A PUBLICATION FOR THE MIDDLE SCHOOLS OF THE REPUBLIC OF SENEGAL
APPROVED BY THE MINISTRY OF EDUCATION

Introduction to Physical Science

Grades 9 and 10

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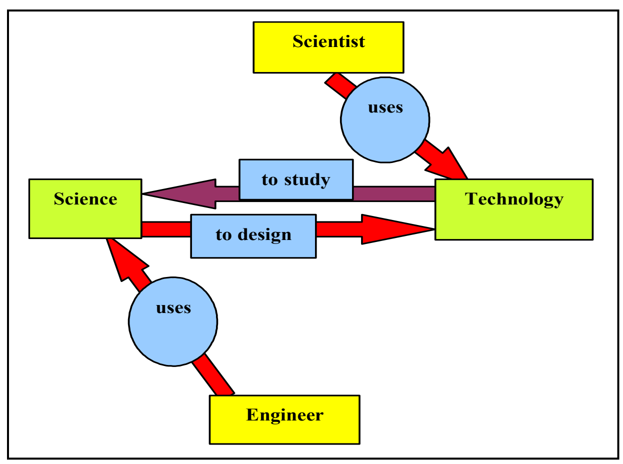
Theme I: What is Scien
ce, How Do We Use It?

Lesson 1: Science, Technology, and Engineering

Do You Know?

A computer, radio, television, a cell phone, and a satellite are all examples of technologies. But technology includes much more than complicated machines.

One of the earliest technologies created by humans was a cutting tool made from a rock. They sharpened the rock by chipping at the sides with another rock. Then they attached the rock to a wooden handle to make an ax. How was the ax "technology'? It was a tool that people made to do a job or solve a problem.



The development of technology depends on the work of both scientists and engineers. A **scientist** is someone who studies the natural world. An **engineer** is someone who designs technology to solve problems.

Engineers must understand science in order to design technologies. For example, understanding the properties of magnets allowed scientist and engineer Michael Faraday to invent the electric generator. A generator uses magnets to produce electricity.

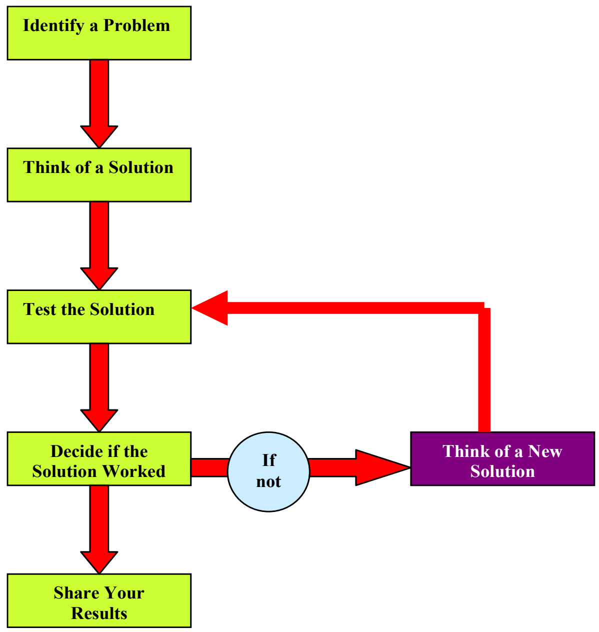
Sometimes, ideas for new technology come from observing nature. For example, engineers in Japan studied butterfly wings to see what made them waterproof. They used their findings to create a similar kind of waterproof material in the laboratory.

Scientists and engineers are not always different people. Many scientists throughout history have acted as engineers and invented new technologies.

Science, Technology, and Engineering

Designing Technology

When engineers are designing a new technology, they go through a series of steps. Every technology is designed to solve a problem. So you know that the first step must be identifying a problem.



This chart shows the steps in technology design.

a. **Identify a problem**: A phone booth on the side of country road needs lights so people can see when they are inside it. But there is no electric power to the phone booth.
b. **Think of a Solution**: Put a solar panel on top of the booth. The energy from sunlight can be used to power a light bulb in the booth at night.
c. **Test the Solution**: Put up the solar panel. Connect wires from the panel to a light source in the booth. Also connect a sensor that will "tell" the lighting system when it is dark. See if the bulb lights at night.
d. **Decide If the Solution Worked**: The bulb stayed lit all night. It worked!
e. **Share Your Results**: Write a report about what you did and learned. Share your report with other people who might have a similar problem.

There is never just one way to solve a problem. Engineers often test many different ideas before they choose a good solution.

Science, Technology, and Engineering

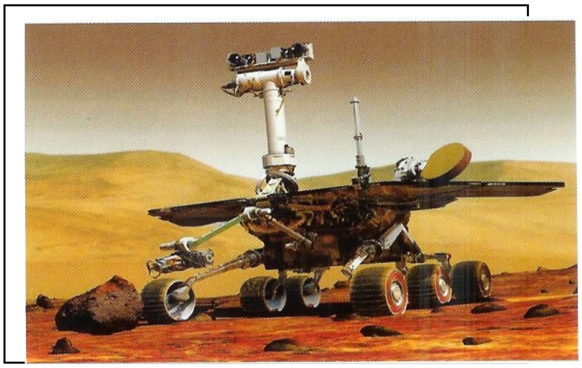
How Technology Helps Scientists

Scientists are always asking questions about the natural world and then trying to find the answers. Observation is an important part of that process. Technology helps scientists with their observations.

Think about a scientist observing tiny organisms with a microscope. Or a meteorologist using satellite pictures to track a hurricane. Or an astronomer using a telescope to view the Moon. Scientists use technology to help them see things that they cannot see with just their eyes.

Technology helps scientists get more information about the natural world. This information might answer a question the scientists had. For example, some new Photographs from Mars provided what looked like dry riverbeds on the planet's surface. This observation led scientists to wonder whether there had been liquid water on Mars's surface in the ancient past.

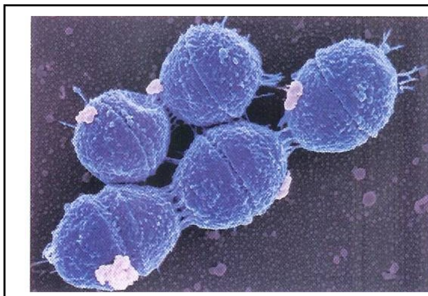
Engineers designed and built a space probe to visit Mars. The probe carried a robot rover named Spirit that would look for evidence of water on Mars in the past. On January 3, 2004, the probe landed on Mars, and Spirit began its mission. The question of whether or not Mars had water is being analyzed from the information and materials collected by Spirit.



The robot Spirit on the surface of Mars.

New discoveries often give scientists ideas for new kinds of technology. For example, hundred of years ago, scientists did not know that bacteria existed. Then in 1683, a Dutch scientist named Anton von Leeuwnhoek developed a new technology. He made curved lenses that magnified objects. Leeuwenhoek used the lenses to build the first microscope.

Once scientists had microscopes, they could observe the tiny bacteria and other organisms that cause diseases in people and animals. Then they discovered that some natural substances could kill bacteria. These substances are called antibiotics. Scientists used technology to produce medicines from natural antibiotics. Later, they found ways to create new antibiotics in laboratories.



Bacteria are too small to see with just your eyes. These are the bacteria that cause strep throat.

Science, Technology, and Engineering

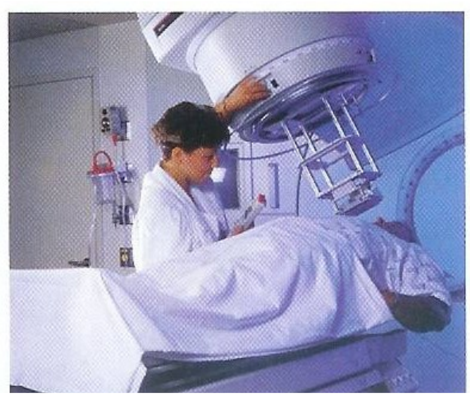
How Technology Helps All of Us

Technology helps people live safer, healthier, and more comfortable lives.

In the Past Today

Years ago, there was not always enough food to eat. Plowing and harvesting were hard work and took a long time. Today, farm technology allows people in the United States and other developed countries to grow huge quantities of food.

In the past, garbage and other waste piled up in the streets. The wastes attracted rats and spread disease. Today, garbage collection and sewage systems remove wastes from where people live.



In the Past Today

Not very long ago, many people died of common diseases. Today's technology helps doctors find out what is wrong with a patient. Vaccines prevent serious diseases such as polio and smallpox. Many kinds of medicines are available to treat illnesses like Malaria.

Modern technologies are not available to everyone in the world. Many people still struggle with hunger and disease every day.

Science, Technology, and Engineering

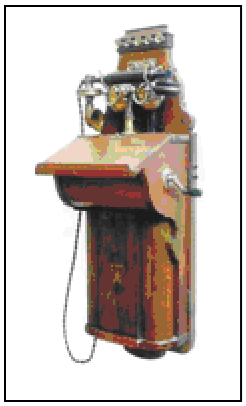
Technology Is Always Changing

No technology is ever a final solution. Technologies can always be improved. One example is the telephone.

In 1840, the fastest way to send a message over a long distance was to use a telegraph. The telegraph is a machine that sends electrical signals through wires. The signals are short and long clicking noises.

The telegraph machine required trained telegraph operators to send and receive messages.

The in 1876, while he was experimenting with a telegraph machine, American inventor Alexander Graham Bell discovered how to send voice messages through telegraph wires. The first telephone was created.



The photo to the left is an example of an early telephone that had to be wound up with a hand crank before making a call. The call had to go through an operator.

In time, telephone technology improved enough that telephone operators were no longer needed. People could just pick up a phone and call anyone anywhere.

Today, cellular telephones let people make and receive phone calls wherever they happen to be. Some cell phones even send pictures and e-mail.

Technologies are developed to solve problems. But that does not mean they only do good. Some technologies create new problems while trying to solve others.

Antibacterial soap is a good example. Antibacterial soap contains antibiotics, which are substances that kill bacteria. Antibacterial soap was developed to kill harmful bacteria that might be on our hands or our dirty dishes. Since some bacteria cause diseases, killing them seemed like a good idea.

Unfortunately, not all kinds of harmful bacteria are killed by the antibiotics in soaps. Scientists say that these kinds of bacteria are "resistant" to antibiotics. Resistant bacteria survive and reproduce. Their offspring are also resistant. Over time, all those kinds of bacteria are resistant to the antibiotics.

Resistant bacteria are dangerous to public health. That is because doctors use antibiotics to cure people who are infected with harmful bacteria. But when resistant bacteria get into our bodies and make us sick, antibiotics can't kill them. These resistant bacteria then move easily from one person to another, making lots of people sick.

Science, Technology, and Engineering

Activity 1

1. What is technology?
2. What is science?
3. What is engineering?
4. Can one who is a scientist also be an engineer?
5. What are the steps used to technology design?
6. Give an example as to how technology can help improve science.
7. Give an example as to how technology helped to improve people's lives in general.
8. Does technology constantly change; explain your answer by example.
9. Give an example of a very helpful use of technology.
10. Give an example showing how technology is not perfect.

Theme I: What is Science, How Do We Use It?

Lesson 2: What is Sciences; Specifically, What is Physical Science

Do You Know?

Science is a way we study all aspects of life, our world, and our environment to learn facts and gain understanding. Scientists often ask questions about what they observe. They call on many skills to help them answer these questions. This process of asking and answering questions in science is called inquiry.

In the study of any aspect of the world, life or our environment, science and scientists study many things in a systematic and structured way that is often called the scientific method. In particular, they make scientific investigations that can be repeated by others who wish to study or learn the same thing for themselves.

Using the scientific method to do science investigations requires scientists to carefully do and consider many things. Steps in a Scientific Investigation, using the Scientific Method:

STEP	**MEANING**
Asking a question	asking *What, How, When, where,* or *Why*
Making a hypothesis	making a smart guess about the answer to the question
Planning the investigation	deciding how to gather evidence to answer the question
Collecting – recording data	gathering and recording information to test the hypothesis
Organizing data	making graphs and tables to better understand the Information that has been gathered
Explaining results	figuring out what the information means
Thinking of new questions	using the information that you gathered to identify new questions
Sharing results	sharing the information with other investigators

Definition: An **experiment** is a scientific investigation that tests a hypothesis; using the scientific method

What is Sciences; Specifically, What is Physical Science

Scientific Method Continued

Listed are twenty-five (25) of the more common things that are done by scientists do in the study of science; while doing science investigations using the Scientific Method.

To **analyze** means to separate anything into its parts to find out what it is made of and how it is pub together.

To **ask questions** means to make an inquiry about what you do not know, based on what you see around you.

Cause and effect is the consideration of something (cause) that brings about a change in something else (effect).

To **classify** means to group objects according to certain designated characteristics.

To **collect data** means to learn all useful information one can about what is under investigation.

To **communicate** means to share information.

To **compare and contrast** means to find our how things are the same (compare) and how they are different (contrast).

To **define** means to develop a description that is based on observations and experience.

To **draw conclusions** mean to put together in a statement all the facts you have learned and tell what they summarize.

Evidence means information and clues used to solve a problem.

An **experiment** is a test that is used to discover or prove something.

To **explain** means to tell the meaning of or tell how to do something

A **hypothesis** is a statement (sometimes agrees) in answer to a question; one then test the statement or guess to determine whether or not it is true.

To **identify** means to name or recognize.

To **infer** means to form and idea from facts or observations.

To **interpret data** means to use the information that has been gathered to answer questions or solve a problem.

What is Sciences; Specifically, What is Physical Science

Scientific Method Continued

To **make decisions** means to select from many choices what one believe is the correct choice.

To **measure** means to find the size, volume, area, mass, weight, or temperature of an object or how long an event occurs.

To **model** is something that represents an object or event.

To **observe** means to use one or more of the senses to identify or learn about an object or event.

To **plan** means to outline ahead of time how something is to be done or made, including methods, materials and approaches.

To **predict** means to state possible results of an event or experiment before it occurs.

To **repeat** means to do something again the same way to see if the results are the same

To **test** means to conduct an examination of a substance or event to see what it is or why it happens.

A **theory** is an explanation based on observation and reasoning.

To **use numbers** means to explain data by ordering, counting, adding, subtracting, multiplying, and dividing.

Definition: **Variables** are things in an experiment that can be changed or controlled.

What is Sciences; Specifically, What is Physical Science

Keeping Records

Scientists keep careful records of their investigations. So should you. This page shows what a careful record should look lie.

Cheik Wade

February 15, 2004

Always write your name and the date at the top of each page. If you need more than one page, also number the pages.

Hypothesis: The temperature goes up in the morning, is highest at noon, and then goes down in the afternoon.

Write the idea that you want to test.

List the materials and tools you used.

Materials: outdoor thermometer, paper, pencil

Procedure

In this section, describe all the steps in your investigation. List the steps in the order you did

1. Put a thermometer outside a window
2. Read and record the temperature every hour for 4 hours.

Record all data right away. Also make sure you record data accurately, even if you think the data are wrong or if other students have collected different data.

Data

Time	Temperature
11:00 A.M.	22˚ F
12: 00 noon	25˚ F
1:00 P.M.	27˚ F
2:00 P.M.	28˚ F
3:00 P.M.	26˚ F

Record the units for all measurements. Don't record just the numbers.

Write your ideas about what the data mean and whether they support your hypothesis.

What the Data Mean: The data do not support my hypothesis. The temperature keeps going up after 12:00 noon. It doesn't start to go down until later in the afternoon.

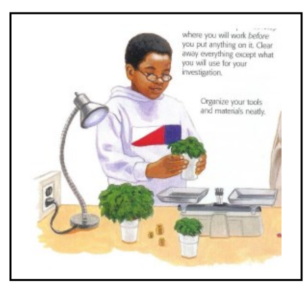
Remark: Never cross out or change data so that your results come out the way you think they should. Remember, you are trying to answer a question. Do not decide on the answer before you finish the investigation!

What is Sciences; Specifically, What is Physical Science

Always Practice Safety when Conducting a Scientific Investigation

Investigating the mysteries of nature and our environment can be exciting. But some investigations can be dangerous if you're not careful. Here are some suggestions to keep you safe when you do science investigations:

- Always wait for your teacher's permission to being an investigation.
- Follow all directions you are given.
- Request help from an adult if you don't understand any directions.
- Never play around during an investigation.
- Only use equipment the way it is supposed to be used.
- Keep your work area neat and clean.
- Always wear appropriate safety equipment such as goggles.
- Learn what to do in case of an emergency or accident.
- Never taste any substance you are using in science investigation unless your teacher tells you to do so.
- The best way to stay safe is to follow instructions exactly as you get them.
- Always follow steps in the order they are given to you. Don't skip steps or do them out of order.
- Always stop work right away when your teacher tells you to.
- Always pay attention to what's going on around you. If something is happening that you think is dangerous, tell the adult in charge.
- If it is a group investigation, you and all the other members of your group need to work together. The whole group should plan the investigation.
- Washing your hands before and after your work to stay healthy.
- Handle science equipment with care and respect; do not do anything that might damage them.
- Keep science equipment in good working order; make sure your science tools are clean before you use them; clean them each time after you use them.
- When you are finished using science equipment, put them back where they belong; that way, you or another student will be able to find them again.
- Do not waste materials; you might run out before you are finished.
- Do not use another student's materials unless you have permission.
- You should organize your science work area carefully; always clean up your area when you are finished.



What is Sciences; Specifically, What is Physical Science

Many different People Contribute to Science

Scientific research has been going on for thousands of years. So has the development of new technologies. Medicines are good examples of the result of scientific research.

Since ancient times, people have used natural materials to treat infections and diseases. Several hundred years ago, people in Peru discovered that the bark of the cinchona tree would bring down a high fever when someone had malaria, a serious tropical disease. Bark was taken to Europe, where many people were dying of malaria. The South American medicine saved many European lives.

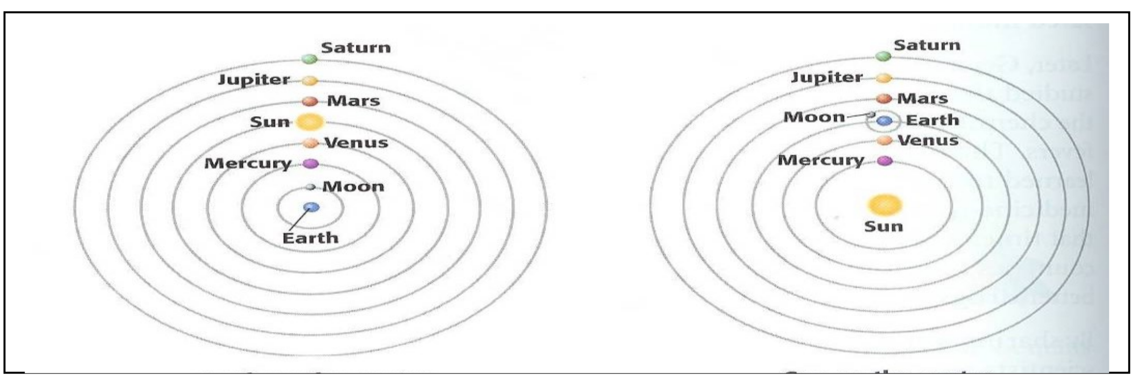
Later, German scientists study the bark. They found the chemical that reduced high fevers. They used what they learned to make malaria medicine in a laboratory. Since that time, scientists in other countries have developed even better drugs to treat malaria.

By sharing information, all scientists help each other make scientific discoveries.

Not every scientific idea is immediately accepted by a society. That is because scientific ideas sometimes do not agree with the strong beliefs that a society holds. For example, consider the case of Galileo.

Galileo was an Italian astronomer who lived from 1564 to 1642. Galileo was interested in how Earth, the planets, and the sun move in space. From Earth, it looks like the sun and planets revolve around Earth. Most people in Galileo's time believed that Earth is the center of our solar system.

Galileo has made careful observations and had done some experiments. His results led him to think that the sun is the center of our solar system. Galileo said that Earth and the other planets revolve around the sun.



Earth as center of the solar system Sun as the center of the solar system

The planets beyond Saturn – Uranus, Neptune, and Pluto – were not known in Galileo's time.

What is Sciences; Specifically, What is Physical Science

The idea that the sun is the center of the solar system was first suggested by Nicolaus Copernicus, a Polish astronomer, Galileo is the one who collected data to support the idea. Other scientists accepted it. When Galileo presented this idea to his society, they rejected it. The people had always believed that Earth is the center of the universe. Galileo's idea said that Earth is not the center. You can probably see why an idea that went against everything you believed about the world would be very frightening.

Members of Galileo's society decided to put him on trial, like a criminal. They made him announce to everyone that his idea was wrong. He was forced to spend the rest of his life imprisoned in his own home.

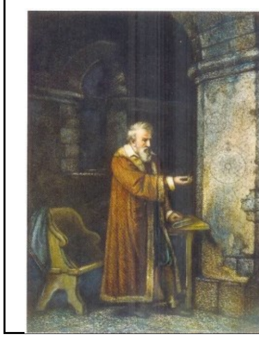


Photo of Galileo

Scientists who came after Galileo gathered more data. The data showed that the sun, not Earth, is at the center of our solar system. In time, all members of society accepted Galileo's idea.

Even in modern times, scientists must deal with the beliefs and fears of the members of their society. For example, when vaccines were first developed, people were afraid to be vaccinated. They thought vaccines would make them sick. But over time, many scientific tests showed that vaccines help prevent disease. Society began to accept vaccination as a way to stay healthy.

What kinds of scientific investigations are conducted by Physical Science or physical scientists? Physical Science is the study of matter, forces, motion, and energy. It is the study of the branch of science called chemistry and the one called physics. The themes and topics of this book will focus on these major aspects of physical science.

Activity 1

1. What is science; specifically what is physical science?

2. Name at least five (5) things that scientists commonly do.

3. How were treatments and drugs for malaria first discovered?

4. How did society initially accept Galileo's scientific result about the sun being the center of the universe; how does society accept that idea today?

5. Name five (5) suggestions for safe science investigations.

Theme I: What is Science, How Do We Use It?

Lesson 3: The History of Science and Technology (Some Milestones)

Do You Know?

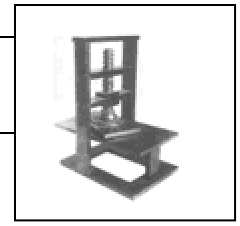
The History of Science and Technology includes a time line of some events and inventions, that have occurred over the years. We begin with the year 1450 and continue until 2000. A time line lists important events and inventions in the order they took place. An invention is a new device, technology, for providing a service or accomplishing a task. This lesson does not include every event and invention in science. It's impossible to tell the whole story of science discoveries and inventions in just a few pages. However, this History gives a brief look at some well known science events and inventions, technologies, over the past 550 years.

The History of Science and Technology (Some Milestones)

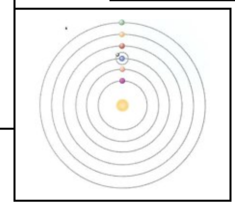
Science and Technology Time Line 1450-2000

1450 | 1500 | 1543 | 1550 | 1590 | 1600 | 1608 | 1609 | 1610 | 1620 | 1630 | 1632 | 1640 | 1643 | 1650 | 1660 | 1665

1450
Johann Guttenberg invents the printing press



1543
Nicolaus Coprnicus publishes his theory that the sun, not Earth, is at the centre of "the universe"

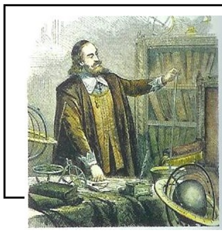


1590
First microscope with two lenses is built

1608
Hans Lipppershey invents the refracting telescope

1609-1610
Galileo builds a telescope and discovers Jupiter's moons

1632
Galileo publishes his book supporting Copernicus's theory of 1543



1643
Evangelista Torricelli invents the barometer

1665
Robert Hooke observes the smallest units in the body and named them "cells"

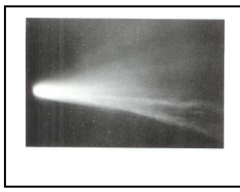
The History of Science and Technology (Some Milestones)

1666
1668
1670
1680
1687
1705
1714
1735
1742
1752
1781
1784

1666
Issac Newton discovers that “white” light is made of all the colors of the rainbow

1668
Issac Newton invents the reflecting telescope

1687
Isaac Newton describes his laws of motion and gravity

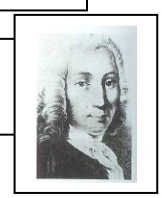


1705
Edmund Halley predicts that a certain comet will return in 1758; it does and is named Halley’s comet

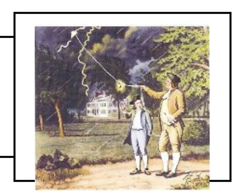
1714
Gabriel Fahrenheit invents the mercury thermometer and a temperature scale

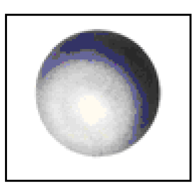
1735
Carolus Linnaeus publishes the first modern method of classifying living things

1742
Anders Celsius invents his temperature scale



1752
Benjamin Franklin shows that lightning is electricity





1781
Planet Uranus is discovered

1784
Benjamin Franklin invents bifocal eyeglasses

The History of Science and Technology (Some Milestones)

1790 → **1790**
France commissions the creation of the first metric system of measurement

1794 → **1794**
Eli Whitney patents his cotton gin

1796 → **1796**
First vaccination protects people against smallpox

1808 →

1808
John Dalton publishes a book that describes the first modern theory of the atom

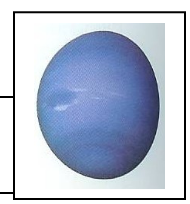
1820 → **1820**
Hans Christian Oersted discovers that an electric current produces a magnetic field

1831 → **1831**
Michael Faraday discovers that a magnetic field can produce an electric current

1837 →

1837
Samuel Morse patents the telegraph

1846 → **1846**
Planet Neptune is discovered



1856 → **1856**
Henry Bessemer invents a converter that makes steel easier to produce

The History of Science and Technology (Some Milestones)

1859

1865

1876

1879

1880

1898

1902

1903

1905

1912

1859
Charles Darwin publishes *Origin of Species*, which outlines his theory of evolution

1865
Gregor Mendel publishes his experiments with pea plants, starting the science of genetics

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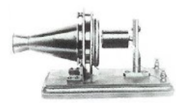
Gregor Mendel publishes his experiments with pea plants, starting the science of genetics



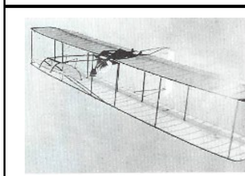
1876 Alexander Graham Bell patents the telephone

1879
Thomas Edison invents the light bulb

1880
Louis Pasteur connects germ theory to certain diseases

1898
Marie and Pierre Curie discover the radioactive elements polonium and radium

1902
Guglielmo Marconi makes the first transatlantic radio transmission



1903
Brothers Orville and Wilbur Wright fly their airplane at Kitty Haw, North Carolina

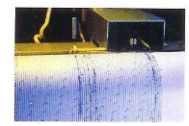
1905
Albert Einstein publishes his theory of relativity

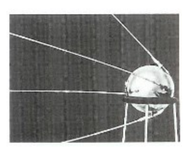
1912
Alfred Wegener presents his idea that the continents have moved

The

History of Science and Technology (Some Milestones)

Year	Event
1926	**1926** Robert Goddard successfully launches a liquid-fueled rocket
1928	**1928** First antibiotic medicine is discovered
1928	**1928** Philo T. Farnsworth invents electronic television
1935	**1935** The first successful synthetic fiber, nylon, is invented
1935	**1935** Charles Richter develops his scale for comparing the strength of earthquakes
1945	**1945** First electronic computer, ENIAC, is finished
1953	**1953** Structure of DNA is decoded
1954	**1954** Polio vaccine is first used
1957	**1957** The first artificial satellite, *Sputnik*, is launched
1962	**1962** First American, John Glenn, orbits Earth
1962	**1962** Rachel Carson publishes *Silent Spring*
1962	**1962** Rachel Carson publishes *Silent Spring*





The History of Science and Technology (Some Milestones)

1969

1969-1972
Apollo astronauts land on the moon

1972

1972
First Pioneer space probe is launched

1976

1976
Viking space probes land on Mars

1977

1977
First home computer goes on sale

1977
Voyager space proves are launched to explore the outer solar system

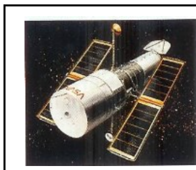
1980

1980
Luis and Walter Alvarez propose their asteroid theory of dinosaur extinction

1981

1981
First space shuttle is launched into Earth orbit

1990



1990
Hubble Space Telescope is launched

1991

1991
World Wide Web is started

2000

2000
Human DNA is mapped

The History of Science and Technology (Some Milestones)

Activity 1

1. Name five (5) important science events of discoveries that were not included in this history.

2. Name five (5) new inventions or science discoveries that might occur in your lifetime.

Theme I: What is Science, How Do We Use It?

Lesson 4: Measurements and Important Formulas in Physical Science

Do You Know?

Measuring tools allow you to collect accurate data. Measurements are more accurate than the guesses or estimates you would make if you used just your senses.

Throughout the study of physical science one will encounter and will continue to encounter numerous properties of matter, energy, etc. that are quantitative, or measurable. When a number is used to represent a measured quantity, the units of that quantity must always be specified. The units used for scientific measurements are those of the metric system, which is based on units of ten Computations using metric units are relatively simple compared with those of the English system. See Table of Measurements below.

SI (International System) of Units	English System of Units
Temperature Water freezes at 0 degrees Celsius (°C) and boils at 100°C; (Kelvin K) K = C + 273°	**Temperature** Water freezes at 32 degrees Fahrenheit (°F) and boils at 212°F.
Length and Distance 10 millimeters (mm) = 1 centimeter (cm) 100 centimeters = 1 meter (m) 1,000 meters = 1 kilometer (km)	**Length and Distance** 12 inches (in.) = 1 foot (ft) 3 feet = 1 yard (yd); 1760 yd = 1 mile (mi) 5,280 ft = 1 mi
Volume of Fluids 1 cubic centimeter (cm^3) = 1 milliliter (mL) 1,000 milliliters = 1 liter (L) 1 kiloliter (kL) = 1,000 L 1 cubic meter (m^3) = 1,000 L	**Volume of Fluids** 8 fluid ounces (fl oz) = 1 cup (c) 2 cups = 1 pint (pt) 2 pints = 1 quart (qt) 4 quarts = 1 gallon (gal)
Mass 1,000 milligrams (mg) = 1 gram (g) 1,000 grams = 1 kilogram (kg)	**Weight** 16 ounces (oz) = 1 pound (lb) 2,000 pounds = 1 ton (T)
Area 1 sq kilometer (km^2) = 1 km x 1 km 1 hectare = 10,000 square meters (m^2) 100 hectare = 1 sq kilometer	**Area** 144 square (sq) inches = 1 sq foot 9 sq ft =1 sq yard (yd); 4840 sq yd = 1 acre 640 acres = 1 sq mile
Rate cm/s = cm per second (s) m/min = m per minute (min) km/h = km per hour (h)	**Rate** ft/s = feet per second; yd/min = yd per min mph = miles per hour
Force 1 newton (N) = 1 kg x m/s^2	**Force** 1 N = 0.2248 lb; 1 lb = 4.448 N

What is Science, How Do We Use It?

Measurements and
Important Formulas in Physical Science

Within the metric system, more than one unit can be used to describe the same property. Different scientists, therefore, might use different units to measure the same quantity, making communication difficult. This problem was solved by an international agreement among scientists to use only certain metric units. This subgroup of preferred metric units is known as SI units (from the French *Système International d'Unités*). There are seven fundamental SI units from which all other necessary units can be derived. The seven base units, the physical quantities they measure, and the abbreviation for each is shown below.

SI Base Units		
Physical Quantity	**Name of Unit**	**Abbreviation**
Mass	Kilogram	Kg
Length	Meter	M
Time	Second	s
Electric current	Ampere	A
Temperature	Kelvin	K
Luminous intensity	Candela	Cd
Amount of a substance	mole	Mol

As with any change, switching from one system of measurement units to another comes about slowly. So although non-SI units are being phased out, there are still some that are commonly used by scientists. You have encountered most of these non-SI units in this textbook as well as in your daily life. When you see or use these units, you must recognize that they are not SI units and are not as universally understandable as their SI counterparts. And someday, these non-SI units may be uncommon as well.

Common Non-SI Units and Other SI Units		
Physical Quantity	**Non-SI Unit**	**SI Unit**
Volume	liter, L	Cubic meter, m^3
Pressure	Atmosphere, atm Millimeters of mercury, mm HG	pascal, Pa
Temperature	Celsius degree, C°	kelvin, K
Heat energy	Calorie, cal	joule, J
Atomic mass unit (mass)		amu
Molarity (concentration)		M
Newton (force)		N
Volt (electric potential difference)		V
Bequerel (nuclear activity)		Bq

What is Science, How Do We Use It?

Measurements and Important Formulas in Physical Science

The Prefixes Used with SI Units			
Prefix	**Symbol**	**Meaning**	**Scientific Notation**
Exa-	E	1,000,000,000,000,000,000	10^{18}
Peta-	P	1,000,000,000,000,000	10^{15}
Tera-	T	1,000,000,000,000	10^{12}
Giga-	G	1,000,000,000	10^{9}
Mega-	M	1,000,000	10^{6}
Kilo-	k	1,000	10^{3}
Hecto-	h	100	10^{2}
Deka-	da	10	10^{1}
-	-	1	10^{0}
Deci-	d	0.1	10^{-1}
Centi-	c	0.01	10^{-2}
Milli-	m	0.001	10^{-3}
Micro-	µ	0.000001	10^{-6}
Nano-	n	0.000000001	10^{-9}
Pico-	p	0.000000000001	10^{-12}
Femto-	f	0.000000000000001	10^{-15}
Atto-	a	0.000000000000000001	10^{-18}

Common Abbreviations

s	second	lb	pound
°C	degrees Celsius	°F	degrees Fahrenheit
cm	centimeter	gal	gallon
cm^2	square centimeter	mi	mile
cm^3, cc	Cubic centimeter	pt	pint
dm	decimeter	ft	foot
g	Gram	fl oz	fluid ounce
h	Hour	in.	inch
m	Meter	yd	yard
kg	kilogram	qt	quart
l	Liter	C	cup
ml	milliliter	oz	ounce
min	minute	tsp	teaspoon
mg	milligram	Y	year
mm	millimeter	T	tablespoon

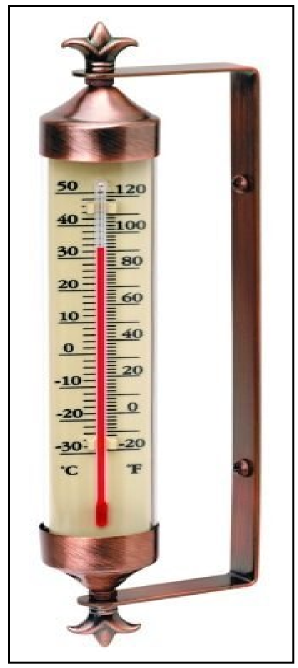
What is Science, How Do We Use It?

Measurements and
Important Formulas in Physical Science

Measuring Temperature

A thermometer measures temperature. Thermometers come in many shapes and sizes. Scientists measure temperature in degrees Celsius (ºC). People in most other countries measure temperature in degrees Celsius; however, the United States of America and some other countries measure temperature in degrees Fahrenheit.

How does one read a thermometer that has a liquid column? Look at the top of the liquid column. Then look at the mark on the thermometer that the top of the column reaches. Read the value for that mark.



Temperature Scales: Fahrenheit and Celsius

We convert Fahrenheit degrees to Celsius degrees by this formula: **ºF = (C * 9/5) + 32**

We convert Celsius degrees to Fahrenheit degrees by this formula: **ºC = (F – 32) * 5/9**

Examples:

Normal body temperature is 37.0ºC. What is the temperature in Fahrenheit?

F = (C * 9/5) + 32
= (37.0 * 9/5) + 32
= (37.0 * 1.8) + 32
= 66.6 + 32
= 98.6 ºF

A typical room temperature in Celsius is 70ºF. What is the temperature in Celsius?

C = (F – 32) * 5/9
= (70 – 32) * 5/9
= (70 – 32) * 0.56
= 38 * 0.56
= 21.28 ºC

What is Science, How Do We Use It?

Measurements and Important Formulas in Physical Science

Temperature Scales: Celsius and Kelvin

Although both the Fahrenheit and Celsius temperature scales are extremely useful for various applications, a third scale is part of the International System of Units. The SI scale used to measure temperature is the Kelvin scale. The Kelvin scale is named after the English physicist and mathematician William Thomson, Lord Kelvin (1824-1907). The unit of temperature on the Kelvin scale is the Kelvin (K). Although the degree symbol (°) is not used with Kelvin, the Kelvin is the same size as the Celsius degree. In other words, a temperature change of 1 Kelvin is the same as a change of 1 Celsius degree: 2 K – 1 K = 2ºC - 1ºC

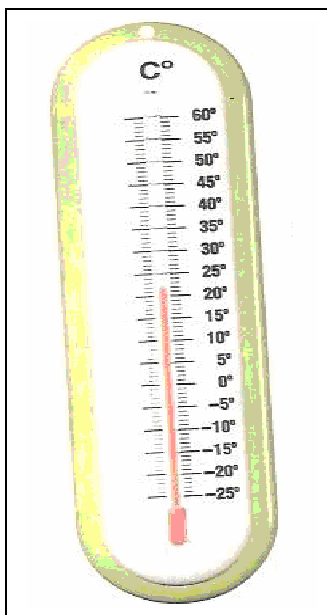
The difference between the Kelvin and the Celsius scales is the location of the zero point. The zero point of the Kelvin scale, called **absolute zero**, corresponds to -273ºC. Absolute zero is the point at which the motion of particles of matter, their kinetic energy, ceases

To convert Celsius temperatures to the Kelvin scale, add 273; K = ºC + 273.

For example, the boiling point of water is, 100ºC and 373 K:
K = 100ºC + 273; K = 373 K

To convert Kelvin temperatures to the Celsius scale, subtract 273; ºC = K – 273.

For example, temperatures close to absolute zero are incredibly cold.
At 50 K, air will freeze into a solid! Convert 50 K to the Celsius scale.
ºC = K – 273; C = 50 K – 273; C = -223 ºC



What is Science, How Do We Use It?

Measurements and Important Formulas in Physical Science

Several Common Temperatures Expressed in Fahrenheit, Celsius and Kelvin

	Fahrenheit	**Celsius**	**Kelvin**
Boiling point of water	212 Fahrenheit degrees 212º F	100 Celsius degrees 100º C	100 Kelvin 373 K
Freezing point of water	32º F	0º C	273 K
Absolute zero	-459.4 º F	-273º C	0 K
Typical room temperature	70ºF	21ºC	294 K
"Normal" body temperature	98.6ºF	37.0ºC	310 K
Typical oven temperature for baking	325ºF	163ºC	436 K
Surface of the sun	10,000ºF	6000ºC	6273 K

Temperature Conversion Table

From	**To Fahrenheit**	**To Celsius**	**To Kelvin**
Fahrenheit (F)	F	(F-32)*5/9	(F–32)*5/9 +273.15
Celsius (C or º)	(C * 9/5)+32	C	C+273.15
Kelvin (K)	(K–273.15)*9/5+32	K–273.15	K

Remark

Notice that all temperatures on the Kelvin scale are positive. This is meaningful because temperature is an indicator of the kinetic energy (energy in motion) of particles within a sample, energy cannot be negative. Also notice that a Kelvin degree and a Celsius degree are identical in magnitude. A temperature on the Kelvin scale is always 273° higher than the parallel measure on the Celsius scale.

What is Science, How Do We Use It?

Measurements and
Important Formulas in Physical Science

Measuring Energy

A common unit of energy is the calorie (cal). One calorie is the amount of heat needed to raise the temperature of 1 gram of water by 1 Celsius degree (1 cal = 1 g x 1 C°). How many calories of heat do you think would be needed to raise the temperature of 5 grams of water by 1 Celsius degree? You are correct if you said 5 calories (5 cal = 5 g x 1 C°).

The energy stored in food is often given in a unit that is related to the calorie. The Calorie (Cal), spelled with a capital C, is the same as exactly 1000 calories or 1 kilocalorie. A typical chocolate bar can supply 200 Calories, or 200 kilocalories, of energy. Depending on your weight and activity level, a typical student requires between 2000 and 3000 Calories per day.

The SI unit of energy is the joule. To picture the size of 1 joule (J), imagine lifting a medium-sized apple a distance of 1 meter against the force of gravity. This task requires about 1 joule of energy. The joule is named for James Prescott Joule (1818-1889), an English physicist, who made pioneering advances in our understanding of energy.

In the 1800s, it was not known whether heat was related to various forms of energy, such as the energy involved in lifting an apple. James Joule investigated this question. As a result of his observations and experiments, Joule realized that the changes produced by heating a substance could also be produced by mechanical energy. Expressed in modern units, Joule's work can be summarized by the following unit equality:

1 cal = 4.184 J

What is Science, How Do We Use It?

Measurements and Important Formulas in Physical Science

In other words, four medium-sized apples falling through a distance of 1 meter can supply the same energy as 1 calorie of heat. (Of course, Joule did not use apples in his experiments!) Joule has discovered that mechanical energy is indeed related to heat.

Equations and Formulas

An equation is a mathematical sentence that contains a variable and an equal sign. An equation expresses a relationship between two or more quantities. A formula is a special kind of equation. A formula shows relationships between quantities that are always true. To solve for a value in an equation or formula, substitute the known values. **Be sure to include the correct units.**

Example

Find the mass of a sample of aluminum with a volume of 5 cm^3 and a density of 2.7 g/cm^3. **Density** = $\frac{mass}{volume}$;

$d = \frac{m}{v}$; 2.7 $g/cm^3 = \frac{mass}{5cm^3}$; 5 cm^3 x 2.7 g/cm^3 = mass ; 13.5 g = mass

Scientific Notation

Scientific notation is used to express a very large or a very small number. To express a number that is greater than 1, you can group the powers of ten together. One method of determining the correct scientific notation is to move the decimal point to the left until it is located to the right of the first nonzero number. The number of places the decimal was moved becomes the positive exponent of 10 in the notation.

Examples

2,500,000 be expressed as $2.5 \times 10^6 = 2.5 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10$

18,930,000 can be expressed as $1.893 \times 10^7 = 1.893 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10$

For a number smaller than 1 in scientific notation, move the decimal point to the right until it is located to the right of the first nonzero number. Count the number of places the decimal point was moved and write this number as the negative exponent of 10.

Examples

0.000056 can be written as $5.6 \times 10^{-5} = \frac{5.6}{10\times10\times10\times10\times10}$

0.0027 can be written as $2.7 \times 10^{-3} = \frac{2.7}{10\times10\times10}$

What is Science, How Do We Use It?

Measurements and Important Formulas in Physical Science

To add or subtract numbers in scientific notation, the exponents of the numbers must be the same. If they are different, you must rewrite one number to make them the same. Rewrite the answer so that only one number is to the left of the decimal point.

Examples

Add 3.2×10^3 and 5.1×10^3

$$\begin{array}{rl} 32 & \times 10^3 \\ + \ 5.1 & \times 10^3 \\ \hline 37.1 & \times 10^3 \rightarrow 3.71 \times 10^3 \end{array}$$

Subtract 5.4×10^7 from 6.8×10^7

$$\begin{array}{r} 6.8 \times 10^7 \\ - \ 5.4 \times 10^7 \\ \hline 1.4 \times 10^7 \end{array} \rightarrow 1.4 \times 10^7$$

To multiply or divide numbers in scientific notation, the exponents must be added or subtracted.

Examples

Find the product of 1.2×10^3 and 3.4×10^4
$(1.2 \times 10^3)(3.4 \times 10^4) = (4.08 \times 10^{3+4}) = 4.08 \times 10^7$

Divide 5.0×10^9 by 2.5×10^6
$(5.0 \times 10^9) \div (2.5 \times 10^6) = (2.0 \times 10^{9-6}) = 2.0 \times 10^3$

What is Science, How Do We Use It?

Measurements and Important Formulas in Physical Science

Important Formulas, Equations, and Constants

Density (d)

Density = $\frac{mass}{volume}$ d = $\frac{m}{v}$

Percent Error

Percent error = $\frac{\text{measured value} - \text{accepted value}}{\text{accepted value}}$ x 100%

Percent Yield

Percent yield = $\frac{\text{actual yield}}{\text{expected yield}}$ x 100%

Percentage Composition

Percentage composition by mass = $\frac{\text{mass of element}}{\text{mass of compound}}$ x 100%

Planck's Equation

E = hv
Where h is Planck's constant, E is energy,
And v is frequency

Kinetic Energy (KE)

Kinetic energy = $\frac{mass \times velocity^2}{2}$

KE = $\frac{mv^2}{2}$

Gravitational Potential Energy (GPE)

Gravitational potential energy =
Mass x acceleration due to gravity x Height
GPE = mgh

What is Science, How Do We Use It?

Measurements and Important Formulas in Physical Science

Amount of Gas (n) in a Sample

$$n = \frac{\text{mass}}{\text{molar mass}} = \frac{m\ (g)}{M\ (g/mol)}$$

Boyle's Law

$P_1V_1 = P_2V_2$

Charles's Law

$V_1T_2 = V_2T_1$

Avogadro's Law

$V = k_3n$

Where k_3 is Avogadro's law constant and n is the number of moles

Dalton's Law of Partial Pressures

$P_T = P_a + P_b + P_c + \ldots$

Ideal Gas Law

$PV = nRT$

Molarlity (M)

$$\text{molarlity} = \frac{\text{moles of solute}}{\text{liter of solution}}$$

Molality (m)

$$\text{molality} = \frac{\text{moles of solute}}{\text{kilogram of solution}}$$

Mole Fraction (χ)

$$\text{Mole fraction} = \frac{\text{moles of solute or solvent}}{\text{total moles of solution}}$$

Boiling Point Elevation

$\Delta T_b = K_bm$

Where K_b is the molal boiling point elevation constant

What is Science, How Do We Use It?

Measurements and Important Formulas in Physical Science

Freezing Point Depression

$\Delta T_f = K_f m$

Where K_f is the molal boiling point elevation constant

Rate of Reaction

Rate = $k[A]^x[B]^y$

Where [A] and [B] are molar concentrations of reactants and k is a rate constant

Entropy Change

$\Delta S = S_{products} - S_{reactants}$

Gibbs Free Energy

$\Delta G = \Delta H - T\Delta S$

Avogadro's number	6.02 x 10^{23}
Speed of light in a vacuum	3.00 x 10^{8} m/s
Atomic mass unit (amu)	1.66054 x 10^{-27} kg
Charge of an electron	1.60 x 10^{-19} C
Mass of an electron	9.11 x 10^{-31} kg 0.0006 amu
Mass of a proton	1.0073 amu 1.6726 x 10^{-27} kg
Mass of a neutron	1.0087 amu 1.6749 x 10^{-27} kg
Planck's constant (h)	6.6262 x 10^{-34} J-s
Gas constant ®	0.08206 atm-L/mol-K 8.314 Pa-qm^3/mol-K 8.314 J/mol-K
Molar volume of a gas at STP	22.4 L

****

Changing Units from SI to English and the Reverse

To Change	Multiply By	To Change	Multiply By
cm to in.	0.40	in. to cm	2.54
m to yd	1.09	yd to m	0.91
km to mi	0.62	mi to km	1.61
ml to fl oz	0.03	fl oz to ml	29.57
l to gal	0.26	gal to l	3.79
g to oz	0.04	oz to g	28.35
kg to lb	2.21	lb to kg	0.45

What is Science, How Do We Use It?

Measurements and Important Formulas in Physical Science

Activity I

1. What is the name of the system with units of measures that scientists and many countries use?

2. What is the name of the three (3) temperature scales?

3. Which temperature scale is used most frequently by scientist?

4. What two different scales where the measure of 1 unit in one is identically the same measure of one unit in the other?

5. What is meant by absolute zero?

6. Express 85°F in C, Celsius and in K, Kelvin.

7. Express the temperature 15°C in both F, Fahrenheit and K, Kelvin.

8. Convert

   a. Add 2.3×10^8 and 1.5×10^8

   b. Subtract 4.5×10^{17} from 8.6×10^{17}

   c. Find the product of 2.1×10^5 and 4.3×10^5

   d. Divide 12.5×10^{16} by 3.5×10^6

9. Calculate

   a. 15 m to yd

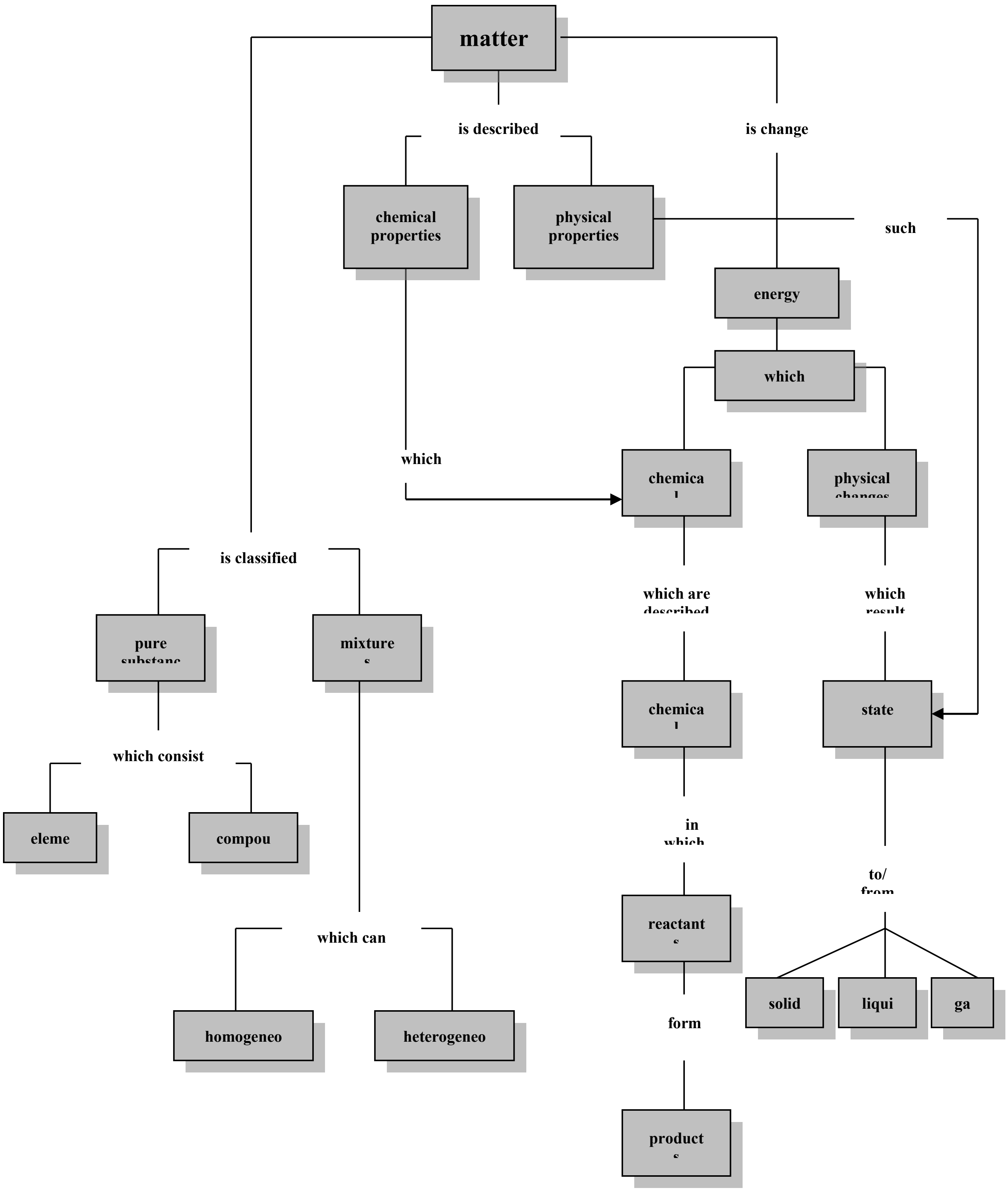
   b. 25 gal to l

   c. 150 km to mi

   d. 60 lb to kg

Using the density formula and d = 20 g/cm^3; mass = 125 g; calculate the volume, given the correct units.

Theme II: The Introduction to Chemistry: The Study of the Composition of Matter and the Study of the Change of Matter



Theme II: Introduction to Chemistry: The Study of the Composition of Matter and The Changes of Matter

Lesson 1: The Fundamental Physical Properties of Matter

Do You Know?

In science the "stuff" that everything is made of is called **matter**. People are made of matter. A basketball is made of matter. Water is matter. So is the air in a balloon and the air around the balloon. All objects and substances are made of matter.

One can use the five (5) senses to detect matter. One can feel the shape and roughness of a rock. One can taste the juice of an orange. One can smell popcorn. One can see the crowd at a soccer game.

However, some kinds of matter, such as air, are invisible. These cannot be easily detected. They don't have a taste or odor. So how does one know that air is made of matter? One knows because when air moves, one can feel it. One can see it blow leaves across the ground. One can see a kite lifted high by the wind. And one can feel the kite pull against the string as the wind blows it.

Also some types of matter, such as viruses and the cells that make up our body, are too small to see with the eyes alone. The only way one can see most cells is to look at them through a microscope. But even when something is too tiny to see with the naked eye, it is still made of matter.

Properties of Matter

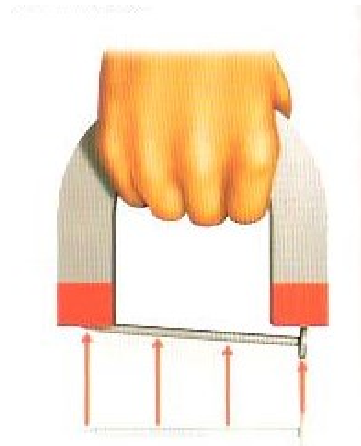
All matter has two kinds of properties – physical properties and chemical properties. A **physical property** is a property that can be observed, measured, or changed without changing the substance itself.

Properties are the characteristics of a substance. The way a substance tastes is one of its properties. The way it smells is another property. So is its color. Other properties include whether it is attracted to a magnet, whether it dissolves in water, and whether it is a solid, a liquid, or a gas at room temperature. No two substances have exactly the same set of properties.

The Fundamental Physical Properties of Matter

For example, you can measure the mass and length of a nail. You can bend the nail. You can test it to see if it's attracted to a magnet. You can cut it into little pieces. You can melt it. Measuring the nail, bending it, testing it with a magnet, cutting it up, and melting it don't change the substance that makes up the nail.

Being magnetic is a physical property of the nail.



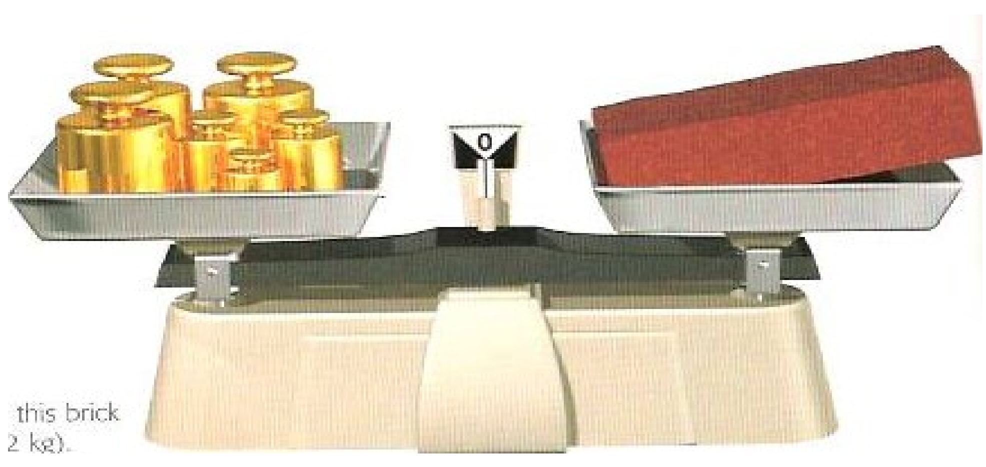
What are the Fundamental Physical Properties of Matter?

Both sugar and salt are white, grainy substances. You know that sugar tastes sweet and salt does not. Could one tell these substances apart without tasting them? Yes, if one knew some of their other properties.

Three major physical properties (characteristics) of all matter are mass, volume and density.

Mass All matter has mass. **Mass** is the amount of matter in an object or substance. A person's mass is greater than the mass of a brick. That's because your body contains more matter than a brick does.

Mass is measured in kilograms (kg), grams (g), and milligrams (mg). The mass of an object can be measured with a balance.

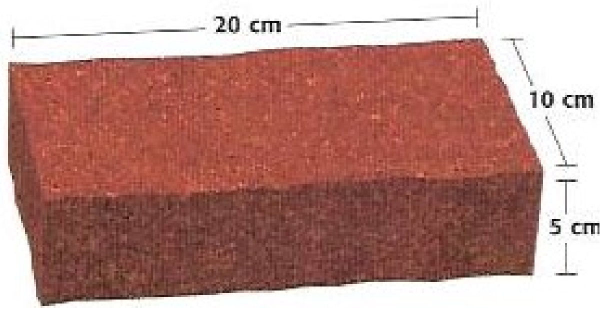


The mass of this brick is 2,000 g (2 kg).

The Fundamental Physical Properties of Matter

Volume All matter takes up space. The amount of space that an object or substance takes up is its **volume**. A person's body takes up more space than a brick does.

The volume of block-shaped objects, such as bricks, boxes, and rooms, is measured in cubic centimeters (cm^3) and cubic meters (m^3). To find the volume of a block-shaped object, first you have to measure its length, width, and height. Then multiply those measurements to find the volume.



The volume of this brick is 1,000 cm^3.

20 cm x 10 cm x 5 cm = 1,000 cm^3

The volume of liquids and powders is measured in milliliters (mL), liters (L), and kiloliters (kL). Measuring cups and graduated cylinders are used to measure the volume of liquids and powders.

Density The amount of mass in a known volume of an object is the object's **density**. To find the density of an object, divide its mass by its volume.

Density = $\frac{mass}{volume}$ or $d = \frac{m}{v}$.; This is a very important formula in science.

The brick's density = $\frac{2{,}000g}{1{,}000cm^3}$ or the brick's density is 2 g/cm^3
(two grams per cubic centimeter).

From the formula $d = \frac{m}{v}$ we also have the formulas:

$$v = \frac{m}{d} \qquad \text{and} \qquad m = v \cdot d$$

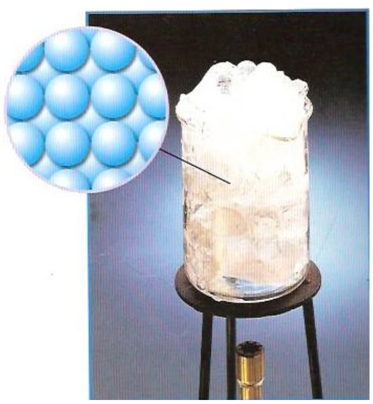
The Fundamental Physical Properties of Matter

State of Matter

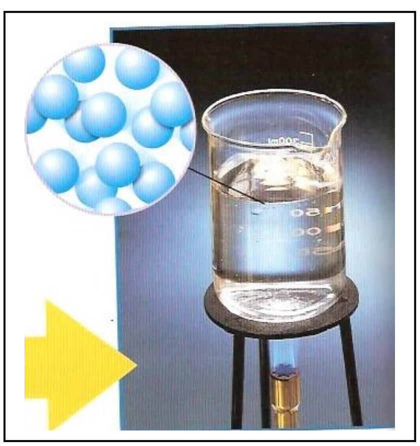
The three (3) states of matter are: solid, liquid and gas. All substances may exist in any of these three physical states of matter.

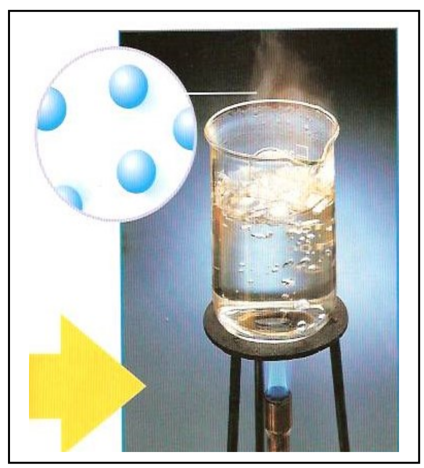
Substances such as water and iron can exist as solids, liquids, or gases. Solid, liquid, and gas are **states of matter**. These are physical properties of matter.

A substance changes state when enough heat energy is added to it or subtracted from it. If one adds enough heat energy to ice, it turns into liquid water. If one adds enough heat energy to liquid water, it turns into a gas called water vapor. If one cools the substance by subtracting heat energy, one can reverse these changes. One can turn a gas into a liquid and a liquid into a solid. Changing from one state to another is a physical change.



Solids The particles of a solid are fixed. They move only a little. They vibrate more rapidly when heat energy is added to them. If enough heat energy is added, a solid may melt and form a liquid.





Liquids Particles of a liquid move past one another. Adding more heat energy causes the particles to move fast enough so that they break away from one another. Some particles may escape as a gas.

Gas Particles of a gas are very far apart. They move very fast. Adding heat energy moves them faster and farther apart. The mass and amount of the water particles remains the same no matter what state they are in.

The Fundamental Physical Properties of Matter

The table below summarizes the major characteristics of solids, liquids, and gases.

State	Description
Solid	has a definite shape and a definite volume
Liquid	has a definite volume but takes the shape of its container
Gas	takes the shape and volume of its container

The mass of an object will remain the same no matter what its state is. What makes matter change state from solid to liquid to gas? The answer is heat energy. Heat energy makes the particles of matter move faster. The more heat energy matter has, the faster its particles move. Taking away heat energy slows particles down.

Remarks Some substances seem to be partway between a solid and a liquid. For example, a lump of silicone putty holds it shape for a while, like a solid. Then it flows very slowly until it takes the shape of its container, like a liquid.

Changing States of Matter

You probably don't think that gold could ever exist as a gas. But it can! Almost all substances, including gold, can exist in all three states of matter.

Water is the only common substance on Earth that exists in all three states at ordinary temperatures.

Melting point The **melting point** of a substance is the temperature at which it changes from a solid to a liquid. The melting point of ice is 0ºC. When ice is heated to 0ºC, it begins to melt.

The **freezing point** of a substance is the temperature at which it changes from a liquid to a solid. A substance's freezing point is the same as its melting point. For example, ice melts at 0ºC, and water freezes at 0ºC.

The Fundamental Physical Properties of Matter

Boiling point The **boiling point** of a substance is the temperature at which it changes from a liquid to a gas. The boiling point of water is 100ºC.

Condensation point When molecules of water vapor are cooled, they condense and form liquid water. The **condensation point** of a substance is the temperature at which it changes from a gas to a liquid. A substance's condensation point is the same as its boiling point. Water boils as 100ºC, and water vapor condenses at 100ºC.

The melting and freezing points of a substance and its boiling and condensation points are physical properties of the substance. Every substance has its own set of values for these points. That is on way you can tell one substance from another.

For example, a mineral called "fool's gold" looks like real gold. But fool's gold is made of iron and sulfur. It is not valuable. You could be fooled into thinking a lump of fool's gold was real gold. But you could tell the difference if you measured the lump's melting point. Fool's gold melts at 1,171ºC. Real gold melts at 1,063ºC.

Some Other Physical Properties of Matter

Property	What It Means	Example
Color	The color of a substance	Iron is gray. Rust is red.
Texture	how a substance feels or looks	Sandpaper is rough. Glass is smooth.
Odor	how a substance smells	Water has no odor. Vinegar has a sharp odor.
conducts heat	how easily heat moves through a substance	Metals conduct heat well. Plastics do not conduct heat well.
conducts electricity	how easily electricity moves through a substance	Copper is a good conductor of electricity. Rubber is not.
Magnetic	is attracted to a magnet	Iron is magnetic. Aluminum is not.
floats or sinks in water	is more dense or less dense than an equal volume of water	Lead sinks in water. Oil floats on water.
Solubility	the ability to dissolve in another substance	Sugar dissolves in water. Sand does not.

In summary, physical changes are changes in matter that do not alter the identity of the matter itself. For example:

1. Size – The blowing of a balloon with air.
2. Shape – The cutting of paper into smaller pieces.
3. Change in position or texture – changing hair style
4. Dilutions – diluting a solution
5. State: solid – liquid – gas and vice versa

The Fundamental Physical Properties of Matter

Activity 1

How Heat Energy Affects Evaporation

When you perform an experiment, you first form a hypothesis. Then you test your hypothesis. Follow the steps to test how heat energy affects evaporation.

Materials

3 paper towels
3 rubber bands
three 10-oz clear plastic glasses
thermometer
clock or watch
desk lamp
container of water

Procedures

1. Place a wet paper towel across the top of each plastic glass.

2. **Hypothesis:** Place one glass where you think the paper towel will dry fastest. Place another where you think it will dry slower. Place the third where you think it will dry slowest.

3. **Measure:** Use the thermometer to measure the temperature near each glass. Record the temperatures.

4. Record the time you start timing. Then touch each paper towel every two minutes. Record the time the first paper towel is dry.

5. Repeat step 4 until the other towels are dry.

Drawing Conclusions

1. **Interpret:** In which place did a paper towel dry the fastest? What was the temperature?

2. **Interpret:** In which place did a paper towel dry the slowest? What was the temperature?

3. **Experiment:** Would water evaporate from a paper towel as fast if you put an inverted glass over it? Try it.

Theme II: Introduction to Chemistry: The Study of the Composition of Matter and The Changes of Matter

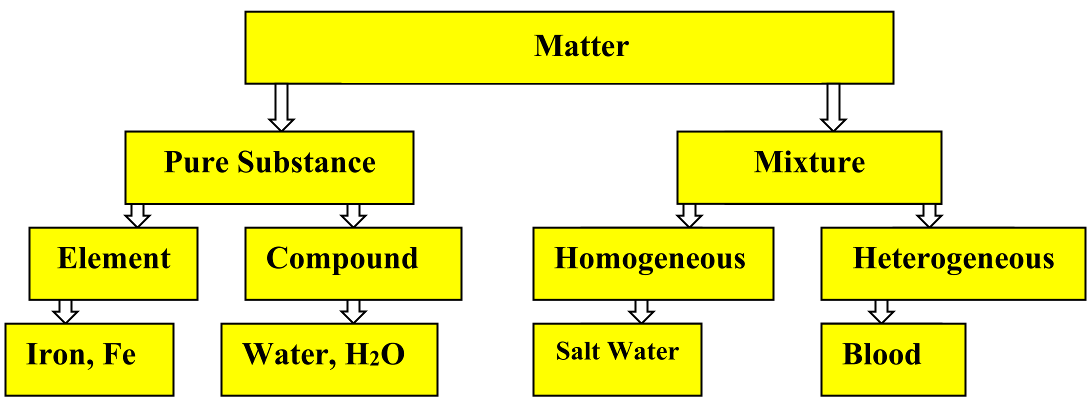
Lesson 2: The Structure, Composition, and Classification of Matter

Do You Know?

All matter has two kinds of properties - physical properties and chemical properties.

A **chemical property** is the ability of a substance to change into a new substance with different properties. We sometimes think of the various substance to which matter can change as being the classifications of matter.

The Chemical Classification of Matter



The subject of chemistry is the study of the composition of matter and the study of changes in matter. Chemistry is divided into several larger subfields which include:

A. **General Chemistry**: An overview of the study of all aspects of chemistry
B. **Inorganic chemistry**, the chemistry associated with non-living things;
C. **Qualitative and Quantitative chemistry**, which is the chemistry that involves the measurements, purity and precise content of matter under various conditions.
C. **Organic chemistry**, the chemistry associated with living organisms;
D. **Physical chemistry**, the the study of the general physical properties of matter;
E. **Nuclear chemistry**, the chemistry associated with atoms;

The Structure, Composition, and Classification of Matter

Atoms

How many pieces can you divide a pure substance into? You can divide it until you just have one atom of it. An **atom** is the smallest particle of a substance that has all the properties of the substance.

Gold is made of atoms of gold. All gold atoms are alike. All gold atoms have the same properties. Silver is made of atoms of silver. All atoms of silver are alike. They are not like gold atoms or the atoms of any other substance.

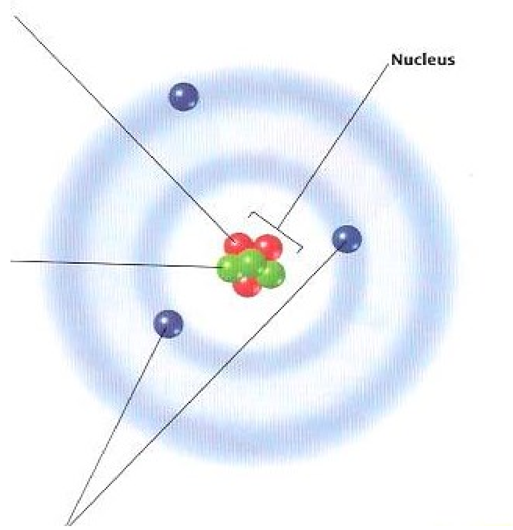
Atoms are very tiny. They are tinier than the cells in your body. They are tinier than germs. They are too small to be seen with ordinary microscopes.

It would take about 100 million of the smallest atoms laid end-to-end to stretch across ones thumb. A hydrogen atom is 100,000 times smaller than one of your red blood cells.

Parts of an Atom

An atom is made up of still smaller parts. These parts determine what the atom is, its mass, and how it behaves. The parts are protons, neutrons, and electrons. Protons and neutrons are packed together in the atom's center, called the **nucleus**. Electrons are in the space outside the nucleus. All protons, neutrons, and electrons are the same, no matter what kind of atom they are in.

Protons are positively charged particles in the nucleus of an atom. The number of protons tells what kind of atom it is. For example, atoms with one proton are hydrogen atoms. Atoms with two protons are helium atoms. The atom in this drawing has three protons. It is an atom of light metal called lithium.



Neutrons are also in the nucleus of an atom. They are not charged. Neutrons add mass to an atom. The number of neutrons in an atom is usually the same as the number of protons. But some atoms of the same kind may have different numbers of neutrons. The number of neutrons does not change what kind of atom it is.

Electrons are negatively charged particles. The number of electrons in an atom is usually the same as the number of protons. Electrons are in spaces called "clouds" outside the nucleus. The number and arrangement of electrons determine how an atom will interact with other atoms. In other words, electrons determine an atom's chemical properties

The Structure, Composition, and Classification of Matter

Elements

An **element** is a pure substance made of only one kind of atom. Gold is an element. So are iron, hydrogen, and oxygen. Water is not an element because it is made of hydrogen and oxygen atoms joined together.

All the atoms of an element are alike. Different elements have different kinds of atoms. For example, all atoms of hydrogen are alike. All atoms of oxygen are alike. Atoms of hydrogen are different from atoms of oxygen.

The Number of Known Elements

There are about 110 known elements on Earth and in the universe. Of these, 94 elements occur naturally on Earth, on other planets, and in the stars. The other 16 elements have been made by scientists in laboratories.

Chemical Symbols for Elements Each element has a chemical symbol. The symbol is a short way of writing the element's name. Some symbols are the first one or two letters of the element's name or the first letter plus another letter in the name. For example, **C** is the symbol for carbon. **He** is the symbol for helium. **Mg** is the symbol for magnesium. Some symbols come from an element's Latin name. The Latin name for iron is *ferrum*. The chemical symbol for iron is **Fe**.

A List of Elements That Are Widely Known

Element	Symbol	Atomic Number	Atomic Mass
Hydrogen	H	1	1.00794
Helium	He	2	4.002602
Sodium	Na	11	22.989768
Carbon	C	6	12.011
Nitrogen	N	7	14.00674
Oxygen	O	8	15.9994
Neon	Ne	10	20.1797
Aluminum	Al	13	26.981539
Silicon	Si	14	28.0855
Chlorine	Cl	17	35.4527
Calcium	Ca	20	40.078
Iron	Fe	26	55.847
Copper	Cu	29	63.546
Silver	Ag	47	107.8682
Gold	Au	79	196.96654
Uranium	U	92	238.0289

Atomic number - the number of protons in the nucleus of an atom of an element.
Atomic mass - the weighted average of the masses of the isotopes of an element; the atomic mass is the mass of the nucleus of an element.
Isotope - atoms of the same element that have the same atomic number but different atomic masses due to a different number of neutrons.
The **Periodic Chart** shows for each element its symbol, atomic number and atomic mass.

The Structure, Composition, and Classification of Matter

TABLEAU PÉRIODIQUE DES ÉLÉMENTS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 **H** 1.0079																	2 **He** 4.0026
2	3 **Li** 6.941	4 **Be** 9.0122											5 **B** 10.811	6 **C** 12.011	7 **N** 14.007	8 **O** 15.999	9 **F** 18.998	10 **Ne** 20.180
3	11 **Na** 22.990	12 **Mg** 24.305											13 **Al** 26.982	14 **Si** 28.086	15 **P** 30.974	16 **S** 32.066	17 **Cl** 35.453	18 **Ar** 39.948
4	19 **K** 39.098	20 **Ca** 40.078	21 **Sc** 44.956	22 **Ti** 47.867	23 **V** 50.942	24 **Cr** 51.996	25 **Mn** 54.938	26 **Fe** 55.845	27 **Co** 58.933	28 **Ni** 58.693	29 **Cu** 63.546	30 **Zn** 65.409	31 **Ga** 69.723	32 **Ge** 72.64	33 **As** 74.922	34 **Se** 78.96	35 **Br** 79.904	36 **Kr** 83.798
5	37 **Rb** 85.468	38 **Sr** 87.62	39 **Y** 88.906	40 **Zr** 91.224	41 **Nb** 92.906	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.07	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.29
6	55 **Cs** 132.91	56 **Ba** 137.33	57 - 71 La-Lu	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.84	75 **Re** 186.21	76 **Os** 190.23	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
7	87 **Fr** (223)	88 **Ra** (226)	89 -103 Ac-Lr	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (266)	107 **Bh** (264)	108 **Hs** (277)	109 **Mt** (268)	110 **Ds** (271)	111 **Rg** (272)							

Lanthanides	57 **La** 138.91	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.36	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.04	71 **Lu** 174.97
Actinides	89 **Ac** (227)	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

EniG. HOME

SOLIDE LIQUIDE GAZ 100 °C 101 kPa ÉLÉMENT ARTIFICIEL

La masse atomique relative est donnée avec cinq chiffres significatifs. Pour les éléments qui n'ont pas de nucléides stables, la valeur entre parenthèses indique le nombre de masse de l'isotope de l'élément ayant la durée de vie la plus grande. Toutefois, pour les trois éléments Th, Pa et U qui ont une composition isotopique terrestre connue, une masse atomique est indiquée (*Atomic Weights of the Elements 2005*, Pure Appl. Chem., Vol. **78**, No. 11

The Structure, Composition, and Classification of Matter

Molecules

Atoms join together to form molecules. A **molecule** is made up of two or more atoms joined tightly together. The word molecule refers to the smallest electrically neutral particle of a substance that has all the properties of that substance.

A molecule can be made up of atoms of only one element. A molecule can also be made up of atoms of two or more different elements.

Compounds

The word compound refers to the name and chemical (atomic) composition of the entire substance. There are two types of compounds. Molecular compounds and ionic compounds.

Molecular compounds are compounds composed of molecules. That is, a molecule (an electrically neutrally particle) is the smallest unit of the compound.

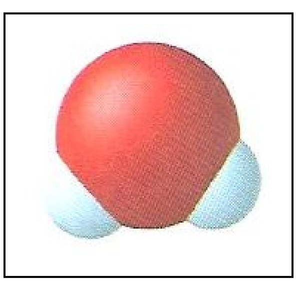
Examples:

Water (H_2O) is an example of a molecular compound. Plants and animals need water to survive.

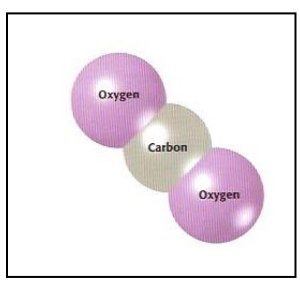
Carbon Dioxide, CO_2, is an example of a molecular compound.

Carbon Monoxide, CO, is a molecular compound. Carbon monoxide is a poisonous gas produced by the burning of gasoline in internal-combustion engines.

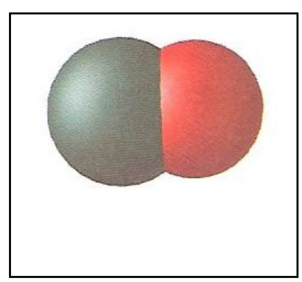
Molecular compounds usually have relatively low melting and boiling points. Many of these compounds exist as gases or liquids at room temperature. The molecules in most molecular compounds are composed of atoms of two or more nonmetals. For a specific molecular compound, all the molecules are the same. However, the molecules of different compounds are different with each molecular compound.



H_2O, Water



CO_2, Carbon Dioxide



CO, Carbon Monoxide

The Structure, Composition, and Classification of Matter

Ions and Ionic Compounds

Not all compounds are molecular. Many compounds are composed of particles called ions. **Ions** are atoms or groups of atoms that have a positive or negative charge. An ion forms when an atom or group of atoms loses or gains electrons. Recall that an atom is electrically neutral because it has equal numbers of protons and electrons. For example, an atom of sodium (Na) has 11 positively charge protons and 11 negatively charged electrons. The net change on a sodium atom is zero [11 + (-11) = 0]. When forming a chemical compound an atom of sodium tends to lose one of its electrons. The number of electrons in the atom is then no longer equal to the number or protons. The atom of sodium becomes an ion. Because there are more positive changes (protons) than negative charges (electrons), the sodium ion has a positive charge.

A **cation** is any atom or group of atoms that has a positive charge. A cation has fewer electrons than the electrically neutral atom from which it formed. An ionic charge is written as a number followed by a sign. The number 1 is usually omitted when writing the complete symbol for the ion; thus Na^{1+} and Na^{+} are equivalent. Magnesium (Mg) is another example of an atom that tends to form cations. Magnesium does so by losing two electrons. Therefore, a magnesium cation has a charge of 2+ because it has 12 pounds but only 10 electrons. Its symbol is Mg^{2+}.

For metallic elements, the name of a cation is the same as the name of the element.

Examples of other cations

Lithium (Li); Li^{+}; Aluminum (Al); Al^{3+}; Calcium (Ca); Ca^{2+}

Although their names are the same, there are many important chemical differences between metals and their cations. Sodium metal, for example, reacts explosively with water. By contrast, sodium cations are quite unreactive. As you know, they are a component of table salt, a compound that is very stable in water.

Atoms of nonmetallic elements tend to form ions by gaining one or more electrons. In this way they form **anions**, which are atoms or groups of atoms that have a negative charge. An anion has more electrons than the electrically neutral atom from which it formed. The chloride anion has 17 protons and 18 electrons. Therefore, it has an ionic charge of 1-. The chloride anion is written as Cl^{-}. Notice that the same name of an anion of a nonmetallic element is not the same as the element name. The name typically ends in –ide.

Examples of other anions

Oxygen (O), Oxide O^{2}; Sulfur (S), Sulfide, S^{2-}; Bromine (Br), bromide, Br^{-}

The Structure, Composition, and Classification of Matter

Ionic Compounds are compounds composed of cation and anions. Ionic compounds are usually composed of metal cations and nonmetal anions. The total positive charge of the cations equal to the total negative charge of the anions. Although they are composed of ions, ionic compounds have electrically neutral molecules.

Examples of ionic compounds

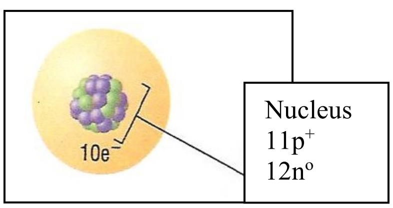
$NACl$, sodium chloride; CO_2, carbon dioxide Al_2O_3, aluminum oxide

Polyatomic Ions

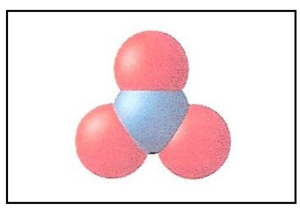
All the ions mentioned earlier are monatomic ions; that is they are composed on only one atom. **Polyatomic ions**, such as sulfate (SO_4^{2-}), are tightly bound groups of atoms that behave as a unit and carry a charge.

The charge on each polyatomic ion in a given pair is the same. The –ite ending indicates one less oxygen atom than the –ate ending. Look at the charge on each ion in the pair, the number of oxygen atoms, and the endings on each name. You should be able to discern a pattern in the naming convention.

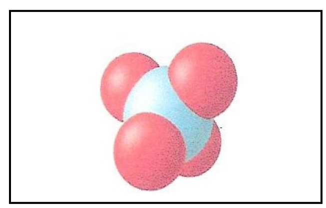
-ite		**-ate**	
	SO_3^{2-}, sulfite		SO_4^{2-}, sulfate
	NO_2^-, nitrite		NO_3^-, nitrate
	CIO_2^-, chlorite		CIO_3^-, chlorate



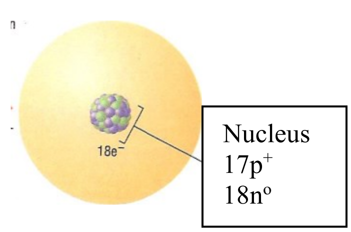
Sodium ion (Na^+)



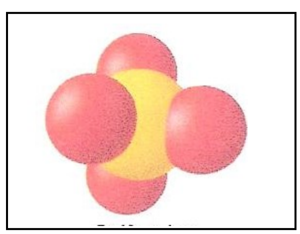
Nitrate ion (NO_3^-)



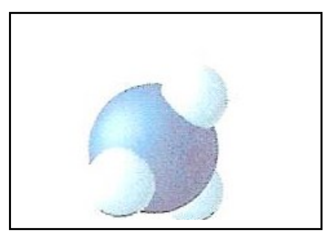
Phosphate ion (PO_4^{3-})



Chloride ion (Cl^-)



Sulfate ion (SO_4^{2-})



Ammonium ion (NH_4^+)

Calcium carbonate ($CaCO_3$) is an example of a **ternary compound**; it contains atoms of three different elements. Usually a ternary ionic compound contains a polyatomic ion.

The Structure, Composition, and Classification of Matter

Some Common Ions

Cation	Symbol	Anion	Symbol
Aluminum	Al^{3+}	**Acetate**	CH_3COO^-
Ammonium	NH_4^+	**Bromide**	Br^-
Arsenic (III)	As^{3+}	**Carbonate**	CO_3^{2-}
Barium	Ba^{2+}	**Chlorate**	ClO_3^-
Calcium	Ca^{2+}	**Chloride**	Cl^-
Chromium (II)	Cr^{2+}	**Chlorite**	ClO_2^-
Chromium (III)	Cr^{3+}	**Chromate**	CrO_4^{2-}
Cobalt (II)	Co^{2+}	**Cyanide**	CN^-
Cobalt (III)	Co^{3+}	**Dichromate**	$Cr_2O_7^{2-}$
Copper (I)	Cu^+	**Fluoride**	F^-
Copper (II)	Cu^{2+}	**Hexacyanoferrate (II)**	$Fe(CN)_6^{4-}$
Hydronium	H_3O^+	**Hexacyanoferrate (III)**	$Fe(CN)_6^{3-}$
Iron (II)	Fe^{2+}	**Hydride**	H^-
Iron (III)	Fe^{3+}	**Hydrogen carbonate**	HCO_3^-
Lead (II)	Pb^{2+}	**Hydrogen sulfate**	HSO_4^-
Magnesium	Mg^{2+}	**Hydroxide**	OH^-
Mercury (I)	Hg_2^{2+}	**Hypochlorite**	ClO^-
Mercury (II)	Hg^{2+}	**Iodide**	I^-
Nickel (II)	Ni^{2+}	**Nitrate**	NO_3^-
Potassium	K^+	**Nitrite**	NO_2^-
Silver	Ag^+	**Oxide**	O^{2-}
Sodium	Na^+	**Perchlorate**	ClO_4^-
Strontium	Sr^{2+}	**Permanganate**	MnO_4^-
Tin (II)	Sn^{2+}	**Peroxide**	O_2^{2-}
Tin (IV)	Sn^{4+}	**Phosphate**	PO_4^{3-}
Titanium (III)	Ti^{3+}	**Sulfate**	SO_4^{2-}
Titanium (IV	Ti^{4+}	**Sulfide**	S^{2-}
Zinc	Zn^{2+}	**sulfite**	SO_3^{2-}

The Building Blocks of Matter

There is a limited number of atoms, a limited number of monotonic ions and a limited number of polyatomic ions. Many elements in their natural state exist as a molecule of two or more atoms of the same element. Thus all matter exists as atoms or molecules of a single type element, a molecule of two or more different elements or a molecule of two or more different ions. Thus many scientists refer to atoms, molecules, and ions as the building blocks of all matter or substances.

The Structure, Composition, and Classification of Matter

Mixtures

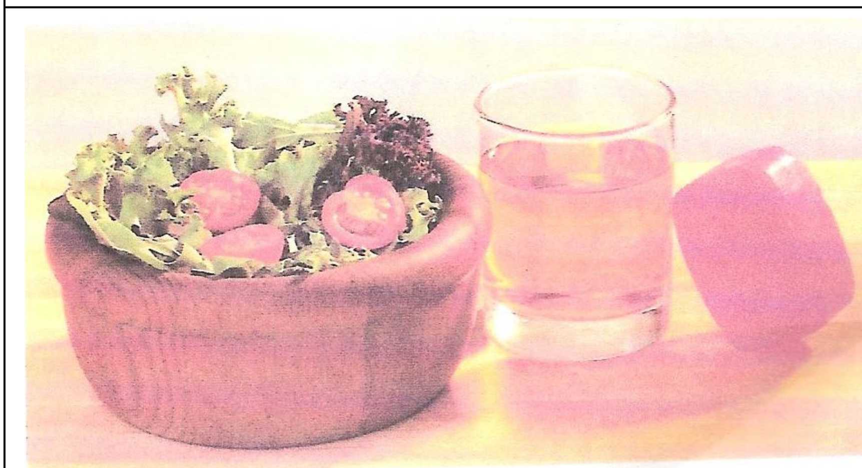
A **mixture** is a physical blend of two or more substances that do not form a new substance. If the combination did form a new substance, it would be called a compound. One important characteristic of mixtures is that their compositions may vary. A dinner salad can have varying amounts of tomatoes or lettuce in it. The composition of air in a forest may differ from that in an industrial city, particularly in the amounts of pollutants. Blood, a mixture of water, various chemicals, and cells, varies somewhat in composition from one individual to another and, from time to time, in a given individual.

Mixtures can be of two kinds: heterogeneous or homogeneous. A **heterogeneous mixture** is one that is not uniform in composition. If you were to sample one portion of such a mixture, its composition would be different from that of another portion. A salad is heterogeneous. A **homogeneous mixture** in contrast, is one that has a completely uniform composition. Its components are evenly distributed throughout the sample. A sample of salt water is the same throughout. Thus salt water is an example of a homogeneous mixture.

Solutions

Homogeneous mixtures are so important in chemistry that chemists give them the special name of solutions. Thus a **solution** is simply a homogeneous mixture with one substance spread out evenly in another substance. The substances are spread out so evenly that you cannot tell one from the other. For example, when you stir sugar into milk, the sugar seems to disappear. But if you taste the milk, it tastes sweet. That means the sugar is mixed with the milk and one can not determine by observation or taste, which part is sugar or which part is milk, the sugar is distributed evenly in the milk. Thus, the sweet milk is a solution.

All of these items are mixtures. The bar of soap and the beverage are homogeneous mixtures; they have uniform compositions. The salad is a heterogeneous mixture; it consists of several phases containing components that are not evenly distributed.



The Structure, Composition, and Classification of Matter

Activity 1

1. Name four (4) ways that one often classify or identify types of matter.

2. What are the two different names used for identifying distinctly different or pure substances of matter.

3. What is the smallest part of an element that exists and still have all the characteristics of the element.?

4. What is the smallest part of a compound that exists and still have all the Characteristics of that compound?

5. Name the three (3) major parts of an atom and describe each.

6. Name the two (2) major types of compounds and a specific example of each; giving both the chemical name and chemical formula of each.

7. What are major differences between atoms, molecules and ions; why do you think that many scientists call them the building blocks of matter?

8. What is the different between a cation and an anion; what is the difference between the two different kinds of compounds and how did each type compound get its name?.

9. Write the chemical formulas for these compounds.

   a. water b. salt c. zinc sulfide d. aluminum floride

10. Write the chemical names for these formulas

    a. CO_2 b. CaO c. AlF_3 d. HPO_4^{2-}

Theme II: Introduction to Chemistry: The Study of the Composition of Matter and The Changes of Matter

Lesson 3: Chemical Changes in Matter

Do You Know?

A firefly's light results from a chemical reaction.

Chemical changes are responsible for many of the things we encounter in everyday life.

What Are Chemical Changes?

In order for copper to turn green, it must undergo a **chemical change**. **Chemical changes** are changes in matter itself. In a chemical change, you start with one kind of substance and end with another different substance. The new substance has properties different from the substance with which one started. A chemical change is also called a **chemical reaction**.

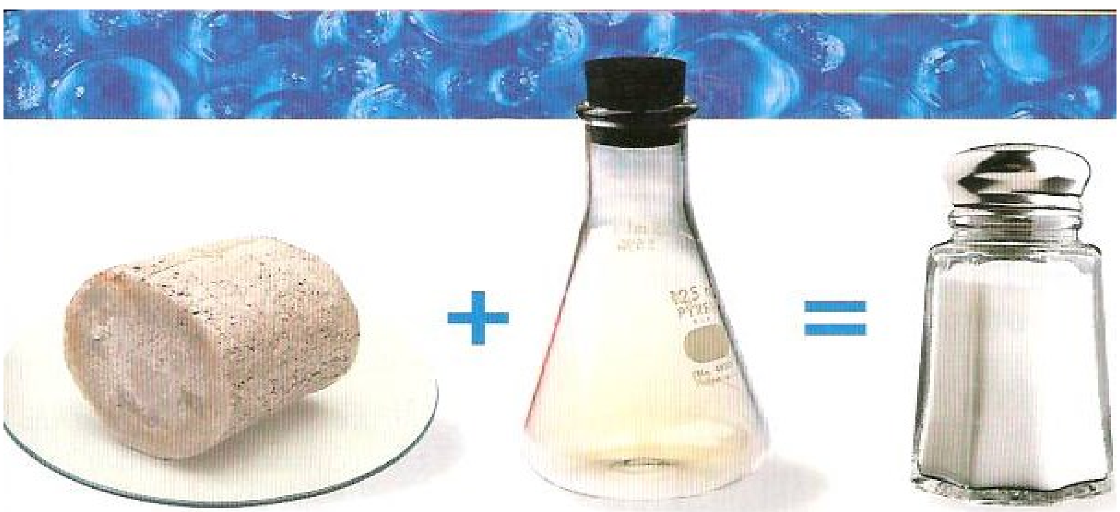
Chemical changes have another characteristic. They involve energy. All chemical changes either require or release energy. The energy may be in the form of electricity, heat, or light. Sometimes a change takes place so slowly, one cannot notice that light or heat is required or released. Sometimes the amount released is so small, it can hardly be noticed.

If one exposes copper to vinegar vapors, one can cause a chemical reaction. The copper reacts with the vinegar to create a compound called copper acetate. Copper acetate has properties different from copper and vinegar. It is not hard and shiny like copper. It is not liquid like vinegar.

Not all materials respond the same way to what is done to them. For example, plastic has no reaction to vinegar vapors.

Chemical Changes in Matter

Copper Vinegar vapors Copper acetate



Sodium Chlorine gas Salt

One can find evidence of chemical changes all around us if one knows where to look. Does table salt look like the shiny metal sodium and the yellow-green poisonous gas chlorine? No! However, it is the result of a chemical reaction between those elements that produces salt.

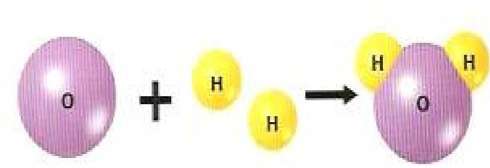
Does sugar look like the black element carbon? No! However, it is the result of a chemical reaction between carbon and the gases oxygen and hydrogen that produces sugar.

Chemical Changes in Matter

Tarnish is a compound that forms on some metals like keys when they are exposed to air. Although tarnish is not harmful, it can be annoying. It coats shiny silver with a dull black finish. Tarnish is a compound that forms from a chemical reaction, or change.

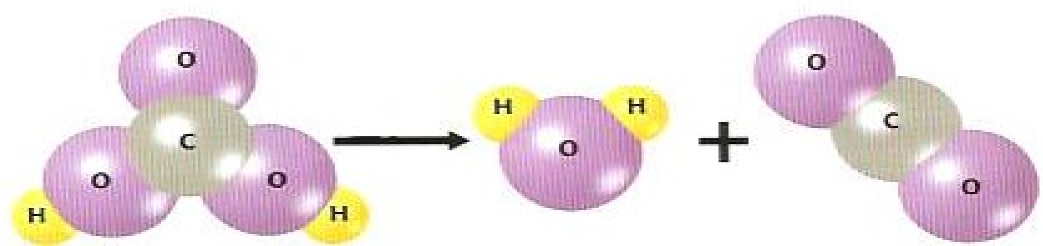
What are some chemical changes?

In other chemical reactions, the atoms or molecules of two substances join together to form a new substance. For example, hydrogen atoms and oxygen atoms join together to make molecules of water.



Oxygen atom **Hydrogen atoms** **Water molecule (H_2O)**

In still other chemical reactions, the molecules of one substance break apart to form molecules of other substances. This is what happens when carbonic acid breaks apart to form water and carbon dioxide.



Carbonic acid molecule **(H_2CO_3)** Water molecule **(H_2O)** Carbon dioxide molecule **(CO_2)**

Remark During a chemical reaction, the atoms in molecules are rearranged to form new molecules. The total number of atoms does not change during the reaction.

Substances react with each other in predictable ways. For example, mixing baking soda with vinegar will always produce carbon dioxide. But one would not get the same result if one mixed baking soda with water. That is because substances react only with certain other substances. For example, iron reacts with oxygen to form rust. But gold does not react with oxygen at all.

Chemical Changes in Matter

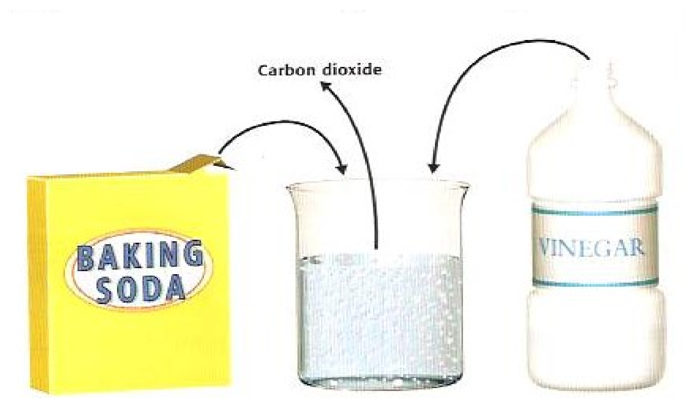
What Are the Products of Chemical Changes?

In a chemical change, the product has properties different from the substance with which one started. Sometimes the product is a compound.

If you leave an iron nail outdoors long enough, it will rust. Rust is not iron. It is a new substance made of iron and oxygen. If you leave a nail outdoors where it can get wet, the nail rusts. Iron in the nail combines with oxygen in the air to form rust. The properties of rust are different from the properties of iron and the properties of oxygen. The rust is a new substance.

The ability of iron to combine with oxygen and form rust is a chemical property of iron.

Let us consider another example. Baking soda is a solid. Vinegar is a liquid. Mixing baking soda with vinegar produces bubbles of a gas called carbon dioxide. Carbon dioxide has different properties from either baking soda or vinegar.



In some chemical reactions, two substances may exchange parts of their molecules to make new substances. This is what happens when you mix baking soda with vinegar.

What can people do to prevent, or at least slow down, some chemical changes? Some silver polishes add a protective layer to the silver as it is being cleaned. This slows down the tarnishing (a chemical change) of the silver. Some bridges are built so that a small amount of electricity can be run through the metal supporting structure. This helps slow the formation of rust on the iron..

Chemical Changes in Matter

The Conversation of Matter and Energy

Over the years scientists have learned from experiments and observations, using the scientific method, that the total quantity of matter and energy available in the universe is a fixed amount. It may change form but it never changes the amount. These discoveries have lead to the formulation of two of the most important laws in science. They are the Law of the Conservation of Matter and the Law of the Conversation of Energy.

A. The Law of Conservation of Matter:

The Law of Conservation of Matter states that matter cannot be created or destroyed, only redistributed. In chemistry, this is represented by the fact that the sum of the masses of the reactants (the parts used to create the product) are equal to the sum of the products formed in a chemical reaction.

When a piece of copper metal is heated in air, it comes together with oxygen in the air. Then if it is weighed, it is found to have a greater mass than the original piece of metal. If However, when the mass of the oxygen of the air that combines with the metal is considered, the mass of the product is within the limits of accuracy of any measuring instrument, equal to the sum of the masses of the copper and that of oxygen combined.

The Conversion of one type of matter into another type of mater is always accompanied by the conversion of one form of energy into another form of energy.. Every material contains thermal energy. Identical masses of substances may contain different amounts of thermal energy sometimes at the same temperature. **Heat capacity** is the quantity of thermal energy required to raise the temperature of an object by one degree. **Specific heat** is the amount of thermal energy required to raise the temperature of one gram of a substance by one degree

Law of Conservation of Energy

Energy cannot be created or destroyed in a chemical reaction (or any transformation of energy). During a chemical reaction, energy can change from one form to another.

Example: Chemical bonds can be viewed as potential energy. So during the reaction:

$2CH_4$ (g) + $3O_2$ (g) $\longrightarrow$ $2CO_2$ (g) + 2 H_2O (l) + thermal energy + light some potential energy is converted to thermal energy and light.

During a chemical reaction, usually heat is absorbed or produced, but sometimes the conversion involves light or electrical energy instead of heat energy (required or released). Many transformations of energy occur that do not involve chemical changes. Electrical energy can be changed into either mechanical, light, heat or potential energy without chemical changes.

The Law of the Conservation of Energy holds for all transformations of energy.

Chemical Changes in Matter

Activity 1

1. What is a chemical reaction?

2. Discuss how energy is involved with a chemical reaction.

3. Can a chemical reaction produce a product with different physical properties from the original substances?

4. Ask you teacher to do an experiment to show how carbon dioxide is formed. Is carbon dioxide harmful to humans?

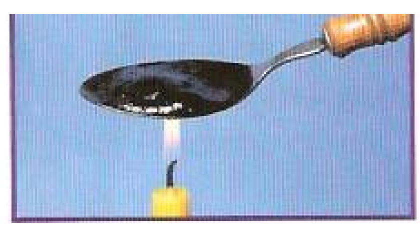
5. Ask your teacher to do the following experiment with sugar.

Making and Breaking Down Sugar

Carbon Oxygen Hydrogen Sugar

Experiment

1. A chemical change makes a new substance. When carbon, oxygen, and hydrogen are combined in the right amounts; they form sugar. Sugar is a compound. A compound does not look like the elements of which it is made. Compounds have different properties.



2. A chemical change can break compounds apart. What is left behind are the elements and simpler compounds of which they were made. For example, the compound sugar can be broken down into water and carbon. This type of chemical change needs energy to take place. Energy is always involved in a chemical change. Some changes require energy to occur. Others release energy.

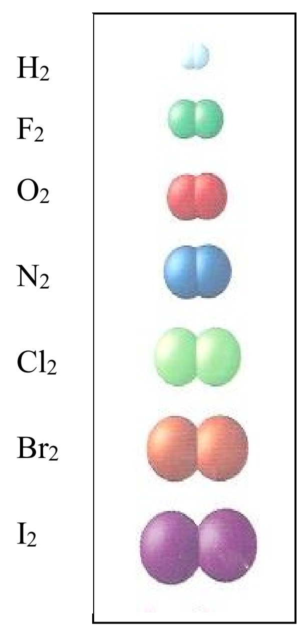
Theme II: Introduction to Chemistry: The Study of the Composition of Matter and The Changes of Matter

Lesson 4: Chemical Names, Formulas and Reactions

Do You Know?

Elements, molecules and ions are the building blocks of all matter (substances) that make up living and non-living things. Although there are only about 100 different elements, a limited number of molecules consisting of atoms of the same element and a limited number of ions, both monatomic and polyatomic, atoms molecules and ions can join in almost limitless combinations. Thus a very large number of matter (substance) exists. Every substance can be identified by a chemical name. Each chemical name has associated with it a chemical symbol, formulas or equation.

Chemists have identified more than ten million compounds. Some of these are molecular compounds such as the proteins and hormones in our body. Others are ionic compounds such as the salts in body fluids. No two of these compounds have the same identical properties. No two of them have the same identical chemical name, formula or equation. However, chemists have come up with a systematic way of identifying, naming and studying the chemical names of matter (substances). Chemists do this by studying the chemical composition of matter (substances) and how they were formed from certain chemical reactions.



A **chemical formula** shows the kinds of numbers of atoms contained in the smallest representative unit of the substances.

Examples

- Chemical formulas of some monatomic elements He, helium; Ne, Neon.
- Chemical formulas of some diatomic elements.

Hydrogen (H_2)	Fluorine (F_2)
Oxygen (O_2)	Nitrogen (N_2)
Chlorine (Cl_2)	Bromine (Br_2)
Iodine (I_2)	

Chemical Names, Formulas and Reactions

The chemical formula of a molecular compound is called a molecular formula. The **molecular formula** shows the kind and number of the compound.

Examples

H_2O, water
C_2H_6, ethane, a compound of natural gas
NH_3, ammonia gas, a gas (g)
C_2H_2O, ethanol, a gas (g)

Observe that a molecular formula does not indicate the arrangement of atoms within a molecule. This arrangement is called **molecular structure**.

A **covalent bond** is formed by a shared pair of electrons between two atoms.
By sharing electrons, the molecule of molecular compounds remain electrically neutral. Specifically, molecular compounds have covalent bonding.

Ionic compounds show the kind and number of cations and anion contained in the smallest representation (a molecule) of the compound.

Examples

Na^+	+	I^-	→	NaI
Sodium ion		Iodine ion		Sodium iodine
K^+	+	S^{2-}	→	K_2S
Potassium ion		Sulfur ion		Potassium Sulfide
Sn^{2+}	+	Cl^-	→	$SnCl_2$
Stannous ion		Chlorine ion		Stannous chloride
LiH^{4+}	+	SO_4^{2-}	→	$LiHSO_4$
Lithium hydrogen		Sulfate		Lithium hydrogen sulfate
NH^{4+}	+	$Cr_2O_7^{2-}$	→	$(NH_4)_2Cr_2O_7$
Ammonium		Dichromate		Ammonium dichromate

Ionic compounds do not share electrons as molecules do in molecular compounds. Instead, in ionic compounds the plus (+) charges of one element complement the negative (-) charge of the other element to make the molecule electrically neutral.

Chemical Names, Formulas and Reactions

Oxidation and Reduction

The charges on the ions composing an ionic compound reflect the electron distribution of the compound. In order to indicate the general distribution of electrons among the bonded atoms in a molecular compound or a molecular ion, **oxidation numbers**, also called **oxidation states**, are assigned to the atoms composing the compound or ion. Unlike ionic charges, oxidation numbers do not have an exact physical meaning. In fact, in some cases they are quite arbitrary. However, oxidation numbers are useful in naming compounds, in writing formulas, and in balancing chemical equations.

Rules for Assigning Oxidation Numbers

Rule	Example
1. The oxidation number of any uncombined element is 0.	The oxidation number of Na(s) is 0.
2. The oxidation number of a monatomic ion equals the charge on the ion.	The oxidation number of Cl^- is -1.
3. The more-electronegative element in a binary compound is assigned the number equal to the charge it would have if it were an ion.	The oxidation number of O in NO is -2.
4. The oxidation number of fluorine in a compound is always -1.	The oxidation number of F in LiF is -1.
5. Oxygen has an oxidation number of -2 unless it is combined with F, when it is +2, or it is in a peroxide, such as H_2O_2, when it is -1.	The oxidation number of O in NO is -2.
6. The oxidation state of hydrogen in most of its compounds is +1 unless it is combined with a metal, in which case it is -1.	The oxidation number of H in LiH is -1.
7. In compounds, the elements of Group 1 and 2 as well as aluminum have oxidation numbers of +1, +2, and +3, respectively.	The oxidation number of Ca in $CaCO_3$ is +2.
8. The sum of the oxidation numbers of all atoms in a neutral compound is 0.	The oxidation number of C in $CaCO_3$ is +4.
9. The sum of the oxidation numbers of all atoms in a polyatomic ion equals the charge of the ion.	The oxidation number of P in $H_2PO_4^-$ is +5.

Chemical Names, Formulas and Reactions

Oxidation and Reduction as Processes

Any chemical process in which elements undergo changes in oxidation number is an **oxidation-reduction reaction** often shortened to **redox reaction**. Reactions in which the atoms or ions of an element experience an increase in oxidation state are **oxidation** processes. The chemical equation for this reaction is written as follows.

$$2Na(s) \quad + \quad Cl_2(g) \longrightarrow 2NaCl(s)$$

The formation of sodium ions illustrates an oxidation process because each sodium atom loses an electron to become a sodium ion. The oxidation state is represented by placing an oxidation number above the symbol of the atom and the ion.

$$\overset{0}{Na} \longrightarrow \overset{+1}{Na^+} + e^-$$

Reactions in which the oxidation state of an element decreases are **reduction** processes. Consider the behavior of chlorine in its reaction with sodium. Each chlorine atom accepts an electron and becomes a chloride ion. The oxidation state of chlorine decreases from 0 to -1 for the chloride ion.

$$\overset{0}{Cl_2} + 2e^- \longrightarrow \overset{-1}{2Cl^-}$$

A species that undergoes a decrease in oxidation state is **reduced**. The chlorine atom is reduced to the chloride ion.

$$\overset{0}{3Cu} \longrightarrow \overset{+2}{3Cu^{2+}} + 6e^- \qquad \text{(oxidation)}$$

$$2\overset{+5}{N}\overset{-2}{O_3} + 6e^- + 8\overset{+1}{H^+} \longrightarrow 2\overset{+2}{N}\overset{-2}{O} + 4\overset{+1}{H_2}\overset{-2}{O} \qquad \text{(reduction)}$$

$$\overset{0}{3Cu} + 2\overset{+5}{NO_3^-} + 8H^+ \longrightarrow \overset{+2}{3Cu^{2+}} + 2\overset{+2}{NO} + 4H_2O \qquad \text{(redox reacion)}$$

Oxidation States of Chromium (Cr)

Chemical Names, Formulas and Reactions

Chemical Equations

A chemical reaction is the process by which one or more substances are changed into one or more different substances. In any chemical reaction, the original substances are known as the reactants and the resulting substances are known as the products. According to the law of conservation of mass, the total mass of reactants must equal to the total mass of products for any given chemical reaction.

Chemical reactions are described by chemical equations. A **chemical equation** represents, with symbols and formulas, the identities and relative amounts of the reactants and products in a chemical reaction. For example, the following chemical equation shows that the reactant ammonium dichromate yields the products nitrogen, chromium (III) oxide, and water.

$$(NH_4)_2Cr_2O(s) \longrightarrow N_2(g) + Cr_2O_3(s) + 4H_2O(g)$$

Symbols Used in Chemical Equations

Symbol	**Explanation**
$\longrightarrow$	"Yields"; indicates result of reaction
$\rightleftarrows$	Used in place of a single arrow to indicate a reversible reaction
(*s*)	A reactant or product in the solid state; also used to indicate a precipitate
$\downarrow$	Alternate to (s), but used only to indicate a precipitate
(*l*)	A reactant or product in the liquid state
(*aq*)	A reactant or product in an aqueous solution (dissolved in water)
(*g*)	A reactant or product in the gaseous state
$\uparrow$	Alternative to (g), but used only to indicate a gaseous product
$\xrightarrow{\Delta}$ or $\xrightarrow{heat}$	Reactants are heated
$\xrightarrow{2\ atm}$	Pressure at which reaction is carried out, in this case 2 atm
$\xrightarrow{pressure}$	Pressure at which reaction is carried out exceeds normal atmospheric pressure
$\xrightarrow{0^{\circ}C}$	Temperature at which reaction is carried out, in this case 0˚C
$\xrightarrow{MnO_2}$	Formula of catalyst, in this case manganese dioxide, used to alter the rate of the reaction

Chemical Names, Formulas and Reactions

Solid aluminum carbide, AL_4C_3, reacts with water to produce methane gas and solid aluminum hydroxide. Write a balanced chemical equation for this reaction.

The reactants are aluminum carbide and water. The products are methane and aluminum hydroxide. The formula equation is written as follows.

$$Al_4C_3(s) + H_2O(l) \longrightarrow CH_4(g) + Al(OH)_3(s) \quad \text{(not balanced)}$$

Begin balancing the formula equation by counting either aluminum atoms or carbon atoms. (Remember that hydrogen and oxygen atoms are balanced last.) There are four Al atoms on the left. To balance Al atoms, place the coefficient 4 before $Al(OH)_3$ on the right.

$$Al_4C_3(s) + H_2O(l) \longrightarrow CH_4(g) + 4Al(OH)_3(s) \quad \text{(partially balanced)}$$

Now balance the carbon atoms. With three C atoms on the left, the coefficient 3 must be placed before CH_4 on the right.

$$Al_4C_3(s) + H_2O(l) \longrightarrow 3CH_4(g) + 4Al(OH)_3(s) \quad \text{(partially balanced)}$$

Balance oxygen atoms next because oxygen, unlike hydrogen, appears only once on each side of the equation. There is one O atom on the left and 12 O atoms in the four $Al(OH)_3$ formula units on the right. Placing the coefficient 12 before H_2O balances the O atoms.

$$Al_4C_3(s) + 12H_2O(l) \longrightarrow 3CH_4(g) + 4Al(OH)_3(s)$$

This leaves the hydrogen atoms to be balanced. There are 24 H atoms on the left. On the right, there are 12 H atoms in the methane molecules and 12 in the aluminum hydroxide formula units, totaling 24 H atoms. The H atoms are balanced.

$$Al_4C_3(s) + 12H_2O(l) \longrightarrow 3CH_4(g) + 4Al(OH)_3(s)$$
$$(4Al + 3C) + (24H + 12O) = (3C + 12H) + (4AL + 12H + 12O)$$

The equation is balanced.

Chemical Names, Formulas and Reactions

The reaction of zinc with aqueous hydrochloric acid produces a solution of zinc chloride and hydrogen gas. This reaction is shown at the right. Write a balanced chemical equation for the reaction.

Solution

1. **Analyze** Write the word equation.

   zinc + hydrochloric acid $\longrightarrow$ zinc chloride + hydrogen

2. **Plan** Write the formula equation.

   $Zn(s) + HCl(aq) \longrightarrow ZnCl_2(aq) + H_2(g)$ (not balanced)

3. **Compute** Adjust the coefficients. Note that chlorine and hydrogen each appear only once on each side of the equation. We balance chlorine first because it is combined on both sides of the equation. Also, recall from the guidelines on the previous page that hydrogen and oxygen are balanced only after all other elements in the reaction are balanced. To balance chlorine, we place the coefficient 2 before HCl. Two molecules of hydrogen chloride also yield the required two hydrogen atoms on the right. Finally, note that there is one zinc atom on each side in the formula equation. Therefore, no further coefficients are needed.

   $Zn(s) + 2HCl(aq) \longrightarrow ZnCl_2(aq) + H_2(g)$

Solid zinc reacts with hydrochloric acid to form aqueous zinc chloride and hydrogen gas.

4. **Evaluate** Count atoms to check balance.

   $Zn(s) + 2HCl(aq) \longrightarrow ZnCl_2(aq) + H_2(g)$
   (1Zn) + (2H + 2Cl) = (1Zn + 2CL) + (2H)

   The equation is balanced.

Translate the following chemical equation into a sentence:

$$\mathbf{PbCl_2(aq) + Na_2CrO_4(aq) \longrightarrow PbCrO_4(s) + 2NaCl(aq)}$$

Solution Each reactant is an ionic compound and is named according to the rules for such compounds. Both reactants are in aqueous solution. One product is a precipitate and the other remains in solution. The equation is translated as follows: Aqueous solutions of lead (II) chloride and sodium chromate react to produce a precipitate of lead (II) chromate plus sodium chloride in aqueous solution.

Chemical Names, Formulas and Reactions

Activity I

Write word, formula, and balanced chemical equations for each of the following reactions:

1. Magnesium and hydrochloric acid react to produce magnesium chloride and hydrogen.

2. Aqueous nitric acid reacts with solid magnesium hydroxide to produce aqueous magnesium nitrate and water.

3. Solid calcium reacts with solid sulfur to produce solid calcium sulfide.

4. Hydrogen gas reacts with fluorine gas to produce hydrogen fluoride gas.

5. Solid aluminum metal reacts with aqueous zinc chloride to produce solid zinc metal and aqueous aluminum chloride.

6. When aqueous solutions of sulfuric acid and barium chloride are mixed, barium sulfate precipitated from an aqueous solution of hydrochloric acid.

7. Aluminum sulfate, an ingredient in antiperspirants, is made by the reaction of solid aluminum oxide with aqueous sulfuric acid. In addition to aqueous aluminum sulfate, water is also produced.

Theme II: Introduction to Chemistry: The Study of the Composition of Matter and The Changes of Matter

Lesson 5: Aqueous Solutions, Acids, Bases and Salts

Do You Know?

Aqueous Solution

A **solution** is a mixture (usually liquid) of two or more substances where all substances are evenly or smoothly spread throughout all parts of the mixture; a solution is the same as a homogenous mixture. All solutions have at least two major components: the solvent and the solute(s). The **solvent** is the part of the solution that is the substance with the most physically identifiable properties and most physically abundant substance of the solution. It is sometimes viewed as the "host" part of the solution that does the dissolving. The **solute** is the substance with the least physically identifiable properties and it has the smaller quantity of the solution. It is sometimes viewed as the "guest" of the solution and it is the substance that is dissolved in the solution.

An **aqueous solution** is a solution of which water is the solvent.

Water

- Dissolves a large variety of ionic compounds.
- Dissolves a large variety of molecular or covalent compounds.
- Does not dissolve all substances (for example water does not dissolve oil).
- Dissolves "like" substances; especially, those that contain H_2 (hydrogen) or O_2 (oxygen) atoms or ions with these substances; hydrogen bonds are formed by strong interactions between hydrogen atoms.
- Is said to be "hard" if it has a significant concentration (a measurable amount) of certain ions, usually Ca^{2+} (calcium) and/or Mg^{2+} (magnesium).
- Is said to be "soft" when it has a significant concentration of Na^{+} (sodium) ions and a much smaller concentration of Ca^{2+} and/or Mg^{2+}.
- Has a high boiling point for its molecular size and most water is not "pure" but has dissolved substances.

Aqueous Solutions, Acids, Bases and Salts

There are several properties that water has that are properties of solutions in general.

Solutions

- Can be saturated (have dissolved the maximum amount of a given solute).
- Can be diluted (have dissolved less than the maximum amount of solute).
- Can be supersaturated (by changing the temperature or other factors by having absorbed more than the maximum amount under regular conditions).
- Can be measured by percent of mass.
- Can be measured by molarity.
- Can be affected by temperature.
- Can be an electrolyte (conducts electricity) or a non-electrolyte (does not conduct electricity).

What are Acids, Bases, and Salts?

- **Acids** are compounds that increases the concentration of hydrogen ions in water.

Example $HCl \xrightarrow{\text{water}} H^+ + Cl^-$

- **Bases** are compounds that increases the concentration of hydroxide ions in water.

Example $NaOH \xrightarrow{\text{water}} Na^+ + OH^-$

- **Salts** are the ions that remain after an acid and a base react with each other; it is the neutralization of an acid and a base.

Example $HCl_{(aq)} + NaOH_{(aq)} \xrightarrow{\text{water}} Na\,Cl_{(aq)} + H_2O_{(l)}$

A number of acids exists that have more than one ionizable hydrogen. They are called **ployprotic acids**.

Examples

H_3PO_4	Phosphoric Acid
H_2SO_4	Sulfuric Acid
$H_2C_2O_4$	Oxalic Acid
H_2CO_3	Carbonic Acid

Aqueous Solutions, Acids, Bases and Salts

Properties of Acids and Bases

Defining and understanding even the simplest things in our lives is not always an easy task. This also is true in chemistry. As early as the seventeenth century, chemists recognized two important classes of compounds, which they called **acids** and **bases**. As you will see, recognizing acids and bases is easy, but defining and understanding them takes a little more effort. Over time, as chemists gained a better understanding of acid-base behavior, they have broadened the original definition of acids and bases.

Take a look at the two bottles. The bottle on the left contains a solution of hydrochloric, a common acid and the bottle on the right contains a solution of ammonium hydroxide, a common base. However, if the labels on these bottles were removed, you could not tell the difference between these solutions based on their appearance alone. Often water solutions of both acids and bases look identical to pure water.

Appearance in water, however, is one of the few properties that hydrochloric acid and ammonium hydroxide have a common. As you will discover, there are several differences among acid solutions, basic solutions, and solutions – like pure water – that have the properties of neither an acid nor a base. Let's examine some of the properties of acids and bases.

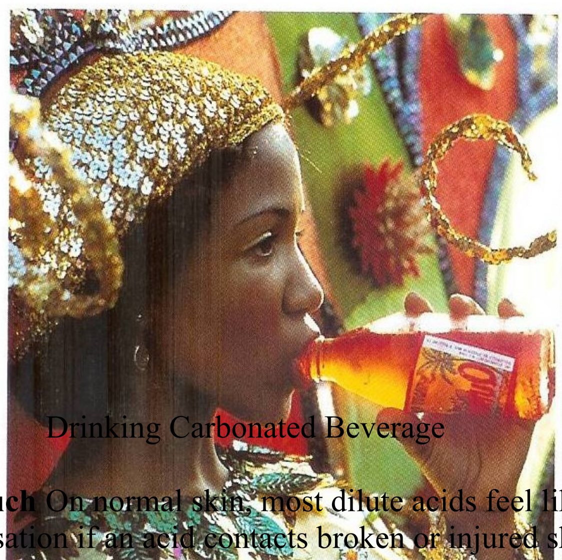
Aqueous Solutions, Acids, Bases and Salts

Taste The word acid comes from a Latin word acidus, meaning sour or tart. When an acid is dissolved in water, the solution tastes sour. You taste such solutions every day in the food you eat. Foods that contain acids include:

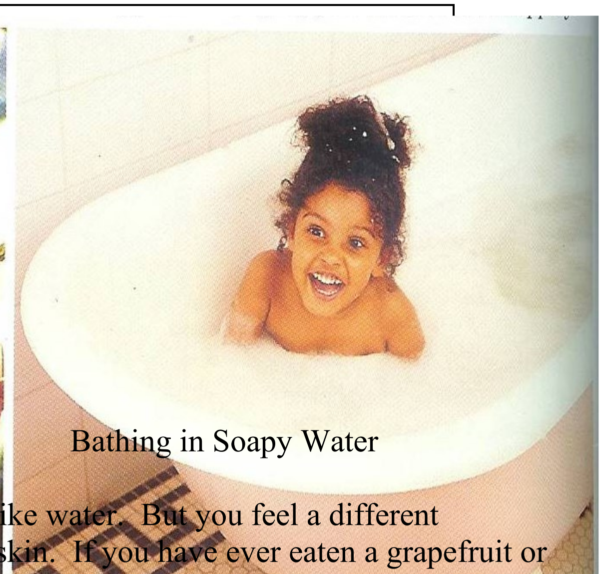
- citrus fruits, such as oranges and grapefruit, which contain citric acid;
- yogurt and sour milk, which contain lactic acid;
- carbonated beverages, which contain carbonic acid; and
- vinegar, which contains acetic acid.

Water solutions of bases, on the other hand, have a characteristic bitter taste. If you have ever put soap or soapy water in your mouth (either accidentally or on purpose), then you are acquainted with the bitter taste of bases.

In the laboratory; however, taste is a property that you should never test. Never eat or drink in the laboratory, and never taste any laboratory chemical. Although some laboratory chemicals are harmless, others are dangerous and toxic.



Drinking Carbonated Beverage



Bathing in Soapy Water

Touch On normal skin, most dilute acids feel like water. But you feel a different sensation if an acid contacts broken or injured skin. If you have ever eaten a grapefruit or orange when you had a sore in your mouth, then you know the sharp sting that an acid can give.

Mild basic solutions do not sting – except in your eyes. Everywhere else on your body, basic solutions feel smooth, soothing, and slippery. One very common basic solution – soapy water – is an excellent example of this smooth, slippery feel.

Again, remember that many laboratory chemicals are dangerous and toxic. Do not touch any laboratory chemicals or place them on your skin or clothing. If you accidentally spill any chemical in the laboratory, alert your teacher and clean up the spilled chemical immediately.

Aqueous Solutions, Acids, Bases and Salts

Reactions with metals Acids often react violently with some metals, including magnesium, zinc, iron, and aluminum. Bases, however, do not react with most metals. The reaction between hydrochloric acid and a ribbon of magnesium produces a gas. This gas can be collected in a beaker and tested with a burning splint. The result is a "popping" noise, which indicates that the gas is hydrogen (H_2). Acids react with magnesium or with the other metals listed earlier to produce hydrogen gas. As you will discover later, this reaction provides a key to understanding an acid's chemical properties.

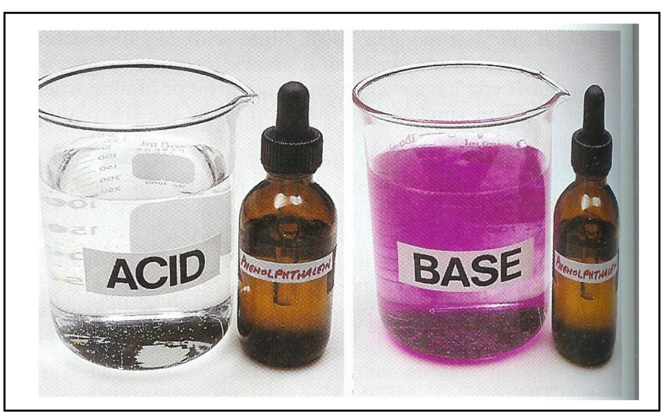
Electrical Conductivity Pure water is an extremely poor conductor of electricity. However, a solution of hydrochloric acid conducts electricity quite well, as does a solution of sodium hydroxide, a base.

Both acids and bases are examples of electrolytes. An **electrolyt**e is a substance that ionizes when it dissolves in water. A solution that contains electrolytes conducts electricity.

Indicators An acid-base **indicator** is a substance that turns one color in an acid solution and another color in a basic solution. One of the most common acid-base indicators is **litmus**, a kind of dye that comes from a species of lichen. (You may have seen lichens growing on rocks or on a wall.)

You are probably familiar with litmus in the form of litmus paper, which is litmus coated onto small paper strips. **An acid turns litmus paper from blue to red**, and **a base turns litmus from red to blue**.

Placing a drop of an unknown solution onto a strip of litmus paper is a quick, easy way to determine whether the solution is acidic or basic. Such a procedure is called a **litmus test**. Although the term litmus test has a specific meaning in chemistry, in other contexts it has come to mean any simple test or question that reveals an important characteristic. In politics, if a voter supports or rejects a candidate based on the candidate's stand on a single issue, then that voter is said to be applying a litmus test.



Phenolphthalein is an acid-base indicator, a substance that has different colors in acidic and basic solutions.

Aside from litmus, popular indicators include phenolphthalein, methyl red, and thymol blue. Each of these indicators changes color at different levels of acidity or basicity.

Aqueous Solutions, Acids, Bases and Salts

Neutralization Mix together an acid and a base, and they quickly react with each other. If the proper amounts of acid and base are used, the result is a solution that has none of the distinctive properties of an acid or a base. In other words, the properties of both the acid and the base have been neutralized or destroyed. For this reason, the reaction between an acid and a base is called an acid-base neutralization reaction. In such a reaction, the acid neutralizes the base and the base neutralizes the acid. The product of this neutralization is called a **salt**.

Names and Formulas of Acids and Bases

An **acid** is a compound that produces hydrogen ions when dissolved in water. Therefore, the chemical formulas of acids are of the general form HX, where X is a monatomic or polyatomic anion. When the compound HCl(g) (hydrogen chloride) dissolves in water to form (HCl)(aq), it is named as an acid. How, then, is an acid named? To illustrate the naming of an acid, consider the following three rules as applied to the acid HX dissolved in water. Notice that the rules focus on the name of the acid, in particular the suffix of the anion name.

1. When the name of the anion (X) ends in –ide, the acid name begins with the prefix hydro-. The stem of the anion has the suffix –ic and is hydrochloric acid. H_2S(aq) (X = sulfide) is named hydrosulfuric acid.
2. When the anion name ends in –ite, the acid name is the stem of the anion with the suffix –ous, followed by the word acid. Thus H_2SO_3(aq) (X = sulfite) is named sulfurous acid.
3. When the anion name ends in –ate, the acid name is the stem of the anion with the suffix –ic, followed by the word acid. Thus HNO_3(aq) (X = nitrate) is named nitric acid.

These rules can be used in reverse fashion to write the formulas of acids when given their names. For example, what is the formula of chloric acid? According to Rule 3, chloric acid (-ic ending) must be a combination of hydrogen ion (H^+) and chlorate ion (ClO_3^-). The formula of chloric acid is $HClO_3$. What is the formula of hydrobromic acid? Following Rule 1, hydrobromic acid (hydro- prefix and –ic suffix) must be a combination of hydrogen ion and bromide ion (Br^-). The formula of hydrobromic acid is HBr. What is the formula for phosphorous acid? Using Rule 2, hydrogen ion and phosphate ion (PO_3^{3-}) must be the components of phosphorous acid. The formula of phosphorous acid is H_3PO_3. (Note: Do not confuse phosphorous with phosphorus, the element name.)

Aqueous Solutions, Acids, Bases and Salts

Naming Acids			
Anion ending	**Example**	**Acid name**	**Example**
-ide	Cl^- chloride	Hydro- (stem)-ic acid	Hydrochloric acid
-ite	SO_3^{2-} sulfite	(stem)-ous acid	Sulfurous acid
-ate	NO_3^- nitrate	(stem)-ic acid	Nitric acid

A **base** is a compound that produces hydroxide ions when dissolved in water. Ionic compounds that are bases are named in the same way as any other ionic compound – the name of the cation followed by the name of the anion. For example, NaOH, a base used in making paper pulp, detergents, and soap, is called sodium hydroxide. What would one call $Ca(OH)_2$? One writes the formulas for bases by balancing the ionic charges, just as one does for any ionic compound. We list the names of four strong and four weak bases.

Four strong bases: (1) calcium oxide (CaO), (2) sodium hydroxide (NaOH)
(3) potassium hydroxide, (4) Calcium hydroxide ($Ca(OH)_2$) .

Four weak bases: (1) ammonia (NH_3), (2) hydrazine (H_2NNH_2)
(3) carbonate ion (CO_3^{2-}), (4) phosphate ion (PO_4^{3-}) .

Name these compounds as acids: a. HClO b. HCN c. H_3PO_4, using the rules.

1. **Analyze** Plan a problem-solving strategy.
The rules for naming acids can be applied because the formulas of the acids are given.
2. **Solve** Apply the problem-solving strategy.
a. Use Rule 2. The anion name (hypochlorite) ends in –ite, so add the suffix –ous to the anion stem, followed by the word acid. The correct name is **hypochlorous acid**.
b. Use Rule 1. The anion name (cyanide) ends in –ide, so this acid name begins with the prefix hydro- and ends with the suffix –ic, followed by the word acid. The correct name is hydrocyanic acid.
c. Use Rule 3. The anion name (phosphate) ends in –ate. So add the suffix –ic to the anion stem (in the case, modified slightly to phosphor), followed by the word acid. The correct name is **phosphoric acid**.
3. **Evaluate** Do the results make sense? The names are consistent with the rules.

Hydrogen Ions from Water

As you already know, water molecules are highly polar and are in continuous motion, even at room temperature. Occasionally, the collisions between water molecules are energetic enough to transfer a hydrogen ion from one water molecule to another. A water molecule that loses a hydrogen ion becomes a negatively charged **hydroxide ion (OH^-).** A water molecule that gains a hydrogen ion becomes a positively charged **hydronium ion (H_3O^+).**

Aqueous Solutions, Acids, Bases and Salts

The reaction in which two water molecules produces ions is called the **self-ionization of water**. This reaction can also be written as a simple dissociation.

$H_2O(l)$	$\rightarrow$	$H^+(aq)$	+	$OH^-(aq)$
		Hydrogen ion		Hydroxide ion

In water or aqueous solution, hydrogen ions (H^+) are always joined to water molecules as hydronium (H_3O^+). The hydronium ions are themselves solvated to form species such as $H_9O_4^+$. Hydrogen ions in aqueous solution have several names. Some chemists call them protons. Others prefer to call them hydrogen ions, hydronium ions, or solvated protons.

The self-ionization of water occurs to a very small extent. In pure water at 25˚C, the concentration of hydrogen ions ($[H^+]$) and the concentration of hydroxide ions ($[OH^-]$) are each only 1.0×10^{-7}M. This means that the concentrations of H^+ and OH^- are equal in pure water. Any aqueous solution in which $[H^+]$ and $[OH^-]$ are equal is described as a **neutral solution**. The product of this neutralization is called a **salt.**

Acid-Base Properties of Salts

As one learned earlier, a **salt** consists of an anion from an acid and a cation from a base, and it forms as a result of a neutralization reaction. Although solutions of many salts are neutral, there are some that are partially acidic and others that are partially basic.

Salts are strong electrolytes. When they dissolve in water, they dissociate into their component cations and anions. In many cases, these ions are weak Brønsted-Lowry acids or bases. The reactions of ions from salts to form H_3O^- or OH^- ions are called **salt hydrolysis reactions**.

It is possible to predict whether a salt hydrolysis reaction produces an acidic solution (containing H_3O^+ ions) or a basic solution (containing OH^- ions). One simple way is to consider the acid and base from which the salt is formed. There are four possibilities.

Salts of Strong Acids and Strong Bases Solutions of these salts are neither acidic nor basic; they are neutral. For example, the neutralization reaction between NaOH and HCl produces the salt NaCl. A water solution of NaCl is neither acidic nor basic.

NaOH (aq) +	HCl (aq)	NaCl (aq) + H_2O (l)
strong	strong	neutral
base	acid	

Aqueous Solutions, Acids, Bases and Salts

Salts of Strong Acids and Weak Bases Solutions of these salts are acidic. For example, NH_4Cl is a salt formed by the neutralization reaction between NH_3 and HCl. Its water solutions are slightly acidic:

NH_3 (aq) + HCl (aq)		NH_4Cl (aq)
weak base	strong acid	slightly acidic

The solution is acidic because the NH^{4+} ion is a Brønsted-Lowry acid and donates H+ ions to water:

$$NH_4^+ (aq) + H_2O (l) \qquad NH_3 (aq) + H_3O^+ (aq)$$

$$K_a = 5.6 \times 10^{-10}$$

The chloride (Cl^-) ion, being the conjugate base of a strong acid (HCl), has virtually no affinity for H^+ ions. It is merely a spectator ion in the solution.

Salts of Weak Acids and Strong Bases Solutions of these salts are basic. For example, Na_2CO_3 is a salt formed by the neutralization reaction between NaOH and H_2CO_3. Its water solutions are basic:

2 NaOH (aq) + H_2CO_3 (aq)		Na_2CO_3 (aq) + 2 H_2O (l)
strong base	weak acid	slightly basic

The solution is basic because the CO_3^{2-} ion is a weak Brønsted-Lowry base and accepts H+ ions from water:

$$CO_3^{2-} (aq) + H_2O (l) \qquad HCO_3^- (aq) + OH^- (aq)$$

$$K_a = 1.8 \times 10^{-4}$$

The Na^+ ion is merely a spectator ion in the reaction.

Salts of Weak Acids and Weak Bases Aqueous solutions of these can be acidic, basic, and neutral, depending on the relative strengths of the acids and bases from which the salt is formed. In this case, both the cation and the anion react with water. Predicting the behavior of these salts is beyond the scope of this lesson.

Acids, bases and salts in aqueous solutions are some of the most important compounds in chemistry. They have a variety of important uses in everyday living.

Aqueous Solutions, Acids, Bases and Salts

Activity 1

True or False

1. To identify an acid or a base in the laboratory, one should taste or touch it.
2. An acid and a base destroy each others properties in a neutralization process.
3. Acids react violently with some metals.
4. Acids and bases are not named the same way.
5. acids, bases and salts are electrolytes
6. An acid has a sour taste.
7. A base has a bitter taste.
8. All homogenous mixtures are solutions.
9. All solutions are aqueous.
10. No acid, base or salt is harmful to the human body.
11. Write the formula for each acid or base:
    (a) barium hydroxide, (b) hydrochromic acid
12. Write the name of each acid or base:
    (a) HF, (b) $HClO_3$

Theme II: Introduction to Chemistry: The Study of the Composition of Matter and The Changes of Matter

Lesson 6: Some Important Applications of Chemistry

Do You Know?

Why Study Chemistry?

One should study chemistry because understanding chemistry helps us to understand the world around us. Cooking is chemistry. Everything one can touch or taste or smell is a chemical. When one studies chemistry, one comes to understand about substances (matter); what are things made and how things can change.. Chemistry is not secret knowledge, useless to anyone but a scientist. It is the explanation for everyday things, like why laundry detergent works better in hot water or how baking soda works or why all pain relievers do not work equally well on a headache. If one knows some chemistry, one can make educated choices about substances (products) that one uses.

What Other Fields of Study Use Chemistry?

One may use chemistry in most fields, but it's commonly seen in the sciences and in medicine. Chemists, physicists, biologists, and engineers study chemistry. Doctors, nurses, dentists, pharmacists, physical therapists, and veterinarians all take chemistry courses. Science teachers study chemistry. Fire fighters and people who make fireworks learn about chemistry. So do truck drivers, plumbers, artists, hairdressers, chefs… the list is very long.

What Will This Lesson Highlight?

This lesson will highlight some of the important applications of chemistry without providing all the details.

Some Important Applications of Chemistry

Binding Energy – Theory of Relativity

The study of transformation in energy as it relates to mass and as it occurs in nuclear reactions led to the discovery of binding energy and Einstein's Laws of Relativity. **Binding energy** is a measure of stability gained when protons and neutrons get together to form a nucleus. The equation that shows the relationship between mass and energy is:

$$E = mc^2$$

Which is Einstein's Law of Relativity. We can use this relationship to determine how much energy is produced by a decrease in mass. In the above equation, E is for energy, m is for mass and c is the square of the speed of light in a vacuum (299,792,458 m/s). Einstein's Law of Relativity has helped scientists to unlock many mysteries of the world of the atom (atomic particles), the microcosam, and the world of plantery movement and behavior, the world of the Macrocosm.. Further studies in nuclear chemistry have led to even more fascinating applications.

Nuclear Chemistry

Listed below are some of the more valuable things that are studied in nuclear chemistry.

Radioactive Decay Processes
Induced Nuclear Reactions
Rates of Nuclear Reactions
Factors in Nuclear Stability
Decay Series
Energy Changes and Nuclear Reactions
Fission and Fusion
Biological Effects of Radiation
Practical Uses of Radionuclides

Uses of Radionuclides

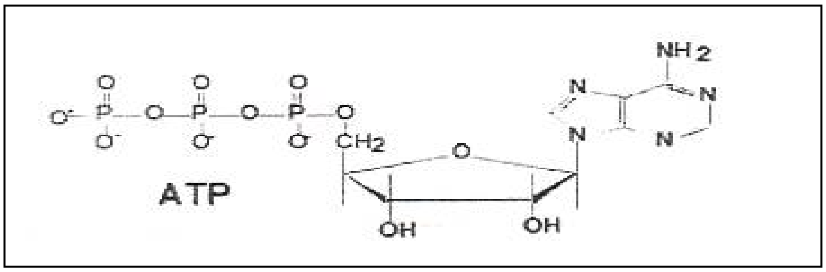
Our ability to measure radioactivity is very sensitive. As a result, radioisotopes have a number of uses. In addition, its interaction with living matter can also be used to do many valuable things. These uses include:

- Dating techniques – used to determine how old substances are
- Cancer treatment -- used to kill cancer cells
- Tracers -- used to follow substances in the human body and elsewhere
- Imaging --used to do visual imaging of different models
- Testing methods -- used to determine the composition of certain substances.

Some Important Applications of Chemistry

Organic chemistry

The complex chemical compound, Adenosine triphosphate (ATP), is the principal energy carrier in living organisms.



Removal of a phosphate, denoted by PO_3^- will result in the release of 31 kJ/mol. This energy is used to drive many of the chemical reactions in the body of living organisms.

The Nucleotides (Nucleic Acids)

(A) Adenine

(T) Thymine

(C) Cytosine

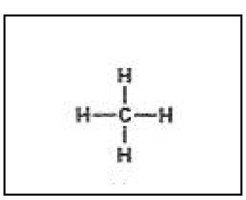
(G) Guanine

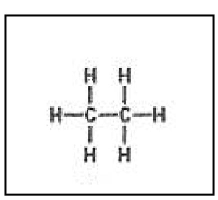
Are the major components of DNA and RNA sequences. Through DNA sequence

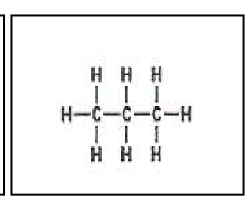
applications one can identify individual persons, their relatives and their ancestors with great accuracy.

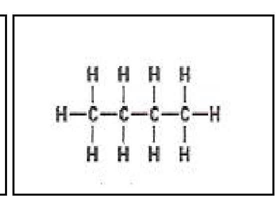
In organic chemistry, the carbon atom is involved with most molecules. e.

This key feature of carbon is that it permits a vast number of compounds to exist. One simple class of carbon compounds is the alkane which has only C, H and single bonds.


methane


ethane


propane


butane

Some Important Applications of Chemistry

There are many, many more interesting aspects of chemistry that have important applications. However, we will end this lesson with an aspect of chemistry with important applications by considering and illustrating some of the most import laws of chemistry, the gas laws.

Gas Laws

Gases have various **properties** (characteristics) which we can observe with our senses, including their pressure, temperature, mass and the volume which contains the gas. Careful, scientific observation has determined that these **variables** (their values can change) are related to one another, and the values of these properties determine the state the gas.

In the mid 1600's, Robert Boyle studied the relationship between the pressure P and the volume V of a confined gas held at a constant temperature. Boyle observed that the product of the pressure and volume are observed to be nearly constant. The product of pressure and volume is exactly a constant for an ideal gas.

$$P * V = \text{constant}$$

This relationship between pressure and volume is called **Boyle's Law** in his honor. For example, suppose we have a theoretical gas confined in a jar with a piston at the top. The initial state of the gas has a volume equal to 4.0 cubic meters and the pressure is 1.0 kilopascal. With the temperature and the number of moles held constant, weights are slowly added to the top of the piston to increase the pressure. When the pressure is 1.33 kilopascals the volume decreases to 3.0 cubic meters. The product of pressure and volume remains a constant (4 x 1.0 = 3 x 1.33333). Concisely, the Law states the following:

Boyle's Law

The volume of a gas is inversely proportional to its pressure.

$$PV = k$$

or

$$P_1 V_1 = P_2 V_2$$

Temperature and number of moles (mass) must be held constant!

Some Important Applications of Chemistry

An Application of Boyle Law

A high-altitude balloon contains 30.0 L of helium gas at 103 kPa. What is the volume when the balloon rises to an altitude where the pressure is only 25.0 kPa? (Assume that the temperature remains constant.)

---

1. **ANALYZE** ***List the knowns and the unknown.***

Knowns	Unknown
• P_1 = 103 kPa	• V_2 = ?L
• V_1 = 30.0 L	
• P_2 = 25.0 kPa	

Use the known values and Boyle's law $\left(P_1 \times V_1 = P_2 \times V_2\right)$ to calculate the unknown value (V_2).

---

2. **CALCULATE** ***Solve for the unknown.***
   Rearrange trhe expression for Boyle's law to isolate V_2.

$$V_2 = \frac{V_1 \times P_1}{P_2}$$

   Substitute the known values for P_1, V_1, and P_2 into the equation and solve.

$$V_2 = \frac{30.0L \times 103\cancel{kPa}}{25.0\cancel{kPa}}$$

$$= 1.24 \times 10^2 L$$

---

3. **EVALUATE** ***Does the result make sense?***
   Using kinetic theory, a decrease in pressure at constant temperature must correspond to a proportional increase in volume. The calculated result aggress with both the kinetic theory and the pressure-temperature relationship. Also, the units have canceled correctly and the answer is expressed to the proper number of significant figures..

Some Important Applications of Chemistry

Similar to Boyle, the properties of gases were also studied in earlier centuries (1780 - 90) by Jacques Charles, a Frenchman; a law was named in his honor.

Charles' Law

The volume of a gas is directly proportional to the absolute temperature (K).

$$\frac{V}{T} = k \quad \text{or} \quad \frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Pressure and number of moles must be held constant!

Also the properties of gases were studied in earlier centuries by _______ Gay and ______ Lussac. A law was named in their honor.

An Application of Charles Law

A balloon inflated in a room at 24 ºC has a volume of 4.00 L. The balloon is then heated to a room temperature of 58 ºC. What is the new volume if the pressure remains constant?

....

1. **ANALYZE** ***List the knowns and the unknown.***

Knowns	Unknown
• V_1 = 400.0 L	• V_2 = ?L
• 24 ºC	
• 58 ºC	

Use the known values and Charles's law $(V_1 / T_1 = V_2 \times T_2)$ to calculate the value (V_2).

....

2. **CALCULATE** ***Solve for the unknown.***
   Because the gas laws will be applied, express the temperatures in kelvins.

$$T_1 = 24°C + 273 = 297K$$
$$T_2 = 58°C + 273 = 331K$$

Rearrange the expression for Charles's law to isolate $V_2 = \frac{V_1 \times T_2}{T_1}$ V_2.

Substitute the known values for T_1, V_1, and T_2 into the equation and solve. $V_2 = \frac{4.00L \times 331K}{297K} = 4.46L$

3. **EVALUATE** ***Does the result make sense?***
   From kinetic theory, the volume should increase with an increase in temperature (at constant pressure). This result agrees with the kinetic theory and Charles's law. The volume does increase with increasing temperature.

Some Important Applications of Chemistry

Gay–Lussac's Law

The **Combined Gas Law** is a gas law which combines Charles's law, Boyle's law and Gay-Lussac's law. In each of these laws, pressure, temperature, and volume, respectively must remain constant for the law to be true. In the combined gas law, any of these properties can be found mathematically.

The Combined Gas Law states

The product of the volume of a gas and its pressure over the temperature is equal to a constant.

Expressed mathematically, the formula is: $\frac{PV}{T} = r$; where:

p is the pressure.
V is the volume.
T is the temperature.
r is a constant.

For comparing the same substance under two different sets of conditions, the law can be written as:

$$\frac{p_1V_1}{n_1T_1} = \frac{p_2V_2}{n_2T_2}$$

One can however remove *n* from the equation because it is a constant when changing only conditions, to make:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Some Important Applications of Chemistry

An Application of Gay-Lussac Law

The gas left in a used aerosol can is ata pressure of 103 kPa at 25 ºC. if this can is thrown onto a fire, what is the pressure of the gas when its temperature reaches 928 ºC? (Calculating the answer to this problem will show you why it is dangerous to dispose of aerosol cans in a fire. Most aerosol cans carry warnings on their labels that clearly say not to incinerate (burn) or to store above a certain temperature.)

....

1. **ANALYZE** ***List the knowns and the unknown.***

Knowns	Unknown
• P_1 = 400.0 L	• P_2 = ?kPa
• T_1 = 25 ºC	
• T_1 = 928 ºC	

Use the known values and Gay-Lussac's Law (P1/T1=P2/T2) to calculate the unknown (P2). Remember, because this problem involves temperatures and a gas law, the temperatures must be expressed in kelvins.

....

2. **CALCULATE** ***Solve for the unknown.***
   First convert degrees Celsius to kelvins.

$$T_1 = 25°C + 273 = 298K$$
$$T_2 = 928°C + 273 = 1201K$$

   Substitute the known values for P_1, T_2, and T_1 into the equation and solve.

$$P_2 = \frac{103kPa \times 1201K}{298K} = 4415kPa$$
$$= 4.15 \times 10^2 kPa$$

....

3. **EVALUATE** ***Does the result make sense?***
   From kinetic theory, one would expect the increase in temperature of a gas to produce an increase in pressure if the volume remains constant. The calculated value does show such an increase.

The addition of Avogadro's law to the combined gas law yields the ideal gas law.

Some Important Applications of Chemistry

The Ideal Gas Law

A combination of Boyle's, Charles' and Avogadro's Laws

$PV = nRT$

P = pressure, atm
V = volume, L
n = moles
T = temperature, K
R = 0.08206 L atm/K mol (gas law constant)

An Application of the Combined Gas Law

The volume of a gas-filled balloon is 30.0 L at 40 ºC and 150 kPa pressure. What volume will the balloon have at standard temperature and pressure (STP)?

1. **ANALYZE** ***List the knowns and the unknown.***

Knowns
- V_1 = 30.0 L
- T_1 = 40 ºC
- T_2 = 273 K (standard temperature)
- P_1 = 153 kPa
- P_2 = 101.3 kPa (standard pressure)

Unknown
- V_2 = ?L

Use the known values and combine gas law to calculate the unknown (V_2).

2. **CALCULATE** ***Solve for the unknown.***
Convert degrees Celsius to kelvins. $T_1 = 40°C + 273 = 313K$

Substitute the known quantities into the equation and solve.

$$V_2 = \frac{30.0L \times 153kPa \times 273K}{101.3kPa \times 313K} = 39.5L$$

3. **EVALUATE** ***Does the result make sense?***
The temperature decreases; therefore, the temperature ratio less than 1 (273 K / 313 K). The pressure decreases, so the pressure ratio is greater than 1

(153 kPa / 101.3 kPa). Recalculate by multiplying the initial volume of gas by these two ratios.

$$V_2 = 30.0L \frac{153kPa}{101.3kPa} \times \frac{273K}{313K} = 39.5L$$

The result is the same.

An Application of the Ideal Gas Law

You fill a rigid steel cylinder that has a volume of 20.0 L with nitrogen gas (N_2) (g) to a final pressure of 2.00 X 10^4 kPa at 28 ºC. How many moles of N_2(g) does the cylinder contain?

---

1. **ANALYZE** ***List the knowns and the unknown.***

Knowns	Unknown
• P = 2.00 X 10^4 kPa	• n = ? mol N_2(g)
• V = 20.0 L	
• T = 28 ºC	

Use the known values and the ideal gas law to calculate the unknown *(n)*.

---

2. **CALCULATE** ***Solve for the unknown.***
   Convert degrees Celsius to kelvins. $28°C + 273 = 301K$

   Rearrange the ideal gas law to isolate *n*. $n = \frac{P \times V}{R \times T}$

   Substitute the known values for P_1, T_2, and T_1 into the equation and solve.

$$n = \frac{2.00 \times 10^4 kPa \times 20.0L}{8.31 \frac{L \times kPa}{K \times mol} \times 301K} = 160 mol(N_2)(g)$$

$$= 160 \times 10^2 mol(N_2)(g)$$

---

3. **EVALUATE** ***Does the result make sense?***
   The gas is at a high pressure, but the volume is not large. This means that a large number of moles of gas must be compressed into the volume. The large answer is thus reasonable, and the units have canceled correctly.

Some Important Applications of Chemistry

Another Application of the Ideal Gas Law

A deep underground cavern contains 2.24 X 10^6 L of methane gas (CH_4)(g) at a pressure of 1.50 X 10^3 kPa and a temperature of 42 ºC. How many kilograms of CH_4 does this natural-gas deposit contain?

---

1. **ANALYZE** ***List the knowns and the unknown.***

Knowns
- P = 1.50 X 10^3 kPa
- V = 2.24 X 10^6
- T = 42 ºC

Unknown
- m = ? kg H_4

Calculate the number of moles *(n)* using the ideal gas law. Convert moles to grams, using the molar mass of methane, and then convert grams to kilograms.

---

2. **CALCULATE** ***Solve for the unknown.***

Convert degrees Celsius to kelvins.

$$42°C + 273 = 315K$$

Rearrange the equation for the ideal gas law to isolate *n*, the number of moles of methane..

$$n = \frac{P \times V}{R \times T}$$

Substitute the known quantities into the equation to find the number of moles of methane.

$$n = \frac{1.50 \times 10^3 kPa \times (2.24 \times 10^6 L}{8.31 \frac{L \times kPa}{K \times mol} \times 315K} = 1.28 \times 10^6 mol(CH_4)$$

Convert moles of methane to grams.

$$\text{molar mass } CH_4 = \left(4mol(H) \times \frac{1.0g(H)}{1mol(H)} \right) + \frac{12.0g(C)}{1mol(C)} = 16.0g(CH_4)/mol(CH_4)$$

A mole-mass conversion gives the number of grams of methane.

$$1.28 \times 10^6 mol(CH_4 \times \frac{16.0g(CH_4)}{1mol(CH_4)} = 20.5 \times 10^6 g(CH_4)$$

Convert this answer to $= 2.05 \times 10^7 g(CH_4)$ kilograms.

$$2.05 \times 10^7 g(CH_4) \times \frac{1kg}{1000g} = 2.05 \times 10^4 kg(CH_4)$$

EVALUATE ***Does the result make sense?***

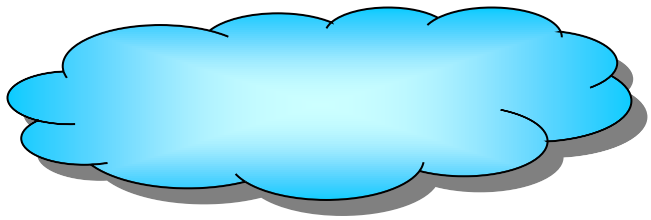
The volume and pressure of the methane are very large. It is reasonable that the cavern contains the large mass of methane gas found as the solution to the problem. Also, the units canceled correctly, and the answer is expressed to the proper number of significant figures.

Activity 1

1. Why is it important to know chemistry?
2. Name some of the kinds of professionals or workers who study and use chemistry.
3. What is the significant or use of Einstein's Law of Relativity?
4. Name at least three practical applications of nuclear chemistry (Radionuclides).
5. How does ATP help living organisms ?
6. Name some valuable uses of Nucleotides (DNA) sequences.
7. What are some of the special features of the carbon atom?
8. Discuss the significance and meaning of Boyle's Law.
9. Discuss the significance and meaning of Charle's Law.
10. Discuss the significance and meaning of Gay-Lussac's Law.
11. Discuss the significance and meaning of the Ideal Gas Law.
12. Why should you use Boyle's Law for problem 13?
13. The pressure on 2.50 L of anesthetic gas changes from 105 kPa to 40.5 kPa ; what will be the new volume if the temperature remains constant ? (6.48 L)
14. Why should you use Charle's Law for problem 15?
15. Exactly 5.00 L of air at -50.0 degrees Celsius is warmed up to 100 degrees Celsius; What is the new volume if the pressure remains constant? (8.36 L)

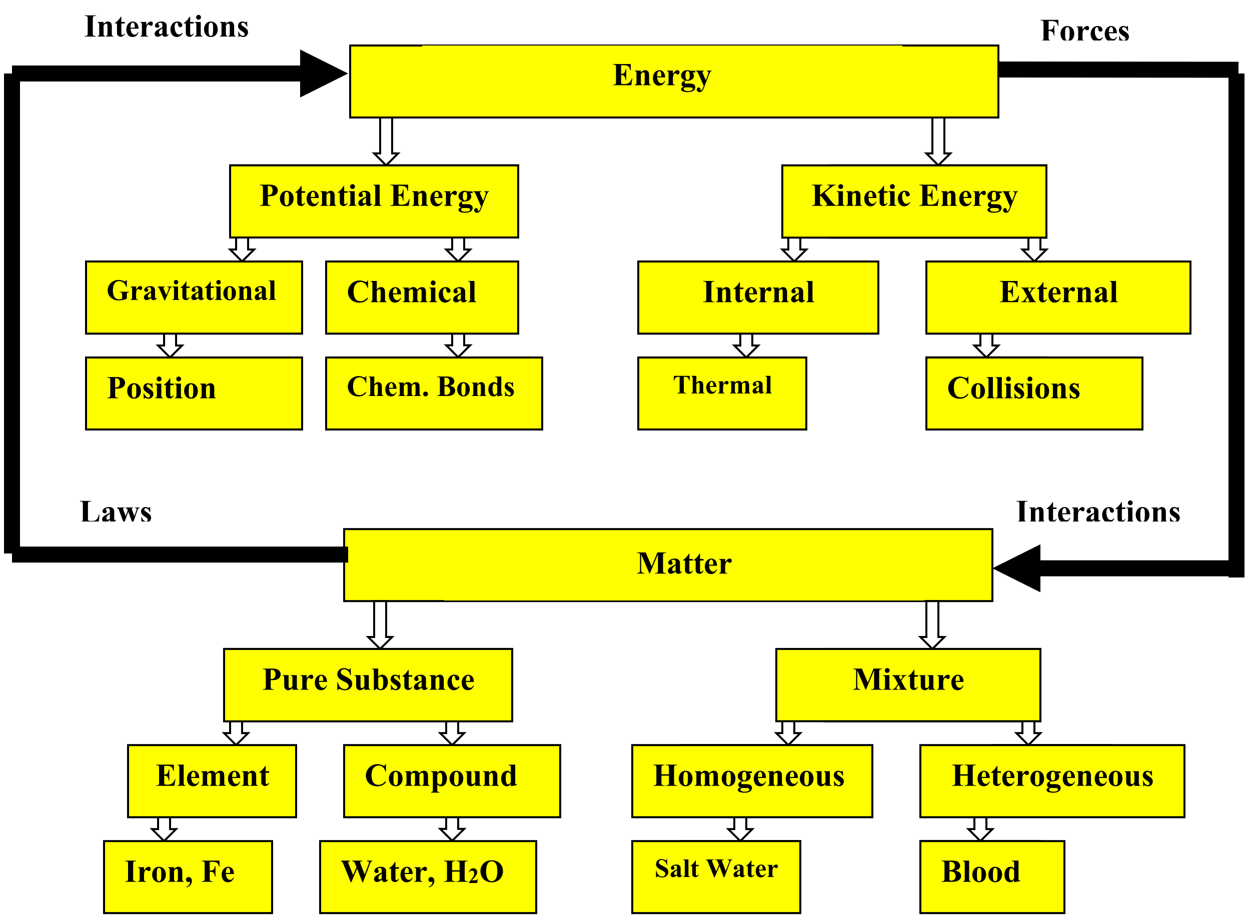
Theme III: Introduction to Physics:
The Study of Energy, Matter, and
The Laws Governing Their Interactions

Lesson 1: Energy and Energy Conservation



In that physics is the study of energy, matter, and the laws governing their interactions, the subject of physics recognizes that the interaction of all matter is associated with a web of forces that binds every entity in the Universe together. Thus both energy and forces play an important part in what interactions actually occur with matter.

The two diagrams below give an overview of energy and matter.



Energy and Energy Conservation

Our first lesson focuses on learning about energy and energy conservation.
We begin this lesson with some fundamental definitions related to energy.
Momentum is defined as the product of the mass of a moving object times its velocity;

$$\text{Momentum} = \text{mass} \times \text{velocity} = mv$$

Force is defined as mass times acceleration that is;

$$F = \text{mass} \times \text{acceleration}; \qquad F = \text{mass} \times \frac{\text{change in velocity}}{\text{time}} = m\frac{(v - v_o)}{t}$$

$$F = m\frac{(v - v_o)}{t} = \frac{mv - mv_o}{t} = \frac{\text{change in momentum}}{\text{time}}$$

Impulse is the product of force and time that is

$$\text{Impluse} = F \times t = mv - mv_o = \text{change in momentum}$$

Work is defined as force applied times distance that is $\text{Work} = F \times d$

Power is defined as the rate of doing work; $\text{Power} = \frac{\text{work}}{\text{time}} \qquad P = \frac{w}{t}$

The units for power were suggested by Thomas Savery (1650-1715), whose pumping engine was the first device to use steam power in industry. Since horses had been used to pump water in draining coal mines, Savery proposed as a standard of power the rate at which a horse could do work. James Watt (1736-1819) improved the steam engine, and in trying to sell his engines to mine owners was often asked, "If I buy one of your engines, how many horses will it replace?" To find out, Watt took Savery's suggestion and harnessed strong work horses to a load. He found that an average horse walking at the rate of $2\frac{1}{2}$ miles per hour would steadily exert a 150-pound force for several hours. The rate at which a horse performed work became the standard **horsepower** (hp). It has a value of 33,000 foot-pounds per minute, or 550 foot-pounds per second. In SI units, the unit of power is defined as that capable of performing work at a rate of 1 joule/second, or 1 watt:

$$1\frac{joule}{\sec ond} = 1 \text{ watt} \qquad \text{and 1 horsepower} = 746 \text{ watts.}$$

A larger unit of power, the kilowatt (kw), is useful in rating engines and motors; it is equal to 1000 watts. A still larger unit, the megawatt (Mw), 10^6 watts, is applied to the rating of power plants. Although they are basically mechanical units, the watt and kilowatt can be used to express any power unit, such as electric power.

Energy and Energy Conservation

Energy is often defined as the ability to do work. There are two basic forms of energy: potential energy and kinetic energy. For objects that have structure (interacting parts) it is convenient to recognize two different occurrences of both potential energy and kinetic energy: internal and external.

Potential energy (PE) is the energy possessed by an object by virtue of its position or condition.

Kinetic energy (KE) is the energy a moving object has by virtue of its motion: $\text{KE} = \frac{1}{2}mv^2$.

Units of Energy

The units of kinetic energy are determined by taking the product of the units for mass (kg) and velocity squared (m^2/s^2). Thus the units of KE are (not surprisingly) kg · m^2/s^2, or joules. **The unit of energy is the joule, whether it is kinetic energy or potential energy.** There is a very small unit of energy often used is the electron-volt (eV), which is equal to 1.602×10^{-19} J.

There are different types of potential energy.

Gravitational potential energy is potential energy that is related to moving objects in a gravitational field and is calculated as the product of the object's weight and its height above some defined zero-level. We often write gravitational potential energy (GPE) as

$$\text{GPE} = \text{Weight} \times \text{Height}$$

where weight is mass times the acceleration of gravity, or $\text{GPE} = mgh$

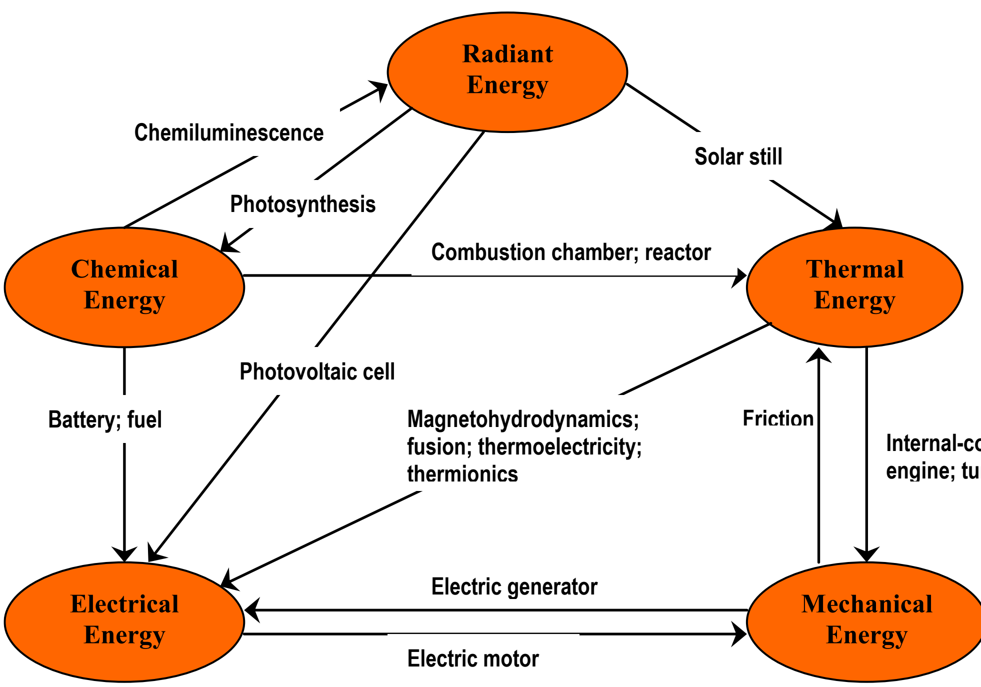
Notice that the unit of gravitational potential energy is Newton meter (N · m, that is joules), the same unit used to measure work. If we do work on an object (by lifting it above our head, for example), we give it an amount of potential energy equal to the work we did!

Chemical potential energy is the stored energy in chemical bonds. The gas tank in your car contains chemical potential energy, because when the gas is burned in the engine the engine can do work exerting a force to move your car through a certain distance.

From the formula for kinetic energy, $\text{KE} = \frac{1}{2}mv^2$ it should be apparent that the more mass an object has, and the faster it is moving the more kinetic energy it possesses. Thus, a slow-moving truck and a fast-moving bullet may have an equivalent amount of kinetic energy, although their masses are very different.

Energy and Energy Conservation

The potential energy of water at the top of a dam is converted to kinetic energy as it falls. The kinetic energy turns the turbine which generates electric energy.

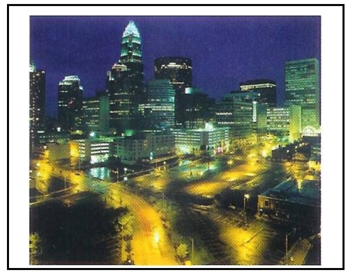


Some forms of energy and their conversion pathways.

Energy and Energy Conservation

In science, the word energy has a special meaning. **Energy** is the ability to do work. And work has a special meaning in science, too. It does not mean cleaning your house or cleaning the yards. Instead it means efforts and activities that move an object.

Energy can cause motion. Energy can also cause changes in matter.



Plants use the energy in sunlight to change carbon dioxide gas and water into a simple sugar for food.

People use electrical energy to start car engines, run the headlights and taillights, and light buildings and streets.

Forms of Energy

There are many different forms of energy. These forms are all around you.

A List of Some Forms of Energy

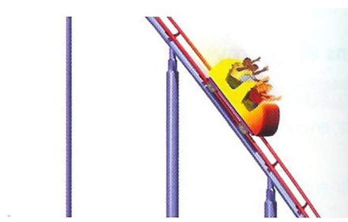
Form	Examples
Heat energy	Heat from an oven, a furnace, a toaster, or the sun Heat in your body
Light energy	Light from a light bulb, the stars, or a computer screen Lightning flashing in the sky
Sound energy	Sound from a loudspeaker, a radio, or a TV The sound of the wind, thunder, or someone's voice
Electrical energy	Electricity from a power plant, a car battery, or a dry cell in a flashlight
Chemical energy	Energy stored in the foods you eat Energy stored in fuels such as wood and gasoline
Nuclear energy	Energy used to generate electricity in a nuclear power plant Energy used to kill cancer cells
Mechanical energy	**Kinetic energy:** The energy of a bowling ball rolling down an alley **Potential energy:** The energy of a roller coaster car at the top of a hill
Thermal energy	The sum of the kinetic energy, rotational energy, and kinetic energy molecules. Heat is one of the special kinds of thermal energy

Energy and Energy Conservation

Notice that two forms of mechanical energy are listed in the table. **Kinetic energy** is the energy of motion. The faster an object moves and the greater its mass, the more kinetic energy it has. A bus going 70 kilometers per hour had more kinetic energy than a car going 70 kilometer per hour.

Potential energy is stored energy. The higher above ground an object is and the greater its mass, the more potential energy it has. A large rock at the top of a hill has more potential energy than a small rock halfway down the hill.

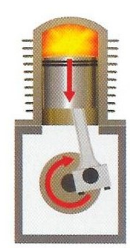
Energy can change from one form to another. Here are just a few examples.



A roller coaster car at the top of a hill has potential energy.

As the car moves downhill, potential energy changes to kinetic energy.

A hydroelectric power plant changes the kinetic energy of moving water into electrical energy.	A light bulb changes electrical energy to light energy and heat energy.



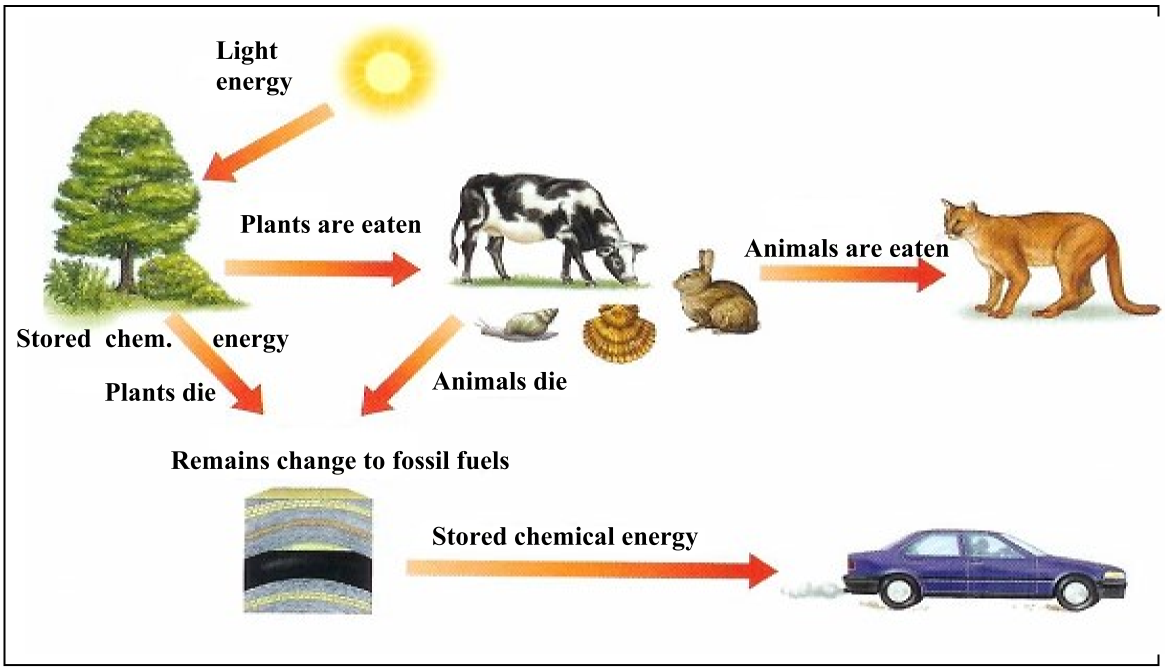
When wood burns, chemical energy stored in the wood changes to heat energy and light energy.	When gasoline burns in a car's engine, engine parts move. Chemical energy changes to kinetic energy

Remarks: Energy cannot be created or destroyed. The same amount of energy exists before and after it changes form.

Energy and Energy Conservation

Energy From the Sun

Most of the energy on Earth comes from the sun. The sun's energy heats Earth's surface, and the surface heats the air above it. The sun's energy also heats water on Earth's surface and makes it evaporate. When water vapor cools, it forms clouds. Clouds produce rain, snow, sleet, and hail. In these ways, the sun's energy creates Earth's weather, winds, storms, and climate.



Plants use the energy in sunlight to make food. In the process, the sun's light energy is changed to chemical energy. Some of the chemical energy is stored in the plant. Animals that eat plants take in this chemical energy. And animals that eat plant-eating animals take in chemical energy, too. Humans and other animals use this energy to stay alive.

The chemical energy in fuels also comes from the sun's energy. It is the stored chemical energy in the decayed bodies of ancient plants and animals. The organisms died and decayed. Over millions of years, their bodies were changed into oil, coal, and natural gas. Today we burn these fuels to release the chemical energy that is stored in them.

Energy and Energy Conservation

Exploration A

A truck and a bullet are heading toward you. The truck is a 5000-kg truck, moving at 50 km/h, the bullet is a 100-g bullet, moving at 500 m/s. which object has more momentum? Which one has more kinetic energy?

Answer:

Momentum is mass times velocity, so to compare mangos with mangos, let's convert all the masses to kilograms and all the velocities to meters per second. First, let's calculate the **momenta**:

Truck: p = mv
= (5000 kg)(50 km/h)(1 h/3600 s)(1000 m/1 km) = 70,000 kg·m/s

Bullet: p = mv
= (100 g)(1 kg/1000 g)(500 m/s) = 50 kg·m/s

Kinetic energy:

Truck: KE $= \frac{1}{2}mv^2$

$= \frac{1}{2}$(5000 kg)[(50 km/h)(1 h/3600 s)(1000 m/1 km)]^2

= 480,000 kg m^2/s^2, or 4.8×10^5

Bullet: KE $= \frac{1}{2}mv^2$

$= \frac{1}{2}$(0.1 kg)(500 m/s)2 = 13,000 kg m^2/s^2, or 1.3×10^4

Thus although the truck has over 1000 times more momentum than the bullet, it has only about 50 times more kinetic energy.

Energy and Energy Conservation

Exploration B

An 80-kilogram man runs up a flight of stairs 5 meters high in 10 seconds. What is the man's power output in watts and in horsepower?

Solution

Since work = force × distance, the man's weight (force) must be considered. We can determine his weight, w, from the product of his mass and the acceleration due to gravity. Knowing the time, we can also determine his power and express it in appropriate units.

m = 80 kg s = 5 m $g = 9.8\ \frac{m}{\sec^2}$ t = 10 sec F = w = mg

$$P = \frac{W}{t} = \frac{F \cdot s}{t} = \frac{(mg)s}{t} = \frac{(80kg)\left(9.8\frac{m}{\sec^2}\right)(5m)}{10\sec}$$

$$= 392\frac{newton - meters}{\sec} = 392\frac{joules}{\sec} = \boxed{392 \text{ watts}} \times \frac{1hp}{746watts} = \boxed{0.525 \text{ hp}}$$

Conservation of Energy

The result of understanding energy transformations is one of the most powerful generalization in physical science, the **law of conservation of energy:**

> The total energy content of a closed system is constant. Energy is never created or destroyed. Energy may be transformed from one kind into another, but its total amount remains the same.

If we ignore small effects like friction and air resistance, we can say that the total energy of a system, represented by the sum of its kinetic and potential energy, is conserved. Mathematically, we can express the law of conservation of energy as

Total Energy = Kinetic Energy + Potential Energy or TE = KE + PE

Imagine you are holding two glasses, one full of water and one empty. Label the full glass KE and the other glass PE. Now, pour half of the water from the glass labeled KE to the glass labeled PE. The total amount of water that you have in the two glasses remains constant, although the amount in each glass may change as you pour water back and forth. One can see that one may have more potential energy or more kinetic energy at any instant, but the total (in an ideal world) does not change.

What really happens as one pours the water back and forth? Does a little water spill? If one were to pour the water back and forth many times, the total amount of water would decline slightly. That is really like how a real system works. Moreover, over time, some energy is "lost" to processes like friction and air resistance. However, this amount is neglible on the large scale of things.

Energy and Energy Conservation

Activity I

1. A boy pulls a wagon. Assume that the horizontal component of the force he applies is 15 Newtons, how much work does he do while pulling the wagon 300 meters? (Answer: 4500 N-m or joules)

2. A pump lifts 30 kg of water a vertical distance of 20 m each second. How much power is extended? (Answer: 5.9×10^3 watts)

3. A girl on a bicycle reaches the bottom of the hill going 20 $\frac{m}{\text{sec}}$. If her total mass, including the bicycle, is 60 kilograms, what kinetic energy was exerted? (Answer: 12,000 Newton-meters, joules)

4. Which has more potential energy, a 500-kg iron anchor suspended 10 m in the air, or a 3-kg bowling ball suspended at 200 m. How much work was required to get each object from the ground to their higher potential energy positions? (Answer: _________________)

5. In the course of a 30-min workout session you lift a total of 10,000 kg, an average of 50 cm. How much work did you do? How much power was required for your workout? (Answer: ___________________)

6. A student is pushing a box of her belongings across a wooden floor. A constant force of 200 N is required, and she pushes the box over a distance of 10 m. How much work does the student do? (Answer: _________________)

7. a boy stands on a 50-m-high bridge with his model airplane. The airplane has a real parachute. The boy drops airplane from the bridge, but tragically the chute fails to deploy. Foul play? If the airplane has a mass of 100 g and it never reaches terminal velocity, how fast will the airplane be traveling when it strikes the river? (Answer: _______________)

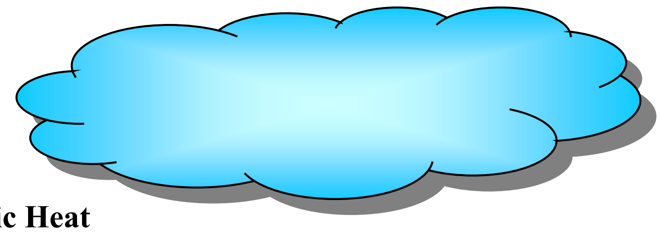
8. Explain how the energy in fossil fuel is related to energy from the sun.

9. Explain how some of the energy transformations in the chart in this lesson might occur.

10. Share with your classmates examples of both kinetic and potential energy that can be observed in your community.

Theme III: Introduction to Physics: The Study of Energy, Matter, and The Laws Governing Their Interactions

Lesson 2: Heat – A Form of Energy



Heat and Specific Heat

Heat is thermal energy that can be transferred between two objects that are at different temperatures. Heat naturally flows from an object at higher temperature to an object at a lower temperature. The amount of thermal energy that an object contains depends on two quantities, its temperature and the amount of material it contains, that is, its mass. A tiny speck of metal may have less thermal energy than a bucket of hot water. And the speck of metal, as a result, will cool off much more quickly.

The common unit used for heat is the calorie. A **calorie** is defined as the amount of heat required to change the temperature of 1 g of water by $1^{\circ}C$. A **kilocalorie** (C) is 1000 calories, and the ratings of calories in foods are actually in kilocalories. Calories are units of energy, the energy content of food could just as easily be measured in joules (J).

Other substances generally require less heat than does water to change their temperature by $1^{\circ}C$. Scientists know this from experimenting. It takes a bowl of soup – made mostly of water – a lot longer to cool off (come into equilibrium temperature with its surroundings) than it does a piece of toast. We say that soup (water) has a higher specific heat than toast.

The **specific heat** of a substance is the amount of heat required to raise the temperature of 1 g of the substance by $1^{\circ}C$. Water absorbs more heat than most other substances before its temperature increases by 1° and, as a result, can burn your tongue for a while after it has been heated! This property of water serves to moderate temperature changes in regions near a large body of water such as a lake or an ocean. Conversely, desert environments experience more extreme temperature changes, due to the lack of water vapors being available to help influence the temperature.

The amount of heat required to raise the temperature of a substance can be calculated if you know the specific heat of the substance. In general, the amount of heat required to change the temperature of a substance is proportional to the mass of the substance and the change in temperature, according to the following relation:

Heat – A Form of Energy

$$Q = mc\Delta T$$

where Q is the heat required (in joules or calories), m is the mass of the substance, c is the specific heat of the substance, and ΔT is the change in temperature. The table below gives the specific heats for a variety of substances at 20°C and 1 atm pressure.

Specific Heats of Various Substances

Substance	**Specific Heat (J/kg·°C)**
Air	1050
ethyl alcohol	2430
Aluminum	920
Glass	840
Soil	1050
Wood	1680
Water	4186

Heating a substance involves increasing the average energy of its molecules; cooling a substance removes this energy. Because increasing the average internal energy of molecules increases their average separation, substances generally expand when they are heated and contract when they are cooled, but they do so at different rates.

Solid objects increase in length by a certain fraction for each rise in temperature. This fraction, which can be converted to either degrees Fahrenheit or degrees Celsius, is called the **coefficient of linear expansion**.

The change in length of a given material is given by the formula

$$\Delta L/L = \alpha \, \Delta T$$

where ΔL is the change in length, L is the original length, α is the coefficient of linear expansion, and ΔT is the change in temperature. The coefficients for a small number of substances are given in the table below.

Coefficients of Linear Expansion for Selected Materials

Material	**Coefficient (1/°C)**
aluminum	0.000024
Brass	0.000019
Iron	0.000012
ordinary glass	0.000009
Pyrex™ glass	0.0000033
Steel	0.000012

Heat – A Form of Energy

Because the change in length is proportional to the original length, changes observed for small lengths of a material are rather small, but over long distances, the size of a bridge for example, the changes in length can be significant. For example, a 1-m length of steel whose temperature rises from the freezing point of water (0ºC) to 40ºC will expand by

$$\Delta L = L\ \alpha\ \Delta T$$
$$\Delta L = 1\text{ m} \times (0.000012\ 1/^{\circ}\text{C} \times 40^{\circ}\text{C}) = 4.8 \times 10^{-4}\text{m, or } 0.048\text{ cm}$$

which is a very small change in length–less than 1 mm. The change in length of a 1000-ft steel bridge, however, will be a significant factor in its design.

Exploration A

Suppose you were designing a 1000-ft-long steel bridge. How much expansion would you need to allow for between a winter temperature of -10ºC and a summer temperature of + 40ºC?

The temperature change (ΔT) you must consider is 50ºC. Using an expansion coefficient for steel of 0.000012/ºC, the total expansion (and contraction) would be 0.000012 × 50 × 1000 ft, and you find that your bridge will expand and contract between the extremes of temperature by a total of 0.17 m. Clearly, expansions at this level must be engineered into the design in what are called expansion joints.

Most liquids expand and contract with temperature the same way that solids do, but water is an exception. Between the freezing point and about +4ºC, water contracts very slightly. At temperatures higher that +4ºC, water again expands like a normal liquid. This property of water, together with the fact that it freezes at a moderate temperature, makes water vital to life.

THE LAWS OF THERMODYNAMICS AND IDEAL GASES

Thermodynamics

Thermodynamics is the study of the relationship between heat and mechanical energy. Thermodynamics is a science founded on energy conservation principles. There are two fundamental laws of thermodynamics, based on empirical observations of physical systems.

The **first law of thermodynamics** states that adding heat to a system or doing work on it results in an increase in the internal energy of a system; conversely, if the system does work or if heat is removed from it, its internal energy decreases. The basic idea here is that energy must be conserved when heat (energy) is added to or removed from a system. From one perspective, the **first law of thermodynamics** is another way to state the law of conservation of energy: energy is never created or destroyed; it is just transformed..

Heat – A Form of Energy

The **second law of thermodynamics** states that heat flows spontaneously from a hot object to a cold object. It is a statement about the natural direction in which heat (energy) flows. The second law of thermodynamics is also sometimes called the **law of entropy**, since in general, natural systems proceed to states of greater disorder. **Entropy** is a measure of the amount of disorder in a system – flowers whither, dishes break, mountains erode – and the entropy of a system increases with time.

Ideal Gases and Gas Laws

An **ideal gas** is a gas in which the molecules or atoms can be thought of as individual, point-like particles that do not exert intermolecular forces on one another. Of course, no gases are truly ideal, but air in our atmosphere and many gases under normal conditions behave like ideal gases – that is, they expand when heated and contract when cooled, much like solids and liquids do.

For an ideal gas at constant temperature the ratio of volume to its Kelvin temperature remains a constant. This law can be stated as follows:

$$V/T = \text{constant, or } V_1/T_1 = V_2/T_2$$

This law is sometimes referred to as **Charles's law** (after Jacques Charles, 1746-1823). Also, for an ideal gas at constant temperature, the product of pressure and volume is a constant, or

$$PV = \text{constant} \qquad \text{or} \qquad P_1V_1 = P_2V_2$$

which is referred to as **Boyle's law** (after Robert Boyle, 1627-1691). The two laws can be combined into what is referred to as the ideal-gas law, or

$$P_1V_1/T_1 = P_2V_2/T_2$$

The **Ideal-gas law** is also sometimes written as

$$PV = nRT$$

where the pressure (P) and volume (V) of an ideal gas are related to its Kelvin temperature (T), the number of moles of the gas (n) and a constant called the universal gas constant R, (where R = 8.3145 J/mol·K).

Note: A **mole** is the number of particles (atoms or molecules) contained in a sample of element or compound with a mass in grams equal to the atomic or molecular weight. This mass contains what is called Avogadro's number (6.0221367×10^{23}) of atoms or molecules. For example, a mole of carbon atoms has a mass of 12 g and contains 6.022×10^{23} carbon atoms.

Heat – A Form of Energy

Exploration B

A helium balloon has a volume of 0.1 m^3 and a temperature of 27ºC. If the temperature of the balloon rises to 42ºC when it is left in a car with the windows rolled up, what will be its new volume?

Using Charles's law (and converting temperatures from degrees Celsius to Kelvin), we say that

$$V_1/T_1 = V_2/T_2 = (0.1\ m^3)/300\ K = V_2/(315\ K) \text{ or } V_2 = 0.105\ m^3$$

This is an increase in volume of 5 percent and, depending on the strength of the balloon material, it could cause it to pop!

Similar to our knowledge of the buoyancy of objects in water, objects can also be buoyant in air. An object "submerged" in Earth's atmosphere will feel more pressure on its bottom side than on its top side (for the same reasons as described for an object submersed in a liquid), resulting in a net upward force. If the weight of a container (say a hot air balloon) and its contents (hot gas) are less than the weight of the air displaced, then the balloon will float.

Observation: Unfortunately, a high-velocity wind blowing over the roof of an airtight house can make the roof go airborne if the wind velocity is sufficiently high.

Heat Transfer

Heat can be transferred between substances in a number of ways, including by conduction, convection, and radiation.

Conduction

We previously stated that heat is simply a transfer of thermal energy between two objects, energy associated with the random motion of molecules.

When two objects are put in contact, the faster-moving molecules of the warmer object collide with the slower-moving molecules of the colder object, transferring some of its energy to the molecules in the cooler object. The warmer object loses energy (decreases in temperature) while the cooler one gains energy (rises in temperature) until the two objects or substances are at the same temperature. This type of heat transfer, in which collisions between molecules transfer heat, is called **conduction**. All materials conduct heat at different rates, and metals are some of the best conductors. Stone is a moderately good conductor, and wood, paper, cloth, and air are relatively poor conductors.

Heat – A Form of Energy

Materials that conduct heat poorly are called **insulators**. Air, for example, makes an excellent insulation material when it is trapped between spaces. Wool clothes, synthetic foams, and materials filled with loose fibers, feathers, or other material (like a comforter) insulate by means of the air trapped within them.

Convection

Because of their relatively low density and smaller number of molecular and atomic collisions, most liquids and all gases are poor conductors; however, gases and liquids can transfer heat in another way: through convection. **Convection** is the movement or circulation of a heated liquid or gas.

Consider this example: Directly above a fire, the air is warmed, causing it to expand and become less dense than the surrounding air. The air above the fire rises.

Convection cycles occur in Earth's atmosphere giving rise to winds, and also in earth's oceans, giving rise to currents.

Thermal Radiation

If you were sitting next to the fire in the preceding convection example, you would feel the warmth of the fire. Yet, that heat is not reaching you by convection – we know that the hot air is in fact going straight up and being replaced by cooler air from the sides.

Also, the heat conductivity of air (a gas) is very low. So how do you feel the warmth of the fire? Energy is leaving the fire through the process of radiation and is being absorbed by your body. **Radiation** is simply the transfer of energy from one point in space to another through the oscillation of electromagnetic fields. The motion (jiggling) of the electrons in the object that is emitting radiation generates electromagnetic waves. These waves are transmitted through empty space, and when they strike you body, the electrons in your body absorb the radiation; the atoms in your body start to move around at a greater velocity, and your warm up.

In this way, electromagnetic waves can carry energy between two points that are not connected physically. So, unlike conduction and convection, radiation does not require direct contact between two substances in order to transfer heat.

Observation: Almost all the energy available to us on Earth (aside from geothermal energy) comes to us directly or indirectly from the Sun. The Sun is an extremely hot object – its surface temperature is around 6000 K. Radiation from the Sun provides heat for the Earth's surface, bodies of water, and for plants and animals. When we burn coal or petroleum, we are just releasing potential chemical energy from the Sun that was stored in plants and animals millions of years ago.

Heat – A Form of Energy

Even a hydroelectric power plant in which falling water turns the turbines that generate electricity derives its energy from the cycle of evaporation and condensation maintained by the Sun: water is lifted from lakes and oceans and condensed into rain that feed streams and waterfalls.

All objects – buildings, trees, and your body – radiate heat into their surroundings. The air in a crowded theater can become warm because each person in it is radiating heat equal to that given out by a 75-W light bulb. Night-vision goggles, which are sensitive to infrared radiation, allows one to see the heat radiation given off by people around them.

Activity I

1. Why is hot water a good choice for filling a bottle to keep your bed warm at night? Why would it not be a good choice to put that hot water in an insulated thermos bottle if you wanted to feel the warmth?

2. Which requires more energy, raising the temperature of a 1-kg block of aluminum by 20°C, or raising the temperature of 500 g of water by 5°C?

3. How much energy is required to melt a 1-kg block of ice?

4. The steel panel of a car door is 1.00 m long. Assuming that it expands in ______, what is a safe separation between the door panel and the body of the car that will allow the panel to expand?

5. How does one explain the ordered nature of living things if the second law of thermodynamics is correct?

6. What are conductors of heat; give some examples.

7. What are insulators of heat; give some examples

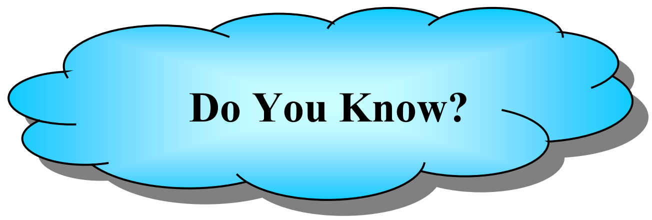
8. Why is the sun and why water so vital to life on earth?

9. What are the three standard ways that heat is transferred; define and discuss each individually?

10. Describe how radiation is distinctly different from the other two ways of transferring heat and give several examples of radiation heat transfer.

Theme III: Introduction to Physics:
The Study of Energy, Matter, and
The Laws Governing Their Interactions

Lesson 3: Work and Simple Machines



In science, the word *work* has a special meaning. **Work** happens when a force moves an object through a distance. The greater the force and the greater the distance the object moves, the more work that is done.

Work equals force times distance.

W = F x d

A **simple machine** is a tool that makes work easier. Most simple machines permit one to use less force to move an object. But when you use less force, you have to apply it for a longer distance. Some simple machines let you move an object a longer distance. This requires one to apply more force, but for a shorter distance.

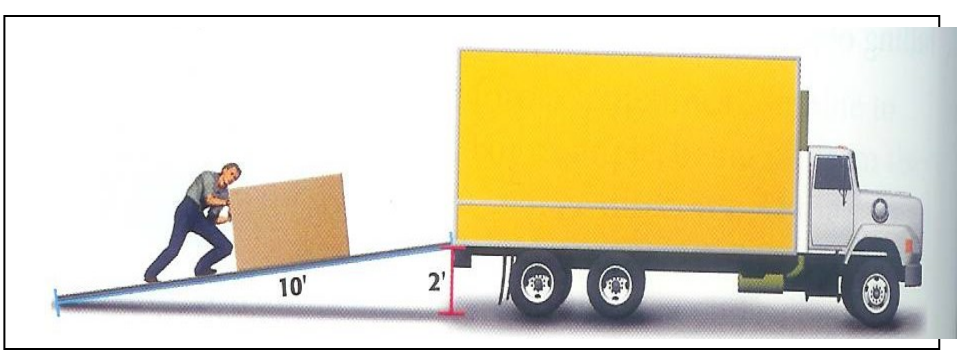
With any kind of simple machine, the amount of work you do does not change. What changes is the amount of force you apply and the distance you apply it.

There are six kinds of simple machines. They are an inclined plane, a wedge, a screw, a lever, a wheel and axle, and a pulley.

Inclined Plane

An **inclined plane** is a flat surface that slopes. Pushing a heavy box up an inclined plane takes less force than lifting the box straight up. But you have to push the box for a longer distance.

You apply less force, but you have to apply it for a longer distance.



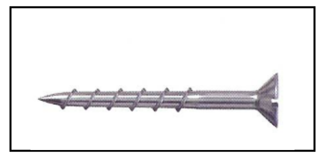
Work and Simple Machines

Wedge

A **wedge** is an object (usually a metal) such as an ax, a knife, or scissors used to split, separate, cut, etc. other materials into smaller pieces. A wedge reduces the amount of force that is needed to split apart an object. But you have to apply the force for a longer distance.

You apply force for a long distance. The wedge moves the object's pieces a short distance.

Screw



A **screw** is a device with grooved ridges wrapped around a small rod (usually) metal. When one turns the screw, the ridges pull the board up to the screw. One uses less force to turn a screw than to hammer a nail of the same size into a board. But one has to turn the screw more times than you would have to hammer a nail. One has to move the screw for the entire length of the rod that it is wrapped around.

Lever

A **lever** is a long bar or board that turns around a support that does not move. The support is called the **fulcrum**. There are three kinds of levers.

The fulcrum is between the object you are moving and the force you are applying.

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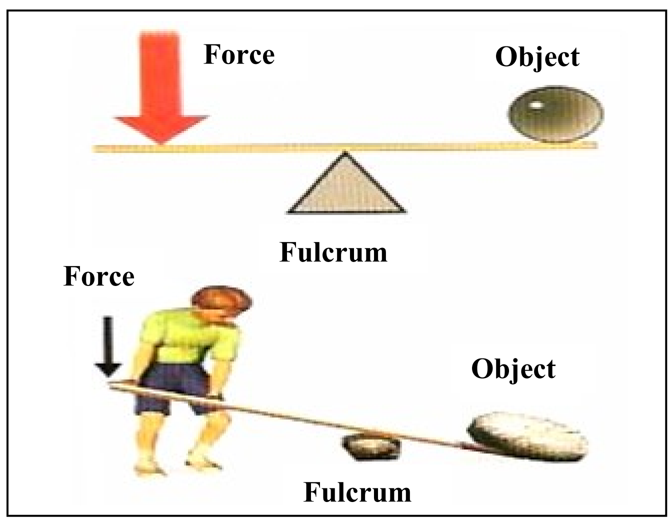
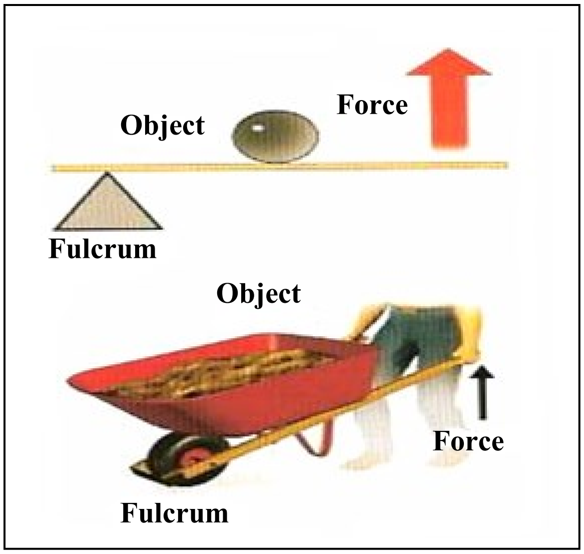
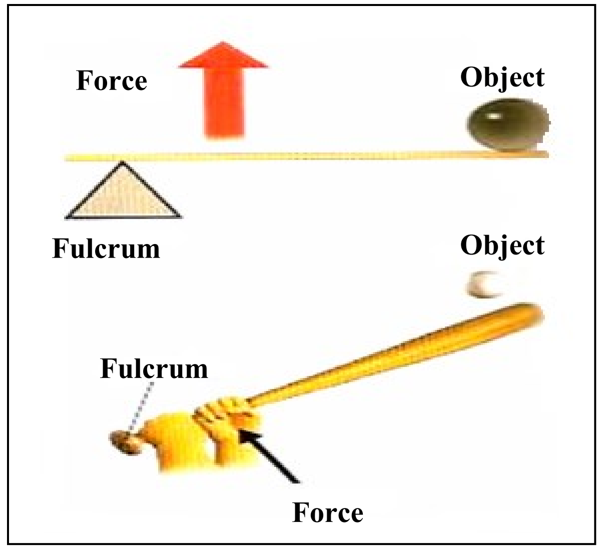


Work and Simple Machines



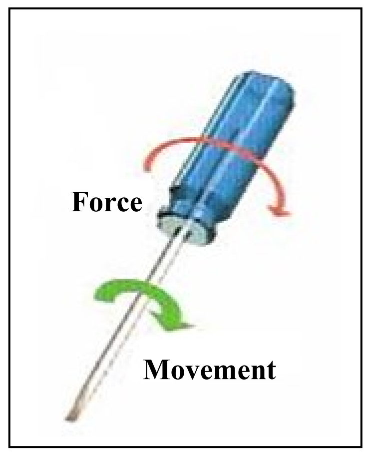


The object you are moving is between the fulcrum and the force you are applying.

You apply force between the fulcrum and the object you are moving.

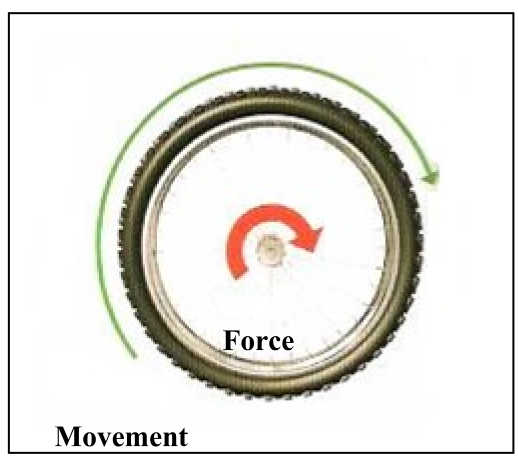
Wheel and Axle

A **wheel and axle** is a wheel that turns around a rod, called the axle. The axle goes through the center of the wheel. A wheel and axle reduces the force you have to apply or reduces the distance you apply the force.



When you turn the handle of a screwdriver, you apply force to the wheel part of a wheel and axle. A small force on the handle is magnified into a force on the axle.

When you pedal a bicycle, you apply force to the axle. That is where the chain is attached. Every turn of the axle makes the tire turn a greater distance.

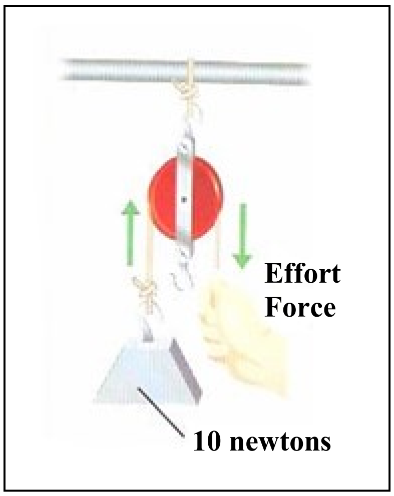


Work and Simple Machines

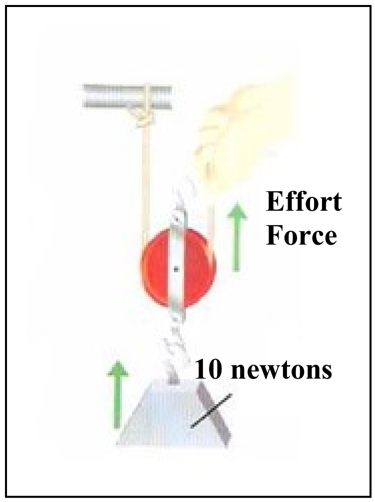
Pulley

A **pulley** is a wheel with a rope or chain wrapped around it. Pulleys are used to lift heavy objects. For example, auto mechanics use pulleys to lift an engine out of a car. A pulley reduces the force that is needed to lift the object or it changes the direction of the force. There are three kinds of pulleys.

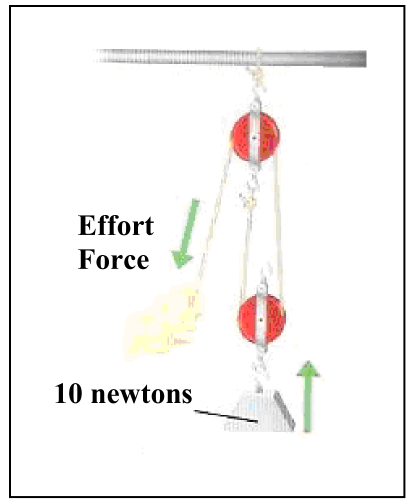
Fixed Pulley



Movable Pulley



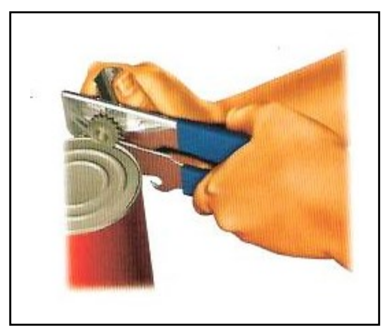
Fixed and Movable Pulley



Force is measured in units called Newtons.

Compound Machines

A **compound machine** is made of two or more simple machines. A hand operated can opener is a compound machine. Its two handles are levers. Its cutting part is a wedge. And one turns a wheel and axle to move the cutting part around the top of the can.

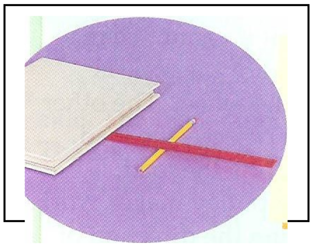


Work and Simple Machines

Activity 1

Make A Lever

Hypothesize What happens to the direction of the force when you use a lever? Write a hypothesis in your Science Journal.



MATERIALS
- Book
- Ruler
- Pencil
- *Science* Journal

PROCEDURES

1. Make a Model Place about an inch of the ruler under the edge of the book. Place the pencil under the ruler close the book.
2. Push down on the other end of the ruler. Record what happened in your *Science* Journal.
3. Place a much of the ruler under the book as fits. Remove the pencil.
4. Lift up on the end of the ruler sticking out from under the book. Record what happens.

Conclude and Apply
1. When you pushed down in step 2, which way did the lever push?
2. DRAW CONCLUSIONS Can a lever change the direction of the force? Explain.
3. DRAW CONCLUSIONS What kind of lever did you make? Explain.

Activity 2

1. Name and describe each of the simple machines presented in this lesson.
2. Name and identify at least three (3) compounded machines
3. Identify the use of several simple machines in your community.
4. Bring at least one simple machine to class and illustrate its use.
5. Make at least one simple machine and illustrate it in class.

Theme III: Introduction to Physics: The Study of Energy, Matter, and The Laws Governing Their Interactions

Lesson 4: Forces, Motion and Planetary Motion

Do You Know?

What is Force?

In the simplest sense, a **force** is a push or a pull exerted on an object. When you go to the gym and lift weights, you are exerting force. When you run across the parking lot in the rain to your car, your legs are pushing on the ground, and the ground returns the favor by pushing you forward. **Velocity** is a quantity that we represent with a vector, because it has both magnitude (length or size) and direction. A downward force is fundamentally different from an upward force. An upward force can accelerate you into space!

When you kick a soccer ball, you are applying a force to the ball. When you pull a wagon up a rocky hill, you are applying a force to the wagon. A **force** is a push or pull. When you kick a soccer ball, you give it a push. When you carry a container of water up a hill, you give a lift or pull to the container of water. In these examples, the objects move when you apply the force. A force can make an object start moving, change speed, or change direction. Here are some more examples.

When you start to run, you apply a force to the ground. Your feet push backward on the ground. This makes you move. When you catch a ball, you stop the ball's downward motion. You do this by applying a force to the ball. The force is the upward push of your hand. When you kick a soccer ball, you change the direction that the ball is moving. The force you apply to the ball makes it move away from you instead of continuing toward you. When you pedal a bicycle, you can change its speed by pedaling faster or by braking. You do this by applying force to the pedals or the brakes.

The unit of force in the metric system is the Newton (N). **One Newton** is about the force you would need to lift a smaller fish.

Forces, Motion and Planetary Motion

Common Forces

Every minute of the day, forces act on you and on all the objects around you. Four main forces are gravity, buoyant force, magnetic force, and friction.

Gravity

All objects attract each other. The sun and Earth attract each other. The moon and Earth attract each other. You and Earth attract each other. The force that attracts objects to each other is **gravity**. Gravity keeps the Earth and the other planets in orbit around the sun. It keeps the moon in orbit around Earth. On Earth, it makes objects fall to the ground.

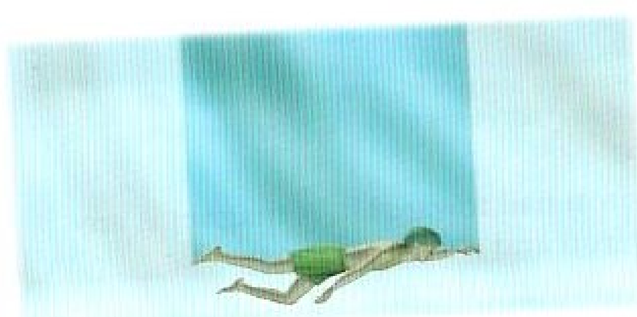
Factors That Affect the Force of Gravity The force of gravity between two objects depends on two things. They are the mass of the objects and the distance between them. Objects that have greater mass produce a greater force of gravity. Objects that are closer together produce a greater force of gravity.

Mass and Weight Different planets in the solar system have different masses. Because of this, the force of gravity that the planets put on other objects is different. That makes the weight of an object different on different planets. **Weight** is a measure of the pull of gravity on an object. **Mass** is the amount of matter in an object. An object's mass is the same wherever it is. But its weight can change.

For example, suppose your mass is 30 kilograms. On Earth you would weigh about 60 kilograms. The force of gravity on the moon is about one-sixth the force of gravity on Earth. So if you were on the moon, you would weigh only 10 kilograms. But your mass would still be 30 kilograms.

Atmospheric Pressure Air has mass. The pull of Earth's gravity on air gives air weight. That weight is greatest on Earth's surface. High on a mountain, the weight of air is less because there is less air pushing down from above.

Water Pressure Earth's gravity pulls on water, too. This produces water pressure on any objects that are in the water. Water pressure is greater at the bottom of a river. That is because there is more water pushing down from above.



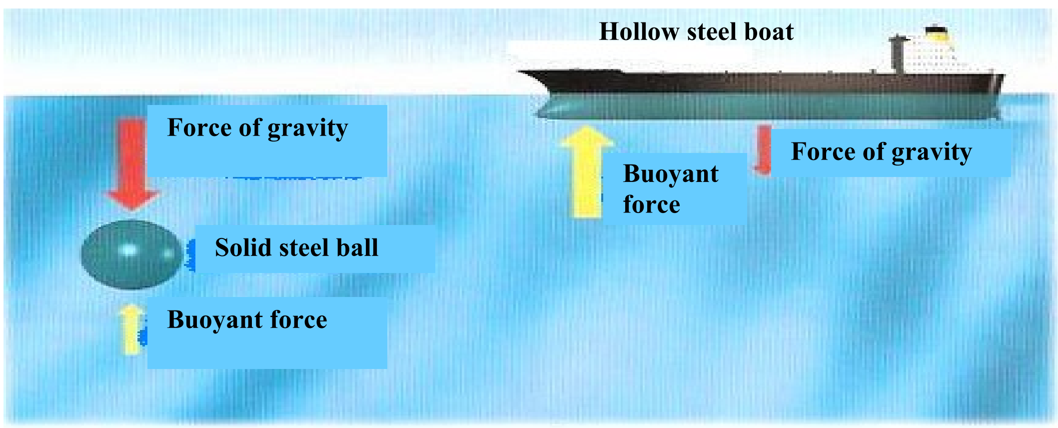
Forces, Motion and Planetary Motion

Buoyant Force

If you drop a steel ball into water, it sinks. But if you mold the same amount of steel into the shape of a small boat, the boat floats. A steel boat floats because of buoyant force. **Buoyant force** is the upward push of a liquid or gas on an object.

The upward push of the buoyant force works against the downward pull of gravity. As long as the upward push of the buoyant force is greater than the downward pull of gravity, an object will float.

The weight of a steel ball is greater than the buoyant force of water. So the ball sinks. If you mold the steel into the shape of a boat, the shape holds air. Now the weight of the steel and the air inside it is less than the buoyant force of the water. The boat floats.

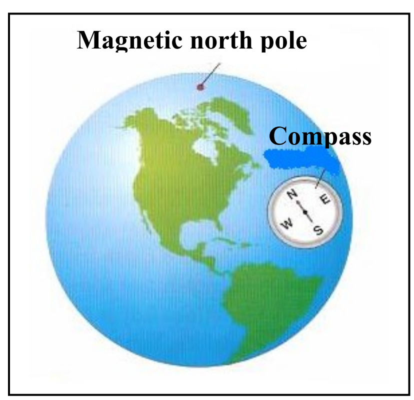


Magnetic Force

A magnet pulls an iron nail towards it. A **magnet** is any object that attracts iron and a few other magnetic materials. A magnet changes the motion of the nail. The magnet pulls the nail toward it. **Magnetism** is a force. The force of magnetism works at a distance. For example, a magnet attracts a nail that is some distance from the magnet. When the distance between the objects increases, the force of magnetism decreases. The area around a magnet where the force of magnetism can be felt is called a **magnetic field**.

No matter what its shape, every magnet has a north pole and a south pole. Opposite poles attract, or pull on, each other. Like poles repel, or push against, each other. Magnetism is strongest near the magnet's poles.

Earth as a Magnet Earth acts as if it has a bar magnet pushed through its center from north to south. One end of this imaginary magnet is called the north magnetic pole. The other end is called the south magnetic pole. A compass needle lines up with Earth's magnetic poles.



Forces, Motion and Planetary Motion

Earth has two north poles and two south poles. The magnetic north and south poles are points where Earth's magnetism is strongest. The geographic North and South Poles are points at the ends of Earth's axis. The magnetic poles and the geographic poles are not in exactly the same places.

Friction

Imagine that you are riding your bicycle. Suddenly a goat jumps in front of you. You apply the brakes. The bike's wheels stop turning. The tires rub against the ground, and you stop. One object rubbing against another object produces a force called friction. **Friction** is a force that works against motion.

The amount of friction depends on two things. One is the surfaces that are rubbing against each other. Rough surfaces produce more friction than smooth surfaces. For example, a rubber tire sliding on cement produces a lot of friction. But suppose you tried to stop you bike on an icy surface. You would travel much farther before stopping.

The second thing is the amount of force pushing the surfaces together. The greater this force, the greater the friction. The tires of a heavy car produce more friction with the ground than the tires of your bicycle do.

A meteor is a streak of light produced when a space rock plunges through Earth's atmosphere. The rock rubs against molecules of air. This produces friction. The friction produces heat that burns up the rock.

The Restless Universe - Motion

The universe is filled with things in motion, from majestic galaxies, stars, and planets, to atoms. The motions may be fast or slow, smooth or erratic, simple or complex. A change of position is called **motion**. The words that describe motion suggest an awareness of its variety: soaring, flying, leaping, running, galloping, etc. Challenged by the limitations imposed upon us by nature, humans invent things to move faster, farther, higher, and deeper.

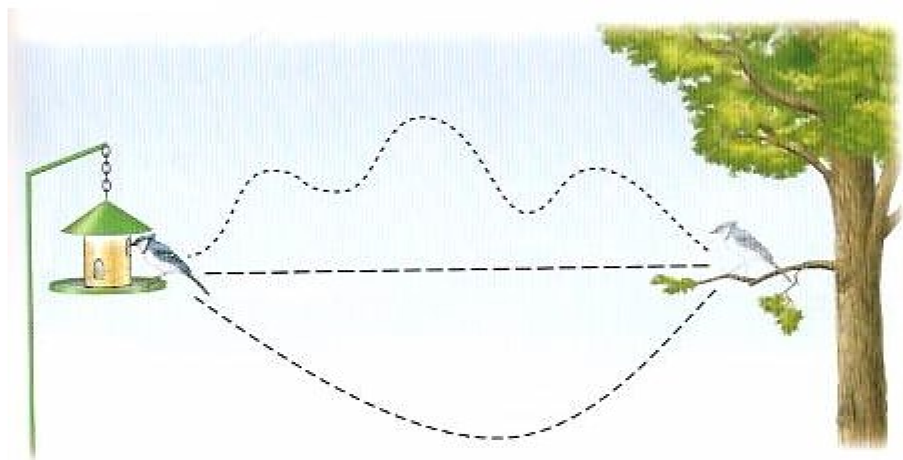
Point of View

You see the movement of an object from your point of view, or your position. If you are standing on the corner of a busy street, you see cars move past you. But if you are riding in one of the cars, you see the buildings, the sidewalk, and people on the sidewalk move past you.

Even when one is standing still, one is moving. That is because Earth turns on its axis. As Earth turns, its surface carries everything along with it. You are really traveling hundreds of kilometers per hour!

Forces, Motion and Planetary Motion

Some motions are simple. An athlete races down a track, going from start to finish in the shortest possible time. He or she is undergoing motion in a straight line (linear motion), the simplest kind of motion. A record-player turntable undergoes circular motion, repeating the same path in a cycle over and over. This motion is also simple.



It is possible that the bird has taken different paths to go from the tree to the “feeder” for food. The lines indicate some of the paths it might have taken. Two are not simple.

Kinematic: Position, Speed, Velocity, and Acceleration

The key concepts of **kinematic** – the scientific description of motion, without regard to its cause – are position, speed, velocity, and acceleration. They are derived from two of the fundamental quantities: length and time.

There are important connections and differences between the position, speed, velocity, and acceleration of an object. The object **position** is simply an object’s location in space [often indicated by the letter x, for one dimension; (x, y) for two and (x, y, z) for three]. An object’s **speed** is a measure of how fast an object travels in a fixed period of time. Its **velocity** (v) is the rate of change in its position over time, and its **acceleration** (a) is the rate of change of its velocity. We will describe each of these important measured quantities individually.

Position

One fundamental aspect of an object that we can measure is its position. Position is a “relative” measurement. One might say “I am two kilometers south of the elementary school,” or “I live in a house that is three Kilometers west of the river.

Forces, Motion and Planetary Motion

Measurements of position require a zero point, and the zero point that we choose is arbitrary or one that we agree. In a laboratory experiment, you might be measuring the motion of a cart at the top of an inclined plane at the start of an experiment is its zero point; its motion (down the incline) is measured from that arbitrary zero point.

Many of us are most familiar with position in one dimension: a number on a number line has a position, or distance from zero. We usually use the variable x to indicate position in one dimension. In two-dimensional space, there are many choices for variables indicating position, but we generally use the Cartesian plane (named after French philosopher and mathematician Renee Descartes [1596-1650]), or the *x-y* plane. The *x-y* plane is used frequently in problems in this lesson, because we can pinpoint an object in two-dimensional space. In three-dimensional space the x-, y- and z-coordinates are used to locate an object.

In studies of motion, we are connected with the measurement of the change in position of an object. For an example, we might want to know that in a specified period of time, an object covered a measured distance. The position of an object, and how it changes as a function of time, are basic measurements that we can make, and we can use these measurements to test our theories of how objects move through space. Distances are typically measured in meters or multiples of this unit (e.g., centimeters, kilometers).

Speed and Velocity

People often use the term speed and velocity interchangeably, but in physics they are two different quantities. In properly measuring the motion of an object, however, we must specify two quantities: how fast it is moving (the rate of change in its position) and in what direction. How fast an object moves (measured in meters per second or in kilometers per hour) is its **speed**.

Speed=Distance/Time (how far and how long) or $s = \frac{d}{t}$ or $\bar{s} = \frac{d}{t}$

In physics, one uses $\bar{s}$ to indicate an average value of that quantity.

You probably use this formula all the time. For example, let's say you have a 400 kilometer trip to make (distance). Because you know that you will go about 895 kilometers per hour (speed), you estimate that the trip will take about 5 h.
Common units of speed are kilometers per hour minute, or meters per second.

The greater the distance traveled in a given time, the greater the speed. An automobile traveling a distance of 70 kilometers in one hour has a lower speed than a jet airplane covering a distance of 700 kilometers in the same time. In either case, however, it is unlikely that a uniform speed was maintained for a period of one hour. The automobile may have had to slow down on curves or hills, or to stop for traffic lights or cattle crossing; conversely, it may have picked up speed on open stretches and while passing. In other words, we should say that the average speed is 70 kilometers/hour.

Forces, Motion and Planetary Motion

Some forms of energy travel at a constant speed. For example, the speed of light is almost 300,000 kilometers per second. The speed of sound in air is about 340 meters per second.

Speed associated with a direction is **velocity**; therefore, whether one is traveling at 80 kilometers/h to the west or 80 kilometers/h to the north is an important piece of information. These same two speeds (but with different velocities) will land you in very different final locations. Because the direction of motion is typically an important piece of information, problems in physics generally involve velocities, which are represented by a vector. A **vector** is simply any measured quantity that has both a direction and a magnitude, size, or distance.

Velocity is a vector quantity, and speed is a scalar quantity. A **scalar** quantity is one that has a magnitude (distance or size), but no direction. Mass, or the amount of matter an object contains, is another example of a scalar quantity. **Velocity**, then, can be defined as a change in distance (with a specific direction) divided by a change in time.

$$\text{Velocity} = \frac{\Delta x}{\Delta t} \qquad \text{or} \qquad \text{v} = \frac{\Delta x}{\Delta t}$$

Acceleration

So far, we have considered only motions involving constant velocity. In the real world, of course, velocities are always varying and are rarely constant. Acceleration is defined as the rate of change of the velocity; that is, the change in velocity divided by the time it takes for the change to occur, or

$$\text{Acceleration} = \frac{\Delta v}{\Delta t} \qquad \text{or} \qquad \text{a} = \frac{\Delta v}{\Delta t}$$

Remember that the Greek letter delta (Δ) stands for "change in" the quantity that it precedes. Because velocity is measured in meters per second (m/s) and time is measured in seconds (s), the typical unit of acceleration is meters per second per second (m/s^2).

Imagine that you are waiting at a traffic light. The light turns green. You press on the gas pedal (the accelerator) and the car moves from a velocity of 0 km/h to velocity of 35 km/h. This change in velocity is called acceleration, and the rate at which your velocity changes tells you how great your acceleration is. Car buyers often pay a premium for engines that can take them from 0 to 60 in 6 s instead of 10 s. Why? They are paying for greater acceleration: they are paying to get from 0 to 60 km/h in a shorter period of time.

Accelerations determine the final velocity of an object. To determine an object's final velocity (v), given that it started at some initial velocity (v_0) and experienced acceleration (a) over5 a period of time (t), use the equation

$$v = v_0 + at$$

This equation, again, can be derived from the definition of acceleration.

For example, if you are in a car that starts at rest (with an initial velocity $v_0 = 0$) and you accelerate for 5 s at an acceleration rate of $10 m/s^2$, then what will be your final velocity? Using the equation

$v = v_0 + at$

you see that you will end up (5 s later) at a velocity of

$v = 0 m/s + (10 m/s^2) x (5 s)$

or

v = 50 km/s

Before we move on, it is important to note that a change in direction (not just a change in speed) also constitutes acceleration. Why is this? Well, our definition of velocity is a speed in a given direction. Therefore, a change in direction is a change in velocity, and any change in velocity is acceleration (as we have just defined it).

Thus when you leave the freeway and enter a curved off-ramp, even if you are moving at a constant speed of 50 km/h, you are accelerating. This should not come as a surprise, as you can usually "feel" acceleration. Whether you are feeling your car accelerate from 0 to 60, or feeling it as you round a curve, you are feeling the acceleration.

Let's think just a bit more about the example of our accelerating car. Let's say that after 1 s it is going 10 mi/h. Its acceleration is then 10mi/h/s—not a unit that you use every day but still a proper unit of acceleration (as unit of velocity divided by a unit of time). What if the car is traveling 20 mi/h after 2 s? The acceleration is still 10 mi/h/s, since its velocity (20 mi/h) divided by the time required to reach that velocity (2 s) is 20/2 or 10 mi/h/s; and if the car is going 60 mi/h after 6s, the acceleration is still 10 mi/h/s. This would be an expensive car.

Slamming on the brakes would result in another kind of acceleration (a negative acceleration, or slowing down, is typically called deceleration). For example, suppose a car traveling at 10 m/s is brought to rest by its brakes at the uniform rate of $2.5 m/s^2$. How long will it take fir the car to stop? If we know that the braking acceleration is $-2.5 m/s^2$, then the car will slow by 2.5m/s every second. Thus, a car moving at 10m/s will be moving at 7.5 m/s after 1 s, and 5.0 m/s after 2 s, and will be at a standstill after 4 s.

Forces, Motion and Planetary Motion

Planetary Motions

Early peoples took an active interest in the skies. Those who were bound to the land learned from the rising and setting of constellations the times for sowing and harvesting. Seafarers used the stars for planning their voyage and for navigation. As astronomy developed, people mapped the heavens and charted the courses of the planets. The Egyptians and Babylonians were excellent observers of the periodic changes of sunrise and sunset during the year, the phases of the moon, the seasonal appearance and disappearance of constellations, and the more complex motions of the planets. They were aware of the months and the years and made calendars based on the moon cycle, or combinations of the two. Until the Greeks, however, people seemed satisfied to describe the heavens and showed no interest in discovering details about the nature of the heavenly bodies.

The belief that heavenly bodies move along circular paths was linked to the belief in spherical perfections. The circle, with neither beginning nor end, seemed the right path for them to follow. If some of the planetary motions seemed complicated, it was assumed that analysis would reveal that they could be reduced to uniform circular motions. The earth, however, was imagined to be at rest, and the center of the universe. The Greek astronomers Hipparchus of Nicaea (c. 190 – 120 BC) and Claudius Ptolemy of Alexandria (c. 90 – 168 AD) seriously studied the heavenly bodies with great precision. Both saw their tasks not so much as the taking and recording of observations as the mathematical explanation of the facts that the observations revealed. Their work culminated in Ptolemy's encyclopedic masterpiece, the *Almagest.* The *Almagest* displaced earlier works on astronomy and became the standard treatise on astronomy. The *Almagest* developed the Ptolemaic system, a solar system that was completely earth centered.

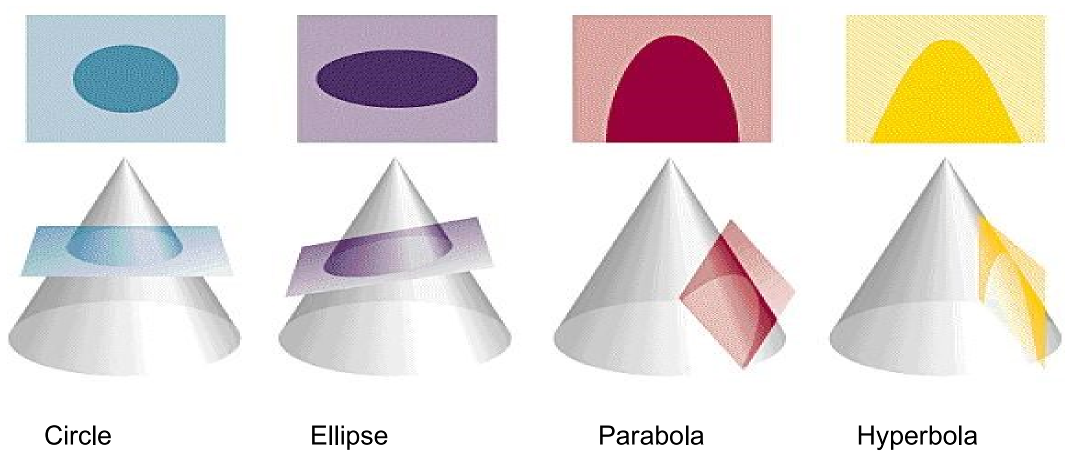
For 1400 years, Ptolemy's astronomical system encountered no serious challenge. Its basis in the geocentric idea—an immobile earth at the center of a finite universe—was satisfying to most people. The Ptolemaic system was in complete harmony with Aristotelian physics which assumed also the principle of uniform, circular motion for celestial bodies. Together, the two systems offered a coherent scientific world view that was, moreover, reconciled with the major religious systems of the West—Judaism, Christianity and Islam.

Copernican Revolution

As astronomical observations improved, discrepancies showed up between observation and theory. When adjustments were made in certain parts of the Ptolemaic theory to account for these, other discrepancies appeared elsewhere. By the fifteenth century, astronomy was in such a sorry state from the point of view of precision that Nicolaus Copernicus (1473- 1543) spoke of it as a "monster" passing for a system of the heavenly bodies. He felt that no system as cumbersome and inaccurate as the Ptolemaic system had become, is worth trying to fix. The Copernican system was set forth in his work, *On the Revolutions of the Celestial Spheres*, published in 1545. Copernicus received a copy of it on his deathbed. It reintroduced the idea of a sun-centered system, proposed 1700 years earlier by the notable Alexandrian astronomer, Aristarchus (c. 310-230 BC), whose works describing this theory have not been preserved. Copernicus replaced the notion of an earth at rest with one in motion. The earth was described as having three motions: a daily rotation on its axis, an annual revolution on its orbit around the sun, and a wobbly motion like that of a spinning top, called precession.

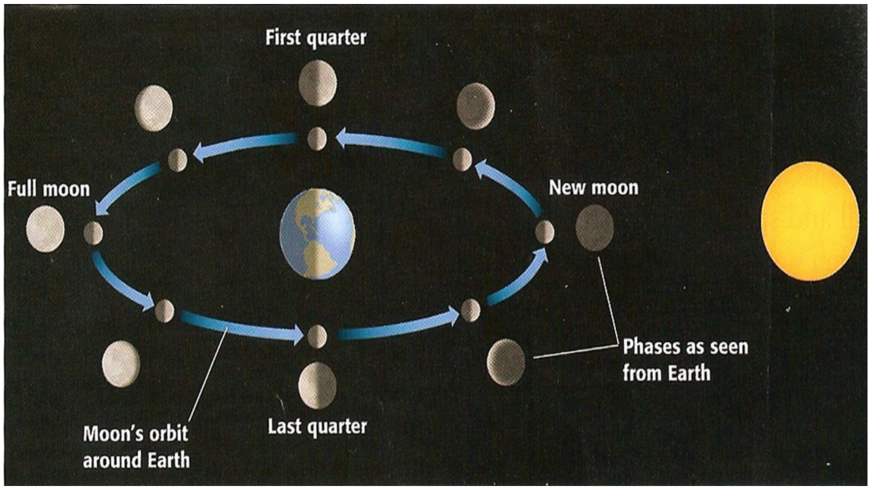
How Planets Move: Johannes Kepler

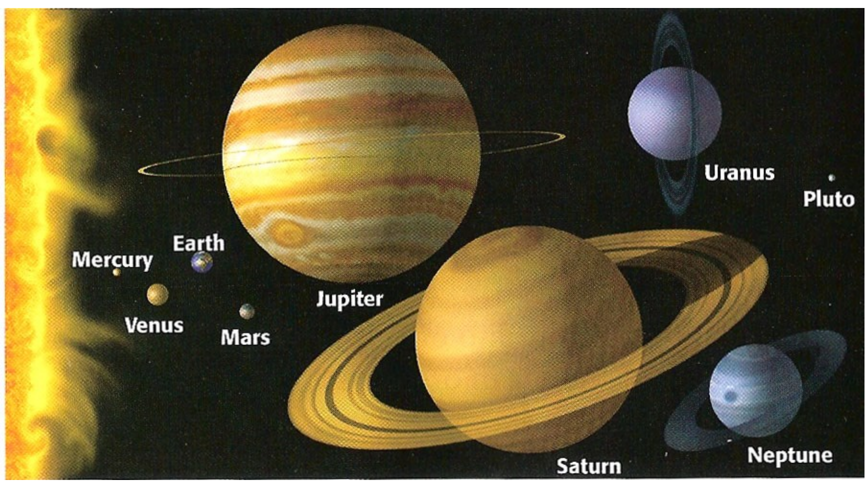
Johannes Kepler (1571-1630), a mathematician in the Copernican tradition, won recognition with his book, *The Cosmographical Mystery* (1596). Kepler was forced to conclude that the orbit of a planet was not a circle but an ellipse, with the sun at one focus. He found that the orbits of all planets, including the earth, are elliptical. This discovery is known as Kepler's *first law*, or the *law of ellipses*: *Each planet travels in an elliptical orbit with the sun at one focus.* Kepler announced his first and second laws in one of the great masterpieces of natural science, *The New Astronomy* (1609). Galileo praised it, but few astronomers took his ideas seriously. Later, Galileo affirmed, with the telescope, that the work of Johannes Kepler, accurately describes planetary motion and places the sun, not the earth, as the center of the universe. Modern astronomy affirms the theories and explanations of the heavenly bodies as presented by Copernicus and Kepler.

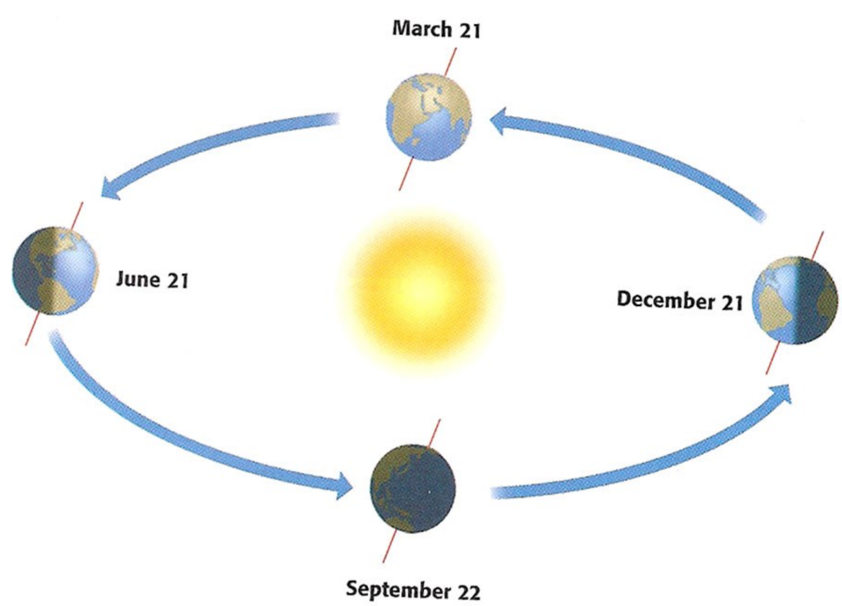


An **ellipse** is a conic section—a curve produced by cutting a cone with plane. If the cut is parallel to the base of the cone, the section is a **circle**. If the cut is made parallel to one side of the cone, the section is a **parabola**. An **ellipse** is obtained by an intermediate cut. A **hyperbola** is made by a cut perpendicular to the base.

Forces, Motion and Planetary Motion







Forces, Motion and Planetary Motion

Activity 1

1) Like velocity, force has both a(n) __________ and a(n) __________.
2) Newton's first law of motion refers to an object's __________.
3) Newton's second law of motion gives the relationship among three quantities: __________, __________, and __________.
4) A truck is parked in the middle of a 100-m-long bridge. If the truck has a mass of 1000 kg, what is the upward force exerted at each end of the bridge? Does the length of the bridge affect your answer?
5) What force is required to hold a 100-kg safe motionless at the surface of Earth? What force is required to move the safe upward with constant velocity? What force is required to accelerate the safe upward with constant velocity? What force is required to accelerate the safe upward at 1 m/s^2? What force is required to accelerate it downward at 9.8 m/s^2?
6) Describe the universe as we know it today in terms of how the various planets relate to the Sun and their moons; what is the path of their orbits?
7) Name three (3) astronomers who made great contributions to our understanding of how heavenly bodies relate to one another and discuss some of their specific contributions.
8) How does the moon affect our ocean waters?
9) Why do objects tend to fall to the ground?
10) Name the four (4) major forces and illustrate how each works.

Theme III: Introduction to Physics:
The Study of Energy, Matter, and The Laws Governing Their Interactions

Lesson 5: Laws of Motion and Gravity

Do You Know?

Newton's Laws of Motion

Sir Isaac Newton was a man of prodigious talent and with extensive interests, especially in the areas of motion, optics, and gravity. In this lesson we describe his fundamental contributions to our understanding of motion. Through careful observation and modeling, Newton was able to describe the motion of objects by three relatively simple statements, now called Newton's laws of motion. These laws include the law of inertia (Newton's first law of motion), the law of constant acceleration (Newton's second law of motion), and the law of momentum (Newton's third law of motion).

Newton's First Law of Motion

Newton's first law states something that is not obvious in the everyday world: **all objects remain in their state of rest, or in motion in a straight line, unless acted upon by another outside force.** The first law is often called the **law of inertia**, because **inertia** is the property of matter that resists changes in its state of motion or non-motion. The "at rest" part may make more sense at first glance. If you run out of gas, you know that it will take a large exertion of force to get your car (at rest) moving. Moving objects, however, do not keep moving in a straight line forever. When you toss a ball in the air, it does not move in a straight line forever; it falls to Earth. The ball falls in a curved path to Earth because it is being acted on by outside forces (the force of gravity and air friction); but in the absence of gravity and air friction, the ball you tossed would move off in a straight line at constant velocity forever. Newton's first law states something rather surprising: that motion at constant velocity is just as natural a condition as rest.

Spacecraft take advantage of this law by firing their engines to get away from Earth and then basically coasting until they get within the gravitational pull of another planet. They move off into space at constant velocity toward their final destination. In some sense, the first law can be thought of as describing objects that are in equilibrium (as described earlier). The net forces acting on them are zero, whether they are at rest or moving in a straight line at constant velocity. Why do they have to be moving in a straight line?

Laws of Motion and Gravity

Recall that if an object is moving in a curved path, its direction is changing, so its velocity is changing, and it is accelerating; and if it is accelerating, it is not in equilibrium.

Newton's Second Law of Motion

Newton's second law can most simply be stated as: **force is equal to the product of mass and acceleration, or F = ma.** The boldface terms force (F) and acceleration (a) indicate that, quite properly, these are both vector quantities; that is, they have a direction.

As we have mentioned in several contexts, when the forces acting on an object are not in equilibrium, there is a nonzero resultant vector, and a net force acts on the object. When a net force is acting on an object, Newton's second law tells us that an object acted upon by a constant force will move with constant acceleration in the direction of the force. The force and the acceleration are vector quantities, and they must therefore act in the same direction. The magnitude of the acceleration will be directly proportional to the acting force and inversely proportional to the mass of the body. Because mass is measured in kilograms (kg) and acceleration is measured in meters per second (m/s^2), the basic unit of force is the product of these units, or kg · m/s^2, the newton (N).

Have you ever heard a reference to g-forces? These are forces that are exerted on pilots and astronauts when they are accelerated at rates higher than that acceleration of gravity. Thus, if you are accelerated at 1 g, then you are accelerating at 9.8 m/s^2 (or 32 ft/s^2), the normal value at the surface of Earth. An acceleration of 2 g is simply double this value, or 19.6 m/s^2 (64 ft/s^2). Being accelerated at rates higher than normal for the surface of Earth will make you feel "heavier," as if someone suddenly doubled the mass of Earth, and your weight doubled. A pilot often feels these accelerations when his aircraft makes a turn. You probably have felt forces like these when you have been on a roller coaster ride or taking off in an airplane. You will feel these g-forces in any situation in which you are accelerating rapidly.

Exploration A

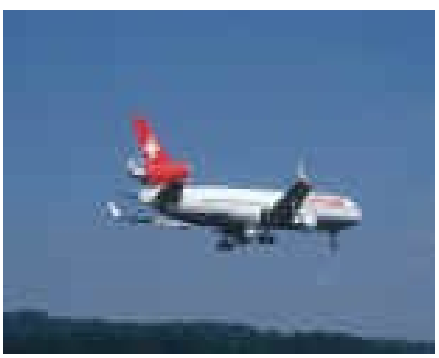
Your weight is actually a measure of the force of gravity acting on the mass of your body. For example, let's say that you want to find your mass in kilograms (kg) using Newton's second law. Use your weight in pounds (lb) and the acceleration of gravity ($g = 9.8\ m/s^2$) to determine your mass in kilograms. (Hint: Use the conversion factor 1 lb = 4.448 N.)

Laws of Motion and Gravity

Newton's Third Law of Motion

Newton's third law states that **for each action there is an equal and opposite reaction.** What does this mean? In the case of your hammering a nail, it means that the hammer exerts a force on the nail (driving it into the wood), and the nail exerts an equal and opposite force on the hammer, stopping its forward motion. In the case of your running down the street it means that your feet push backward on the street, and the street pushes forward on you, pushing you forward. The street (and the earth to which it is attached) is much more massive than you, so your forward motion is much more appreciable than the tiny backward motion of Earth; however, the forces exerted are equal and opposite. Newton's second law ($F = ma$) can help our understanding here. The forces exerted by you and the planet are equal, but your mass is much smaller; therefore, the acceleration that you experience is far greater.

A spaceship moves forward because it expels combusted fuel backward. The forces exerted are equal. The spaceship exerts a backward force on the combusted fuel, and the combusted fuel exerts a forward (opposite in direction) force on the spacecraft.



Newton's laws of motion apply to an enormous array of phenomena, from balls to airplanes to rocket ships. We will revisit Newton's laws many times in studying physics.

Laws of Motion and Gravity

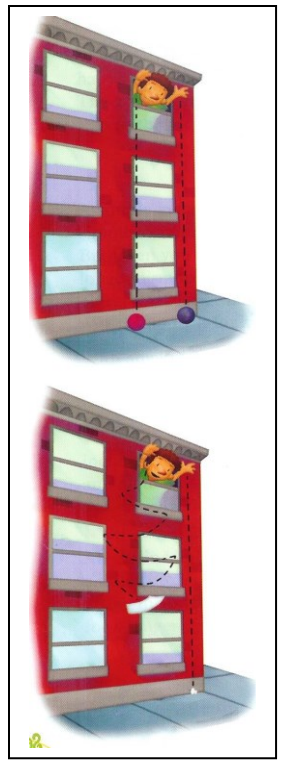
Exploration B

You point a gum at a monkey hanging in a tree. (Note to animal rights activists: this particular monkey is infected with a deadly virus and must be destroyed.) In order to hit the monkey – if it lets go of the branch at the moment you pull the trigger – should you point the gun at the monkey, above the monkey, or below the monkey?

Answer:

Both the monkey and the bullet are subject to the same accelerating force (gravity); therefore, you should point the gun directly at the diseased monkey. In the absence of gravity, the gun pointed at the monkey would deliver the bullet properly. In the presence of a gravitational field, both the monkey and the bullet move downward the same distance in each instant of time, so the bullet will find its mark.

Gravity and Motion



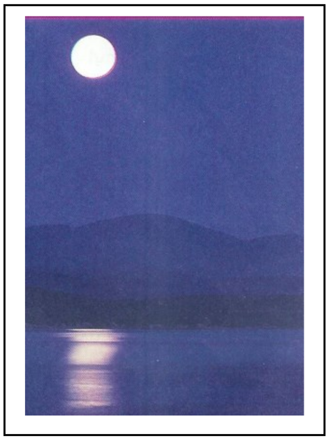
Gravity is a force that pulls one object toward another object. On Earth, gravity pulls objects toward Earth's center. If you let go of an object you are holding, it will fall to the ground. The force of gravity pulls the object down. Without the force of gravity, the object would float in the air when you let go of it.

Objects of the same size and shape fall at the same speed. For example, if you drop an iron ball and a rubber ball of the same size and shape from a building, they will hit the ground at the same time.

If you drop a sheet of paper and a tack of the same weight, the tack will hit the ground first. That's because the sheet of paper has more surface area than the tack. As the paper falls, it has to push aside more air than the tack would. The paper has to overcome the resistance of the air. Remember, air is matter. It gets in the way of falling objects.

Gravity can also cause a sudden physical change. If freezing rain cracks rocks on a hillside, gravity can pull the hill down in a landslide!

Laws of Motion and Gravity



The Moon is about one-fourth as wide as Earth. If the Moon were the size of a tennis ball, Earth would be the size of a basketball. Not only is it smaller than Earth, but is has less mass, too. Gravity on the Moon is weak compared with gravity on Earth because of these facts.

Gravity is the force that holds things on the ground. The pull of gravity between Earth and the Moon keeps the Moon in its orbit around Earth.

Gravity determines how much things weigh. Gravity is six times stronger on Earth than on the Moon. If you stepped on a scale on the Moon, you'd weigh only one sixth of your weight on Earth.

The Moon is Earth's nearest neighbor in space. It is about 384 thousand kilometers (240 thousand miles) away.

What Ocean Motion is Caused by Gravity?

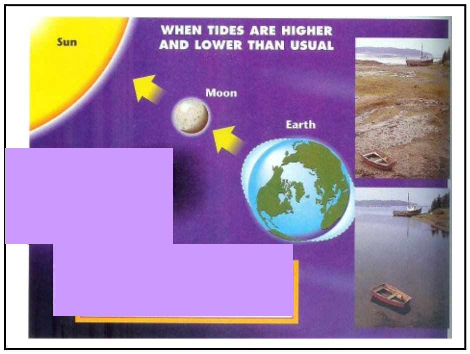
The rise and fall of ocean water levels is called a **tide**. Ocean tides are caused by the pull of gravity between Earth and the Moon and the Sun. The pull is greater by the Moon because it's closer to Earth. Remember what you learned about gravity? The closer objects are together, the stronger the pull of gravity is between them.

The pull of gravity on the side of Earth facing the Moon causes oceans to bulge outward. The bulge moves water higher on the shore, cause a high tide. On the opposite side of Earth, the Moon's pull on solid ground causes oceans to bulge outward, too.

As Earth rotates, the bulge travels around it. Where the water does not bulge, there is a low tide. In a low tide, the ocean water does not come up as far onto the shore.

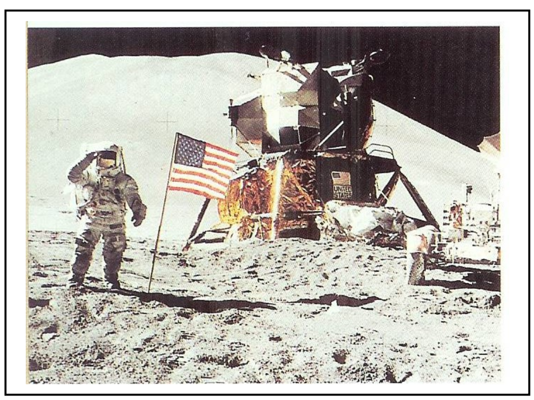
Laws of Motion and Gravity

The Moon's orbit around Earth also causes daily tide changes. In most places there are two high tides and two low tides each day. During a full Moon and a new Moon, the pull of gravity is stronger. The tides are higher and lower than usual.



AUGUST			
High Tide		Low Tide	
A.M.	P.M.	A.M.	P.M.
9:50	9:43	3:31	3:36
10:2	10:26	4:17	4:21

How are Earth and the Moon Different?



The U.S. Apollo 11 astronauts landed on the Moon on July 20, 1969. Information and data gathered affirmed our views about gravity on the moon.

How Motion Behaves Because of Gravity

As noted earlier, everything around us is in constant motion. In this lesson one explores the ways in which physics describes the motion of objects through space and the affect that gravity has on these objects as they are engaged in various motions. Using two fundamental quantities, position and time, we can describe where an object is, where it is headed, and how long it will take to get there.

Laws of Motion and Gravity

Linear Motion

The first type of objects in motion, that were described earlier, was linear motion. Linear motion can be described accurately, using the four fundamental concepts: position, speed, velocity, and acceleration. At this point we wish to consider some applications involving linear motion and circular motion.

Applications

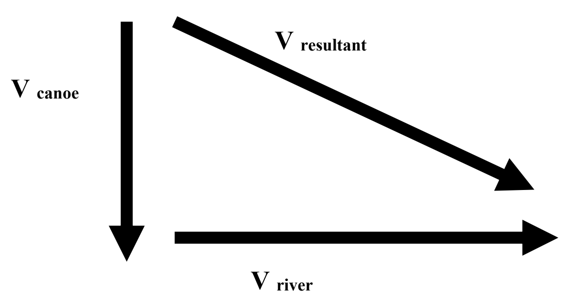
In problems involving the velocity of an object, there are sometimes several velocities involved, and you will be asked to determine the velocity that results from the sum of all velocities described. The resultant velocity is simply the sum of all the velocity vectors.

As an example, imagine a canoe crossing a river. The movement of the water in the river gives that canoe a downstream velocity, and the person paddling in the canoe gives the boat a velocity across the river. The resultant velocity of the canoe is the sum of these two velocity vectors. The resultant can be determined (as just described) or by using some simple geometry. The lengths of the sides of a right triangle are related by the Pythagorean theorem, which states that in a right triangle the square of the length of the hypotenuse (the long side) is equal to the sum of the squares of the other two sides. Generally, the Pythagorean theorem is written as $a^2 + b^2 = c^2$.

In our example of the canoe crossing the river, the two velocity vectors form a right triangle, so that the resultant velocity can be computed with the formula

$v\text{ (total)} = (v_1^2 + v_2^2)^{1/2}$

where v_1 is the velocity of the river, and v_2 is the velocity of the canoe.



Laws of Motion and Gravity

Exploration A

If a river is flowing with a velocity of 4 kilometer/h downstream, and a man in a canoe paddles across the river (perpendicular to the river flow) at 3 kilometers/h, what is the magnitude and direction of the resultant velocity?

Answer
The resultant velocity is

$$v_{total} = \left[(3km/h)^2 + (4km/h)^2\right]^{1/2}$$

v_{total} = 5 km/h

Exploration B

Examine how far a braking car will travel while stopping. If the car goes from 10 m/s to a full stop, then its change in velocity is 10 m/s. If it decelerates at a rate of 2.5 m/s^2, it will take 4 s to stop.

Answer:

Using the acceleration formula $\left(x = x_0 + v_0 t + \frac{1}{2}at^2\right)$, and input values $x_0 = 0$ m, $v_0 = 10$ m/s, $a = -2.5$ m/s^2, and t = 4 s, we find that the car will stop in a distance of

x = 0 m + 10 m/s(4 s) + $\frac{1}{2}$ (-2.5 m/s^2)(4 s)^2 or x = 40 m – 20 mor x = 20 m

Free Fall: An Acceleration of Gravity

Scientists carried out a number of experiments that involved dropping objects from high places and carefully measuring the passage of time. They showed by experimentation that objects appear to fall to Earth with a constant acceleration and that this value (9.8 m/s^2) becomes more obvious as one reduces surrounding effects like air resistance. The acceleration of gravity at the surface of Earth is often referred to as 1g. Larger accelerations can be referred to as 2g, 3g, and so on. Any object that is falling to the surface of Earth owing to acceleration of gravity is **free fall**.

When objects are dropped from a great height, they will eventually stop accelerating and achieve what is called **terminal velocity**, the velocity at which the object will not accelerate any more. A leaf has much smaller terminal velocity than a bowling ball, for example. A feather has a smaller terminal velocity than a rock, and a flat piece of paper has a smaller terminal velocity than the same piece of paper crumpled up.

Laws of Motion and Gravity

Parachutes are perfect example of the usefulness of lowering one's terminal velocity. A parachute adds almost nothing to a person's mass, but it tremendously increases his or her surface area. A typical parachute has an area that is close to 100 times that of a human, and from the preceding examples, it seems that the key to lowering terminal velocity is a high ratio of surface area to mass. The piece of paper is the best example. The same mass object (a piece of paper) will have a much lower terminal velocity when we allow it to have the greatest possible area (flat).

What Galileo had measured what we something call the acceleration of gravity (often abbreviated with the letter g). It is a constant value only at the surface of Earth, and only for the particular mass and radius of our planet; however, if we make a few assumptions (that we are close to the surface of Earth and that air resistance is not a significant factor), we can determine a lot about the time it takes for an object to fall to Earth simply by knowing this value of acceleration. The general equation that can be used to determine the position of an object (x) after a time (t) that has a known initial position (x_0), initial velocity (v_0), and constant acceleration (a) is

$$x = x_0 + v_0 t + \frac{1}{2} at^2$$

Thus, if an object is dropped from a height of 100 m and the only acceleration acting is that of gravity (9.8 m/s^2), then we can say that the initial velocity (v_0) is 0 m/s, and the initial height (x_0) is 100 m. We must take a moment to consider direction. If height is measured up (positive) from the ground, then the acceleration of gravity (pointing in the opposite direction) must be negative, or -9.8 m/s^2. Using all this information, we have

$$0 = 100\text{ m} + 0\text{ m/s }(t) + \frac{1}{2}(-9.8\text{ m/s}^2)t^2 \qquad \text{or} \qquad 100\text{ m} = (4.9\text{ m/s}^2)t^2$$

$$100\text{ m} = (4.9\text{ m/s}^2) = t^2 \qquad \text{or} \qquad t = 4.5\text{ s}$$

so the object takes 4.5 s to strike the ground.

Exploration C

Problem

We can use the acceleration equation to solve a simple problem in free fall. Let us say that one standing at the top of a tall building, and one wants to know how long it will take for the water balloon in ones hand to hit the sidewalk below. Ignoring air friction, the only acceleration involved is the acceleration of gravity (g), and the height of the building is 12 m.

Answer:
In the acceleration equation, we use x = 12 m (when the balloon hits the sidewalk), $x_0 = 0$ m (we take the balloon's starting point at the top of the three-story building to be zero, $v_0 = 0$ m/s (the balloon starts from rest), and g = 9.8 m/s^2 (only gravity is acing on the balloon). Inserting these values into the equation and solving for t, we determine that

$$x = x_0 + v_0 t + \frac{1}{2} at^2 \quad \text{or} \quad 12 \text{ m} = 0 \text{ m} + 0 \text{ m/s(t)} + \frac{1}{2}(9.8 \text{ m/s})t^2 \quad \text{or}$$
$$24/9.8 \text{ s}^2 = t^2 \quad \text{or} \quad t = 1.6 \text{ s}$$

Motion in Two Dimensions

Although we stated how we describe positions in two and three dimensions, we have been discussing motions in only one dimension and in one direction. Of course, in the real world, we are often interested in the motion of objects in two dimensions (and three dimensions for that matter): the path that an arrow travels after being shot from a bow.

The key to understanding motion in two dimensions is to realize that an object's motion can be broken into two perpendicular components, or components that are separated in direction by 90. For example, motions in two dimensions can be separated into a component perpendicular to the ground (the y-direction) and one parallel to the ground (the x-direction). If we treat these two components of velocity separately, we can easily understand two-dimensional motion.

Let us think more about the arrow just mentioned. Once it is shot into the air at some initial velocity, the only acceleration affecting it (ignoring air friction again) is the acceleration of gravity (g), and gravity acts in one direction: downward perpendicular to the ground. (Actually, gravity acts toward the center of Earth, but locally this looks like perpendicular to the ground.) If we ignore air currents, there is no force acting parallel to the ground. Thus, if we divided the velocity vector of the arrow into two components (x- and y-components) the problem becomes much simpler to understand.

Laws of Motion and Gravity

The x-component of its velocity (parallel to the ground) is uncharged during its flight. The y-component of its velocity changes gradually, starting with positive (up) value, slowly changing to zero (as the acceleration of gravity slows it down), and then changing to negative (down) value (as the acceleration of gravity speeds up) The combination of these x- and y-direction motions produces a shape known as a parabola. A **parabola** is the shape defined in the x-y plane by the equation $y = x^2$. Objects (like soccer balls) that move through the air follow a parabolic trajectory, or path.

Let us assume that the arrow was shot from an angle at a 30^o with the Earth's surface and that it leaves the bow at a velocity of 5.0 m/s. What are its vertical and horizontal velocity components? The next figure shows a triangle that represents the vertical and horizontal components of its velocity, and to answer the question posed, we need to remember either the Pythagorean theorem (discussed earlier) or a little simple trigonometry.

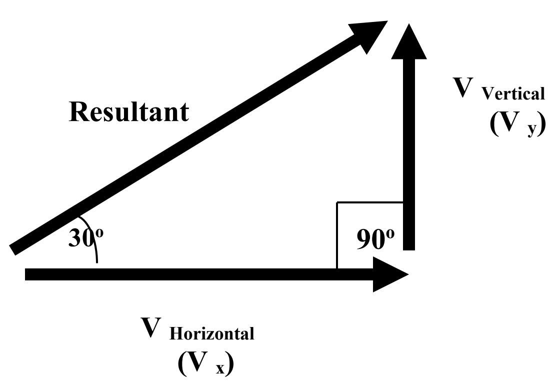
Its vertical velocity component is equal to its initial velocity times the sine of its angle to the surface of the Earth (5.0 sin 30^o m/s), and its horizontal velocity component is equal to its initial velocity times the cosine of its angle to the surface of the Earth (5.0 sin 30^o m/s). Thus, its horizontal (V_x) component is 4.3 m/s, and its vertical (V_y) component is 2.5 m/s. One will notice that one can verify these rounded values with the Pythagorean theorem:

$a^2 + b^2 = c^2$

or

$2.5^2 + 4.3^2 = 5.0^2$

The arrow will sail through the air in the horizontal direction at 4.3 m/s until it comes to rest. Its vertical velocity will change with time, first slowing to zero and then increasing again, because the acceleration of gravity will continuously change the value of its vertical velocity.



Laws of Motion and Gravity

Exploration D

Take a stopwatch and five or six coins to a window on an upper story of a building. Drop one at a time making sure no one is below you. Measure the number of seconds it takes for each coin to hit the ground. Calculate the average of those times. You should be able to use the average time and the height of the fall to estimate the acceleration of gravity (the accepted value is 9.8 m/s^2). Use the equation involving the distance of the fall in meters, x = 0 m/s (you drop the coins from position 0), and *t* being your measured time. Then solve for a (acceleration). What could be some of the reasons why you might get a value different from the accepted value?

Angular Motion

The physical world is filled with examples of circular motion: children on a merry-go-round, planets orbiting the Sun, the propeller of an airplane, a yo-yo. Clearly, circular motion, or more generally, angular motion, is an important part of the way objects move in the world. In this lesson, we define the terms needed to describe and predict angular motion and outline the parallels to our descriptions of linear motion.

When we first describe linear motion, we needed to use a unit of distance: we chose the meter. Linear distances are measured in meters and in other linear units of measure, as displacements from an arbitrary zero-point. Angular motion is measured somewhat differently. Imagine that you are standing facing north. We will call this direction 0^o. Now, rotate your body so that you are facing to the east. You have undergone angular motion; but how "far" have you gone? You have not moved in terms of meters, but you have rotated through an angle of 90^o. Your angular motion was 90^o. Now, keep turning until you are facing south. Now your angular motion is 180^o. Face due west and you have rotated through 270^o, and when you are facing north again you have rotated through 360^o. Thus, angular motion is measured in degrees (^{o}) or radians (rad), which have no "units." There are 2 π rad in one complete revolution, so π rad in a half revolution and π/2 in a quarter revolution.

Exploration E: Degrees and Radians

A **radian** is a unit used to measure a change in angular position. There are 2 π rad in a circle. How do we convert from degrees to radians?

If there are 2 π rad in 360^o, then there are π rad in 180^o. To convert from degrees to radians, we simply multiply: $\text{Radians} = \text{Degrees} \times \left(\frac{\pi}{180}\right)$

To convert from radians to degrees, we multiply: $\text{Degrees} = \text{Radians} \times \left(\frac{180}{\pi}\right)$

Laws of Motion and Gravity

Angular Velocity

You may have noticed that your car has a gauge called a **tachometer** that measures the number of revolutions per minute (rev/min) of the engine's crankshaft. You will notice that when the car is not moving that the tachometer will read somewhere around 500 or 1000 rev/min, sometimes known as the **idle speed**. How can you have any speed when you are idling (not moving)? The speed referred to is the angular speed, or the number of revolutions per minute that the engine's crankshaft is making. When you press the "accelerator" you feed more fuel to the engine, causing the crankshaft to rotate at a higher angular velocity – whether or not the car is moving. The motion of the crankshaft is transferred to the wheels of the car by the transmission (automatic or manual).

Angular velocity is simply a measure of the rate of change in angular position. In our first example, imagine that you make one full revolution in 10 s. Then, your angular speed is 360^o per 10 s, or 36^o per second; you could also say 0.1 rev/s, or 0.2 π rad/s. All these expressions are equivalent, but the most commonly used units in problems are radians per second and revolutions per minute. Because radians are dimensionless units, the unit of angular velocity is simply 1/s.

Angular Acceleration

Of course, it there are angular velocities, then there must be angular accelerations. What does it mean to have an angular acceleration? Picture a stationary merry-go-round. Because it is not rotating, its angular velocity is zero. Now, you start pushing on it so that it starts to turn at a velocity of one revolution every 4 s, or 0.25 rev/s. The merry-go-round has been accelerated to this nonzero angular velocity. Now, if it continues to move at a constant angular velocity, its angular acceleration is zero.

Accelerations are changes in velocity, so the units of angular acceleration are radians per second. Again, because radians are dimensionless units, angular acceleration is measured in units of $1/s^2$. There are parallels to linear motion in all of these situations. Angular position is represented by the Greek letter theta (θ), angular velocity by the Greek letter omega (ω), and angular acceleration by the Greek letter alpha (α). In the same way that velocity is change in position divided by change in time, angular velocity (ω) is change in angular position divided by change in time, or

$$\Omega = \Delta\theta/\Delta t$$

and angular acceleration is change in angular velocity over change in time, or

$$\alpha = \Delta\omega/\Delta t$$

Another way to think of angular velocity is as a linear velocity (v) divided by a radius (r), or

$$\omega = v/r$$

We often refer to this speed as the tangential speed (v_t), or

$$v_t = r\omega$$

This relationship should make sense, because if an object is moving at a given tangential velocity (v_t), the larger the radius of its circular path, the smaller its angular velocity.

In a parallel sense, the tangential acceleration (a_t) can be expressed as

$$a_t = r\omega$$

Torque

The parallel for the linear concept of force is the angular concept of torque, represented by the Greek letter tau (τ), where torque is simply the application of a force at some distance from a pivot point, or

$$\text{Torque} = \text{Force} \times \text{Radius} \qquad \text{or} \qquad \tau = Fr$$

Thus when we discuss rotational motion, instead of referring to an object's mass, we refer to its moment of inertia (I). The rotational equivalent of Newton's second law, then states that torque is equal to the product of the moment of inertia and the angular acceleration:

$$\tau = I\alpha$$

Exploration F

All objects have a point called their center of gravity or center of mass. This is the point in an object where all its mass can be thought to be concentrated. You can find the center of mass of a pencil by trying to balance it (sideways) on your finger.

Angular Momentum

In the same way that moving objects have linear momentum, rotating objects have angular momentum. The parallel-to-linear momentum ($p = mv$) is angular momentum (L) which is equal to the product of the moment of inertia (replacing mass) and angular velocity (replacing velocity):

$$L = I\omega$$

Expressing the preceding equation in terms of the more familiar units of mass, velocity, and radius, we say that a body of mass m moving in a circle of radius r at a velocity v has an angular momentum of

$$L = mvr$$

Laws of Motion and Gravity

Conservation of Angular Momentum

Just like linear momentum, angular momentum is conserved, which means that in a closed system angular momentum is neither created nor destroyed.

Forces in Circular Motion

What keeps objects moving in the circular paths that we have been discussing? In some cases, it is a rope or string.

But what about one of the greatest examples of circular motion: the nearly circular orbits of the planets around the Sun? There is no rope or friction to keep the planets in their curved trajectories. There is no connection between the Sun and the planets, but there is a force – the same force that keeps you stuck to the ground and pulls apples out of trees: gravity.

The Parallel Terms for Linear and Angular Motion

Linear Motion	Units	Angular Motion	Units
Distance (x)	m	Angle (θ)	rad, ^{o}
Velocity (v)	m/s	Angular Velocity (ω)	rad/s, or 1/s
Acceleration (a)	m/s^2	Angular acceleration (α)	rad/s^2, or $1/s^2$
Force (F)	N	Torque (τ)	N · m
F = ma	N	$\tau = I\alpha$	N · m
Mass (m)	kg	Moment of inertia (I)	$kg \cdot m^2$

Universal Gravitation

Johannes Kepler (1571-1630) first proposed, based on the careful observations of Tycho Brahe (1546-1601), that the planets move in elliptical paths around the Sun; but it was Newton who first described the force that makes them move in these paths. Newton made a great intellectual leap at the time, claiming that the same physical laws that can explain how things move here on Earth (balls and apples) can explain the motions of the planets, which are after all, just very big balls. Newton posited that all objects with mass exert an attractive force on all other objects with mass, and that this force is directly proportional to the product of the masses of the two objects and inversely proportional to their distance squared. One of the most pleasing things about the force that Newton proposed was that it predicted (based on theoretical grounds) that the planets should orbit the Sun in elliptical paths, as the observations of Tycho Brahe and the mathematics of Kepler had shown was in fact the case.

Laws of Motion and Gravity

Newton's law of universal gravitation is written:

$F_G = Gm_1m_2/r^2$

where m_1 and m_2 are the masses of the two objects, r is the distance between them, and G is the gravitational constant, a very small number that is a measure of the strength of the gravitational force in the universe.

Exploration G

Use Newton's law of universal gravitation to determine the attractive force between you and Earth. Earth has a radius of about 6.38×10^6 m and a mass of 5.98×10^{24} kg. If your mass is 80 kg (equivalent to about 200 lb), then the force of gravity exerted on you would be

$F = 6.67 \times 10^{-11}\ N \cdot m^2/kg^2(80\ kg)(5.98 \times 10^{24}\ kg)/(6.38 \times 10^6\ m)^2$ or 784 N.

You could also determine this force (otherwise known as your weight) by using the fact that weight is equal to mass times the acceleration of gravity (g).

$W = 80\ kg\ (9.8\ m^2)$ or $W = 784\ N$

Laws of Motion and Gravity

Activity 1

1) You use an Internet map site to calculate the driving distance from your house to your parents' house for the holidays. The results say that the distance is 250 mi, and the travel time is 5 h. What speed is the program assuming you will average for the trip?

2) A skydiver reaches a terminal velocity of 10 mi/h at a height of 1 mi above Earth. How long will it take her to reach the ground in minutes?

3) A plane flies due south at 250 mi/h, in a 60 mi/h crosswind, blowing from the west. What is the resultant velocity (speed and direction) of the plane?

4) A child accidentally drops her doll from a bridge suspended 50 m above a fast moving river. Assuming the doll never reaches terminal velocity, how many seconds will it take for the doll to hit the water?

5) A merry-go-round is rotating once every 5 s. How many degrees does it rotate through in half a revolution? How many radians? After 20 rev, how many degrees has it rotated through? How many radians?

6) The marry-go-round in problem 5 started at rest. If it took 5 s to get it to a rotation rate of once every 5 s, what angular acceleration did the merry-go-round undergo?

7) The planets in the solar system orbit the Sun in elliptical paths. If Venus and Earth have similar masses, and Venus is located at a distance that is approximately three-fourths of Earth's distance from the Sun, what is the ratio of the gravitational force between Venus and the Sun, and Earth and the Sun? That is, what is the ratio of F_G (Venus-Sun) to F_G (Earth-Sun)?

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