96	32
4	256	128	32
5	400	160	32

Suppose an object is fired from a cannon and not dropped. Scholars in Galileo's time argued that a projectile could have only one motion at a time. A projectile is an object that is launched or thrown, like a bullet or a cannonball. Scholars claimed that a ball shot from a cannon would fly out in a straight line until it lost its impulse from the cannon. Gravity would take over, and the ball would fall in a straight line to Earth.

Galileo disagreed. He believed the cannonball could have two motions simultaneously. One of Aristotle's rules to understanding a complicated problem is to separate the problem into individual component parts. First, he would investigate each part separately. When each part of the problem was understood, the task of understanding the whole was made easier.

Galileo used Aristotle's idea. Although the cannonball followed a single curved path, its motion could be separated into two parts. One motion was the constant velocity given by the explosion of powder in the cannon. The other motion was the constantly

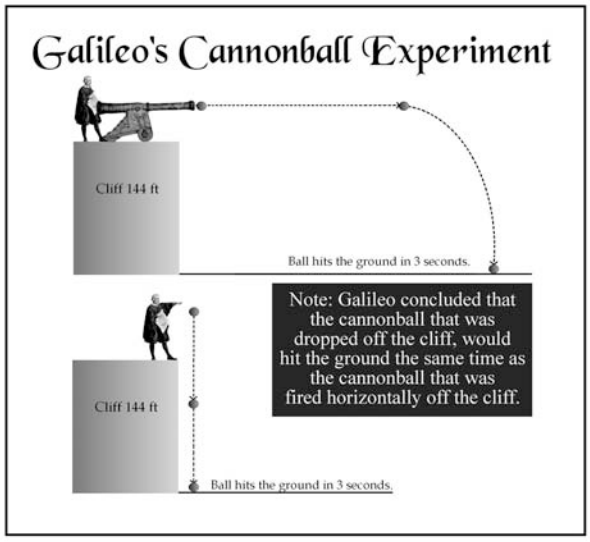


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changing velocity due to the acceleration of gravity.

Galileo studied the two motions of the cannonball. Imagine a cannon placed at the edge of a cliff that is 144 feet high. Suppose the cannon is aimed horizontally or parallel to the ground. When it is fired, it gives the ball a speed of 400 feet per second in the horizontal direction. This constant speed does not change (except for air friction). Although gravity pulls down on the cannonball, that action is at right angles to the horizontal flight of the cannonball. It has no effect on its horizontal speed.

Suppose that instead of being fired

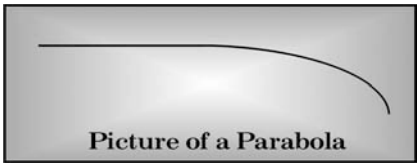


from the cannon, the cannonball had been merely dropped from the edge of the cliff. Gravity causes the cannonball to gain a vertical speed at the rate of 32 ft/sec for every second it falls. Galileo's table shows that for a cliff 144 feet high, the cannonball will strike the ground in 3 seconds.

Galileo discovered that both a dropped cannonball and one fired horizontally from a cannon will fall at the same speed. If the cannonballs start from the same height, both will strike the ground at the same time. The one fired from the cannon at 400 ft/sec will land 1,200 feet away from the side of the cliff, but it will still hit the ground at the same time as the cannonball that is dropped.

If the cannon were aimed at an angle into the air, the two would not impact at the same time. Galileo's results were from a cannon pointed perfectly parallel to the ground.

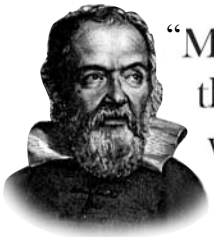
Galileo analyzed the motion of the cannonball and proved that it or any other projectile would follow a parabolic path. A ***parabola*** is a shape like the one shown in the following picture.



Most people believed objects on Earth followed straight lines, while objects in the heavens followed circular orbits. A parabola is neither a circle nor a straight line. If objects on Earth do not follow straight lines, then objects in the heavens may not follow circular orbits. A gunner should point a cannon at an angle to obtain the greatest range. The range is the distance from the cannon to the place where the projectile lands.

Galileo knew that the path of a cannonball was parabolic. If a cannon is fired straight up in the air, 90°, the cannonball will fall right back on the cannon. If a cannon is fired parallel to the ground, 0°, the cannonball embeds itself in the Earth almost immediately. The maximum range results when the cannon is aimed at 45° which is halfway between vertical and horizontal.

Life Principle



"Mathematics is the language with which God wrote the universe."

—Galileo

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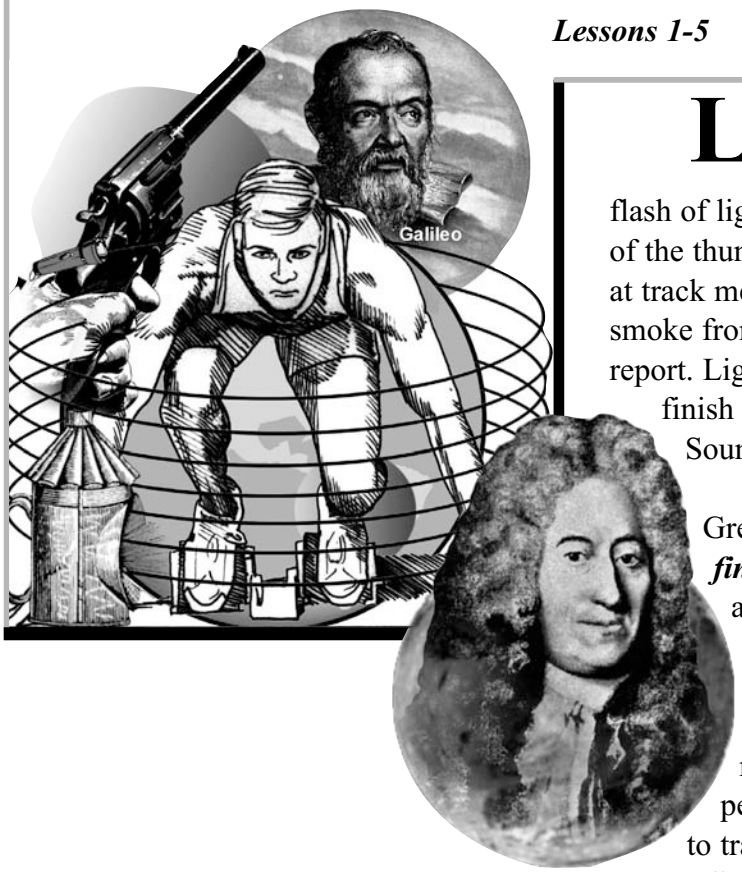
Chapter 2

Lesson 4
Light & Sound

GALILEO, ROEMER AND THE SPEED OF LIGHT

Section 1

Lessons 1-5



Light travels faster than sound. During a thunderstorm, an observer sees the flash of lightning, and moments later the rumble of the thunder arrives. Timers who clock runners at track meets start the stopwatches at the puff of smoke from the starting gun, not the sound of the report. Light goes from the starting blocks to the finish line in a small fraction of a second. Sound lags behind.

Scientists from the time of the ancient Greeks knew that the speed of sound was ***finite***. Suppose a shipbuilder is hammering a peg into a reluctant board. As an observer walks away from the construction, the hammer hits the peg, and then, after a slight delay, the sound reaches the ear. The further away a person walks, the longer the sound takes to travel from the source to the listener.

In Medieval times, when a cannon was fired, the observer first saw the flash of the explosion. Then a short time later, the blast came to the ear. The speed of sound could be calculated by measuring the distance to the cannon, and dividing by the time for the sound to arrive. If the cannon was 565 feet away, and the sound was delayed by 1/2 second, then the speed of sound was 1,130 ft/sec: speed = distance/time = 565 ft / 0.5 sec = 1,130 ft/sec.

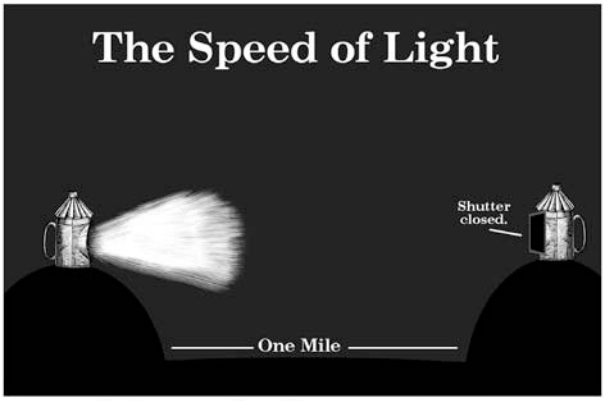
Calculating the speed of sound from the blast of a cannon assumes light does not take any time to travel from the cannon to the observer. In Galileo's day, no one knew the speed of light. Most scientists assumed that light was ***instantaneous***. Some thought that light traveled immediately from one point to another. Others believed the speed of light to be very rapid but finite.

VOCABULARY

Finite: having limits; restricted
Instantaneous: occurring without delay
Eclipse: blocking of light from one object by another relative to an observer
Speed of light: 300,000,000 m/sec (300 million meters per second), or 186,000 mi/sec

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One night Galileo tried to measure the speed of light as he stood on a hilltop with a lantern. The lantern had a shutter so it could reveal the light. An assistant stood on a hilltop one mile away. Galileo opened the shutter. When the assistant saw the light, he opened his shutter. The total time between the moment Galileo opened his shutter and the return of the answering light from his assistant was about 1.5 seconds. The light had traveled 2 miles, from Galileo to the assistant and back again, in 1.5 seconds. This gave it a speed of 2 mi / 1.5 sec = 1.33 mi/sec for the speed of light. Galileo was not sure of this, so he decided to repeat the experiment with the assistant even further away. The experiment still took 1.5 seconds. He tried again with the assistant in a different location across the courtyard from him. In all cases, the experiment took about 1.5 seconds. Galileo realized he was not measuring the speed of light, but the human reaction time of his assistant in opening the shutter. The reaction time is the time it takes to respond to a situation. Galileo could only conclude that the speed of light was "extraordinarily rapid."



Note: Galileo realized he was not measuring the speed of light but the human reaction time of his assistant in opening the shutter.

Galileo and other scientists struggled in their research because they had no accurate way to measure time. Most clocks had only hour hands and kept time poorly. The clocks were big and took up entire towers at city halls and in churches. About sixty years later, scientists had better means of measuring time. In fact, Galileo's own discovery of the Principle of the Pendulum led to the invention of accurate clocks.

Christiaan Huygens, a Dutch physicist, was born a few years before Galileo died. Huygens possessed a sharp mind and practical ability. He built a clock capable of keeping time to the minute. He used the regular back and forth motion of a swinging pendulum to control the gears of the clock, a series of slowly falling weights on a chain kept the pendulum in motion. Instead of a clock tower, the gears and pendulum were placed in a much smaller case, such as a piece of furniture in a person's living room. Clocks of Huygens' design became known as grandfather clocks.

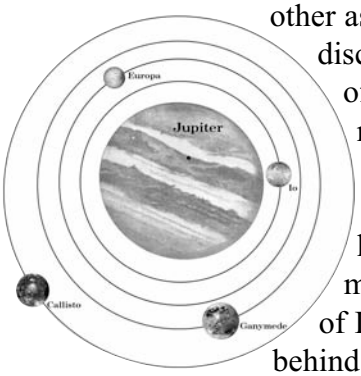
Christiaan Huygens also made a much smaller clock which used the regular back and forth motion of a balance spring to keep time. For the next 200 years, all clocks and watches used the principle of either the pendulum or the balance spring to keep accurate time. Christiaan Huygens helped invent both designs. The accurate instruments improved scientific discoveries.



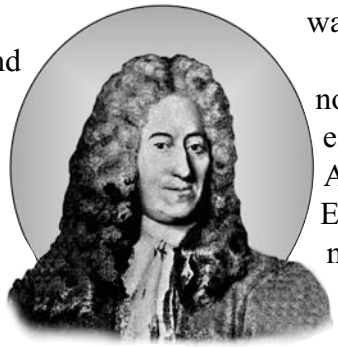
With the improved clock, scientists could tackle problems that were more difficult. In the 1670s, Olaus Roemer, a Danish astronomer, made careful observations of Jupiter's four largest satellites. Galileo had discovered these four large moons. Astronomers named these large moons Ganymede, Callisto, Europa and Io. Ganymede and Callisto are larger than the planet Mercury. All four moons can be seen

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with the smallest telescope. Roemer and other astronomers had discovered the orbit of the innermost moon, Io, which orbited the planet, Jupiter, in 42 hours and 28 minutes. The orbit of Io took the moon behind Jupiter as seen from Earth. Roemer expected the reappearance of Io from behind Jupiter to be very predictable.



Olaus Roemer timed the event every night. As the days passed, Roemer found that prediction and observation did not agree. At first the ***eclipse*** and reappearance came on schedule, then Io began lagging behind schedule. At the end of 6 months, Io fell 1,000 seconds behind schedule, about 17 minutes. Then Io began getting on schedule again. Six months later, the eclipses of Io followed their predicted times.


Olaus Roemer

Olaus Roemer noticed that Io always kept on schedule when Earth was on the same side of the Sun as Jupiter. Io fell behind schedule when Earth was on the other side of the Sun, away from Jupiter. Then Roemer realized the reason for the problem. The problem was not Io; instead, it was the finite speed of light that caused the change in schedule.

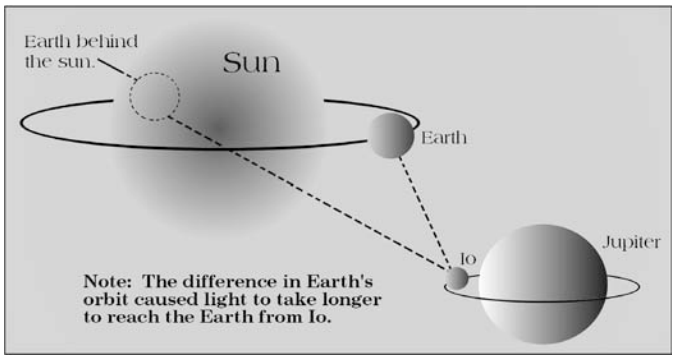
When Io reappeared from behind Jupiter, the light left the orbit of Jupiter and raced toward Earth. When Earth was on the other side of the Sun, the light had to go farther. The light had to travel all the away across Earth's orbit. Light needed more time to travel the extra distance. This caused Io to appear to fall behind schedule.

Roemer was performing Galileo's experiment but on a much larger scale. Rather than hilltops one mile apart, Roemer had Earth in two different locations. The distance separating the two locations was the distance across Earth's orbit.

To calculate the speed of light, Olaus Roemer needed two values. First, he needed the distance from one side of Earth's orbit to the other. Secondly, he needed to know how much time the events varied. Roemer had recorded the time of 1,000 seconds that Io was lagging behind schedule.

The distance across Earth's orbit was not as well known. Astronomers had only an estimate for the size of Earth's orbit. Astronomers believed that the distance from Earth to the Sun was 75,000,000 miles (75 million miles). The diameter of Earth's orbit would be twice that figure or 150,000,000 miles. A simple calculation gave Roemer the speed of light: speed = distance/time = 150,000,000 mi / 1,000 sec = 150,000 mi/sec.

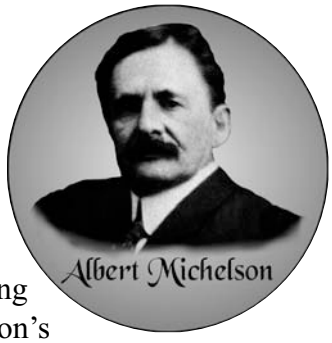
Olaus Roemer's result was too low. The modern value for distance from Earth to the Sun is 93,000,000 miles. The distance across Earth's orbit is 186,000,000 miles. If Olaus Roemer had known the modern value for the distance, his result would have been much better: speed = distance/time = 186,000,000 mi / 1,000 sec = 186,000 mi/sec. The value of 186,000 mi/sec is usually the



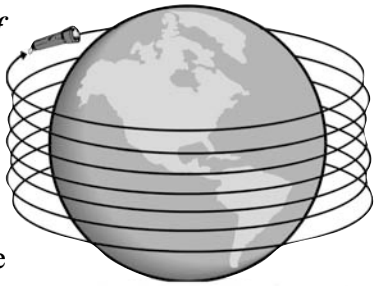
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one given for the speed of light. Olaus Roemer was the first person to show that light had a finite speed and to give a value for that speed. This alone was an important scientific discovery.

Within 50 years after the death of Galileo, Roemer had arrived at a value for the speed of light. This shows the effect Galileo had upon modern science. Physics made great strides because of Galileo's study of moving bodies.



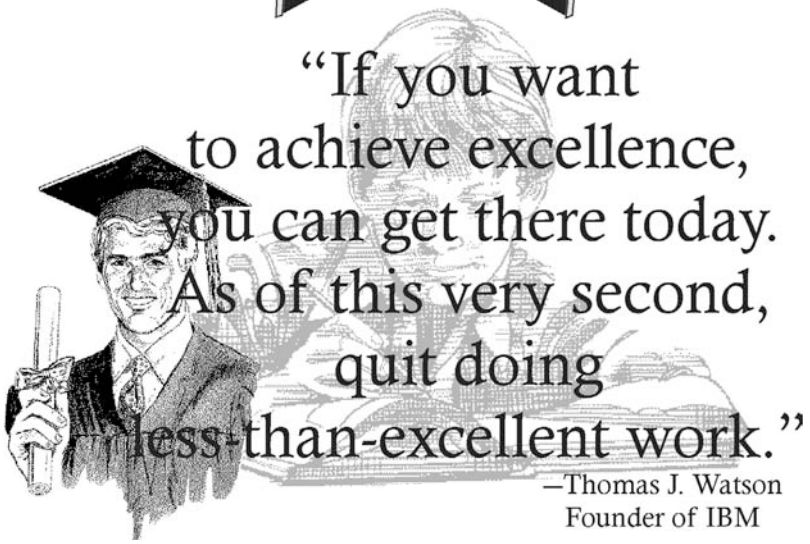
In 1926, Albert Michelson developed a plan to measure the speed of light as a laboratory experiment. To measure the speed of light, Albert Michelson built a rotating 8-sided mirror. Michelson's "assistant" was a mirror, 35 km away. Michelson bounced a beam of light from the 8-sided mirror to the other mirror and back again. He then rotated the 8-sided mirror at a high rate of speed, about 530 revolutions per second. The light could make the round trip in the time that the mirror had turned 1/8 of the way around. Using this device, he calculated the speed of light to be about $2.998 * 10^8$ m/s.



Note: Did you know that light is fast enough to go around the Earth 7 times in 1 second?

The ***speed of light*** is an important quantity in physics. Each year, improved methods are used to measure light's speed. Currently, the best value for the speed of light is 186,282.396 mi/sec, in a vacuum. This is usually rounded off to 186,000 mi/sec. This value in the metric system is 300,000,000 m/sec, 300 million meters per second. Scientists know the speed of light so exactly, they can use it to measure distance. Scientists can measure the distance to the Moon to within a few centimeters by reflecting light from the mirrors left there by the astronauts.

Life Principle



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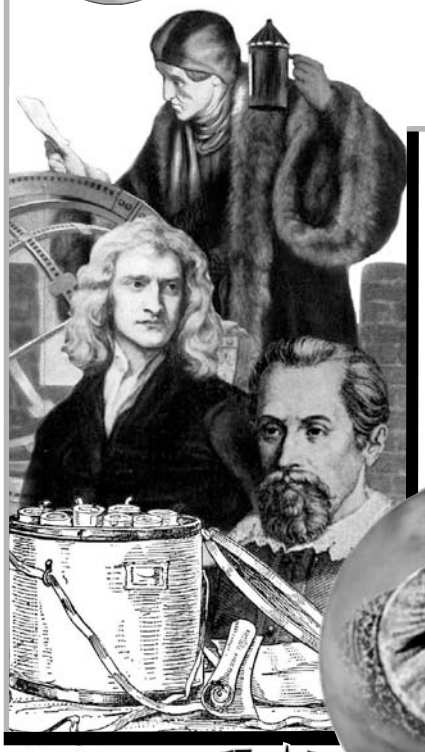
Lesson 5
Planets

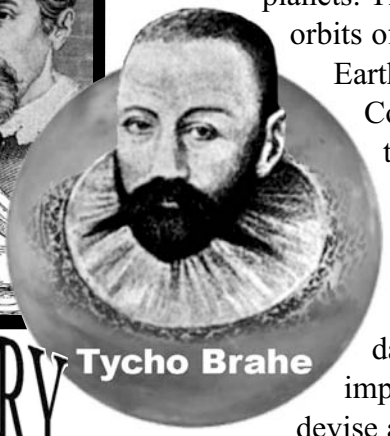
Chapter 2

BRAHE, KEPLER AND COPERNICUS: MOTION IN THE HEAVENS

Section 1

Lessons 1-5



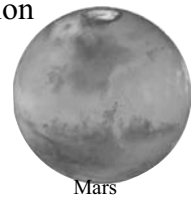


Tycho Brahe, a noted Danish astronomer, was born in 1546 of a noble family. At the age of 14, Brahe observed an eclipse of the Sun. He was impressed that such a spectacular event could be predicted with such accuracy. However, Tycho Brahe discovered that astronomers were not happy with their accuracy in describing the motions of the planets. The astronomers constantly debated the orbits of the planets. Some astronomers placed the Earth at the center of the universe. Others, like Copernicus, placed the Sun at the center of the planetary system. Tycho Brahe believed the debate could best be settled if astronomers had more accurate observations of the planets.

Brahe's idea of first gathering data and then forming a ***theory*** is an important principle of science. In order to devise a theory, carefully experimenting and gathering the facts is better rather than basing a theory on speculation.

Tycho Brahe became an astronomer and spent 20 years making careful measurements of the positions of the planets against the background of stars. Brahe's goal was to measure planetary positions ten times more accurately than the best measurements available. The king of Denmark gave Tycho Brahe a private island and all the money he would need to build the finest observatory in the world.

Brahe's experiments were before the invention of the telescope. Nevertheless, Brahe's observations remained the best available for almost a hundred years after the invention of the telescope. Even today, when astronomers combine observations over several centuries, they continue to use Tycho Brahe's measurements.



Mars

VOCABULARY

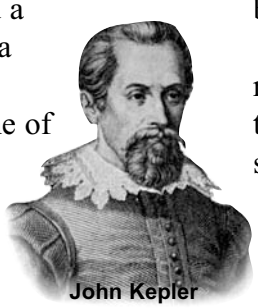
Theory: explanation for a set of observations that have not been fully tested and completely accepted as fact
Celestial: having to do with the Sun, Moon, stars and the appearance of the night sky
Ellipse: a closed curve that looks like a flattened circle
Foci: plural of focus
Focus: for an ellipse, one of two points located on the long axis
Derive: obtain a result from a different source

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Brahe's most careful measurements were of the planet Mars. Mars is known as the Red Planet. The nearest planet to Earth is Venus. However, Mars is visible throughout the night-time hours and is easily observed with the unaided eye. Although Tycho Brahe was an exceptionally gifted observer, he did not have mathematical skills. When calculation of the orbits of the planets was necessary, Tycho gave that task to professional mathematicians.

During this time, astronomers assumed that planetary orbits consisted of circles or combinations of circles. In the case of Mars, Brahe's mathematician had to use several circles to explain all of his data. Tycho Brahe's observations were very exact. If the calculated orbit and his observations disagreed, then he knew the problem was with the calculations. The mathematician Tycho Brahe had employed could not produce an accurate orbit of Mars.

In 1600, Tycho Brahe moved from Denmark to Prague, Czechoslovakia (present day Czech Republic). This put him closer to John Kepler, a teacher of mathematics at the University of Graz in Germany. As part of his duties, John Kepler composed a yearly calendar and almanac, a book that helps farmers and travelers by predicting the time of sunrise, sunset, the full moon and other events. John Kepler found that a sun-centered planetary system made the calculations easier. Kepler quickly embraced Copernicus' theory as being accurate.


John Kepler

The great astronomer, Nicolaus Copernicus, was born in Poland in 1473. He came from a wealthy family. Copernicus could have been a doctor, lawyer, church leader or an ambassador to a foreign country. He became all of these and more. Nicolaus Copernicus served as a Bishop's private physician and faithfully devoted most of his time to church work.

Copernicus studied astronomy in his spare time. He found that calculations could be made easier if he presumed that the Sun, and not Earth, was at the center of the planetary system. Copernicus summarized his ideas in a short, hand-written manuscript. He sent it around to his friends and fellow scientists. Copernicus used circles to describe the planetary motions.


Nicolaus Copernicus

As time passed, Copernicus pointed to additional evidence that planets do orbit the Sun. For instance, Mars changes in brightness. During a period of about two years, Mars fades from bright red to a much dimmer red. Scientists wondered why this happened. Earth-centered planetary system offered no explanation for the difference in the brightness of Mars. According to Aristotle, Mars circled Earth at the same distance and should have been equally as bright all year round.

Copernicus' system explained the reason for the change. Mars and Earth both travel around the Sun, orbiting at different speeds. Sometimes their orbits bring them closer together. During this time Mars looks brighter. At other times, their orbits put them farther apart. When Mars is farther away from the Sun, the planet appears not as bright, as observed from Earth.

Copernicus spent many years gathering evidence for his sun-centered theory. As he observed the planets carefully and made detailed calculations, he improved the original hand-written manuscript. Nicolaus Copernicus' new book was entitled *On the Revolution of the* ***Celestial*** *Sphere.*

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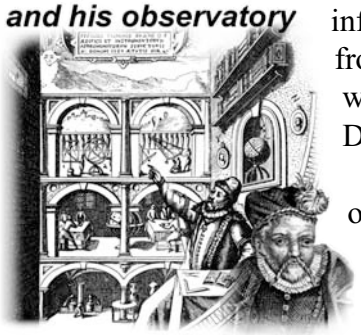
Friends encouraged Copernicus to publish the book. He hesitated out of concern for his own safety. Rulers did not encourage new ideas. These rulers were afraid that the astronomers would remove Earth as the center of the universe. People might think that a king did not belong on his throne at the center of the kingdom. New ideas led to unrest. Rulers in power punished authors of books that caused problems. Copernicus could go to prison for publishing the book.

Copernicus took the dangerous step, sending his manuscript to a printer. On May 24, 1543, Copernicus lay in bed desperately ill when the first copy of the book arrived. A friend of Copernicus put the book in his hands. Copernicus died that same day.

The honor of writing what many believe to be the first modern book on science belongs to Copernicus. He correctly stated that Earth is a globe and rotates on its axis. Earth and all the planets revolve around the Sun. The Moon alone orbits Earth. Copernicus' book was published three years before the birth of Tycho Brahe, and 21 years before the birth of Galileo.

On the Revolution of the Celestial Sphere began a revolution not only in astronomy but also in all science. It would be read, studied and remembered throughout the ages.

John Kepler based his work on Copernicus' ideas. However, Kepler's calculations fell short of predicting celestial events to his satisfaction. He needed recent observations of the planets. John Kepler could get that information only from Tycho Brahe, who lived in Denmark.



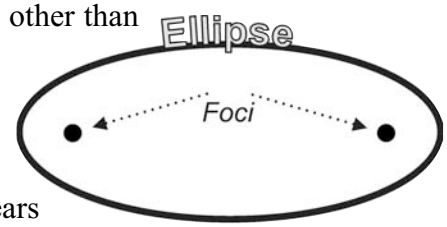
Tycho Brahe and his observatory

Kepler despaired of ever meeting the great Tycho Brahe and seeing the planetary data. About this time, Kepler faced persecution because of his religious faith. He maintained in his research of astronomy that he was merely "thinking God's thoughts after Him." Kepler was ordered to leave his home. He sold his house and most of his possessions and fled to Prague.

The king of Denmark, Tycho Brahe's benefactor, died and Brahe was forced to move. The great astronomer decided to set up a new observatory outside Prague. Brahe invited the young mathematician, Kepler, to work at the observatory as Brahe's chief assistant. In just a few months, Brahe realized the brilliant John Kepler had the mathematical skill to tackle the orbit of Mars. When Tycho Brahe died in 1601, he left all of his years of data to John Kepler. It was his treasure, far more important than gold.

John Kepler worked on the orbit of Mars for days, months and years. Tycho Brahe's observations were particularly unforgiving. The accuracy of the data revealed the slightest errors. No matter how he placed the circles and no matter their size, Kepler could not find a series of circles that fit Mars' orbit.

John Kepler finally realized his error. He, along with the other astronomers, including Copernicus, believed Mars traveled at a constant speed in a circle. John Kepler had the astonishing idea that Mars' orbit must be a figure other than a perfect circle. The solution took more than six years and thousands of pages of calculations. John Kepler proved that Mars traveled around the Sun in





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an ***ellipse***. Like the parabola, the ellipse had been known since the time of the ancient Greeks. All of the circles used to describe a planet's motion could be swept away and replaced with a single ellipse.

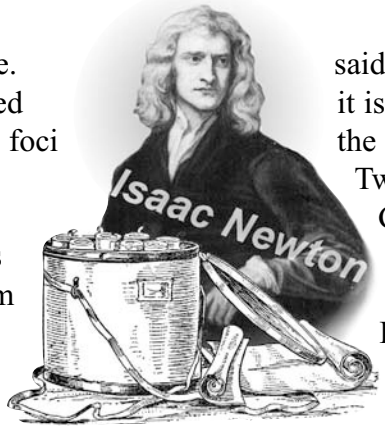
An ellipse is like a flattened circle. Along its central axis are two points called ***foci***. (Each point is called a focus.) If the foci are far apart, then the ellipse is long and skinny. If the foci are close together, the ellipse looks like a circle. The ellipse has the special property that the distance from one ***focus*** to any point on the ellipse and back to the other focus is a fixed distance. Mars' orbit is only slightly elliptical. Its true shape escaped detection until Brahe's data became available. John Kepler summarized his findings in the Three Laws of Planetary Motion.

The First Law of Planetary Motion states that the planets follow elliptical orbits around the Sun. The Sun is at one of the foci. An elliptical orbit brings a planet closer to the Sun at one part of its orbit than at the other. A planet travels faster when near the Sun.

Kepler's Second Law of Planetary Motion states that a line connecting the planet to the Sun will sweep out equal areas in equal intervals of time.

The Third Law of Planetary Motion gives the distances of a planet from the Sun based on the time required for the planet to orbit the Sun. Earth orbits the Sun in one year. Saturn requires more than 29 years. Knowing these times, Kepler could calculate that Saturn is almost ten times as far from the Sun as Earth.

With Kepler's Three Laws of Planetary Motion, astronomers could correctly predict the motions of the planets. Later, John Kepler proved that the moons of Jupiter followed the Three Laws of Motion but with Jupiter at one of the foci, rather than the Sun. John Kepler's laws escaped discovery by generations of great astronomers. Aristotle, Copernicus, Brahe and Galileo never suspected that the planets travel in elliptical orbits rather than circular ones.



Isaac Newton later said, "If I have seen farther, it is because I have stood on the shoulders of giants." Two of the giants were Galileo and Kepler. Isaac Newton combined Kepler's Three Laws of Planetary Motion with Galileo's study of motion on Earth. By studying these laws, Newton developed the Three Laws of Motion and the Law of Universal Gravitation. One reason that scientists readily accepted Newton's Law of Gravity was that the scientists could ***derive*** Kepler's three laws from it. Scientists could start with Newton's law, perform the appropriate calculations and confirm Kepler's three laws.

Like Galileo, John Kepler enjoyed great fame during his life. On any list of the greatest scientists of all time, Galileo and John Kepler are usually in the top ten.



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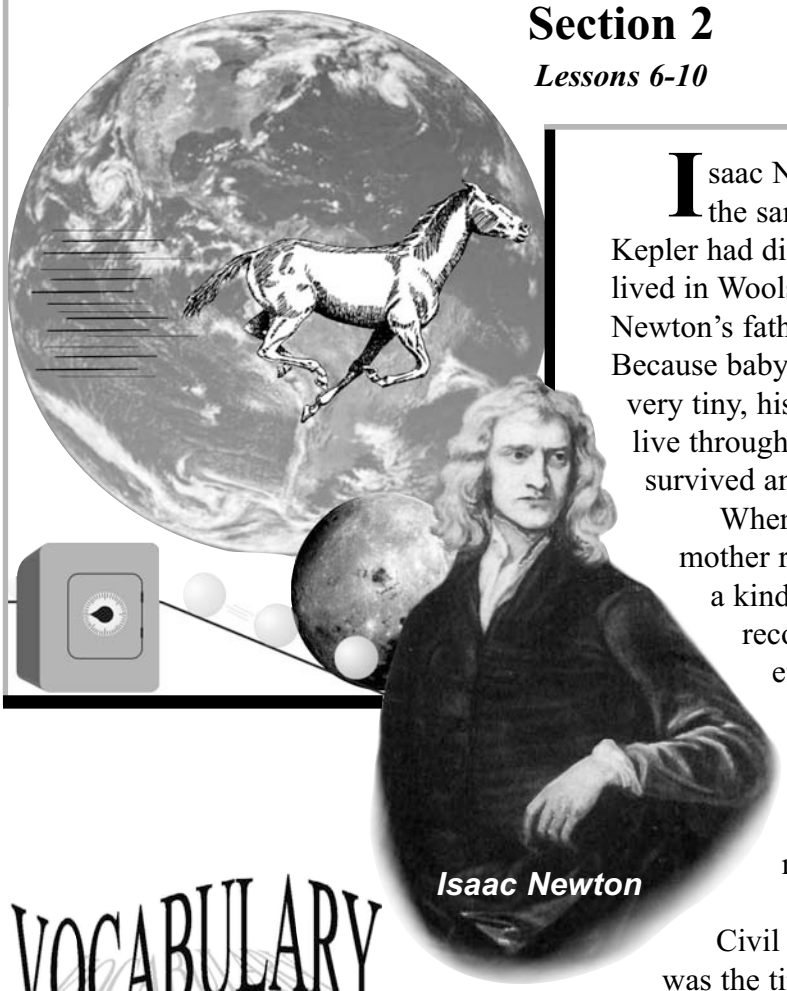
Lesson 6
Motion

Chapter 2

VELOCITY, MASS, ACCELERATION AND FORCE

Section 2

Lessons 6-10



Isaac Newton

Isaac Newton was born December 25, 1642, the same year that Galileo died. John Kepler had died 12 years earlier. Isaac Newton lived in Woolsthorpe, Lincolnshire, England. Isaac Newton's father had died before Isaac's birth. Because baby Isaac was born prematurely and very tiny, his mother feared that he would not live through the harsh winter. Isaac Newton survived and lived to be 85 years old.

When Isaac was three years old, his mother remarried. The man she married was a kind gentleman but set in his ways. He recognized his own inability to be an effective father to the boy and suggested that Isaac be allowed to live with his grandmother. Isaac's mother did not live far away, so the boy was able to visit his mother often.

Isaac Newton lived during the Civil War in England, 1642-1648. This was the time when Oliver Cromwell ruled the country. In 1658, before Oliver Cromwell died, a terrible storm destroyed much of the country. The storm uprooted trees that were huge and very old. After making sure the animals were safely in the barn, Isaac spent a moment jumping first with the wind and again against it. He experienced firsthand the invisible ***force*** of wind.

Isaac Newton was raised by two women who adored him. He could have been a spoiled young man, but instead, Isaac lived an ordinary childhood, spending more time making models than other children his age. He flew kites, made sundials and built a miniature grain mill that actually worked. Isaac Newton attended school and earned acceptable, if not exceptional, grades. No one had any reason to believe that Isaac

VOCABULARY

Force: quantity that causes change in velocity of an object
Fellow: person who takes advanced studies at a university
Black Death: an outbreak of bubonic plague which killed one-fourth of the population of Europe and Asia in the 1500s; transmitted by the bite of fleas from infected rats; named from black areas produced on people's skin

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would become one of the greatest scientists who ever lived.

After seventeen years of local education, an uncle suggested that Isaac attend college. Everyone recognized that Isaac was not suited for farming. One day, Isaac went to get a horse. As he led the horse back by the reigns, the horse slipped out of the bridle. Isaac was thinking so intently about a problem that he came home pulling an empty bridle behind him. He was not aware that the horse was gone.

In 1661, Isaac Newton enrolled in Trinity College at Cambridge University. His family was so poor that they could not pay his tuition. He earned his way by waiting on tables, cleaning the rooms of the instructors and of the wealthy students. Before Isaac graduated, he was made a ***fellow***. This allowed him to remain at college for advanced studies and provided for a room and his meals.

In the summer of 1665, the terrible ***Black Death*** struck London. The Black Death was the spread of a horrible disease which tormented Europe on many occasions. As a safety measure, the university administrators decided to close the university. The recess from school extended for 18 months. Isaac Newton used the time to think about what he had learned at Cambridge.

Isaac investigated color and the nature of light. He proved that sunlight contains all the colors of the rainbow. Isaac invented a powerful form of mathematics known as calculus. As you continue to study science or mathematics, you will learn about calculus. Isaac Newton came to an understanding of motion and the nature of gravity. For the next twenty-five years, he would develop his discoveries.

Isaac Newton realized that scientists would not understand the laws of motion if they did not understand the concepts of velocity, acceleration, mass and force.

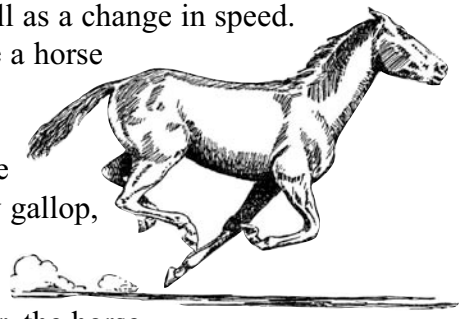
VOCABULARY

Weight: the force of gravitational attraction between an object and Earth; In the metric system, weight is measured in newtons

Newton: metric system unit for force required to accelerate a mass of one kilogram one meter per second per second

VELOCITY

Speed is the change of distance with respect to time: speed = distance/time. In symbols, $v = d/t$ with v the speed (or velocity), d the distance and t the time. *Velocity* includes both speed and direction. If either one changes, then velocity changes. A change in velocity can be a change in direction as well as a change in speed.



Imagine a horse is racing on a circular race track. The horse runs at a steady gallop, neither gaining nor losing speed. However, the horse is changing velocity because it is constantly changing direction.

Imagine a weight at the end of a string. A person holds the string and spins the weight over his head. The weight travels in a circle, held in place by the tension on the string. Although the speed of the weight may be kept constant, the velocity is always changing. The weight is changing direction every moment as it flies in a circle.

Another example is the Moon orbiting Earth. Like planets, the Moon travels in an elliptical orbit. The center of Earth is at one

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focus. However, the Moon's orbit is nearly circular, and it changes speed very little from one day to the next. During part of the month, the Moon is a little closer to Earth and goes a little faster. Later, the Moon is farther from Earth and goes slower.

The Moon is constantly changing its direction. Less than a month is required for the Moon to orbit around Earth (27 days, 7 hr, 43 min). Like the weight at the end of a string, the gravitational attraction between the Moon and Earth constantly bends its straight-line path into a nearly circular one. The Moon is constantly changing its direction of travel and its velocity.

ACCELERATION

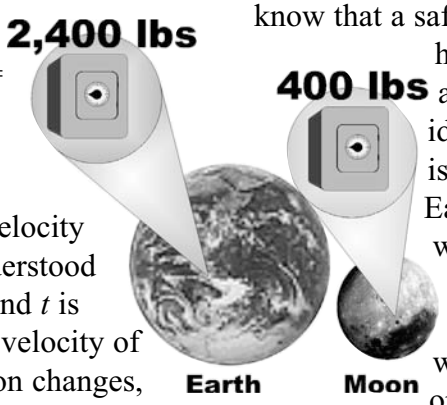
Acceleration is the change in velocity with respect to time: acceleration = change in velocity/change in time. As an equation this is written as $a = v/t$ and read as, "acceleration is equal to the velocity divided by the time." V is understood to be the change in velocity, and t is the change in time. When the velocity of a body changes, its acceleration changes, too. A body that changes direction is accelerating even though it does not change speed. As a car makes sharp turns, the passengers in the car feel the acceleration as they tend to sway to the left and to the right. All the objects in the previous examples (the horse on the circular racetrack, the weight at the end of a string and the Moon in orbit about the Earth) undergo acceleration because the velocity constantly changes. The straight-line speed of the Moon is being changed constantly into circular motion by gravity. The Moon is undergoing acceleration because of change in direction.

Acceleration does not always cause a body to increase in speed. An object that is going slower is undergoing negative acceleration, sometimes called *deceleration*.

MASS

Isaac Newton understood that mass and weight were not identical. Mass is a measure of the amount of matter that makes up an object. Weight is how strongly a body is acted upon by gravity. If two objects with the same mass are located side by side in the same gravity field, they have the same weight. Suppose one object is on Earth, and an identical one is on the Moon. The object on the Moon has the same mass as its twin on Earth. The object's weight is only one-sixth as much, because the Moon has a weaker gravity.

Imagine a large steel safe used to store valuables was placed on the Moon. We know that a safe is massive and that it is very heavy. In ordinary day-to-day activities, mass and weight are identical. Gravity on the Moon is only 1/6th as great as on Earth. On the Moon, the safe's weight is now only 1/6th as much. If the safe weighed 2,400 pounds on Earth, then it would weigh only 400 pounds on the Moon.



Whether on Earth, on the Moon or floating in space, the steel safe has the same mass. The amount of material used to make the safe has not changed. Its mass remains constant regardless of its location.

If a person were to kick the side of a safe here on Earth the safe would likely cause injury to the person's toes. The heavy steel safe would not fly away like a football. On the Moon or in space the injury would not be less, because the safe has the same amount of matter. Even when an object is weightless, matter continues to resist changes in its motion. For that reason, a swift kick of a safe floating in space is just as likely to

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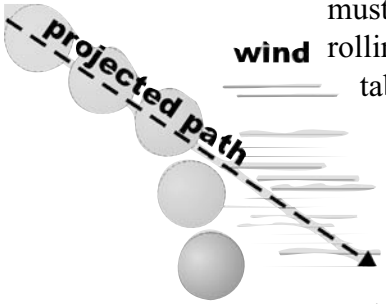
cause injury to the foot as a kick here on Earth.

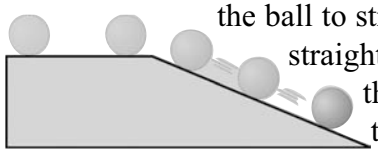
Weight is a measure of the effect of gravity. Mass is a measure of the amount of matter. An object floating freely in space may be weightless, but it still has mass.

In the metric system of weights and measures, the *kilogram* (about 2.2 pounds on Earth) is a measure of mass.

FORCE

As Galileo noticed, an outside agent must act on a ball rolling across a table to change the ball's speed or direction. Friction between the ball and the table would slow the ball's motion. Wind blowing at the ball from the side could cause the ball to stray from its straight-line course. If the table were tilted downward, then gravity could cause the ball to gain speed.

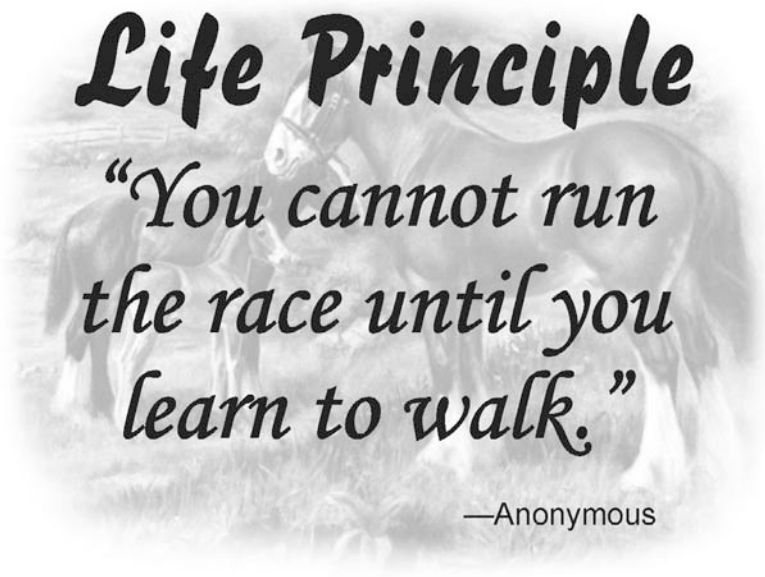




Isaac Newton gave the name *force* to anything that can change the velocity of an object. Friction, wind, gravitational attraction and expanding gases in a cannon — these all produce force. They will cause an object to gain or lose speed or to change direction.

In the metric system, force is measured in ***newtons***. One newton is defined as the force that will cause a one-kilogram of mass to accelerate at 1.00 m/sec^2.

Mass and weight are used interchangeably. In conversation, scientists do not distinguish between weight and mass. They do not ask, "How much does that object mass?" Instead, scientists will ask, "How much does it weigh?" In working physics problems, scientists do keep the two terms separate. The mass of an object, measured in kilograms, describes the amount of matter the mass contains. The weight of an object measured in newtons describes how strongly the object is attracted by gravity.



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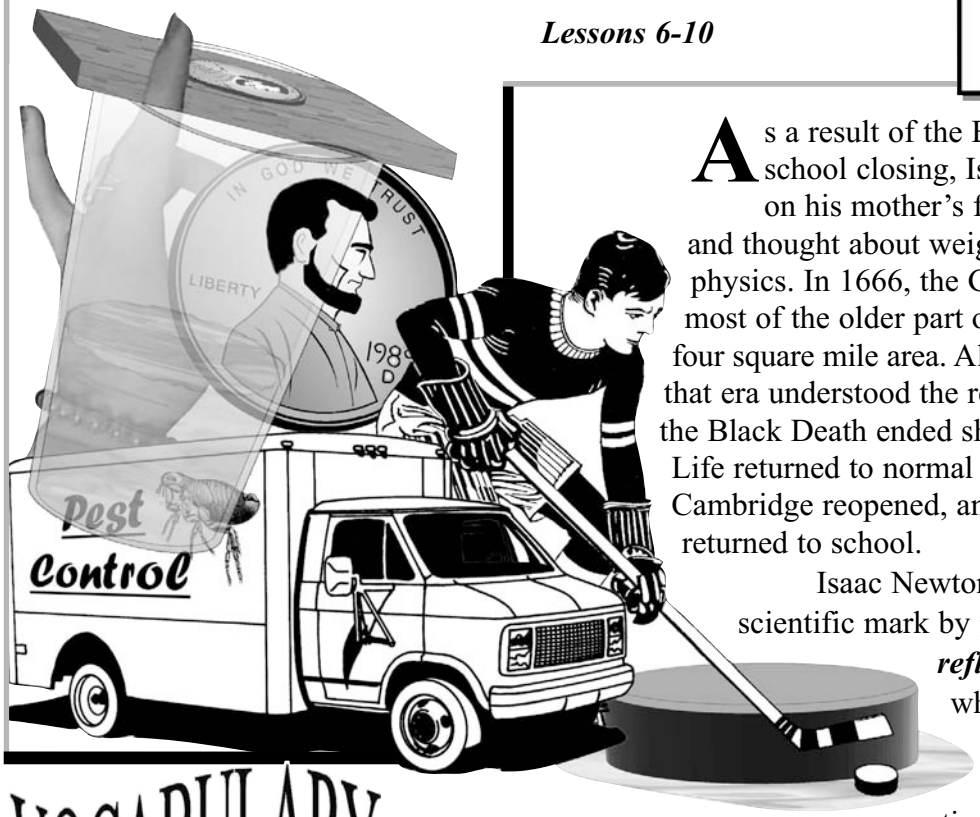
Lesson 7
Motion

Chapter 2

MOTION, GRAVITY AND THE STARS

Section 2

Lessons 6-10



As a result of the Black Death and the school closing, Isaac Newton stayed on his mother's farm for 18 months and thought about weighty problems in physics. In 1666, the Great Fire destroyed most of the older part of central London, a four square mile area. Although no one of that era understood the reason, the spread of the Black Death ended shortly after the fire. Life returned to normal in England. Cambridge reopened, and Isaac Newton returned to school.

Isaac Newton made his first scientific mark by inventing the first ***reflecting telescope***, which brought light to a focus with a mirror. Until this time, all telescopes formed an image by a glass lens. Prior to Newton's invention, astronomers used ***refracting telescopes,*** which had a glass lens, to bend the rays of light and form an image. The lens also acted as a weak prism and introduced false color. Distracting color fringes surrounded the images of bright planets and stars.

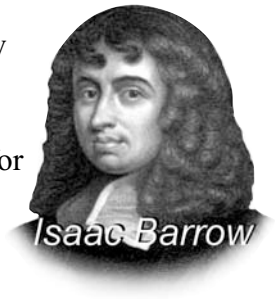
Isaac Newton knew that a mirror reflects all colors equally without introducing false colors. He built a reflecting telescope with a curved mirror that brought light to a focus to form an image. Newton's telescope was about a foot long and as powerful as lens telescopes that measured 15 feet in length. Reflecting telescopes still have many advantages over lens telescopes. The reflecting telescopes can be made compact and cost less money to manufacture. The world's most powerful telescopes use mirrors instead of lenses.

VOCABULARY

Reflecting telescope: a telescope whose primary surface for bringing light to a sharp focus is a mirror
Refracting telescope: a telescope that brings light to focus by bending light as it passes through a lens
Inertia: property of an object that resists acceleration
Proportional: two quantities are proportional if changes in one produces changes in the other by the same ratio

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Isaac Barrow, Newton's mathematics teacher, saw Isaac's ability before anyone else. Barrow had a paid position at Cambridge University that ensured financial income for life. Isaac Newton still did not have a permanent source of income. Isaac Barrow resigned from Cambridge University so Isaac Newton could have the position.



For the next twenty-five years, Isaac Newton stayed at Cambridge and brought great fame to the school. He was a very religious person who had strong Christian beliefs. He wrote two books about the Bible. Much of Newton's research about stars began from Bible passages found in the books of Genesis and Job.

Newton's greatest achievement was his book, *Principia Mathematica Philosophiae Naturalis*, written in Latin in 1687. The title means *Mathematical Principles of Natural Philosophy.* Latin was the language of scholars and scientists. Scientists from Italy, France, Spain, Portugal and other countries corresponded with one another in Latin. Isaac Newton's book is generally considered to be the greatest book ever written on science.

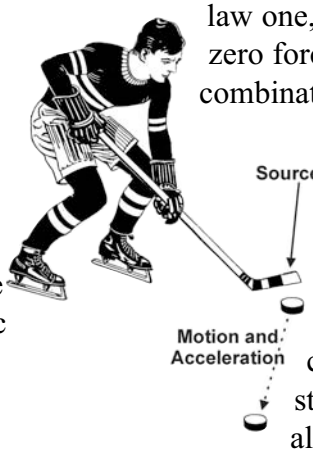
The first part of Newton's book contains the Three Laws of Motion and the Law of Universal Gravitation. In the second part, Newton used his laws to calculate the masses of the Sun and planets and to find their distances. In the third part, he explained tides and showed how to calculate the paths of comets. In one illustration, Isaac Newton shows how a powerful cannon on a mountaintop, high above the atmosphere, could put a cannonball into orbit around Earth. The concept that an artificial satellite could be put in orbit around Earth was birthed more than 300 years ago in 1687.

Newton's First Law of Motion states, "Every body continues in its state of rest, or of uniform motion in a straight line, unless it is compelled to change that state by forces impressed on it." A more modern way of stating this is: "A body at rest will remain at rest and a body in motion will remain in a constant straight line of motion unless acted upon by an outside force."

In mathematical shorthand, this can be written as "If $F = 0$ then $a = 0$." F stands for the force and a stands for the acceleration. If the force is zero, then the acceleration is zero. Acceleration causes a change in velocity, and velocity includes both speed and direction. If no force is acting on a body, then its speed and direction will be unchanged. If a body is at rest, it will remain at rest. Without a force, a body in motion will continue in motion along a straight line.

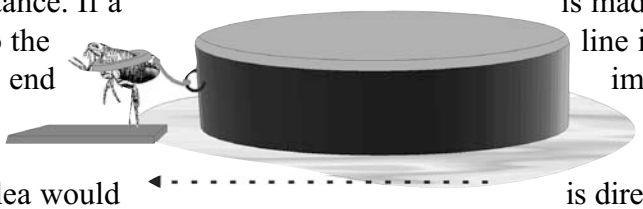
A hockey puck gliding across the ice is an example of a body that follows the first law of motion. Only when a hockey puck is given a slap with a hockey stick or rebounds off the wall will it change direction or speed. This is not a perfect example because of the friction between the puck and the ice, the puck slows down.

For a body to move as described in law one, it is not necessary for zero force to act upon it, but the combination of forces should equal zero. If the combination of forces results in zero net force, then the object will stay at rest if it is motionless, or it will continue unchanged in its straight line motion if it is already in motion. If a bulldozer tries to uproot a tree, and the roots provide sufficient force to match the force of the blade, the tree stays in place.



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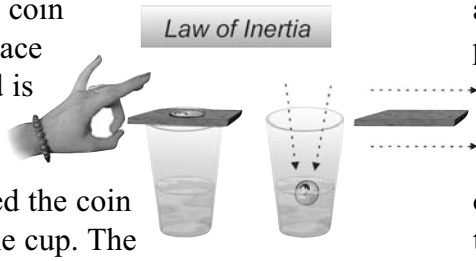
In the absence of any other forces, the slightest unbalanced force can put a body in motion. A hockey puck on ice has very little resistance. If a string is attached to the hockey puck at one end and a flea on a wooden track at the other end, the flea would be able to exert a tiny force on the puck. Because no other forces would be acting on the puck, the tiny insect would be able to cause the hockey puck to start moving.



The First Law of Motion is sometimes called the Law of ***Inertia***. Inertia is the property that causes matter to resist changes in speed and direction. Every body has inertia. The amount of inertia depends upon the amount of matter the body contains. The more matter, the more inertia. A large and heavy dump truck has more inertia than a light motorcycle. The dump truck resists its change in motion more than the motorcycle.

The concept of inertia can be illustrated in several ways. The performer who can briskly pull a tablecloth from a table without upsetting the dishes is making use of inertia. The plates, cups and dinnerware have inertia. Inertia causes the dinnerware to keep their position, even when the tablecloth is moved.

Place a piece of cardboard over a glass and put a coin on the cardboard. Thump the cardboard quickly. The cardboard will fly away, and the coin will drop into the glass. Inertia of the coin keeps it in place until the card is removed. The force of gravity caused the coin to fall into the cup. The friction between the card and coin is too slight to overcome the coin's inertia.



Newton's Second Law of Motion states, "The change in motion is ***proportional*** to the motive force impressed; and is made in the direction of the line in which that force is impressed." A modern way of stating this is: "The acceleration of an object is directly proportional to the net force acting upon it and inversely proportional to its mass and is in the same direction as the force."

The Second Law of Motion states that force and acceleration are directly proportional. Two quantities that are directly proportional will vary in the same ratio and in the same direction. As one increases, so does the other. As one decreases, so does the other.

To understand how the second law relates to force, mass and acceleration, imagine a roller skate with a brick on it. As a person pulls on the skate with a steady force, the roller skate begins to move. It gains speed and accelerates because of the steady force. Assume the roller skate accelerates at 5 cm/sec^2. Now the person repeats the process but applies twice the force to the roller skate. Instead of 5 cm/sec^2, the skate gains speed at the rate of 10 cm/sec^2. The acceleration has doubled because the force has doubled. If the force is three times as great, then the acceleration will be 15 cm/sec^2. If the force is cut in half or cut in thirds, then the acceleration is cut in half or cut in thirds.

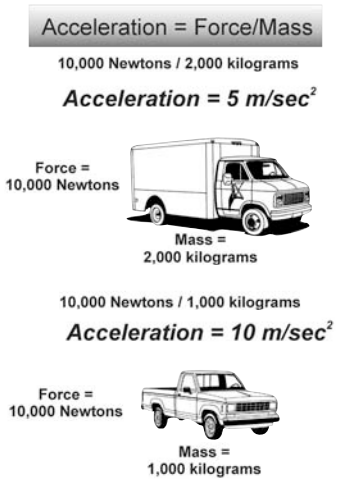
The Second Law of Motion states that acceleration and mass are inversely proportional. Two quantities are inversely proportional if one increases as the other decreases. Suppose a person pulls on the skate with the brick to give an acceleration of 5 cm/sec^2. If enough mass were added to the roller skate and brick so the total mass doubled, the same force will produce one-half as much acceleration, 2.5 cm/sec^2.

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Look at this example. A long railroad train of coal cars is hard to get moving. If the railroad engineer wants to get up to speed more quickly, then additional engines must be added to the train. More engines produce more force, and the acceleration will be greater because force and acceleration are directly related. Or, the number of cars can be reduced to lighten the load. With less mass, the same force gives greater acceleration because mass and acceleration are inversely related.

One way automobile engineers allow the same engine to provide greater performance is to make cars lighter. The less mass a car has, the greater the acceleration even with an engine of the same size.

The second law can be written as an equation: $a = F/m$. The letter a stands for acceleration; F is the force, and m is the mass. The equation is read, "Acceleration is equal to force divided by mass." This equation must have all three quantities in the correct metric units. Acceleration must be m/sec^2; mass must be in kilograms and force in newtons. Notice that force, F, is in the numerator (top) of the fraction on the right side of the equation a = F/m. This shows that acceleration and force are directly related. The mass is in the denominator (bottom). This shows that acceleration and mass are inversely related.



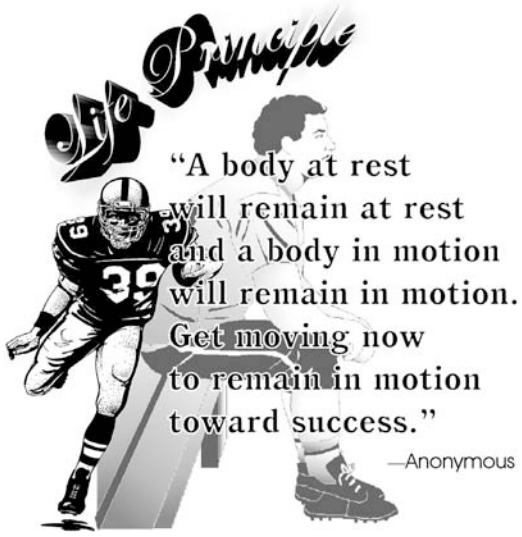
The Second Law of Motion is sometimes called the force equation. The expression $a = F/m$ can be rewritten as $F = m * a$, with F, the force in newtons, m, the mass in kilograms and a, the acceleration in m/sec^2. The asterisk (*) means *to multiply.* To calculate the number of newtons of force, multiply the mass of the object by the acceleration.

Question: What force gives an 8 kg mass an acceleration of 14 m/sec^2?
Solution: F = m * a = 8 kg * 14 m/sec^2 = 112 newtons.

Newton's Third Law of Motion states, "The mutual actions of two bodies upon each other are always equal and directed to contrary parts." In more modern language, the third law states, "To every action there is always an equal and opposite reaction."

In the second law, Isaac Newton showed that a force is necessary to cause a body to accelerate—to change speed or direction. The third law states that such forces always come in pairs, equal but opposite.

Isaac Newton explained the third law this way: "If you press a stone with your finger, the finger is also pressed by the stone. If a horse draws a stone tied to a rope, the horse will be equally drawn back toward the stone." Newton's examples show that forces come in pairs and that they act in opposite directions. In addition, each force acts on a different object not on the same object.



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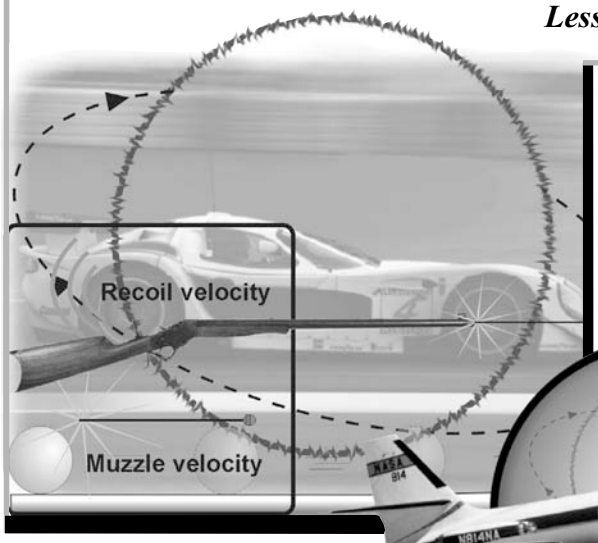
Lesson 8
Motion

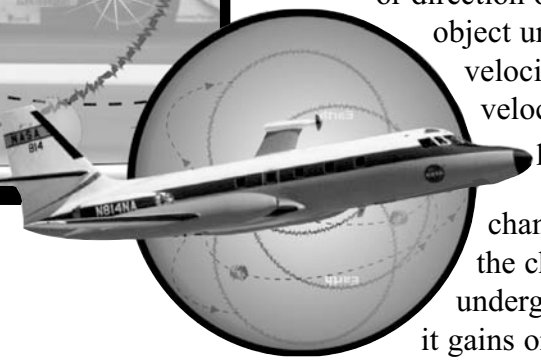
Chapter 2

THE THREE LAWS OF MOTION

Section 2

Lessons 6-10





Speed is the change in distance divided by change in time, speed = distance/time. Velocity includes both speed and direction. Velocity can only be constant if both the speed and direction are constant. As the speed or direction of an object changes, the object undergoes a change in velocity. In the metric system, velocity is measured in meters per second (m/sec).

Acceleration is the change in velocity divided by the change in time. An object undergoes acceleration anytime it gains or loses speed or changes direction. In the metric system, acceleration is measured in meters per second squared (m/sec^2).

The mass of a body is a measure of the matter in the body. For objects on Earth, mass and weight are sometimes used interchangeably. However, an object in space can be weightless, but it still has the same mass as it would on Earth. In the metric system, mass is measured in kilograms (kg).

Force can change an object's direction or speed, which means force can cause acceleration. In the metric system, force is measured in newtons.

The First Law of Motion states: "A body at rest will remain at rest, and a body in motion will remain in a constant straight line motion unless acted upon by an outside force." This is represented by symbols: if $F = 0$, then $a = 0$.

The ancient Greeks taught that objects naturally came to rest. Every object possesses a property that causes it to seek its natural place. For most objects, this is a state of rest on Earth's surface.

VOCABULARY

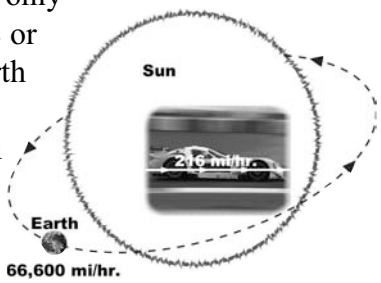
Uniform: unvarying in character; uniform motion is in a straight line at a constant speed
Muzzle velocity: speed at which a projectile leaves a firearm or cannon
Recoil velocity: speed at which a firearm or cannon springs back upon firing
Propulsion: being propelled; being driven forward or onward

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During Aristotle's time, he and other scientists believed that the Earth was motionless. A person could easily understand what was meant when Aristotle said that bodies were at rest. This was an accurate statement as long as the bodies did not move in relation to the surface of the Earth. A building was at rest because it kept the same fixed position on Earth's surface. When a rolling ball came to rest, it no longer moved across the Earth's surface.

During the 1500s and 1600s, Copernicus, Galileo and Kepler showed that the Sun, not Earth, occupied the center of the planetary system. The simple idea of being at rest no longer made sense. Earth rotates or spins around on its axis once every twenty-four hours. At the equator, the surface of Earth is moving slightly more than 1,000 mi/hr. A person at the equator is traveling at that same speed.

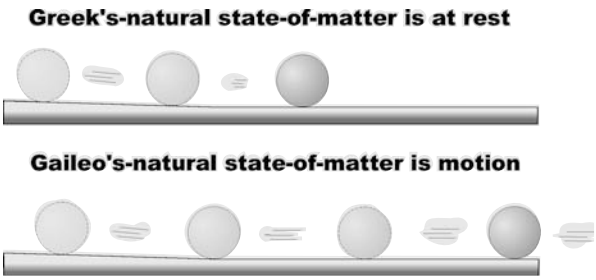
Earth revolves or orbits around the Sun once a year. Earth's motion in orbit is about 18.5 mi/sec. At an automobile race, the fastest cars travel only about 0.06 mi/sec or 216 mi/hr. As Earth orbits the Sun, Earth carries both the cars and spectators along at more than 300 times the speed of the cars at the race.



Because Earth is in motion, we cannot know that an object is truly at rest. Because Galileo understood that the Earth orbited the Sun, he began to question the teachings of the ancient Greeks. Galileo believed the Greeks were wrong to say that a body naturally sought to be at rest. To define clearly what the phrase, "at rest," meant was impossible.

In one of Galileo's experiments, a ball was rolled down a very shallow incline. Slowly the ball gained speed. Then Galileo let the ball roll up a very shallow incline. The ball slowly lost speed. He asked himself, "What would happen if no incline was used?" Clearly, the ball would neither gain nor lose speed. It would go on rolling forever.

The First Law of Motion is also known



as the Law of Inertia. The first law is actually a special case of the second law. The second law shows that if no force is acting on a body, then the acceleration would be zero. Although Isaac Newton realized the second law contained the first one, he wisely stated them as two separate laws to call attention to the fact that motion, not rest, is the natural state. Each object possesses a property that causes it to continue in a state of motion. Inertia is the name given to this property.

When a speeding car suddenly stops, the driver and passenger continue to move forward because of their inertia. A car going 60 miles per hour hits an obstruction. As the car stops, the occupants continue to move forward until they are acted upon by an outside force such as the dash, windshield, air bags or seat belts.

The First Law of Motion avoids the question of a body being at rest by stating that uniform straight-line motion, not rest, is the fundamental property of matter. The first law states that changes in motion, speed or direction, are the results of a force. Once an object is given a new motion and the force ends, the motion will continue without a force. ***Uniform*** motion is the natural state.

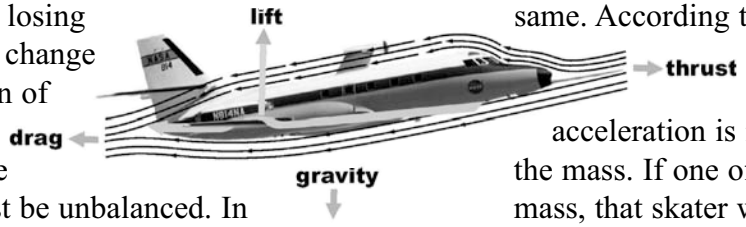
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Changes in speed or direction require action.

According to the Second Law of Motion, the acceleration of an object is directly proportional to the force acting upon it and inversely proportional to its mass. The acceleration is in the same direction as the force. This is expressed in symbols as: $a = F/m$. The Second Law of Motion can be rewritten as the force equation: $F = m * a$.

Several forces can act upon a body and not cause acceleration, provided they cancel one another to give zero force. Sometimes the second law is stated with the words "net force acting on it" or "the unbalanced force acting on it." An overall unbalanced force must be present to change the velocity of an object. Two or more forces that cancel each other would not change the velocity.

If an airplane flies with four forces acting upon it: the thrust of the engine drives it forward, the drag of air resistance holds it back, the lift of the wings makes it rise skyward, and gravity pulls it toward the earth. When all four forces are in balance, the airplane flies straight and level; neither rising nor falling, neither gaining speed nor losing speed. To change the motion of an object, the force must be unbalanced. In the case of the airplane, if one of the forces is unbalanced, then the airplane will change velocity. Depending on how the pilot sets the controls, an increase in engine speed will cause the plane to go faster or to rise in the air. A decrease in engine power will cause drag to slow down the plane or cause the plane to fall under the pull of gravity.



In outer space, objects are weightless. During long space missions, doctors wanted to learn the effect of weightlessness on the bodies of astronauts. Questions were being asked such as: Does their weight change? How do you weigh a person in weightlessness? Instead of measuring weight, they measured mass. While astronauts sat in a spring-loaded chair, scientists noted the amount of force the spring imparted. As the spring was released, the instruments measured the acceleration given to the astronaut. The scientists knew the acceleration and force, therefore, the mass of the astronaut could be calculated. This is an application of the Second Law of Motion.

The Third Law of Motion states: "When two bodies interact, the force exerted by the first body on the second is equal and opposite to the force exerted by the second body on the first."

Forces always occur in pairs. The two forces are equal in size but opposite in direction. Visualize two people on skates facing one another and pressing their palms together. If they push away, each skater will move in the opposite direction. Each skater experiences the same amount of force but in a contrary direction. Their acceleration and final velocity will not necessarily be the same. According to the third law, the forces will be equal, but the second law states that acceleration is inversely proportional to the mass. If one of the skaters has more mass, that skater will not gain as much speed.

The recoil of a rifle is another example of the third law. When the powder explodes, the hot gases drive the bullet out of the rifle barrel. The bullet goes one direction, and the rifle will recoil the opposite direction. The ***muzzle velocity*** is the speed the bullet had when it was fired. The ***recoil velocity*** is the speed the gun is pushed back by the bullet. The muzzle velocity of the bullet does not equal the recoil velocity of the rifle because the rifle and the person holding it

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have far more mass than the bullet. The force on the bullet and the opposite force on the rifle are equal, but the acceleration of the bullet will be far greater because it has a much smaller mass. The muzzle velocity of the bullet is greater than the recoil velocity of the rifle.

People seldom think about the Third Law of Motion. It is obvious and ever present. People only take notice when something happens to call attention to the law. For example, when a person first tries to use in-line skates, a lot of arm waving and feet flying in the air occur because the third law appears no longer to work. The person expects the force from their feet to put them in motion; however, because of the reduced friction, it does not happen. The skater cannot produce a force against the sidewalk and the sidewalk, in turn does not produce a force against the skater. The sidewalk and the skater tend to stay in one place.

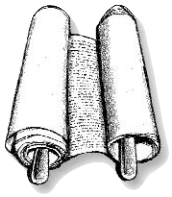
Another example of the Third Law of Motion is rocket ***propulsion***. As the hot gases escape from the engine, the gases drive the rocket forward. The faster the molecules of the gas are shot from the back, the greater the force that drives the rocket in the opposite direction.

For years, scientists thought that a rocket could not operate in the vacuum of space. The scientists claimed that the hot, high-speed gases going from the back of the rocket would have nothing to push against. However, Dr. Robert Goddard, the American rocket pioneer, understood Newton's third law. To prove that the rocket would develop thrust in space, Dr. Goddard pumped air out of a long pipe and fired a small rocket motor inside. The engine developed thrust as the gases escaped in the vacuum. One force acts on the hot gases, and this causes the gases to escape at high speed from the engine. The other force acts on the walls of the engine chamber, causing the rocket to accelerate in the opposite direction.



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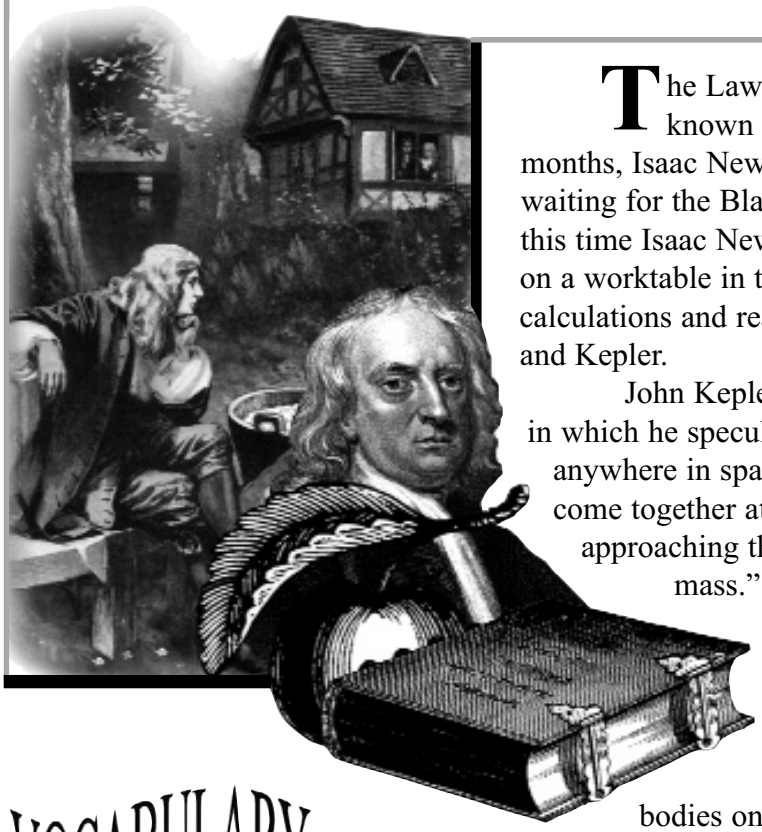
Lesson 9
Scientific Laws

Chapter 2

Section 2

Lessons 6-10

NEWTON AND GRAVITY



The Law of Gravity is Isaac Newton's best-known and most important discovery. For 18 months, Isaac Newton lived on his mother's farm while waiting for the Black Death plague to subside. During this time Isaac Newton could be found studying outside on a worktable in the apple orchard. There, Isaac did his calculations and read the books of Copernicus, Galileo and Kepler.

John Kepler wrote a book, *The New Astronomy*, in which he speculated, "If two stones were placed anywhere in space near to each other, they would come together at an intermediate point, each approaching the other in proportion to the other's mass." Kepler applied the idea to ordinary objects such as two stones. Isaac Newton saw that the idea might also apply to larger objects, such as the Earth and Moon.

Scientists were puzzled because bodies on Earth and in the heavens appeared to follow different laws. Galileo had shown that objects on Earth move in straight lines at constant speeds unless other forces alter the objects' paths. Kepler had shown that objects in space, such as the Moon, move in closed, elliptical orbits. The question was asked: Why does the Moon travel in a closed curve rather than a straight line?

Isaac Newton remembered the force of the wind during the storm. Although the wind was invisible, it changed how far he could jump. The force of the wind in a storm can uproot trees. Newton concluded that a force acts upon the Moon to bend its straight-line path into a closed orbit.



One day, an apple fell from the tree and banged onto Newton's worktable in the

VOCABULARY

Inverse: the direct opposite; reversed; the inverse of addition is subtraction; when one component of a proportion increases, the other decreases

Law of Universal Gravitation: states that the attraction between any two objects is directly proportional to the product of their masses and inversely proportional to the square of the distance separating them

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orchard. As he picked up the apple and held it, he noticed the Moon had risen in the east. He wondered if the Moon and the apple are subject to the same force of gravity. From Galileo's experiments, Isaac Newton knew the Moon should have gone off into space in a straight-line. However, the Moon's straight-line constantly curves as if a cord extending from the center of Earth to the Moon is holding it. This cord is the force of gravity between Earth and Moon. Isaac Newton realized that the courses of both the apple and the Moon were motions directed toward Earth.

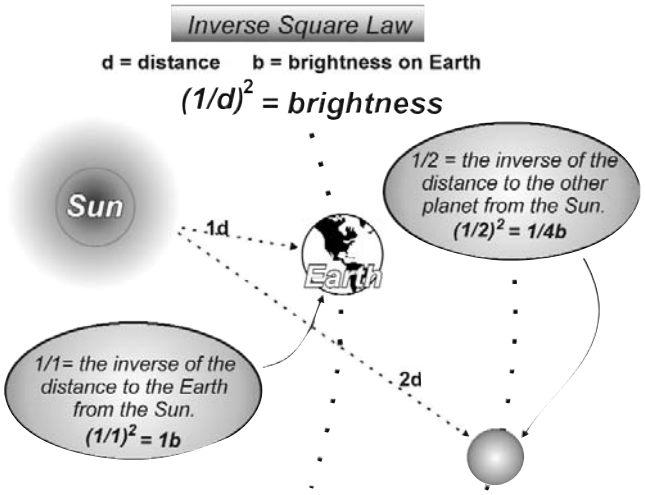
Imagine a cannon that fires a cannonball perfectly horizontally. Because of gravity, the cannonball's flight is not straight and curves toward the surface of Earth. In one second, the cannonball falls 16 feet.

The Moon, like the cannonball, does not follow a straight-line path. Gravity between the Moon and Earth pulls the Moon off course. Isaac Newton could calculate the distance Earth's gravity pulled the Moon off course because he knew the size of the Moon's orbit and its speed in that orbit. The Moon is about 240,000 miles from the center of the Earth and takes 27.3 days to go around Earth. Isaac Newton's calculations showed that in one second, the Moon departed from a straight-line path by only about 1/20 of an inch. He compared the 16 feet that the cannonball fell with the 1/20 inch that the Moon fell. The distance the cannonball fell was 3,600 times the distance the Moon fell. (In the metric system, the cannonball falls 4.9 meters, while the Moon falls but 1.3 millimeters.)

The cannonball is about 4,000 miles from the center of the Earth. The Moon is about 240,000 miles from the center of Earth. This puts the center of the Moon 60 times farther from the center of Earth than the cannonball (240,000 / 4000 = 60).

Isaac Newton expected the force of gravity between Earth and cannonball to be far greater than the force of attraction between Earth and Moon. The cannonball was 60 times closer to the center of Earth than the Moon. The acceleration was greater than 60 times as great. It was 3,600 times as great, which is 60 squared, $60^2 = 3{,}600$.

Gravity follows the *Inverse Square Law* which relates two quantities by the ***inverse*** of the square of the distance separating them. Light follows the Inverse Square Law. Suppose a planet is twice as far from the Sun as Earth. The sunlight falling on the planet's surface would be only one-



fourth as bright as the light falling on the Earth. If the planet were three times as far away, the light from the Sun would be only one-ninth as bright.

The amount of light falling on a subject is inversely proportional to the square of the distance between the source of light and the subject. When a light bulb is placed closer to the page of a book, the light seems to grow brighter. Suppose a light bulb that is four feet away is moved so it is only two feet away. The distance has been divided into two parts, so the light falling on the page is now four times as great. If the bulb is moved from four feet to only one foot away, the light on the page will be 16 times as great.

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Isaac Newton showed that gravity followed the same law. If the Moon were twice as far away, then the gravitational attraction between the Moon and Earth would be only one-fourth as great. If the Moon were three times as far away, the gravitational attraction would be only one-ninth as great.

Isaac Newton proved that all objects attract each other, according to a simple equation. The Sun, Moon, planets, apples and grains of sand are all subject to the Law of Gravity.

Isaac Newton's ***Law of Universal Gravitation*** states "Any two bodies attract one another with a force of gravity that is directly proportional to the product of their masses and inversely proportional to the square of the distance separating them."

When the Black Death ended, Isaac Newton returned to Cambridge and became a professor of mathematics. Newton tested the law in various ways and found that his calculations did not entirely agree with what was known about the size and shape of Earth as well as the distance of the Moon from Earth. The question remained as to whether the astronomers were wrong or his equation was wrong.

Twenty years had passed before a French expedition made a more accurate measure of Earth's size. The new figures showed Newton's Law of Gravity to be correct. Isaac Newton had grown interested in other matters. He did not publish his important discovery. The person who convinced him to present it to the scientific world was Edmund Halley.



Edmund Halley was born in London in 1656. He was 14 years younger than Isaac Newton. Edmund Halley studied at Oxford University but left without a degree. He had become so interested in astronomy that he decided immediately to become a full-time astronomer.

In the 1600s, astronomers knew little of the stars visible from the Southern Hemisphere. Edmund Halley decided to measure accurately the positions of the stars visible in the southern skies. Edmund Halley packed a telescope and traveled to St. Helena, a lonely island in the middle of the South Atlantic. His goal was to locate precisely a network of stars. Astronomers could then track the motions of planets and comets against the network of known stars.

After two years, Halley returned to England and published his report. He had carefully plotted the positions of 341 southern stars. Halley's work earned him the title "Tycho of the South." This was a reference to Tycho Brahe, whose observations had helped Kepler develop the Three Laws of Planetary Motion.

Edmund Halley made his home in London. Scientists of the Royal Society recognized Halley's accomplishments and elected him a member. After the Royal Society meetings, scientists would gather in smaller groups. They discussed the great unsolved problems of their day. In 1686, Edmund Halley met with Christopher Wren and Robert Hooke. The Royal Society employed Robert Hooke to demonstrate each week a new experiment. Robert Hooke invented an improved microscope and made many important discoveries in science. He also served as an assistant to Robert Boyle, the great chemist.



Christopher Wren was a well known resident of London. The king of England had placed Christopher Wren in charge of

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rebuilding the city after the Great Fire. Christopher Wren gave a challenge to Robert Hooke and Edmund Halley. He invited both men to develop a mathematical equation that described the force caused by gravity. Their proof would have to explain why the planets traveled in elliptical orbits and followed John Kepler's Three Laws of Planetary Motion.

Robert Hooke said, "I have no doubt that gravity grows weaker by the square of the distance."

"Can you prove it?" Christopher Wren asked. "I'll give an expensive book as a prize if you can."

Both Robert Hooke and Edmund Halley tried to develop an equation to describe how gravity acts between the Sun and planets. Neither one succeeded.

Edmund Halley took the problem to Isaac Newton, who seldom came to London. Newton lived on the grounds of Cambridge University. Halley's meeting with Newton was in 1686, twenty years after Isaac Newton first thought about the problem while studying in the apple orchard.

"Do you know if gravity follows the Inverse Square Law?" Halley asked.

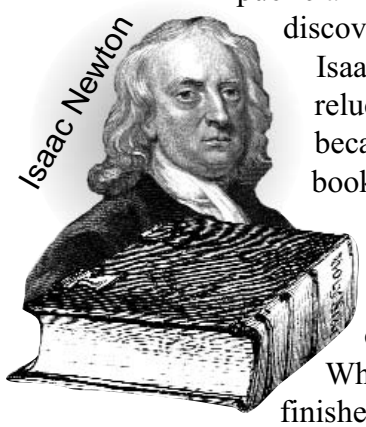
"Yes, it does," Isaac Newton said. "The force of attraction is not just between the Sun and the planets but between any two bodies."

"How do you know?" Halley asked.

"Why, I have proven it," Isaac Newton said.

Isaac Newton started with Kepler's Three Laws of Planetary Motion and Galileo's studies of motion. From these, Newton developed Three Laws of Motion and the Law of Gravity.

Edmund Halley said, "You must make public all of your scientific discoveries."

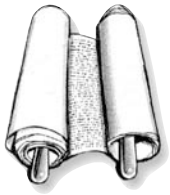


Isaac Newton was reluctant to do so because publishing a book was extremely time consuming. Edmund Halley promised to take care of the details. When Isaac Newton finished his book, *Principia Mathematica Philosophiae Naturalis*, Edmund Halley paid to have it printed. Edmund Halley was not a wealthy person, but he made the sacrifice to see the book published. Halley was rewarded when the book sold well enough for him to earn back printing costs and make a little extra money.



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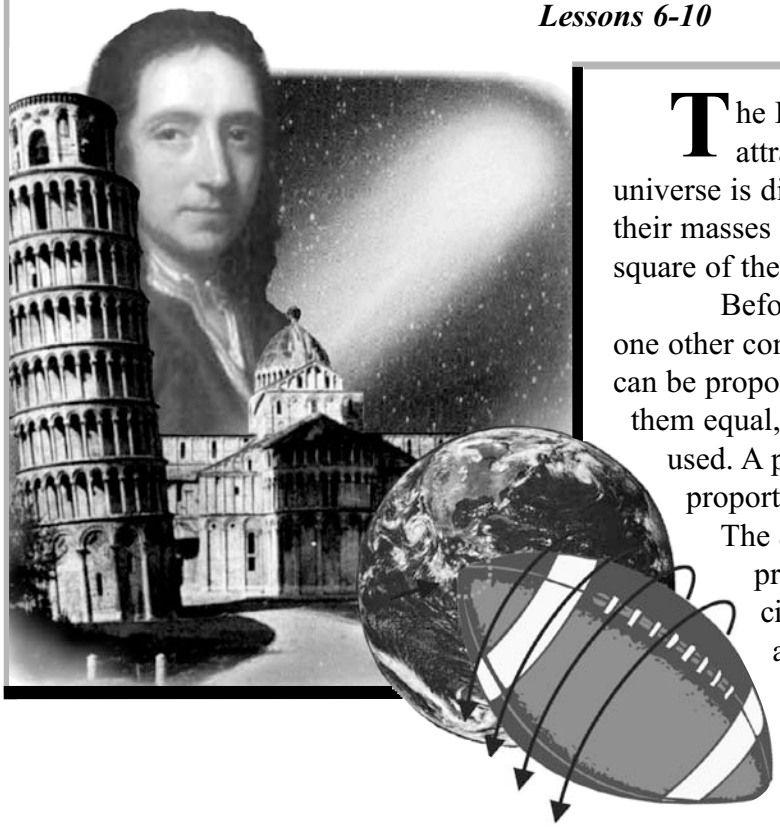
Lesson 10
Scientific Laws

Chapter 2

Section 2

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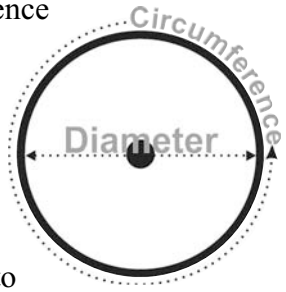
THE LAW OF GRAVITY



The Law of Gravity states: "The force of attraction between any two bodies in the universe is directly proportional to the product of their masses and inversely proportional to the square of the distance separating their centers."

Before writing this law as an equation, one other concept must be clear. Two quantities can be proportional without being equal. To make them equal, a proportionality constant must be used. A proportionality constant changes a proportion into an ***equality***.

The *circumference* of a circle is directly proportional to the *diameter* of the circle. The circumference is the distance around a circle. The diameter is the length of the line that goes from one side of the circle to the other and passes through its center. Although the circumference and diameter are directly proportional, they are not equal. In this case, the proportionality constant is ***π***, *pi*, about 3.14. The equation is $C = \pi d$, with C the circumference and d the diameter. As an approximation, this can be written as C = 3.14 * d. The constant 3.14 changes the proportion into an equation. Although $C = d$ would be incorrect to write, $C = \pi d$ is correct to write.



If the conversion factor is built into the units of measure, a constant is not required. The metric unit of force, the newton, was defined as the force required to give 1 kg of mass an acceleration of 1 m/sec^2. If the mass and acceleration are measured in kg and m/sec^2, then no conversion is needed for an answer in newtons. If the answer is to be in

VOCABULARY

Equality: statement that two quantities are equal
π: (pī) Greek letter; a constant that represents the fraction formed by dividing the circumference of a circle by its diameter; about 22/7 or 3.14.
Density: the mass of an object compared to its volume

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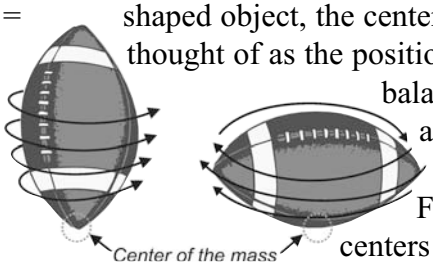
foot-pounds rather than newtons, then a conversion factor is required. In the case of converting from newtons to foot-pounds, the conversion factor is 0.225: 1.00 newton = 0.225 * foot-pounds.

In the case of the Law of Gravity, Isaac Newton used the letter *G* to stand for the gravitational proportionality constant. In symbols, the Law of Gravity can be written as:

$$F = G\frac{m_1 m_2}{r^2}$$

with *F* the force, *G* the gravitational constant, m_1 the mass of the first object, m_2 the mass of the second object and *r* the distance separating their *centers of mass*. If mass is measured in kilograms and distance in meters, then the force will be in newtons.

In applying the Law of Gravity, the distance is measured from the center of mass of the two objects. Newton managed to prove that the Earth is a sphere, and all the particles in it exert a gravitational attraction as if the particles were concentrated at one point at the center. If objects are spherical, such as the Earth, Moon or Sun, the center of mass is the center of the object. For an irregularly shaped object, the center of mass can be thought of as the position where it would balance or the point around which it would rotate if given a spin. For most objects, the centers of mass are their geometric centers or centers of gravity.

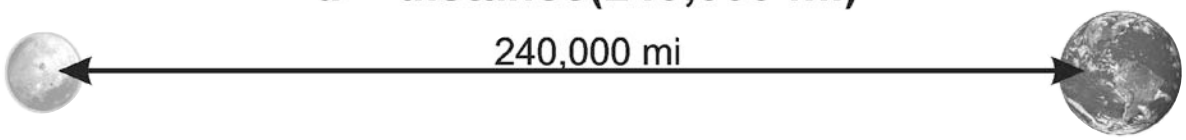


At the surface of Earth, a person is about 4,000 miles from the center of Earth's mass. This distance to the center of Earth's mass, not the distance to the surface of the Earth, is used in the Law of Gravity.

The Law of Gravity contains three essential statements. First, the force of attraction is inversely proportional to the square of the distances from the center of the two masses. Suppose the Moon were not 240,000 miles from the center of Earth but only 60,000 miles. Look at what effect this has on the force of gravity. The distance is one fourth as great (60,000 / 240,000), so the

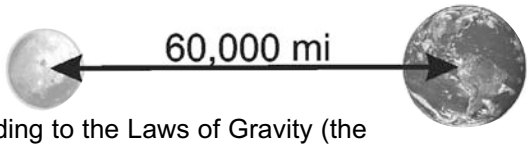
a = attraction(gravitational force)

d = distance(240,000 mi)



In Example A: The actual distance between the centers of the earth and the moon is 240,000 miles.

In Example B:
Suppose the distance between the centers of the earth and the moon was only 60,000 miles.



The gravitational force would then be stronger according to the Laws of Gravity (the force of attraction is inversely proportional to the square of the distances from the centers of the two masses (Earth and the Moon). In applying this law, 60,000 miles equals 1/4 of the actual distance (240,000 miles) between the two masses. 1/4 squared $(1/4)^2$ equals 1/16. The inverse of 1/16 equals 16a (16 times the attraction of the actual gravitational force between Earth and the Moon). The gravitational force is stronger due to the shortening of the distance between the two masses.

60,000 mi / 240,000 mi = 1/4d

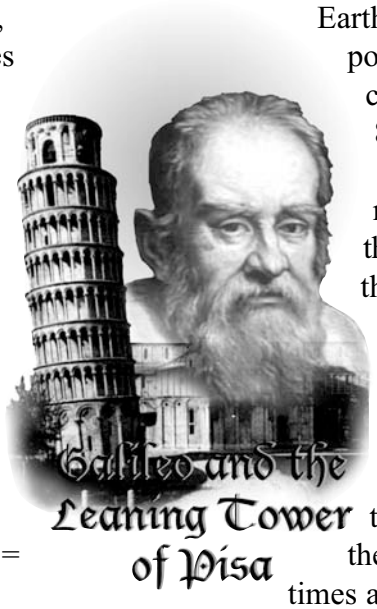
$(1/4)^2$ = 1/16

The inverse of 1/16 = 16a

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attraction will be 16 times as great. The effect of gravity varies by the inverse of the square of the distance: $(1/4)^2 = 1/4 * 1/4 = 1/16$, and the inverse of 1/16 is 16.

In the following example, imagine a giant tower 4,000 miles high being built and dropping an apple from it. This difference in height would change Earth's attraction for the apple, compared to the attraction at the surface of Earth. At the surface, the apple is 4,000 miles from the center of Earth. At the top of the tower, the apple is 8,000 miles from the center of Earth. The distance has doubled, so the attraction at the top of the tower would be 1/4 as great: $2^2 = 2 * 2 = 4$, and the inverse of 4 is 1/4.



The second statement in the Law of Gravity states that the force of attraction between two bodies is directly proportional to the product of their masses. Both objects attract one another. When an apple falls to Earth, both the apple and the Earth attract one another. A person who states that Earth is attracting the falling apple is not completely correct. The apple is also attracting the Earth. As the apple falls toward Earth, the Earth moves toward the apple. Because of the vast difference in their masses, the apple has an imperceptible effect upon the Earth.

In the case of the Moon and Earth, however, both attractions can be detected. The Moon is smaller than the Earth and made of material of less ***density***. Overall, the Moon has a mass of about 1/81 the mass of the Earth. Eighty-one moons would equal the same mass as the Earth. This is enough mass to have an effect on the Earth. Tides are caused in large part by the gravitational attraction of the Moon. The Sun is also a factor in causing tides.

The Moon does not orbit Earth, but instead, the Earth and Moon orbit the common center of gravity of Earth-Moon system. The center of gravity is at a distance 1/81 along a line connecting the center of Earth to the center of the Moon. That point is about 3,000 miles from the center of Earth: 240,000 miles / 81 = 2,963 miles.

The reason the masses are multiplied is clear when you think about Galileo's observation that all bodies fall toward the Earth at the same speed. The legend is that Galileo dropped two metal balls from the Leaning Tower of Pisa. One ball weighed ten times as much as the other. Most scholars believed the heavier ball would fall ten times as fast. Instead, both balls fell at the same speed. The massive ball had ten times as much inertia, which made it ten times harder to move. According to the Law of Gravity, the heavier ball also attracted the Earth with a force that was ten times greater. The greater attractive force overcame the greater inertia.

Suppose the mass of the Moon was doubled, but its distance from the Earth was cut in half. Both actions would cause an increase in the attraction. Changing the distance would have a greater effect. The force of attraction is related to the first power of the masses but by the second power of the distance. Doubling the mass on one object causes a two-fold increase in attraction. Reducing the distance by half causes a four-fold increase in attraction.

Isaac Newton was the first to explain that mass and weight are different quantities. Mass is the amount of matter an object contains. Mass is a measure of inertia. In the metric system, mass is measured in kilograms. Because weight is due to the force of gravity,

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the weight of an object is given in newtons. Weight is the force exerted by the gravitational attraction between an object and the Earth.

One way to calculate weight is to use the force equation: $F = m * a$. In the metric system, the acceleration due to gravity is 9.80 m/sec^2. The force of gravity upon a 1.00 kilogram mass is 9.8 newtons: F = m * a = 1.00 kg * 9.80 m/sec^2 = 9.80 newtons.

To calculate weight, multiply the mass by the acceleration due to gravity. A person who has a mass of 70 kilograms (about 154 pounds) has a weight of F = m*a = m * g = 70 kg * 9.8 m/sec^2 = 686 newtons.

The third fact about the Law of Gravity is that gravity is universal. Gravitational attraction exists between any two objects in the universe. Isaac Newton's Law of Gravity applies not only to the Earth and Moon but also to the Earth, apple and even to two apples. The masses of two apples are too slight for their attraction to one another to be perceived. Such an attraction does exist and under the right circumstances, it can be measured. For instance, when two objects of ordinary size are close to one another in space, their attraction does draw them together.

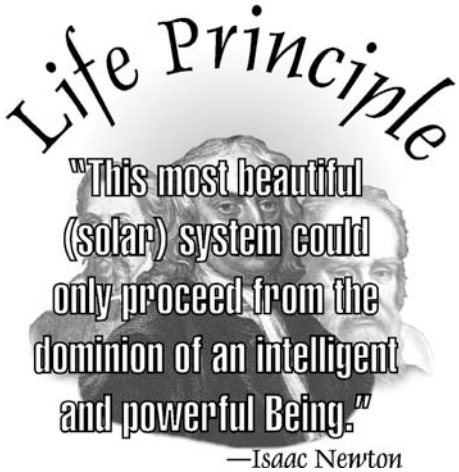
Edmund Halley read the section in the *Principia Mathematica Philosophiae Naturalis* about comets. Isaac Newton applied the Law of Gravity to the motions of comets, too. Comets were unpredictable and appeared to follow no set rules. If comets obeyed the Law of Gravity, the paths would follow predictable courses. Halley looked for reports of bright comets. He had seen one in 1682. A bright comet had been seen in 1531 and 1607. Each sighting had been about 76 years apart.

Edmund Halley boldly stated that the same comet, not three different comets, was returning repeatedly. For most of the orbit the comet was far from the Sun and impossible to see. Halley confidently predicted the comet would return in 1758. Edmund Halley died in 1742, so it was another astronomer who first saw the faithful visitor. The long awaited comet returned right on schedule. The comet appeared again in 1835, 1910 and 1986 and is expected to return in 2061. Halley's Comet's period is not exact because when the comet's orbit is close to Jupiter or one of the larger planets, the gravitational disturbance can retard or advance the comet's motion.



Edmund Halley is best known for discovering the comet which bears his name—Halley's Comet. However, scientists honor him for many other advances to science. One of Halley's greatest achievements was bringing Isaac Newton's discoveries to light.

To predict the return of the comet, Edmund Halley built on the Law of Gravity. Science builds on the discoveries made by earlier scientists. Isaac Newton built on the work of Galileo and John Kepler. Isaac Newton said, "If I have been able to see farther, it is because I have stood on the shoulders of giants."



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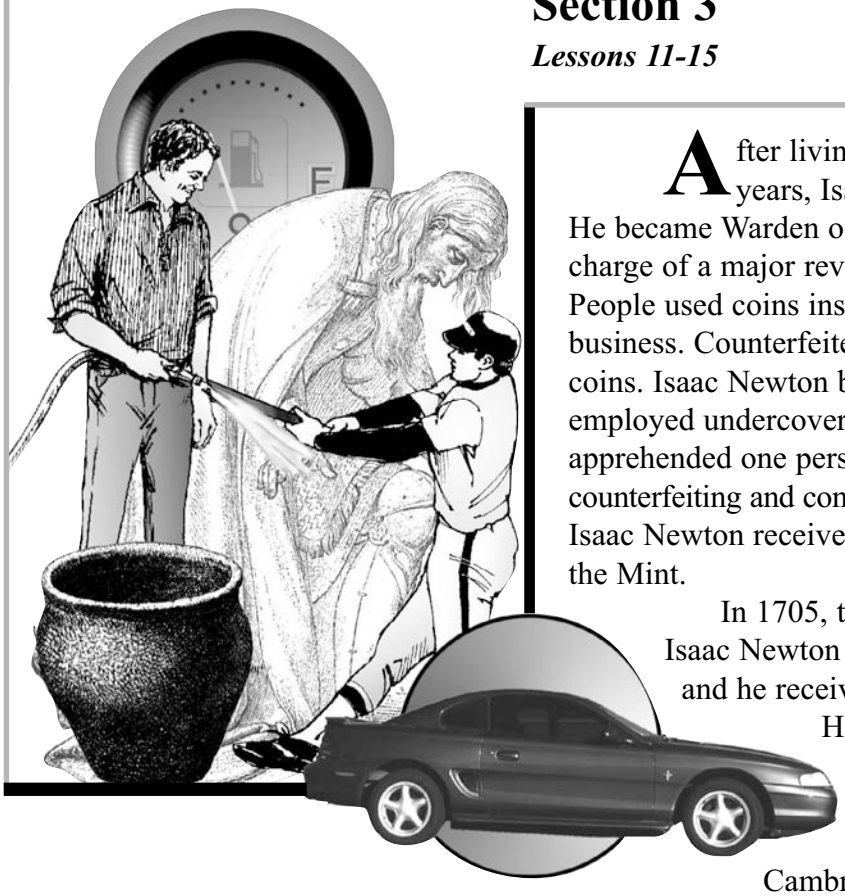
Lesson 11
Motion

Chapter 2

MOMENTUM AND IMPULSE

Section 3

Lessons 11-15



After living in Cambridge for almost 25 years, Isaac Newton moved to London. He became Warden of the Mint and was put in charge of a major revision of England's coinage. People used coins instead of paper money for daily business. Counterfeiters tried to stamp out low value coins. Isaac Newton became a detective and employed undercover agents. Newton successfully apprehended one person responsible for counterfeiting and convicted him for the crimes. Later, Isaac Newton received the higher office as Master of the Mint.

In 1705, the queen of England knighted Isaac Newton for his scientific discoveries, and he received the title *Sir* Isaac Newton. He was the first person to receive knighthood for scientific achievement. The queen and her court traveled to Cambridge for the ceremony to recognize Newton for his scientific work at Cambridge. In London, Isaac Newton served as the president of the Royal Society. He wrote many books, including one on optics. However, the *Principia Mathematica Philosophiae Naturalis* remained his greatest work. Shortly before he died in 1727, Isaac Newton published a revised version of that book. In the revised version, Newton showed the relationship between momentum and impulse.



VOCABULARY

Momentum: measure of the motion of a body equal to the mass times the velocity
Linear: relationship between two quantities that form a straight line
Impulse: product of force and the length of time the force acts

Momentum is defined as the mass of an object times its velocity, $p = m*v$, with p representing the momentum, m for the mass and v for the velocity. P is used as the symbol for momentum because m is already used as the symbol for mass. The momentum of a bullet with a mass of 0.1 kg that leaves a

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rifle at 344 m/sec is 34.4 kg-m/sec: momentum = m * v = 0.1 kg * 344 m/sec = 34.4 kg-m/sec.

Another example of momentum is a skater with a mass of 46 kilograms (about 101 pounds) who is skating at 9 m/sec (about 20 mi/hr) has a momentum of: p = m * v = 46 kg * 9 m/sec = 414 kg-m/sec.

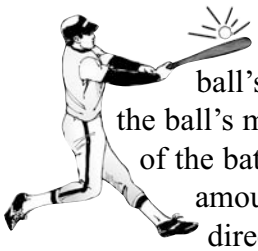
In the equation for momentum, $p = m * v$, both the mass and velocity are to the first power. A ***linear*** relationship is one in which the quantities are both to the first power. The exponent for a quantity to the first power is 1, and it is usually not shown: $p = m^1 * v^1$ is the same as $p = m * v$.
A relationship is called linear if the two related quantities when plotted on a graph result in a straight line. An example of a non-linear relationship is the path of a planet around the Sun, which is an ellipse.

Momentum is directly proportional to the mass and the velocity. If the mass doubles so does the momentum. If the velocity doubles so does the momentum. If both the mass and velocity double (2 * m, 2 * v), then the momentum becomes four times as great (2m * 2v = 4 * m * v = 4 * p). The increased mass doubles the momentum, and the increased velocity doubles it again.

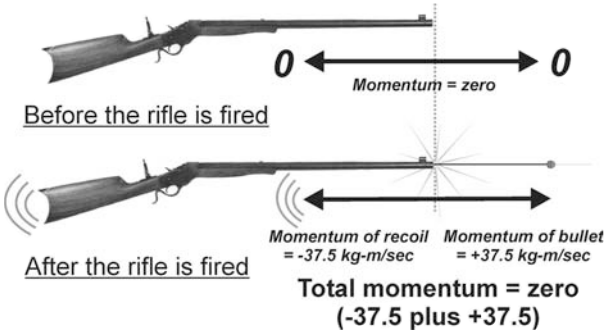
A large truck rolling down a hill has more momentum than a small vehicle going at the same speed. When two football players collide, the larger player has the advantage because of his greater weight. For two players running at the same speed, the heavier one has more momentum. If an offensive player with lesser weight hits the line fast enough, the extra speed will give him enough momentum to break through the line of defenders.

The Third Law of Motion states that every action is accompanied by an equal and opposite reaction. Isaac Newton originally stated the third law in a different form: Whenever one body gains momentum, another body must receive an equal momentum in the opposite direction.

When a bat strikes a ball, the ball is going in one direction at a certain speed. After the bat hits the ball, the ball is going in a different direction at a different speed. Because the ball's velocity has changed so has the ball's momentum. The momentum of the bat changes by the same amount but in the opposite direction.



Suppose a rifle fires a 0.1-kg bullet at 375 m/sec. Before the rifle is fired, the bullet and rifle have zero momentum and their velocities are zero. Once the rifle is fired, the bullet travels at 375 m/sec and is given 37.5 kg-m/sec of momentum. During this time, the rifle must recoil so the momentum of the rifle equals the momentum of the bullet. Assume the rifle has a mass of 3.0 kg. Because the rifle is far more massive than the bullet, its recoil velocity is far less. It will recoil at 12.5 m/sec.



momentum of rifle + momentum of bullet = 0
mass of rifle * velocity of rifle + mass of bullet * velocity of bullet = 0

3.0 kg * ⁻12.5 m/sec + 0.1 kg * 375 m/sec = 0
-37.5 kg-m/sec + 37.5 kg-m/sec = 0

Momentum, like velocity, includes direction. Although the two values for momentum of the rifle and bullet are equal, they are opposite in direction because the two velocities are opposite in direction. The

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velocity for the rifle is shown as 12.5 m/sec. The velocity of the bullet is shown as +375 m/sec. Often the positive sign is not shown. Without a sign, the velocity is understood to be positive. Either the bullet or the rifle could have been given a negative velocity provided the other one is shown with a positive velocity. The two signs show that the directions are opposite each other.

Another term used in physics is ***impulse***, which is the product of force and the length of time the force is applied. In symbols, $I = F*t$ with I the impulse, F the force and t the time. A baseball trainer encourages the batter to follow through when swinging at the ball. The longer the bat stays in contact with the ball, the greater the change in the velocity of the ball. The baseball player who keeps the same force of his bat in contact with the ball for twice as long gives the ball an impulse twice as great.

Skydivers land on the ground by bending their knees. Their contact with the Earth is spread over a greater period of time thus reducing the force of their impact. Whether the Skydivers stop slowly or quickly, their change in momentum will remain the same. However, by spreading force over a greater period of time, there is less chance of an injury.

An impulse applies a force for a period of time to an object. This impulse causes a change in the velocity of the object, which, in turn, changes the momentum. Isaac Newton showed that impulse given to an object is equal to its change in momentum.

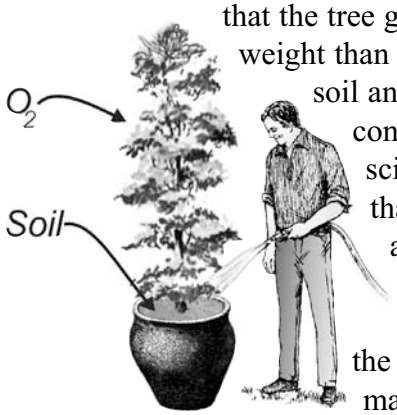
Definition of Momentum

p = m * v	momentum = mass * velocity
p = m * a * t	velocity = acceleration * time, substitute a * t for v
p = F * t	force = mass * acceleration, substitute F for m*a
p = I	impulse = force * time

Impulse and momentum are two ways of looking at motion. Impulse describes how motion is produced. Motion is imparted to an object by applying a force over time: $I = F * t$. Momentum is a measure of the motion based on both velocity and mass: $p = m * v$.

Gravity can create motion. An apple is hanging from its stem on the tree. When the apple ripens, it falls to Earth. Motion appears to come into existence where no motion had existed before. Scientists have learned to be cautious about quantities that seem to appear from nothing.

Chemists who lived during the same time as Galileo investigated the growth of plants. The scientists weighed the amount of soil and water absorbed by a tree and found that the tree gained more weight than the amount of soil and water consumed. Later, scientists learned that oxygen in the air also contributed to the growth of the tree. The total mass of the tree (including the soil, water and oxygen) did not change as the tree grew. As the tree gained mass, the tree took that mass from the soil, water and air.



In science, many quantities follow the conservation laws. A quantity is *conserved* if it remains constant throughout an experiment. Chemists developed the Law of Conservation of Matter, which states that matter can neither be created nor destroyed but merely changed in form. The total mass of all the reactants that go into a chemical reaction equals the total mass of the products at the end of the chemical reaction.

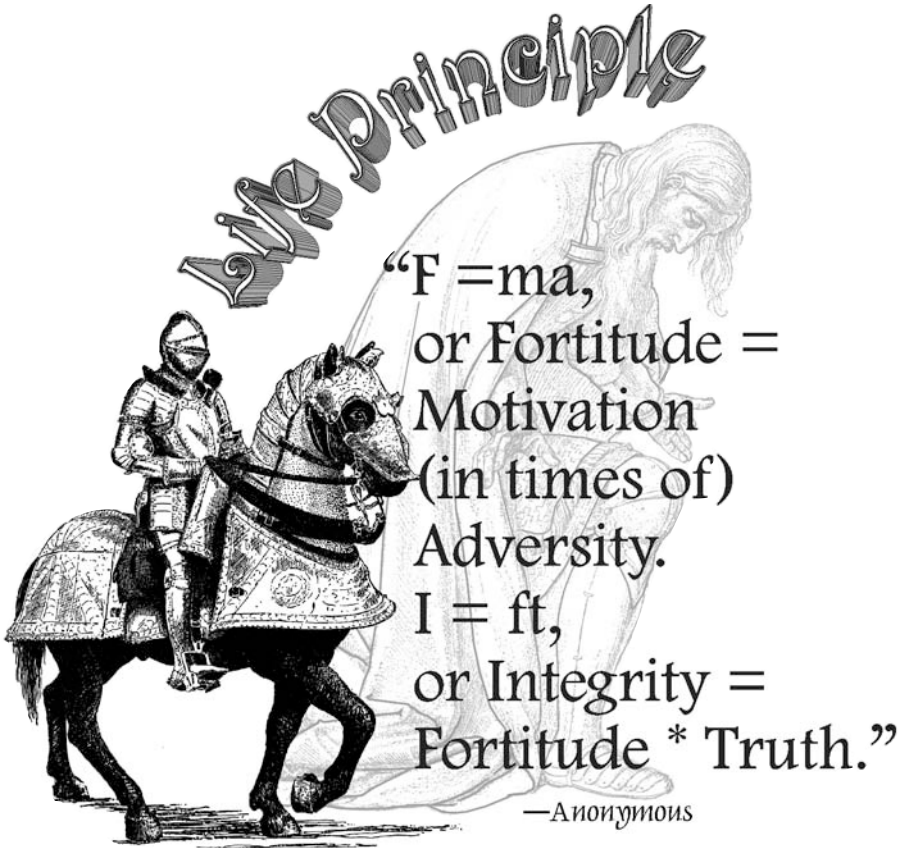
As an illustration of the Law of Conservation of Matter, water can be separated into hydrogen and oxygen through

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the process of electrolysis. The combined weight of the hydrogen and the oxygen after the water is separated is the same as the weight of the water before the water was separated.

Other quantities do change at the expense of something else. For example, an engine can put a car in motion. The motion given to the car comes at the expense of the fuel that runs the engine. An electric motor can cause an elevator to go up and down. The electricity consumed by the motor comes at the expense of chemical energy in the coal burned at the power plant. The Law of Conservation of Energy states that energy can neither be created nor destroyed but merely changed in form. In these examples, the chemical energy of the fuel is changed into the motion of the car or elevator.

One of the important laws of physics is the Law of Conservation of Momentum. The Law of Conservation of Momentum states that in a closed system, one in which all matter and energy are contained within that system, the total momentum remains unchanged over time. Conservation of momentum is one of the most important and universal of the conservation laws of physics.



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Integrated Physics & Chemistry



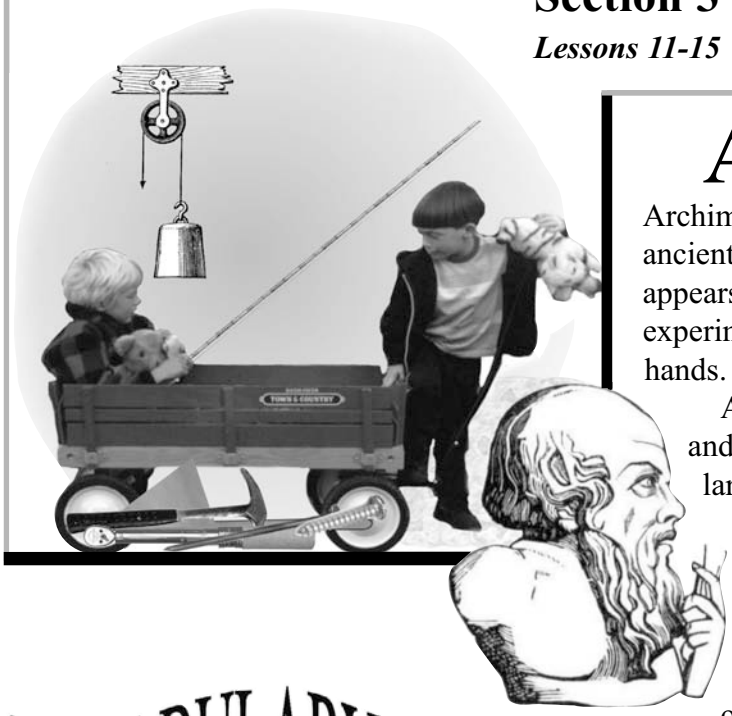
Lesson 12
Inventions & Discoveries

Chapter 2

SIMPLE MACHINES

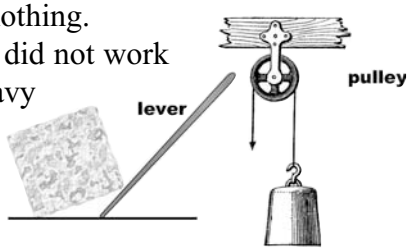
Section 3

Lessons 11-15



Archimedes was born in 287 B.C., about 50 years after Aristotle died. Archimedes was the foremost mathematician of ancient times. Of all the scientists, Archimedes appears to be the most modern. He did experiments and built inventions with his own hands.

Archimedes experimented with ***levers*** and ***pulleys***. People who needed to move large blocks of stone could lift one end with a pry bar. A person of ordinary strength can lift loads that weigh several hundred pounds. A few pounds of force at one end of the bar can exert several hundred pounds of force at the other end, which might seem as if something is being produced from nothing. Archimedes knew the natural world did not work that way. He pointed out that the heavy weight moved only a few inches. The few pounds of effort had to be applied through a much greater distance.



A ***simple machine*** allows a resistance to be overcome at one point by applying a force at some other point. The resistance is called the ***load***, and the force being applied is the *effort*.

Archimedes stated the Law of Simple Machines as "load times distance the load is moved equals effort times the distance the effort is applied." In symbols, $F_L * d_L = F_E * d_E$, with F_L the force or weight of the load, d_L the distance the load is moved, F_E the effort force and d_E the distance the effort is applied. If any three qualities are known, the remaining one can be easily calculated. Load and effort are measured in the same

VOCABULARY

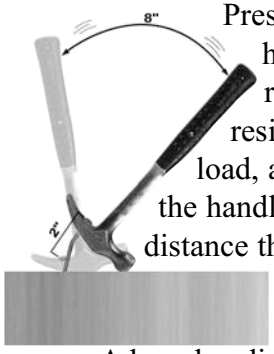
Lever: simple machine made of a bar on a pivot; transmits force from the effort to the load
Pulley: simple machine made of a wheel that can accept a rope or chain for changing the direction of the effort; several pulleys in combination make a block and tackle
Simple machine: device that changes the direction or amount of force needed to move a load
Load: force that must be overcome; For objects being lifted, the load is the force due to gravity; weight of the object

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units as force, newtons in the metric system and pounds in the English system. You recall that weight is the force of gravity between a body and the Earth. Weight is also measured in newtons in the metric system and pounds in the English system.

Simple machines include devices such as the lever, an inclined plane, wheel and axle, pulley, wedge and the screw. Simple machines change the magnitude or direction of a force. A simple machine transfers a force from one place to another. In the process, the force may become greater, smaller or stay the same. A simple machine does not have to have any moving parts. An inclined plane is a simple machine. Even when in use, the inclined plane does not move, but an effort force is used to push an object up the inclined plane.

A claw hammer for pulling out nails is a simple machine. The claw hammer is a lever that changes the direction of the force and the amount of force that must be applied. Pressing against the hammer handle pulls out a reluctant nail. The resistance of the nail is the load, and the force applied to the handle is the effort. The distance the handle moves is greater than the distance the nail moves.



A long handicap ramp used for entrance into a building is an example of an inclined plane. The ramp may be 17 feet long for each foot it rises. The task of rolling up the incline in a wheelchair is made easier. The force for moving one foot vertically is applied through 17 feet along the ramp.

A single pulley suspended overhead allows a person to pull down on a rope to lift a load. In this case, the pulley changes the direction the force must be applied but not the amount of force.

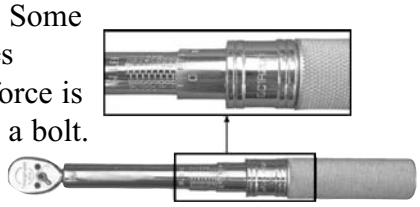
A wheel and axle is a simple machine. For each turn of the axle, the wheel turns once. The rear wheel of a bicycle is a wheel and axle. The axle has gears for the bicycle chain. As the axle turns once so does the wheel. A single turn of the smaller axle results in a larger distance traveled by the outer rim of the wheel.



Other simple machines, such as the wedge, screw, and block and tackle, also change the direction the force needs to be applied, the amount of force or the position of the force. A wedge is made of two inclined planes placed back to back. A wedge is often used for splitting wood. A screw has an inclined plane that has been wound in a spiral shape. A wood screw is an example. The wood screw has a slotted head for a screwdriver. Turning the wood screw causes the spiral-shaped incline plane to go into the wood. The head of the screw must be turned several revolutions for the screw to advance an inch.

The *mechanical advantage* of a simple machine is equal to the load divided by the effort: *M.A. = load/effort*. If the mechanical advantage is greater than one, then a smaller force is needed to overcome a larger force. A simple machine with a mechanical advantage of 5 multiplies the effort force by 5. A person who applies 7 pounds of force can move a load of 35 pounds.

Most wrenches are simple machines. An effort on the handle of the wrench is magnified, which results in a greater force against the bolt head. Some wrenches have gauges showing how much force is being applied against a bolt. These wrenches are



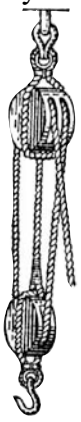
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known as *torque wrenches*. The word *torque* means *to twist*. Torque is the force that results in rotation. Suppose a person applies a force of 20 pounds, and this produces a force of 75 pounds against the bolt. The mechanical advantage is load divided by the effort: M.A. = load/effort = 75 pounds / 20 pounds = 3.75.

According to Archimedes, if the effort force is less than the load, then the effort must be applied through a greater difference. This gives another way to calculate the mechanical advantage: *M.A. = distance effort is applied/distance load moves*. In the example of the wheelchair going up the ramp, the M.A. is 17: M.A. = distance effort is applied/distance load moves = 17 ft/1 ft = 17.

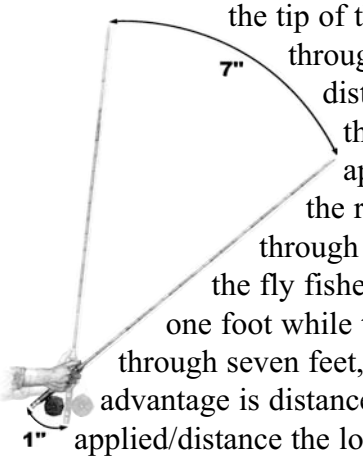
Suppose a steel wedge is 6.0 inches long and 0.75 inches thick at the big end. By driving the steel wedge into a log, the wood is then forced apart. What is the mechanical advantage? The wedge moves 6.0 inches to separate the wood by 0.75 inches. M.A. = distance effort is applied/distance load moves = 6.0 in / 0.75 in = 8.00.

Sometimes the mechanical advantage is one. For instance, a single pulley suspended overhead allows a person to pull down on the rope to lift a load. In this case, the pulley changes the direction the force is applied but not the amount of force. Most people find it easier to pull down on a rope than to lift a load. Changing the direction makes lifting the load more convenient. However, the effort force pulling on the rope equals the load on the other end. When the rope is pulled down a distance of one foot, the load is lifted a distance of one foot. The mechanical advantage is 1.00.



A series of pulleys can give a mechanical advantage greater than one. In a block and tackle, the rope or chain passes through a series of fixed pulleys at the top and through a series of movable pulleys at the bottom, next to the load. The movable pulleys are said to float. With a block and tackle, several feet of rope or chain must be pulled through to lift the load a few inches.

The mechanical advantage may be less than one. A person who uses a fly rod moves the base of the rod only slightly, but the tip of the rod moves through a much greater distance. In this case, the larger force is applied to the base of the rod to send the lure through a greater distance. If the fly fisherman moves the rod one foot while the tip moves through seven feet, then the mechanical advantage is distance the effort is applied/distance the load moves = 1 ft / 7 ft = 1/7.



Archimedes lived in the port city of Syracuse, on the island of Sicily. It was a Greek city. Archimedes told the king of Syracuse that given a place to stand and a long enough lever, he could move the world. The king gave him a real world test. He challenged Archimedes to single-handedly drag a full barge up on the shore. Archimedes attached a system of pulleys to the barge, and he succeeded in pulling the barge ashore.

Archimedes became world famous, but in 215 B.C., the armies of Rome laid siege to the city where he lived. For three years, Archimedes' inventions helped the people of Syracuse keep the opposing army at bay. At last the Romans broke the siege and stormed into the city.

The Roman army was led by Marcellus who ordered that Archimedes' life be spared. One day a Roman soldier came across a 75-year-old man drawing figures in the sand. The soldier ordered the man to move along. Instead of moving, the old man

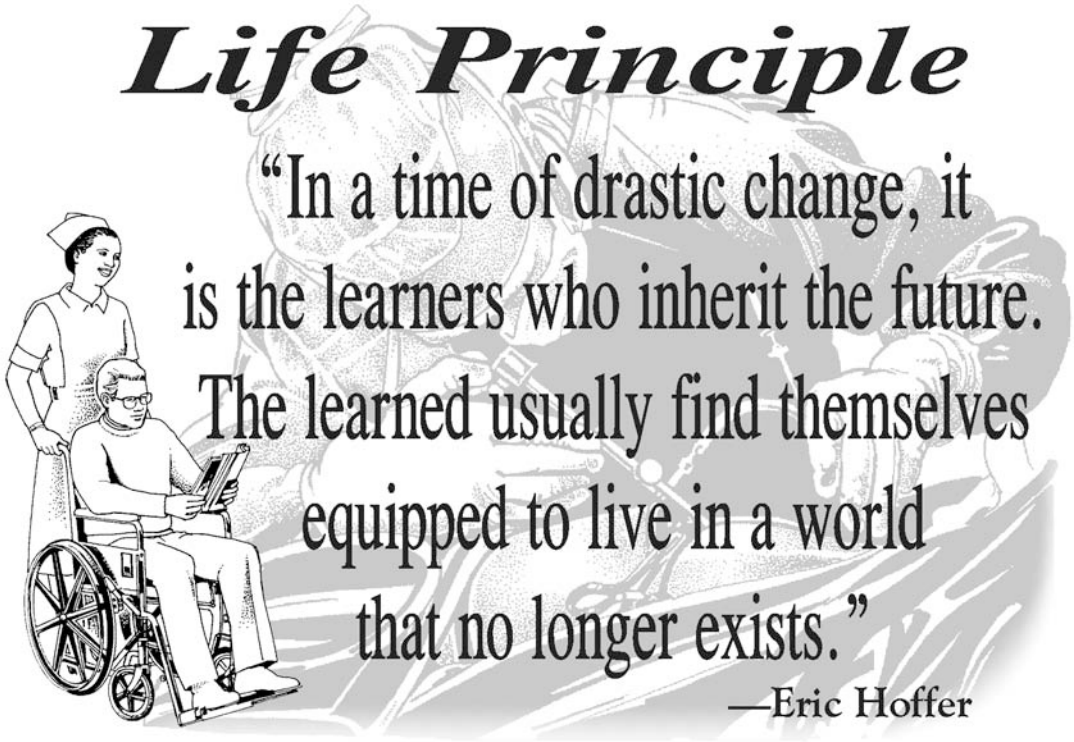
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scolded the Roman soldier for stepping on his figures. The soldier pierced the old man through with his sword, not knowing that he had killed the great scientist.

The block and tackle is still used today for lifting heavy loads. Suppose an automobile engine weighs 650 pounds and is attached to a block and tackle pulley system. The engine can then be lifted with 25 pounds of effort. The mechanical advantage is M.A. = load/effort = 650 / 25 = 26. Knowing that the mechanical advantage is 26, a person can calculate how far the effort must be applied to lift the engine. To raise the engine 3 feet, the effort must be applied through a distance 26 times as great. The person using the block and tackle must pull 78 feet of chain (26 * 3 feet = 78 feet) to lift the engine 3 feet.

An automobile tire jack allows a small force to lift one end of a heavy automobile. A force of 18 pounds on the jack can cause 1,500 pounds to be lifted. The mechanical advantage is M.A. = load/effort = 1,500 / 18 = 83.33, or 83 rounded off to the nearest whole number. How far must the jack handle move to raise the car one foot? It must move 83 times as far or 83 feet. This is done in several pumps of the jack handle.

Examine other common tools and implements to see how they work as simple machines. A wrench, can opener, scissors, common household devices and many other tools make use of the principles first described by Archimedes more than 2,000 years ago.



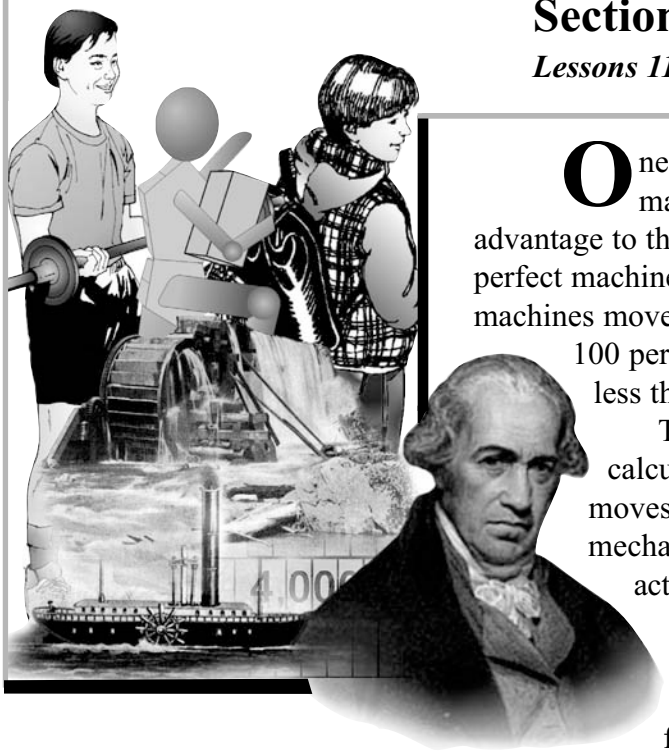
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Chapter 2

Lesson 13
Energy

Section 3
Lessons 11-15

EFFICIENCY OF SIMPLE MACHINES

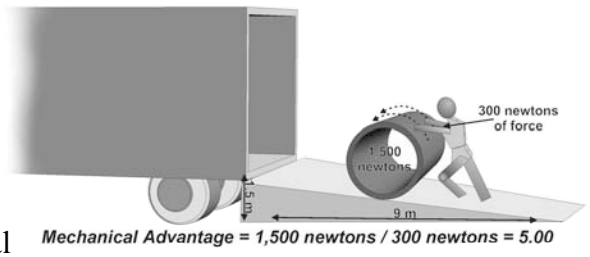


One way to measure the ***efficiency*** of a simple machine is to compare the actual mechanical advantage to the ***theoretical*** mechanical advantage. A perfect machine with no friction or other force to hinder the machines movement would have an efficiency of 1.00 or 100 percent. In the real world, the efficiency will be less than 1.00 and sometimes far less.

The theoretical mechanical advantage can be calculated by dividing the distance the effort moves by the distance the load moves. The actual mechanical advantage is found by dividing the actual effort by the actual load.

A barrel needs to be raised to the back of the truck. One way is to lift the barrel straight up from the ground into the truck. A force equal to the weight of the barrel must be used. To lift a barrel that weighs 1,500 newtons (about 337 pounds), a force of 1,500 newtons is required. Loading ramps make it easier to roll heavy loads into the back of trucks.

The barrel can be moved into the back of the truck with less force by rolling it along a ramp. For a ramp 9 meters long that rises 1.5 meters, the theoretical mechanical advantage is M.A. = distance effort travels/distance load travels = 9 m / 1.5 m = 6.00. The distance the effort moves is the distance along the ramp. Although the barrel is rolled along the ramp, that is not considered the distance the load moves. The load distance is the vertical change from the ground to the back of the truck, a distance of 1.5 meters.



Mechanical Advantage = 1,500 newtons / 300 newtons = 5.00

The theoretical mechanical advantage of 6 means an effort of 250 newtons should roll a barrel that weighs 1,500

VOCABULARY

Efficiency: compares useful output with the total input
Theoretical: (a concept) devised by inference from observed particular factors and proposed as an explanation for their causes or operations
Work: application of a force through a distance
Horsepower: English unit of power; 33,000 ft-lbs of work in one minute

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newtons up the ramp because 6 * 250 = 1,500. Suppose, however, that it takes 300 newtons to move the barrel. An extra 50 newtons of force are required to overcome friction between the barrel and the incline. The actual mechanical advantage is M.A. = load/effort = 1,500 / 300 = 5.00.

With actual and theoretical mechanical advantages known, the efficiency is given by the ratio of those two numbers. Because the efficiency is always less than one, the smaller number is divided by the larger number. Efficiency = actual M.A./theoretical M.A. = 5.00 / 6.00 = 0.83 or 83 percent.

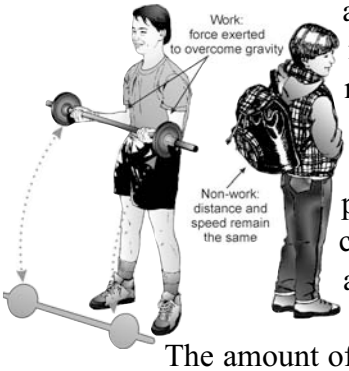
WORK

Scientists define ***work*** as the force times the distance the force is applied. Archimedes stated that for simple machines the load times the distance the load moves equals the effort times the distance the effort is applied. Archimedes' rule for simple machines can be restated as, "The work output by a simple machine is equal to the work input into the machine."

Work input equals work output is true only for machines with 100 percent efficiency. That is seldom the case. In the example above, the ramp has an efficiency of 83 percent. Not all of the work that goes into the machine ends up in rolling the barrel. There seems to be some missing work. For many years the missing work was a great mystery to scientists. In most cases, the missing work would change into heat.

In everyday usage, work has many different meanings. A person may work for a living or may say that studying for an exam is hard work. The word *work* can convey many different ideas. In physics, the term *work* has a very specific meaning. Work only takes place when a force is applied through a distance. The force must be in the same direction as the body that is being moved.

An object lifted from the floor to the top of a table has work done on it because a force overcomes gravity. A student standing still with a book bag on his shoulders is not doing work because the books are not moving. A force does not act through a distance. When the student starts walking, he does some work to put the books in motion. A force acts to change the velocity of the books from zero to the speed at which the student walks. The effort to hold the books on his shoulder after he is walking is not work in the physics sense. The books are staying the same distance above the ground. The books are not getting higher or lower and the books are neither gaining speed nor losing speed. The student is not doing any work, in the physics sense, by carrying the book bag at a constant speed over level ground. The amount of work the student does is zero.



Work is done when a force causes a body to accelerate or change speed. When a car accelerates from 0 mi/hr to 60 mi/hr, work is done to change the car's velocity. A force is provided by the engine and acts on the car during the time it accelerates.

A person's skating speed can be slowed by dragging one of the rubber pads against the ground. The person is doing work because the friction of the pad slows the skater.



Work is defined as force times distance. In symbols $w = F * d$, with w the work, F the force and d the distance. Work in the metric system is measured in *joules*, named after James Prescott Joule. A joule is equal to the force of one newton acting through a distance of one meter.

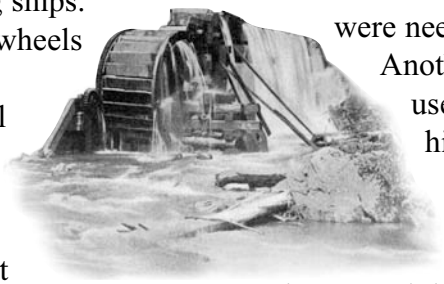
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The amount of work done in joules is calculated by multiplying the force in newtons by the distance in meters. A force of 300 newtons acted through a distance of 12 meters to roll a barrel up the ramp. The work = force * distance = 300 newtons * 12 meters = 3,600 newton-meters = 3,600 joules.

The unit of work in the English system is the *foot-pound*. A foot-pound is equal to the amount of work required to raise a 1-pound weight through an elevation of 1 foot. A 110-pound person walks to the top of a six-story building. Assuming each floor is 10 feet high, then the work = distance * weight = 60 ft * 110 lb = 6,600 ft-lbs.

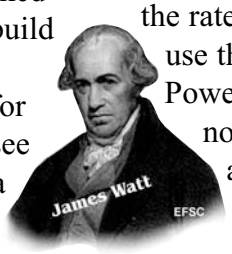
POWER

Until the 1700s, only limited means existed to do work. Muscles, either those of humans or of animals such as horses and oxen, did a lot of the work. Wind turned windmills and drove sailing ships. Falling water turned water wheels for factories and mills.

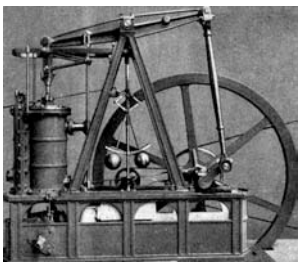


Practical mechanical devices for doing work did not exist. This changed with the invention of a steam engine by James Watt in 1769. James Watt earned a living repairing instruments for scientists at the University of Glasgow. In the late 1600s, the first crude steam engine had been built. The university had a model of one of the engines. The university gave the engine to James Watt to repair. He improved on the original design and built another engine.

James Watt's steam engine worked much more efficiently. He decided to build improved steam engines and sell them. James Watt did not have a good head for business, but he was smart enough to see his shortcomings. James Watt formed a partnership with a fellow businessman. Together the two men went into the steam engine business.



As a selling strategy, James Watt introduced the idea of power. *Power* is how quickly work is done. One common use for horses in James Watt's day was to turn the machinery that kept water from collecting in mines. A horse walked in a circular path with a long pole attached to a harness. As the horse walked in a circle, he turned the pole, which was hooked to gears that operated a pump. The horse did work by lifting the water out of the deep mine.



When water collected in the mineshafts faster than the horse could pump it out, another horse had to be added to help turn the pole. During a set interval of time, a single horse could only do so much work. If more work was needed to be done, then more horses were needed.

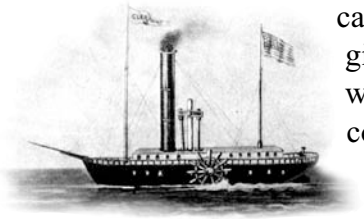
Another selling strategy James Watt used, was to compare the power of his engine with that of a horse. He tested the strength of a sturdy horse. The horse pulled a rope that went over a pulley to a heavy weight. The horse was able to raise 150 pounds to a height of 3.67 feet in a second. Averaged over a minute, this came to 33,000 ft-lbs/min. James Watt called this ***horsepower***, which measures the rate at which work is done. Horsepower is the amount of work done measured against a time interval.

James Watt's steam engines worked at the rate of seven horsepower. Engineers still use the horsepower to measure power. Power is the rate at which work is done and not the total work. A well-trained athletic person can develop about 1/4 of a horsepower for short periods.

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This is equivalent to lifting 8,250 pounds a distance of one foot in one minute: 1/4* 33,000 ft-lbs/min = 8,250 ft-lbs/min. In terms of seconds rather than minutes, one-fourth horsepower is equal to lifting about 138 pounds a distance of one foot in one second: (8,250 ft-lbs/min) / (60 sec/min) = 137.5 or 138 rounded to the nearest whole number.

Because James Watt could relate the power of his steam engines to something people understood, the engines sold briskly. Other inventors put steam engines to new uses. Inventors powered ships and trains with James Watt's steam engines. Steamboats and locomotives revolutionized both land and water transportation. Factories used steam engines rather than waterwheels. Mines used the engines to pump water. James Watt and his partner earned a good profit.



Power is work divided by time. As an equation it reads: *Power = work/time*.

Example: An elevator lifts 950 pounds a height of 75 feet in 2 minutes. Calculate the work and power. Solution: work = force * distance = 950 lbs * 75 ft = 71,250 ft-lb. Power = work/time = 71,250 ft-lbs / 2 min = 35,625 ft-lbs/min. The power of 35,625 ft-lbs/min is slightly more than one horsepower. To obtain the exact value for horsepower, divide 35,625 by 33,000 = 35,625 / 33,000 = 1.08 horsepower.

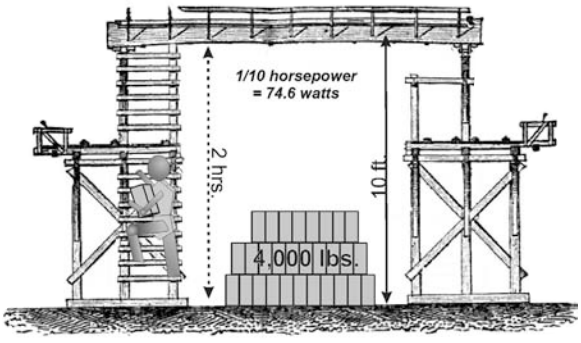
In the metric system, force is the product of mass and acceleration, $F = m * a$. Force is measured in newtons. Work is the product of force and distance, $W = F * d$. Work is measured in joules. Power is the rate at which work is done, *power = work/time*. The metric unit for power was named in honor of James Watt. In the metric system, a *watt* is defined as one joule of work done in one second. One horsepower is 746 watts.

Power measures how quickly work is done. The more powerful of two engines is the one that can do the same amount of work in less time. A motor can exert 760 newtons of force through 10 meters. Calculate the power. Solution: The problem cannot be worked because the time is not given. To calculate power, time must be known.

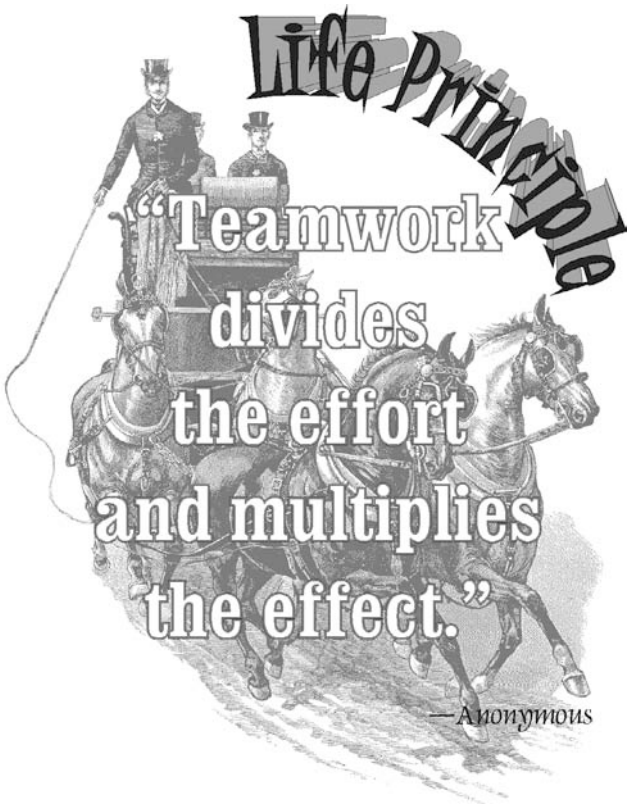
A motor can exert 760 newtons of force through 10 meters in 5 minutes. Calculate the power in watts. This problem can be worked because the time is given. However, the time interval for a watt is seconds, not minutes. First, convert 5 minutes to seconds: 5 min * 60 sec/min = 300 seconds. Power = work/time = (force * distance)/time = (760 newtons * 10 m) / 300 sec = 7600 / 300 newton-m/sec = 25.33 newton-m/sec = 25.33 watts.

A person carries two tons (4,000 pounds) of concrete blocks to the top of a 10-foot scaffold. Calculate the amount of power the person has. Solution: The problem cannot be worked because we do not know how much time it took. To calculate power, time must be known.

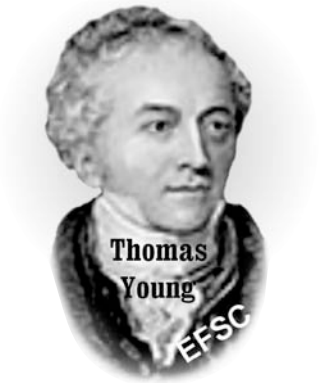
A person carries two tons (4,000 pounds) of concrete blocks to the top of a 10-foot scaffold in two hours (120 minutes). Calculate power in horsepower. Solution: The power is work/time = (4,000 pounds * 10 feet) / (120 minutes) = (40,000 ft-lbs) / (120 min) = 333 ft-lbs/min. Convert 333 ft-lbs/min to horsepower by dividing by 33,000: (333 ft-lbs/min) / 33,000 = 0.10 horsepower, about 1/10 of a horsepower.



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Integrated Physics & Chemistry

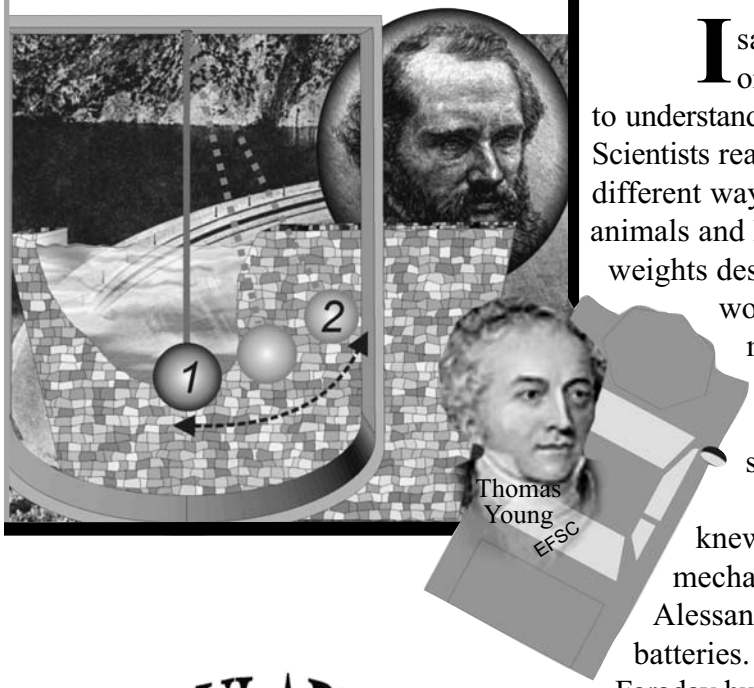
Lesson 14
Energy

Chapter 2

Section 3

Lessons 11-15

KINETIC AND POTENTIAL ENERGY



Isaac Newton died in 1727. For the next one hundred years, scientists struggled to understand the scientific meaning of work. Scientists realized that work could be done in many different ways. The wind, rushing water, muscles of animals and humans, wound up springs and weights descending from a height could all do work. All of these processes are called mechanical motion. With the invention of the steam engine, they found that heat could do work, also. Heat producing steam drives a piston.

At the end of the 1700s, scientists knew of only two ways to do work—by mechanical motion and by heat. In 1800, Alessandro Volta made the first electric batteries. About thirty years later, Michael Faraday built a device that could change electricity into mechanical motion—an electric motor. Electricity was another way to do work.

Science is understood when the vital concepts are clearly defined. Thomas Young used the word *energy* in the scientific sense in 1807. He defined energy as the capacity to do work. The same unit as work—a joule in the metric system and a foot-pound in the English system—measures energy. A joule is the energy needed to provide a force of one newton through a distance of one meter. A foot-pound is the energy required for lifting a one pound weight to a height of one foot.

Although work and energy appear to be nearly identical, some physicists do make a distinction. Work occurs when energy is transferred from one object to another. By swinging a bat that hits a ball, a ballplayer does work because he transfers energy from the bat to the ball. When the energy transfer ceases, then no more work is being done. Although scientists

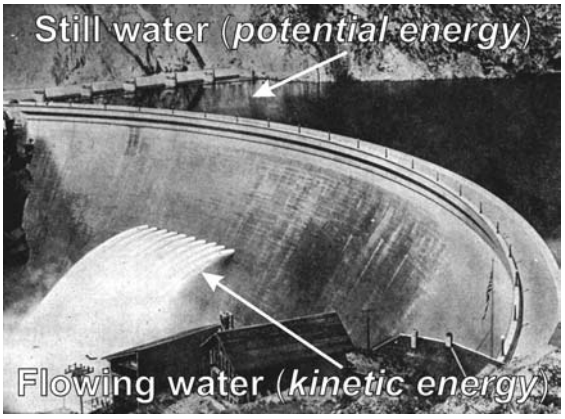
VOCABULARY

Kinetic energy: energy a body has due to its motion
Linear: in an equation, the relationship of terms in the first power or degree; (any exponential notation indicates the relationship between terms is not linear)
Factor: number that indicates an increase or decrease; e.g., if a number is reduced by a factor of three, then the number is divided by three

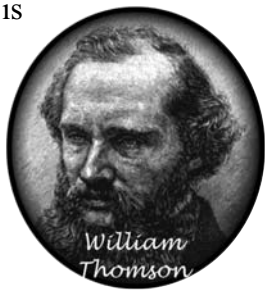
understand this distinction, they nevertheless often use the two words, energy and work, interchangeably.

Energy may be hidden or visible. The still water behind a dam at a hydroelectric plant does not appear to have the ability to do work. The energy of the water is *latent* or hidden. Another name for latent energy is *potential energy*.

The water behind the dam has potential energy. When the water flows down pipes, it gains speed from the force of gravity and can turn the turbines to generate electricity. The fast flowing water has energy due to its motion.



William Thomson invented the term, ***kinetic energy***, in 1856. The word *kinetic* is from a Greek word meaning *motion.* The kinetic energy of an object is equal to one half of the product of its mass and its velocity squared. In symbols it is written as $K.E. = 1/2\ mv^2$, with *m* the mass and *v* the velocity. In the metric system, kinetic energy is measured in the same unit as energy or work, the joule.

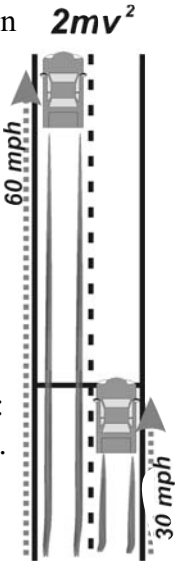


The equation $K.E. = 1/2\ mv^2$ shows that kinetic energy is directly proportional to the *mass* of an object. The relationship is ***linear***. The mass is to the first power, unlike velocity, which is to the second power. If two objects of different mass are traveling at the same speed, the more massive one will have the greater kinetic energy in direct proportion to their masses. A car and a bus are traveling at the same speed, but the bus is 10 times more massive. The bus has 10 times as much kinetic energy.

The equation $K.E. = 1/2\ mv^2$ shows that kinetic energy is directly proportional to the square of the *velocity* of an object. The relationship between kinetic energy and velocity is direct. As one increases, so does the other. The relationship is not linear. Kinetic energy is related to the second power of the velocity.

Because velocity is squared, doubling it has a greater effect. A car that increases its speed from 30 miles an hour to 60 miles an hour has a speed twice as great. The kinetic energy, however, is four times as great. If a car's speed is multiplied by three, from 30 mi/hr to 90 mi/hr, the kinetic energy is multiplied by 9: $3^2 = 9$.

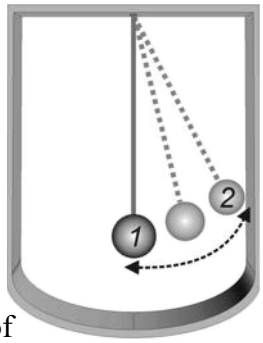
Automobile accident investigators are well aware of how speed affects the stopping distance of an automobile. The kinetic energy of the car, $1/2\ mv^2$, is equal to the work to stop the car, F * d. The braking distance of a car is directly proportional to the kinetic energy of the car. The distance the brakes are applied is shown by skid marks on the road. When a car is going twice as fast, the skid marks are not twice as long—they are four times as long. The force of the brakes must be applied through a distance four times as great. If a car increases its speed by a ***factor*** of three, from 30 mi/hr to 90 mi/hr, the stopping distance now becomes nine times as great: $[(90\ mi/hr) / (30\ mi/hr)]^2 = 3^2 = 9$.



Some of the meteors, rocks falling from space, that

strike the Earth have a mass of only a few grams, no bigger than the bullet from a gun. Yet, as the meteors slam into Earth's atmosphere, they leave a long glowing streak visible for hundreds of miles. The glow comes from the heat of friction as the meteors are slowed by Earth's atmosphere. These small bodies have tremendous energy because of their speed. Meteors can strike Earth at a speed of 24,000 m/sec. A bullet fired from a gun may have a speed of only 300 m/sec. Assuming the bullet and meteor have the same mass, how do their kinetic energies compare? To find the answer, divide the meteor's speed by the bullet's speed and square the result: $(24{,}000 / 300)^2 = 80^2 = 6{,}400$. The meteor has 6,400 times as much kinetic energy as the bullet.

The energy of motion, known as kinetic energy, can be changed into potential energy. As a pendulum swings back and forth, kinetic energy is constantly changing to potential energy and back again. A pendulum swings in an arc. The lowest point in the arc is at the middle of the swing. On either side, the pendulum rises along the arc. At the ends of the pendulum's swing it comes to a brief moment of rest and then begins swinging back in the opposite direction. At this moment, all of the pendulum's kinetic energy has been changed to potential energy. At the midpoint of the pendulum's swing, when the pendulum is at the lowest point, all of the potential energy has been converted to kinetic energy.



1. All potential energy has been converted to kinetic energy.
2. All kinetic energy has been changed to potential energy.

As work is done by lifting an object to a greater height, energy is stored in the form of gravitational potential energy. In Tennessee, an electric company keeps its electric generating stations running at peak efficiency throughout the day and night. At night, when the demand for electricity is lower, the excess electricity is used to pump water to the top of a high mountain. During the day, when the demand for electricity exceeds the capacity of the electric generating stations, the water on the mountain is released. The water flows to the base of the mountain and turns turbines to generate electricity.

The *gravitational potential energy* of an object due to the objects position above the surface of Earth is $P.E. = m * g * h$, with m the mass of the object, g the acceleration due to gravity and h the height of the object above the surface of Earth.

This equation comes from the equation for work and force. Energy (or work) is defined as a force applied through a distance, $E = F * d$, with E the energy, F the force and d the distance. The Second Law of Motion, $a = F/m$, can be rewritten as the force equation, which states that force is the product of the mass and acceleration. This is expressed in symbols as $F = m * a$, with m the mass and a the acceleration. When the acceleration is caused by gravity, physicists use the letter g instead of the letter a. The distance when speaking of gravitational potential energy is the height (h) an object is raised.

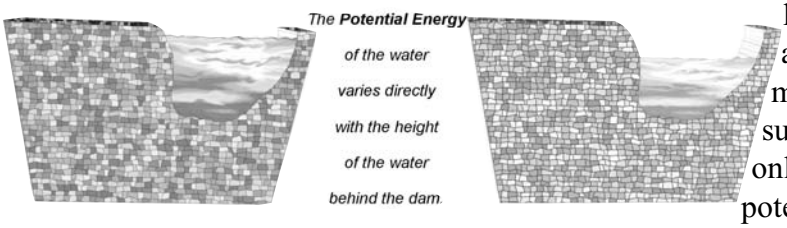
E = F * d	definition of energy
E = m * a * d	F = m* a, substitute *m*a* for *F*
E = m * g * d	substitute *g* for *a*
E = m * g * h	substitute *h* for *d*
P.E. = m * g * h	substitute *Potential Energy* for *Energy*

The gravitational potential energy of an object above the surface of Earth is equal to the product of the objects mass and the

acceleration due to gravity and the objects height above Earth. The relationship of potential energy to each of the quantities mass, acceleration of gravity and height is direct. Because each quantity is to the first power, the relationship is linear.

Potential energy is directly proportional to the mass. A pile driver sets steel piers in the ground by dropping a heavy weight from a height. If the mass of the driver doubles, this will affect the potential energy. The potential energy is directly proportional to the mass, so it doubles as well.

Potential energy is directly proportional to the height. During the time of a drought, the level of a lake behind a hydroelectric dam falls to 80 percent of its normal height. Water falls into the turbines from this lower height. How will the decrease in height affect the potential energy? The potential energy will be 80 percent of the original value because potential energy and height are directly related.



Potential energy is directly proportional to the acceleration due to gravity, 9.8 m/sec^2. A person with a mass of 50 kg is at the top of a building with 6 floors. If each floor is about 3 meters high, what is the person's potential energy? Solution: P.E. = m * g * h = 50 kg * 9.8 m/sec^2 * 18 m = 8,820 kg-m^2/sec^2 = 8,820 joules.

How much energy would be required to lift a 50 kg person to the top of the same building? The potential energy at the top is equal to the work required to lift the person to the top of the building. The energy would be the same, 8,820 joules.

Now suppose the same person is 18 meters above the surface of the Moon where the acceleration due to gravity is only 1/6th as much. How will this change the potential energy of 8,820 joules? On the Moon, a 50 kilogram mass at a height of 18 meters above the surface will have only 1/6th as much potential energy as under the same circumstances on Earth: 8,820 joules * 1/6 = 1,470 joules.



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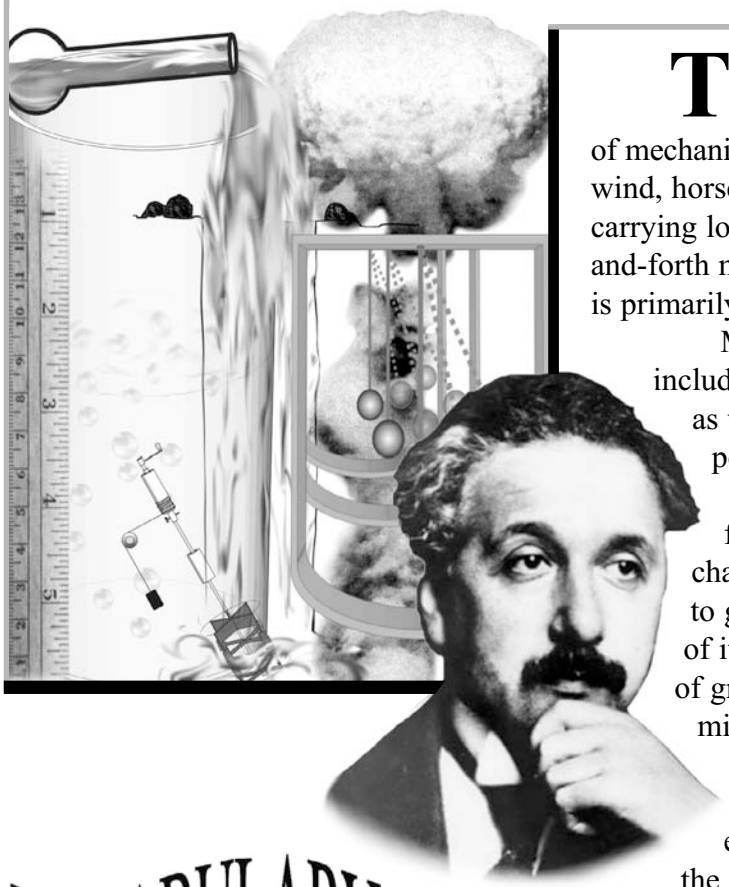
Lesson 15
Energy

Chapter 2

MECHANICAL AND HEAT ENERGY

Section 3

Lessons 11-15



The first type of energy that physicists studied was *mechanical energy*. Examples of mechanical energy include flowing water, rushing wind, horses pulling wagons, human muscles carrying loads, compressed springs or the back-and-forth motion of pendulums. Mechanical energy is primarily energy that puts machines in motion.

Mechanical energy can be potential energy, including gravitational potential energy such as water behind a dam or mechanical potential energy such as wind-up springs.

As a pendulum swings back and forth, the pendulum's energy constantly changes back and forth from kinetic energy to gravitational potential energy. At the top of its swing, all of its energy is in the form of gravitational potential energy. At the midpoint at the bottom of its swing, the energy is entirely kinetic energy. In between, the pendulum has both kinetic energy and potential energy. Throughout the swing, the total energy is the same. At first, scientists believed the sum of the potential energy and kinetic energy remained the same. In symbols, *K.E. + P.E. = constant*.

Scientists found that the statement, *K.E. + P.E. = constant*, was not entirely correct. The pendulum loses energy with the passage of time. The pendulum slows and eventually stops. When the pendulum stops, the total energy would be zero; *K.E. + P.E. = 0*. A pendulum clock is wound by raising weights on a chain. As the weights descend, they provide a small amount of energy to keep the pendulum going. The pendulum provides a steady back-and-forth motion, so the clock keeps accurate time.

When a hammer is given a swift swing, the moving

VOCABULARY

Equivalent: equal in value
Quanta: smallest units that can exist; singular is quantum
Special Theory of Relativity: if two systems are moving uniformly in relation to each other, it is impossible to determine anything about their motion except that it is relative

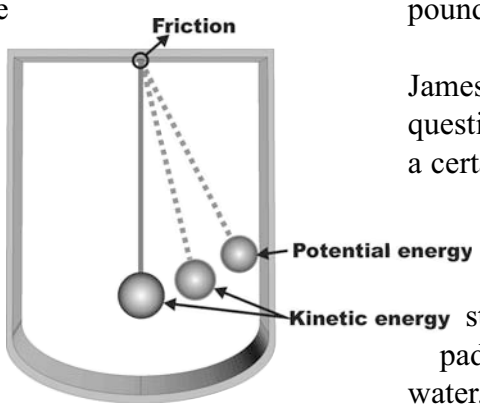
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head of the hammer has the energy of motion. When the hammer strikes the head of the nail, the energy is transferred from the moving hammer into the nail. Work is being done. A force acts against the nail to drive it part of the way into the board. The nail receives the kinetic energy of the hammer, but after going for a short distance into the board, the nail comes to a stop. The kinetic energy seems to disappear.

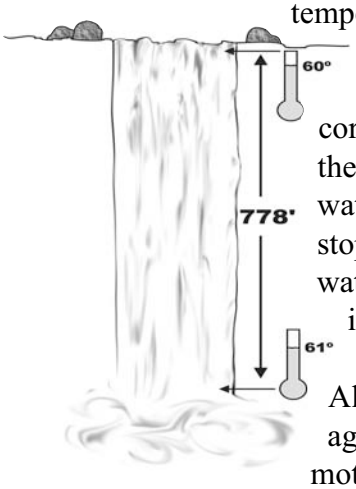
Touch the head of the nail. It will be warm. When a nail is especially difficult to drive into a board, the nail will become hot to the touch. The kinetic energy is changed into heat energy.

Physicists of the early 1800s agreed that heat was the primary cause of energy loss. The nail releases its kinetic energy in the form of heat. The pendulum slows because of air resistance and the slight friction of the pendulum against its support. Friction causes heat.

One of the scientists who saw the role of heat in energy loss was James Prescott Joule. He made extremely accurate thermometers. The thermometers could measure changes of temperature in fractions of degrees. A person could come into a closed room, sit quietly in a chair for a few minutes and then leave. James Prescott Joule's thermometers could detect the change in temperature in the room because of the body heat.



Joule measured the temperature of the water above and below waterfalls. In each case he found that the temperature at the bottom of the falls was warmer than the temperature at the top of the falls. James Prescott Joule correctly concluded that the kinetic energy of the water as it crashed to a stop at the bottom of the waterfall was changed into heat energy.



Although scientists agreed that mechanical motion could be converted into heat, they did not know the conversion factor. The English unit of heat was the *British thermal unit*, defined as the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit. The symbol for the British thermal unit is *Btu*.

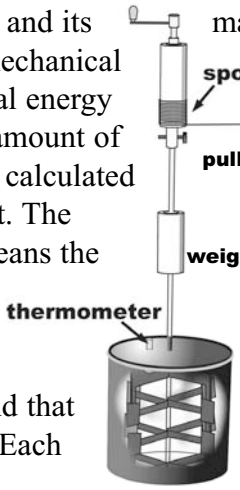
In the English system, the unit for mechanical energy was the foot-pound, which was defined as the amount of work required to raise a weight of one pound to a height of one foot. The symbol for foot-pound is *ft-lb*.

Heat and kinetic energy are related. James Prescott Joule set out to answer the question as to how much heat is produced by a certain amount of mechanical energy.

Joule designed an insulated tub with a paddle wheel inside. He filled the tub with water. Turning the paddle wheel stirred the water, and the energy of the paddle wheel became heat energy in the water. He turned the paddle wheel with a known weight outside the tub. As a known weight fell through a measured distance, it stirred the water. This produced heat in the water. He measured the change in temperature of the water with his extremely accurate thermometers. Joule could compute the heat energy because he knew the change in temperature and amount of water. He

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knew the distance the weight fell and its mass, so he could compute the mechanical energy. The amount of mechanical energy the weight lost was equal to the amount of heat energy the water gained. He calculated the mechanical equivalent of heat. The mechanical ***equivalent*** of heat means the amount of mechanical energy needed to equal a given amount of heat energy.



James Prescott Joule found that 1.00 btu was equal to 778 ft-lbs. Each pound of water that goes over a waterfall 778 feet high will gain one degree Fahrenheit when it splashes into the pool at the bottom of the waterfall.

Because Joule found the mechanical equivalent of heat, the metric unit for work and energy is named in his honor. A *joule* is the energy from exerting a force of one newton through a distance of one meter. The metric unit for heat is the calorie, defined as the heat necessary to raise the temperature of one gram of water by one degree Celsius. In the metric system, the conversion between the joule, *J*, and the calorie, *cal*, is one joule equals 4.86 calories: 1.00 J = 4.86 cal.

The joule is also used to measure the energy of electric circuits. One joule of electricity will light a one-watt light bulb for one second.

When a car gains kinetic energy, the change is visible—the car goes faster. When a glass of water is warmed a few degrees, its gain of heat energy is not visible. The water looks the same. As an object grows warmer, scientists can see nothing to explain how the object gains heat energy.

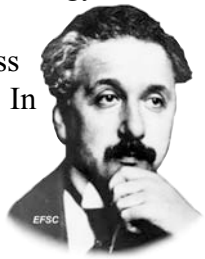
In the early 1800s, John Dalton proposed that matter is made of atoms and molecules. Later, James Clerk Maxwell did mathematical calculations and practical experiments that showed that heat is due to the motion of the atoms and molecules that make up a substance. Heat, then, is kinetic energy but on a molecular level. Heat is the energy resulting from the motion of atoms and molecules.

As physicists experimented with the different forms of energy, they found that one could be changed into another. The potential energy due to the position of water behind a dam could be converted to kinetic energy of motion to drive turbines. The turbines ran electric generators. Cross-country transmission lines distributed the electricity. Electricity ran electric motors and heaters and charged electric batteries. Although one form of energy can be changed into another, the conversion is not 100 percent efficient. Some energy changes into heat. When turbines generate electricity, some friction causes the shafts to become warm. The wires of cross-country transmission lines are heated as current surges through them.

When physicists took into account the energy that changed into heat, they concluded that energy is conserved; the total energy in a closed system is constant.

About the time they came to that conclusion, they made discoveries that shook the foundations of science. From about 1895 to 1905, physicists discovered subatomic particles, radioactivity and nuclear reactions. Physicists found that energy comes in very tiny, but set amounts, called ***quanta***.

Albert Einstein proposed the ***Special Theory of Relativity***, which changed the way physicists thought about space and time. Albert Einstein also stated that energy and mass are equivalent. Energy is equal to the product of the mass and the speed of light squared. In symbols, $E = mc^2$ with E the energy, m the mass and c the speed of light. The energy of



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a nuclear blast comes from the conversion of a small amount of mass into a vast amount of energy. The conversion is so one-sided because the proportionality constant (c^2) is such a huge number.

Many of the established principles of physics changed during the ten years from 1895 to 1905. The Law of Conservation of Energy and the Law of Conservation of Matter were no longer strictly correct because of Einstein's energy equation, $E = mc^2$. Matter can be changed into energy, and energy can have mass.

Some physicists combined the Law of Conservation of Matter and the Law of Conservation of Energy into a single law. The revised Law of Conservation of Matter-Energy states that the total matter and energy in a closed system (such as the universe) is constant.

Chemists, however, made a slight modification to the two conservation laws. Chemists said that matter could neither be created nor destroyed by ordinary chemical means. The chemical version of the Law of Conservation of Energy states that energy can neither be created nor destroyed by ordinary chemical means. The phrase "ordinary chemical means" excludes nuclear reactions.



Mushroom cloud created by Atomic Bomb over Nagasaki



Plutonium used in Atomic Bomb dropped on Nagasaki, Japan

Another approach was to separate physics into two branches. *Modern physics* is the study of nuclear reactions, subatomic particles, energy quanta and relativity. *Classical physics* includes Kepler's Three Laws of Planetary Motion, Galileo's discoveries, Isaac Newton's Three Laws of Motion, the Law of Universal Gravitation, and the concepts of inertia, mass, weight, force, momentum, impulse, work, energy and power.

Physics, chemistry and the other sciences are an on-going effort to understand the physical universe. New facts are uncovered. Sometimes the new information can be *integrated*, or blended, into the existing framework of science. Sometimes, however, the changes are so extensive that fundamental principles of science have to be modified or discarded entirely. People should remain conscious of the fact that science is a process that changes and adapts to new information.

Life Principle

"All of the top achievers I know are life-long learners."

—Dennis Waitley

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