Science and Technology

Scientific Process

Scientific Method

One could argue that scientific knowledge is the sum of all scientific in quiries for truths about the natural world carried out throughout the history of human kind. More simply put, it is thanks to scientific inquiry that we know what we do about the world. Scientists use a number of generally accepted techniques collectively known as the scientific method. The scientific method generally involves carrying out the following steps:
Identifying a problem or posing a question

- Formulating a hypothesis or an educated guess
- Conducting experiments or tests that will provide a basis to solve the problem or answer the question
- Observing the results of the test
- Drawing conclusions

An important part of the scientific method is using acceptable experimentation techniques to ensure results are not skewed. Objectivity is also important if valid results are to be obtained. Another important part of the scientific method is peer review. It is essential that experiments be performed and data be recorded in such a way that experiments can be reproduced to verify results.

A scientific fact is considered an objective and verifiable observation. A scientific theory is a greater body of accepted knowledge, principles, or relationships that might explain a fact. A hypothesis is an educated guess that is not yet proven. It is used to predict the outcome of an experiment in an attempt to solve a problem or answer a question. A law is an explanation of events that always lead to the same outcome. It is a fact that an object falls. The law of gravity explains why an object falls. The theory of relativity, although generally accepted, has been neither proven nor disproved. A model is used to explain something on a smaller scale or in simpler terms to provide an example. It is a representation of an idea that can be used to explain events or applied to new situations to predict outcomes or determine results.

Inquiry

Teaching with the concept of scientific inquiry in mind encourages students to think like scientists rather than merely practice the rote memorization of facts and history. This belief in scientific inquiry puts the burden of learning on students, which is a much different approach than expecting them to simply accept and memorize what they are taught. The standards for science as inquiry are intended to be comprehensive, encompassing a student's K-12 education. More are addressed as students gain knowledge. The National Science Education Standards state that engaging students in inquiry helps them develop the following five skills:

- Understand scientific concepts.
- Appreciate "how we know" what we know in science.

- Understand the nature of science.
- Develop the skills necessary to become independent inquirers about the natural world.
- Develop the skills necessary to use the skills, abilities, and attitudes associated with science.

Abilities that K-4 students should acquire

The six abilities that grades K-4 students should acquire are as follows:

- They should be able to ask questions about objects, organisms, and events in the environment.
- They should be able to devise a simple investigation to answer a question.
- They should be able to use tools such as magnifying glasses, rulers, and balances to gather data and make observations.
- They should be able to use the gathered data and observations to provide an explanation.
- They should be able to talk about, draw pictures, or use another method to communicate the results of an investigation and what they learned.
- With respect to the nature of scientific inquiry and scientists, students should understand that investigations involve formulating questions and answers, using different methods of discovering and disclosing answers, using basic tools, observing, sharing answers, and looking at and understanding others' work.

Abilities that 5-8 students should acquire

The five abilities that grades 5-8 students should acquire are as follows:

- They should be able to reformulate and clarify questions until they can be answered through scientific investigation.
- They should be able to create and carry out a scientific investigation, interpret the data to provide explanations, and use further data to revise explanations.
- They should be able to identify the tools necessary to gather and analyze data. They should be able to use computer hardware and software to store, organize, and gather data.
- They should be able to provide descriptions and explanations, create models, and make predictions based on the body of knowledge they possess.
- They should be able to explain cause and effect relationships using explanations and data from experiments.

Abilities that 9-12 students should acquire

The six abilities that 9-12 students should acquire are as follows:

- They should be able to identify questions and concepts that guide scientific investigation. In other words, they should be able to create a hypothesis and an appropriate experiment to test that hypothesis.
- They should be able to design and conduct a scientific investigation from start to finish. This includes being able to guide the inquiry by choosing the proper technologies and methods, determining variables, selecting an appropriate method for presenting data, and conducting peer review.
- They should be able to use technology and mathematics in investigations.
- They should be able to formulate and revise scientific explanations and models.

- They should be able to recognize and analyze alternative explanations. In other words, they should be able to devise other possibilities based on the current body of knowledge.
- They should be able to communicate and defend a scientific argument in both written and oral form.

Scientific knowledge

The National Science Education Standards suggest that science as a whole and its unifying concepts and processes are a way of thought that is taught throughout a student's K-12 education. There are eight areas of content, and all the concepts, procedures, and underlying principles contained within make up the body of scientific knowledge. The areas of content are: unifying concepts and processes in science, science as inquiry, physical science, life science, earth and space science, science and technology, science in personal and social perspectives, and history and nature of science. Specific unifying concepts and processes included in the standards and repeated throughout the content areas are: systems, order, and organization; evidence, models, and explanation; change, constancy, and measurement; evolution and equilibrium; and form and function.

Evolution of scientific knowledge

When one examines the history of scientific knowledge, it is clear that it is constantly evolving. The body of facts, models, theories, and laws grows and changes over time. In other words, one scientific discovery leads to the next. Some advances in science and technology have important and long-lasting effects on science and society. Some discoveries were so alien to the accepted beliefs of the time that not only were they rejected as wrong, but were also considered outright blasphemy. Today, however, many beliefs once considered incorrect have become an ingrained part of scientific knowledge, and have also been the basis of new advances. Examples of advances include: Copernicus's heliocentric view of the universe, Newton's laws of motion and planetary orbits, relativity, geologic time scale, plate tectonics, atomic theory, nuclear physics, biological evolution, germ theory, industrial revolution, molecular biology, information and communication, quantum theory, galactic universe, and medical and health technology.

Facts, hypotheses, theories, models, and laws

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CGS and MKS

The metric system is the accepted standard of measurement in the scientific community. The International System of Units (SI) is a set of measurements (including the metric system) that is almost globally accepted. The United States, Liberia, and Myanmar have not accepted this system. Standardization is important because it allows the results of experiments to be compared and reproduced without the need to laboriously convert measurements. The SI is based partially on the meter-kilogram-second (MKS) system rather than the centimeter-gram-second (CGS) system. The MKS system considers meters, kilograms, and seconds to be the basic units of measurement, while the CGS system considers centimeters, grams, and seconds to be the basic units of measurement. Under the MKS system, the length of an object would be expressed as 1 meter instead of 100 centimeters, which is how it would be described under the CGS system.

Metric system

Using the metric system is generally accepted as the preferred method for taking measurements. Having a universal standard allows individuals to interpret measurements more easily, regardless of where they are located. The basic units of measurement are: the meter, which measures length; the liter, which measures volume; and the gram, which measures mass. The metric system starts with a base unit and increases or decreases in units of 10. The prefix and the base unit combined are used to indicate an amount. For example, deka is 10 times the base unit. A dekameter is 10 meters; a dekaliter is 10 liters; and a dekagram is 10 grams. The prefix hecto refers to 100 times the base amount; kilo is 1,000 times the base amount. The prefixes that indicate a fraction of the base unit are deci, which is 1/10 of the base unit; centi, which is 1/100 of the base unit; and milli, which is 1/1000 of the base unit.

Metric prefixes for multiples and subdivisions

The prefixes for multiples are as follows: deka (da), 10^1 (deka is the American spelling, but deca is also used); hecto (h), 10^2; kilo (k), 10^3; mega (M), 10^6; giga (G), 10^9; tera (T), 10^{12}; peta (P), 10^{15}; exa (E), 10^{18}; zetta (Z), 10^{21}; and yotta (Y), 10^{24}. The prefixes for subdivisions are as follows: deci (d), 10^{-1}; centi (c), 10^{-2}; milli (m), 10^{-3}; micro (μ), 10^{-6}; nano (n), 10^{-9}; pico (p), 10^{-12}; femto (f), 10^{-15}; atto (a), 10^{-18}; zepto (z), 10^{-21}; and yocto (y), 10^{-24}. The rule of thumb is that prefixes greater than 10^3 are capitalized. These abbreviations do not need a period after them. A decimeter is a tenth of a meter, a deciliter is a tenth of a liter, and a decigram is a tenth of a gram. Pluralization is understood. For example, when referring to 5 mL of water, no "s" needs to be added to the abbreviation.

SI units of measurement

SI uses second(s) to measure time. Fractions of seconds are usually measured in metric terms using prefixes such as millisecond (1/1,000 of a second) or nanosecond (1/1,000,000,000 of a second). Increments of time larger than a second are measured in minutes and hours, which are multiples of 60 and 24. An example of this is a swimmer's time in the 800-meter freestyle being described as 7:32.67, meaning 7 minutes, 32 seconds, and 67 one-hundredths of a second. One second is equal to 1/60 of a minute, 1/3,600 of an hour, and 1/86,400 of a day. Other SI base units are the ampere (A) (used to measure electric current), the kelvin (K) (used to measure thermodynamic temperature), the candela (cd) (used to measure luminous intensity), and the mole (mol) (used to measure the amount of a substance at a molecular level). Meter (m) is used to measure length and kilogram (kg) is used to measure mass.

Significant figures and estimation

The mathematical concept of significant figures or significant digits is often used to determine the accuracy of measurements or the level of confidence one has in a specific measurement. The significant figures of a measurement include all the digits known with certainty plus one estimated or uncertain digit. There are a number of rules for determining which digits are considered "important" or "interesting." They are: all non-zero digits are significant, zeros between digits are significant, and leading and trailing zeros are not significant unless they appear to the right of the non-zero digits in a decimal. For example, in 0.01230 the significant digits are 1230, and this number would be said to be accurate to the hundred-thousandths place. The zero indicates that the amount has actually been measured as 0. Other zeros are considered place holders, and are not important. A decimal point may be placed after zeros to indicate their importance (in 100. for example).

Conversion from decimal notation to scientific notation

Scientific notation is used because values in science can be very large or very small, which makes them unwieldy. A number in decimal notation is 93,000,000. In scientific notation, it is 9.3×10^7. The first number, 9.3, is the coefficient. It is always greater than or equal to 1 and less than 10. This number is followed by a multiplication sign. The base is always 10 in scientific notation. If the number is greater than ten, the exponent is positive. If the number is between zero and one, the exponent is negative. The first digit of the number is followed by a decimal point and then the rest of the number. In this case, the number is 9.3. To get that number, the decimal point was moved seven places from the end of the number, 93,000,000. The number of places, seven, is the exponent.

Graphs and charts

Graphs and charts are effective ways to present scientific data such as observations, statistical analyses, and comparisons between dependent variables and independent variables. On a line chart, the independent variable (the one that is being manipulated for the experiment) is represented on the horizontal axis (the x-axis). Any dependent variables (the ones that may change as the independent variable changes) are represented on the y-axis. An XY or scatter plot is often used to plot many points. A "best fit" line is drawn, which allows outliers to be identified more easily. Charts and their axes should have titles. The x and y interval units should be evenly spaced and labeled. Other types of charts are bar charts and histograms, which can be used to compare differences between the data collected for two variables. A pie chart can graphically show the relation of parts to a whole.

Presentation of data

Data collected during a science lab can be organized and presented in any number of ways. While straight narrative is a suitable method for presenting some lab results, it is not a suitable way to present numbers and quantitative measurements. These types of observations can often be better presented with tables and graphs. Data that is presented in tables and organized in rows and columns may also be used to make graphs quite easily. Other methods of presenting data include illustrations, photographs, video, and even audio formats. In a formal report, tables and figures are labeled and referred to by their labels. For example, a picture of a bubbly solution might be labeled Figure 1, Bubbly Solution. It would be referred to in the text in the following way: "The reaction created bubbles 10 mm in size, as shown in Figure 1, Bubbly Solution." Graphs are also labeled as figures. Tables are labeled in a different way. Examples include: Table 1, Results of Statistical Analysis, or Table 2, Data from Lab 2.

Errors

Errors that occur during an experiment can be classified into two categories: random errors and systematic errors. Random errors can result in collected data that is wildly different from the rest of the data, or they may result in data that is indistinguishable from the rest. Random errors are not consistent across the data set. In large data sets, random errors may contribute to the variability of data, but they will not affect the average. Random errors are sometimes referred to as noise. They may be caused by a student's inability to take the same measurement in exactly the same way or by outside factors that are not considered variables, but influence the data. A systematic error will show up consistently across a sample or data set, and may be the result of a flaw in the experimental design. This type of error affects the average, and is also known as bias.

Vocabulary

Mean
The average, found by taking the sum of a set of numbers and dividing by the number of numbers in the set.

Median
The middle number in a set of numbers sorted from least to greatest. If the set has an even number of entries, the median is the average of the two in the middle.

Mode
The value that appears most frequently in a data set. There may be more than one mode. If no value appears more than once, there is no mode.

Range
The difference between the highest and lowest numbers in a data set.

Standard deviation
Measures the dispersion of a data set or how far from the mean a single data point is likely to be.

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Measures the dispersion of a data set or how far from the mean a single data point is likely to be.

Regression analysis
A method of analyzing sets of data and sets of variables that involves studying how the typical value of the dependent variable changes when any one of the independent variables is varied and the other independent variables remain fixed.

Accident safety measures

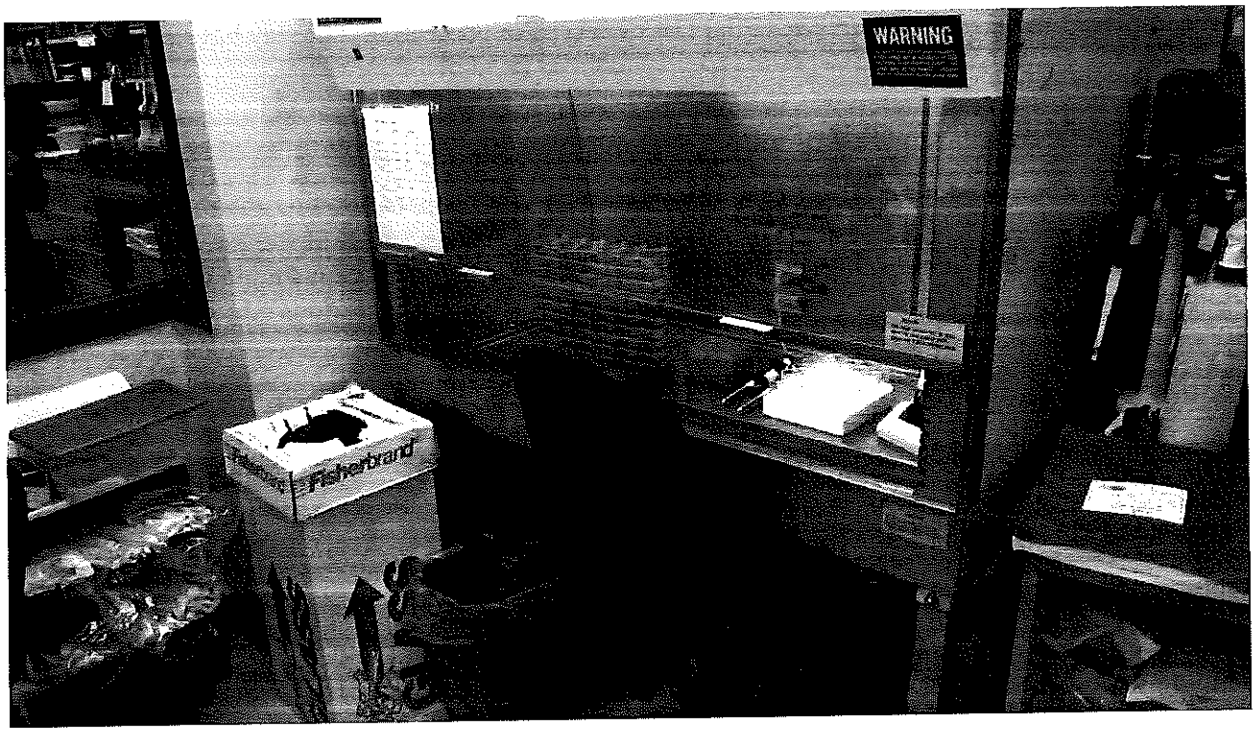
Any spills or accidents should be reported to the teacher so that the teacher can determine the safest clean-up method. The student should start to wash off a chemical spilled on the skin while reporting the incident. Some spills may require removal of contaminated clothing and use of the safety shower. Broken glass should be disposed of in a designated container. If someone's clothing catches fire they should walk to the safety shower and use it to extinguish the flames. A fire blanket may be used to smother a lab fire. A fire extinguisher, phone, spill neutralizers, and a first aid box are other types of safety equipment found in the lab. Students should be familiar with routes out of the room and the building in case of fire. Students should use the eye wash station if a chemical gets in the eyes.

Lab safety measures

Students should wear a lab apron and safety goggles. Loose or dangling clothing and jewelry, necklaces, and earrings should not be worn. Those with long hair should tie it back. Care should always be taken not to splash chemicals. Open-toed shoes such as sandals and flip-flops should not be worn, nor should wrist watches. Glasses are preferable to contact lenses since the latter carries a risk of chemicals getting caught between the lens and the eye. Students should always be supervised. The area where the experiment is taking place and the surrounding floor should be free of clutter. Only the lab book and the items necessary for the experiment should be present. Smoking, eating, and chewing gum are not permitted in the lab. Cords should not be allowed to dangle from work stations. There should be no rough-housing in the lab. Hands should be washed after the lab is complete.

Fume hood

Because of the potential safety hazards associated with chemistry lab experiments, such as fire from vapors and the inhalation of toxic fumes, a fume hood should be used in many instances. A fume hood carries away vapors from reagents or reactions. Equipment or reactions are placed as far back in the hood as practical to help enhance the collection of the fumes. The glass safety shield automatically closes to the appropriate height, and should be low enough to protect the face and body. The safety shield should only be raised to move equipment in and out of the hood. One should not climb inside a hood or stick one's head inside. All spills should be wiped up immediately and the glass should be cleaned if a splash occurs.



Possible safety hazards

Some specific safety hazards possible in a chemistry lab include:

- Fire: Fire can be caused by volatile solvents such as ether, acetone, and benzene being kept in an open beaker or Erlenmeyer flask. Vapors can creep along the table and ignite if they reach a flame or spark. Solvents should be heated in a hood with a steam bath, not on a hot plate.
- Explosion: Heating or creating a reaction in a closed system can cause an explosion, resulting in flying glass and chemical splashes. The system should be vented to prevent this.
- Chemical and thermal burns: Many chemicals are corrosive to the skin and eyes.
- Inhalation of toxic fumes: Some compounds severely irritate membranes in the eyes, nose, throat, and lungs.
- Absorption of toxic chemicals such as dimethyl sulfoxide (DMSO) and nitrobenzene through the skin.
- Ingestion of toxic chemicals.

Safety gloves

There are many types of gloves available to help protect the skin from cuts, burns, and chemical splashes. There are many considerations to take into account when choosing a glove. For example, gloves that are highly protective may limit dexterity. Some gloves may not offer appropriate protection against a specific chemical. Other considerations include degradation rating, which indicates how effective a glove is when exposed to chemicals; breakthrough time, which indicates how quickly a chemical breaks through the surface of the glove; and permeation rate, which indicates how quickly chemicals seep through after the initial breakthrough. Disposable latex, vinyl, or nitrile gloves are usually appropriate for most circumstances, and offer protection from incidental splashes and contact. Other types of gloves include butyl, neoprene, PVC, PVA, viton, silver shield, and natural rubber. Each offers its own type of protection, but may have drawbacks as well. Double-gloving can improve resistance or dexterity in some instances.

Chemical handling and storage

Students should take care when carrying chemicals from one place to another. Chemicals should never be taken from the room, tasted, or touched with bare hands. Safety gloves should be worn when appropriate and glove/chemical interactions and glove deterioration should be considered. Hands should always be washed thoroughly after a lab. Potentially hazardous materials intended for use in chemistry, biology, or other science labs should be secured in a safe area where relevant Safety Data Sheets (SDS) can be accessed. Chemicals and solutions should be used as directed and labels should be read before handling solutions and chemicals. Extra chemicals should not be returned to their original containers, but should be disposed of as directed by the school district's rules or local ordinances. Local municipalities often have hazardous waste disposal programs. Acids should be stored separately from other chemicals. Flammable liquids should be stored away from acids, bases, and oxidizers.

Bunsen burners

When using a Bunsen burner, loose clothing should be tucked in, long hair should be tied back, and safety goggles and aprons should be worn. Students should know what to do in case of a fire or accident. When lighting the burner, strikers should always be used instead of matches. Do not touch the hot barrel. Tongs (never fingers) should be used to hold the material in the flame. To heat liquid, a flask may be set upon wire gauze on a tripod and secured with an iron ring or clamp on a stand. The flame is extinguished by turning off the gas at the source.

Lab animals and dissections

Animals to be used for dissections should be obtained from a company that provides animals for this purpose. Road kill or decaying animals that a student brings in should not be used. It is possible that such an animal may have a pathogen or a virus, such as rabies, which can be transmitted via the saliva of even a dead animal. Students should use gloves and should not participate if they have open sores or moral objections to dissections. It is generally accepted that biological experiments may be performed on lower-order life forms and invertebrates, but not on mammalian vertebrates and birds. No animals should be harmed physiologically. Experimental animals should be kept, cared for, and handled in a safe manner and with compassion. Pathogenic (anything able to cause a disease) substances should not be used in lab experiments.

Earth Science, Chemistry, and Physics

Astronomy

Astronomy is the scientific study of celestial objects and their positions, movements, and structures. Celestial does not refer to the Earth in particular, but does include its motions as it moves through space. Other objects include the Sun, the Moon, planets, satellites, asteroids, meteors, comets, stars, galaxies, the universe, and other space phenomena. The term astronomy has its roots in the Greek words "astro" and "nomos," which means "laws of the stars."

Sun

The Sun is at the center of the solar system. It is composed of 70% hydrogen (H) and 28% helium (He). The remaining 2% is made up of metals. The Sun is one of 100 billion stars in the Milky Way galaxy. Its diameter is 1,390,000 km, its mass is 1.989×10^{30} kg, its surface temperature is 5,800 K, and its core temperature is 15,600,000 K. The Sun represents more than 99.8% of the total mass of the solar system. At the core, the temperature is 15.6 million K, the pressure is 250 billion atmospheres, and the density is more than 150 times that of water. The surface is called the photosphere. The chromosphere lies above this, and the corona, which extends millions of kilometers into space, is next. Sunspots are relatively cool regions on the surface with a temperature of 3,800 K. Temperatures in the corona are over 1,000,000 K. Its magnetosphere, or heliosphere, extends far beyond Pluto.

Moon

The Moon is the fifth largest satellite in the solar system. It orbits the Earth about every 27.3 days. The changes of the Earth, Sun, and Moon in relation to each other cause the phases of the Moon, which repeat every 29.5 days. The Moon's gravitational pull (along with the Sun's) is responsible for the tides on Earth. Its diameter is about 3,474 km and its gravity is about 17% of Earth's. The lunar maria (plural of mare) on the Moon's surface is dark thin layers composed of dark basalt. They were formed by ancient volcanoes. There are many impact craters on the Moon. There were numerous impact craters on Earth at one time, but they have been transformed by erosion over time. Very few are still visible.

It takes about one month for the Moon to go through all its phases. Waxing refers to the two weeks during which the Moon goes from a new moon to a full moon. About two weeks is spent waning, going from a full moon to a new moon. The lit part of the Moon always faces the Sun. The phases of waxing are: new moon, during which the Moon is not illuminated and rises and sets with the Sun; crescent moon, during which a tiny sliver is lit; first quarter, during which half the Moon is lit and the phase of the Moon is due south on the meridian; gibbous, during which more than half of the Moon is lit and has a shape similar to a football; right side, during which the Moon is lit; and full moon, during which the Moon is fully illuminated, rises at sunset, and sets at sunrise. After a full moon, the Moon is waning. The phases of waning are: gibbous, during which the left side is lit and the Moon rises after sunset and sets after sunrise; third quarter, during which the Moon is half lit and rises at midnight and sets at noon; crescent, during which a tiny sliver is lit; and new moon, during which the Moon is not illuminated and rises and sets with the Sun.

Earth-Moon-Sun system

The Earth-Moon-Sun system is responsible for eclipses. From Earth, the Sun and the Moon appear to be about the same size. An eclipse of the Sun occurs during a new Moon, when the side of the Moon facing the Earth is not illuminated. The Moon passes in front of the Sun and blocks its view from Earth. Eclipses do not occur every month because the orbit of the Moon is at about a 5° angle to the plane of Earth's orbit. An eclipse of the Moon happens during the full Moon phase. The Moon passes through the shadow of the Earth and blocks sunlight from reaching it, which temporarily causes darkness. During a lunar eclipse, there are two parts to the shadow. The umbra is the dark, inner region. The sun is completely blocked in this area. The penumbra is a partially lighted area around the umbra. Earth's shadow is four times longer than the Moon's shadow.

Earth's atmosphere

The atmosphere consists of 78% nitrogen, 21% oxygen, and 1% argon. It also includes traces of water vapor, carbon dioxide and other gases, dust particles, and chemicals from Earth. The atmosphere becomes thinner the farther it is from the Earth's surface. It becomes difficult to breathe at about 3 km above sea level. The atmosphere gradually fades into space.

The main layers of the Earth's atmosphere (from lowest to highest) are:

- Troposphere (lowest layer): where life exists and most weather occurs; elevation 0–15 km
- Stratosphere: has the ozone layer, which absorbs UV radiation from the sun; hottest layer; where most satellites orbit; elevation 15–50 km
- Mesosphere: coldest layer; where meteors will burn up; elevation 50–80 km
- Thermosphere: where the international space station orbits; elevation 80–700 km
- Exosphere (outermost layer): consists mainly of hydrogen and helium; extends to ~10,000 km

➤ **Review Video: Earth's Atmosphere**
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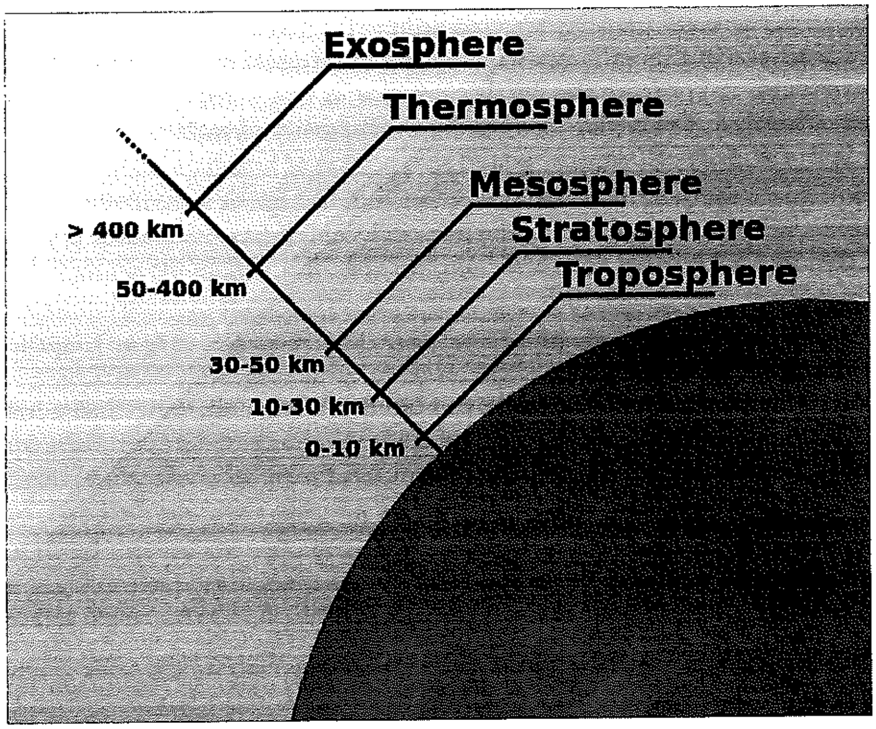
Ozone layer, ionosphere, homosphere, and heterosphere

The ozone layer, although contained within the stratosphere, is determined by ozone (O_3) concentrations. It absorbs the majority of ultraviolet light from the Sun.

The ionosphere encompasses the mesosphere, thermosphere, and parts of the exosphere. The molecules in this layer are partially ionized by solar radiation. It affects radio wave transmission and auroras.

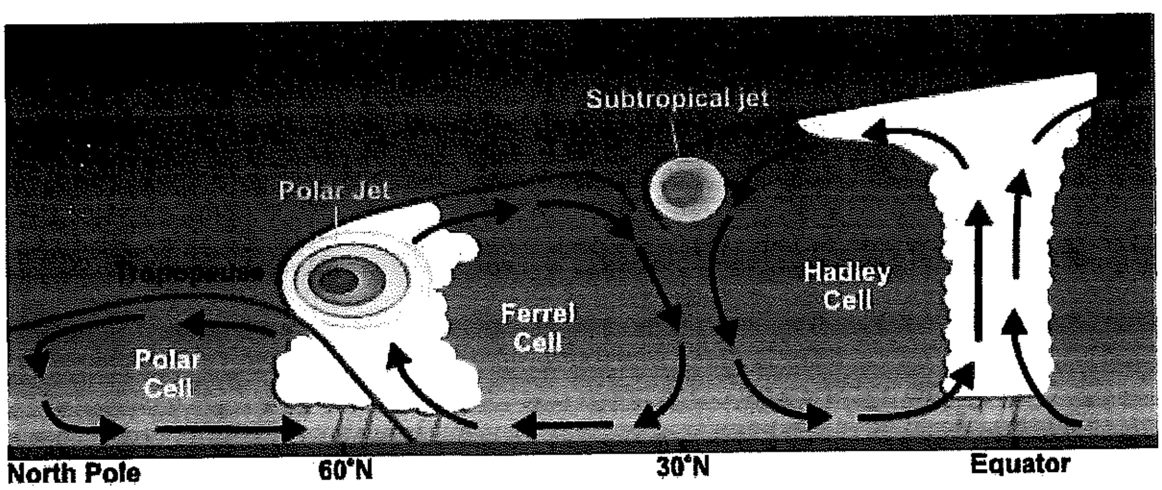
The homosphere encompasses the troposphere, stratosphere, and mesosphere. Gases in the homosphere are considered well mixed.

The heterosphere encompasses the thermosphere and exosphere. In this layer, the distance that particles can move without colliding is large. As a result, gases are stratified according to their molecular weights. Heavier gases such as oxygen and nitrogen occur near the bottom of the heterosphere, while hydrogen, the lightest element, is found at the top.



Tropospheric circulation

Most weather takes place in the troposphere. Air circulates in the atmosphere by convection and in various types of "cells." Air near the equator is warmed by the Sun and rises. Cool air rushes under it, and the higher, warmer air flows toward Earth's poles. At the poles, it cools and descends to the surface. It is now under the hot air, and flows back to the equator. Air currents coupled with ocean currents move heat around the planet, creating winds, weather, and climate. Winds can change direction with the seasons. For example, in Southeast Asia and India, summer monsoons are caused by air being heated by the Sun. This air rises, draws moisture from the ocean, and causes daily rains. In winter, the air cools, sinks, pushes the moist air away, and creates dry weather.



Hydrosphere

Much of Earth is covered by a layer of water or ice called the hydrosphere. Most of the hydrosphere consists of ocean water. The water cycle and the many processes involved in it take place in the hydrosphere. There are several theories regarding how the Earth's hydrosphere was formed. Earth contains more surface water than other planets in the inner solar system. Outgassing, the slow release of trapped water vapor from the Earth's interior, is one theory used to explain the existence of water on Earth. This does not really account for the quantity of water on Earth, however. Another hypothesis is that the early Earth was subjected to a period of bombardment by comets and water-rich asteroids, which resulted in the release of water into the Earth's environment. If this is true, much of the water on the surface of the Earth today originated from the outer parts of the solar system beyond Neptune.

Properties of water

Water contains an extensive network of hydrogen bonds. As a result, water has a high heat capacity, meaning that it can absorb a large amount of heat without changing temperature, and a high heat of vaporization, meaning that it can absorb a large amount of heat before it transforms from a liquid to a gas state. One result of these properties is that water helps to regulate the Earth's climate by absorbing thermal radiation.

The presence of hydrogen bonds is also responsible for capillary action, which allows water to rise into a narrow tube against the force of gravity. This is part of the reason that water can be transported into the body of trees.

When water freezes, it becomes less dense and expands, allowing ice to float on water. This insulates the water below, preventing a lake from freezing from the bottom up. If a lake froze from the bottom up, it might destroy life in the lake, and might not completely thaw during the summer.

Meteorology, weather, and climate

Meteorology is the study of the atmosphere, particularly as it pertains to forecasting the weather and understanding its processes. Weather is the condition of the atmosphere at any given moment. Most weather occurs in the troposphere. Weather includes changing events such as clouds, storms, and temperature, as well as more extreme events such as tornadoes, hurricanes, and blizzards. Climate refers to the average weather for a particular area over time, typically at least 30 years. Latitude is an indicator of climate. Changes in climate occur over long time periods.

Weather phenomena

Common atmospheric conditions that are frequently measured are temperature, precipitation, wind, and humidity. These weather conditions are often measured at permanently fixed weather stations so weather data can be collected and compared over time and by region. Measurements may also be taken by ships, buoys, and underwater instruments. Measurements may also be taken under special circumstances. The measurements taken include temperature, barometric pressure, humidity, wind speed, wind direction, and precipitation. Usually, the following instruments are used: A thermometer is used for measuring temperature; a barometer is used for measuring barometric/air pressure; a hygrometer is used for measuring humidity; an anemometer is used for measuring wind speed; a weather vane is used for measuring wind direction; and a rain gauge is used for measuring precipitation.

Latitudinal variation of solar radiation

Latitude is a measurement of the distance from the equator. The distance from the equator indicates how much solar radiation a particular area receives. The equator receives more sunlight, while polar areas receive less. The Earth tilts slightly on its rotational axis. This tilt determines the seasons and affects weather. There are eight biomes or ecosystems with particular climates that are associated with latitude. Those in the high latitudes, which get the least sunlight, are tundra and taiga. Those in the mid latitudes are grassland, temperate forest, and chaparral. Those in latitudes closest to the equator are the warmest. The sixth and seventh biomes are desert and tropical rain forest. The eighth biome is the ocean, which is unique because it consists of water and spans the entire globe. Insolation refers to incoming solar radiation. Diurnal variations refer to the daily changes in insolation. The greatest insolation occurs at noon.

Tilt of the Earth

The tilt of the Earth on its axis is 23.5°. This tilt causes the seasons and affects the temperature because it affects the amount of Sun the area receives. When the Northern or Southern Hemispheres are tilted toward the Sun, the hemisphere tilted toward the sun experiences summer and the other hemisphere experiences winter. This reverses as the Earth revolves around the Sun. Fall and spring occur between the two extremes. The equator gets the same amount of sunlight every day of the year, about 12 hours, and doesn't experience seasons. Both poles have days during the winter when they are tilted away from the Sun and receive no daylight. The opposite effect occurs during the summer. There are 24 hours of daylight and no night. The summer solstice, the day with the most amount of sunlight, occurs on June 21st in the Northern Hemisphere and on December 21st in the Southern Hemisphere. The winter solstice, the day with the least amount of sunlight, occurs on December 21st in the Northern Hemisphere and on June 21st in the Southern Hemisphere.

Breezes

Sea breezes and land breezes help influence an area's prevailing winds, particularly in areas where the wind flow is light. Sea breezes, also called onshore breezes, are the result of the different capacities for absorbing heat of the ocean and the land. The sea can be warmed to a greater depth than the land. It warms up more slowly than the land's surface. Land heats air above it as its temperature increases. This heated, warmer air is less dense and rises as a result. The cooler air above the sea and higher sea level pressure create a wind flow in the direction of the land. Coastal areas often receive these cooler breezes. Land cools slower at night than the ocean, and coastal breezes weaken at this time. When the land becomes so cool that it is cooler than the sea surface, the pressure over the ocean is lower than the land. This creates a land breeze. This can cause rain and thunderstorms over the ocean.

Wind

Winds are the result of air moving by convection. Masses of warm air rise, and cold air sweeps into their place. The warm air also moves, cools, and sinks. The term "prevailing wind" refers to the wind that usually blows in an area in a single direction. Dominant winds are the winds with the highest speeds. Belts or bands that run latitudinally and blow in a specific direction are associated with convection cells. Hadley cells are formed directly north and south of the equator. The Farrell cells occur at about 30° to 60°. The jet stream runs between the Farrell cells and the polar cells. At the higher and lower latitudes, the direction is easterly. At mid latitudes, the direction is westerly. From the North Pole to the south, the surface winds are Polar High Easterlies, Subpolar Low Westerlies, Subtropical High or Horse Latitudes, North-East Trade winds, Equatorial Low or Doldrums, South-East Trades, Subtropical High or Horse Latitudes, Subpolar Low Easterlies, and Polar High.

Atmospheric variations

Terrain affects several local atmospheric conditions, including temperature, wind speed, and wind direction. When there are land forms, heating of the ground can be greater than the heating of the surrounding air than it would be at the same altitude above sea level. This creates a thermal low in the region and amplifies any existing thermal lows. It also changes the wind circulation. Terrain such as hills and valleys increase friction between the air and the land, which disturbs the air flow. This physical block deflects the wind, and the resulting air flow is called a barrier jet. Just as the heating of the land and air affects sea and land breezes along the coast, rugged terrain affects the wind circulation between mountains and valleys.

Thunderstorms

A thunderstorm is one of the many weather phenomena that can be created during the ongoing process of heat moving through Earth's atmosphere. Thunderstorms form when there is moisture to form rain clouds, unstable air, and lift. Unstable air is usually caused by warm air rising quickly through cold air. Lift can be caused by fronts, sea breezes, and elevated terrain, such as mountains. Single cell thunderstorms have one main draft. Multicell clusters have clusters of storms. Multicell lines have severe thunderstorms along a squall line. Supercell thunderstorms are large and severe, and have the capacity to produce destructive tornadoes. Thunder is a sonic shock wave caused by the rapid expansion of air around lightning. Lightning is the discharge of electricity during a thunderstorm. Lightning can also occur during volcanic eruptions or dust storms.

Cyclones

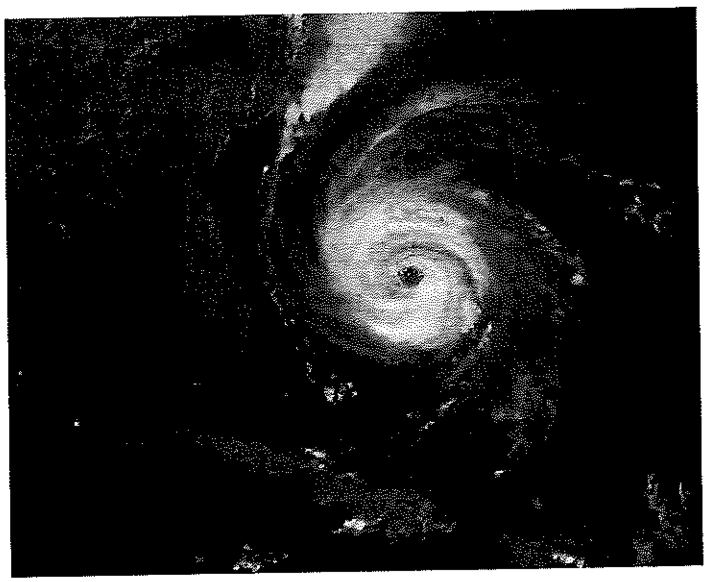
Cyclones generally refer to large air masses rotating in the same direction as the Earth. They are formed in low pressure areas. Cyclones vary in size. Some are mesoscale systems, which vary in size from about 5 km to hundreds of kilometers. Some are synoptic scale systems, which are about 1,000 km in size. The size of subtropical cyclones is somewhere in between. Cold-core polar and extratropical cyclones are synoptic scale systems. Warm-core tropical, polar low, and mesocyclones are mesoscale systems. Extratropical cyclones, sometimes called mid-latitude cyclones or wave cyclones, occur in the middle latitudes. They have neither tropical nor polar characteristics. Extratropical cyclones are everyday phenomena which, along with anticyclones, drive the weather over much of the Earth. They can produce cloudiness, mild showers, heavy gales, and thunderstorms. Anticyclones occur when there is a descending pocket of air of higher than average pressure. Anticyclones are usually associated with clearing skies and drier, cooler air.

Tornados

During a tornado, wind speeds can be upward of 300 miles per hour. Tornados are rotating, funnel-like clouds. They have a very high energy density, which means they are very destructive to a small area. They are also short-lived. About 75% of the world's tornadoes occur in the United States, mostly in an area of the Great Plains known as Tornado Alley. If there are two or more columns of air, it is referred to as a multiple vortex tornado. A satellite tornado is a weak tornado that forms near a larger one within the same mesocyclone. A waterspout is a tornado over water. The severity of tornadoes is measured using the Enhanced Fujita Scale. An EF-0 rating is associated with a 3-second wind gust between 65 and 85 miles per hour, while an EF-5 is associated with wind speeds of greater than 200 mph.

Hurricanes

A hurricane is one of the three weather phenomena that can occur as a result of a tropical cyclone. Hurricanes appear well-organized and sometimes have a recognizable eye with strong rotation. Its wind speed is more than 73 mph. Hurricanes are classified using the Saffir-Simpson Scale, which ranges from category 1 to category 5. A category 5 hurricane has wind speeds greater than 155 mph. Hurricanes are named alphabetically through the season starting with "A." The letters "Q," "U," and "Z" are not used. There are six lists of names that are used from year to year. The names of devastating hurricanes are retired from the list.



Humidity

Humidity refers to water vapor contained in the air. The amount of moisture contained in air depends upon its temperature. The higher the air temperature, the more moisture it can hold. These higher levels of moisture are associated with higher humidity. Absolute humidity refers to the total amount of moisture air is capable of holding at a certain temperature. Relative humidity is the ratio of water vapor in the air compared to the amount the air is capable of holding at its current temperature. As temperature decreases, absolute humidity stays the same and relative humidity increases. A hygrometer is a device used to measure humidity. The dew point is the temperature at which water vapor condenses into water at a particular humidity.

Precipitation

After clouds reach the dew point, precipitation occurs. Precipitation can take the form of a liquid or a solid. It is known by many names, including rain, snow, ice, dew, and frost. Liquid forms of precipitation include rain and drizzle. Rain or drizzle that freezes on contact is known as freezing rain or freezing drizzle. Solid or frozen forms of precipitation include snow, ice needles or diamond dust, sleet or ice pellets, hail, and graupel or snow pellets. Virga is a form of precipitation that evaporates before reaching the ground. It usually looks like sheets or shafts falling from a cloud. The amount of rainfall is measured with a rain gauge. Intensity can be measured according to how fast precipitation is falling or by how severely it limits visibility. Precipitation plays a major role in the water cycle since it is responsible for depositing much of the Earth's fresh water.

Heat waves

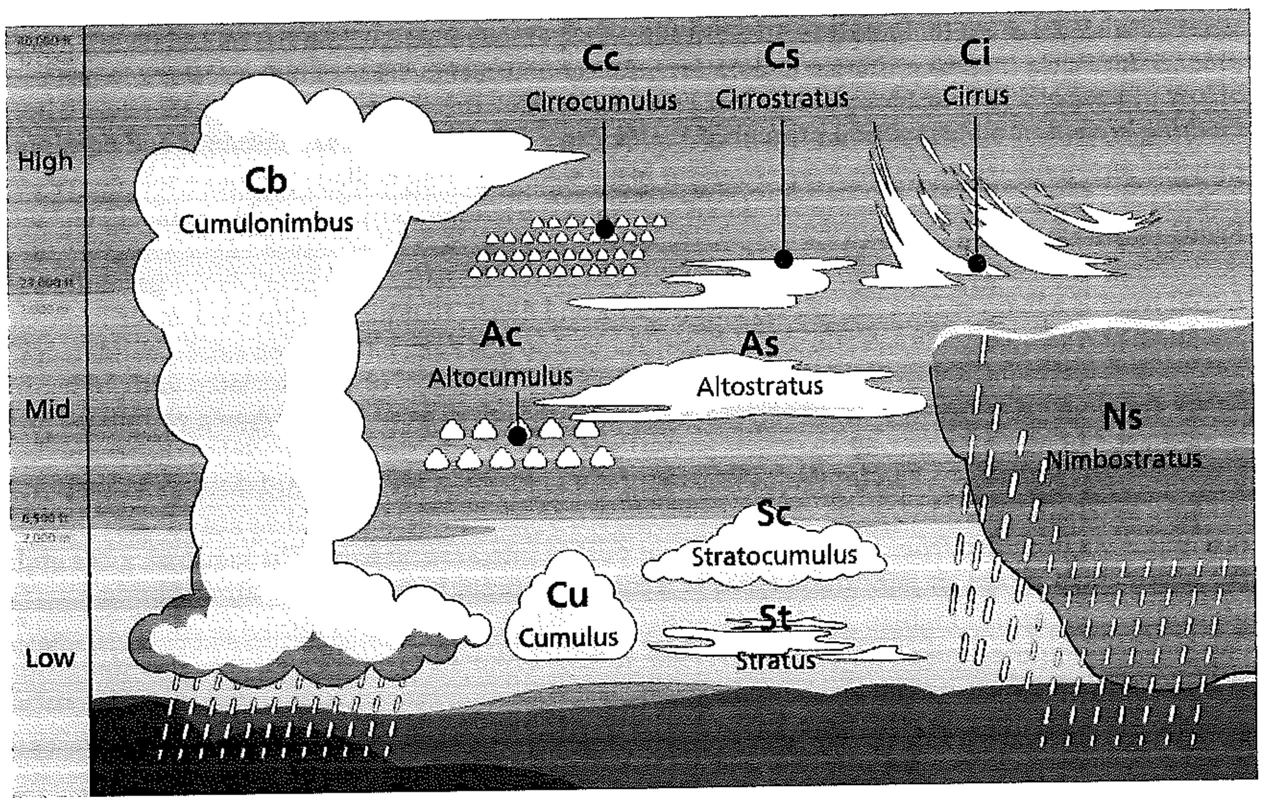
A heat wave is a stretch of hotter than normal weather. Some heat waves may involve high humidity and last longer than a week. Heat waves can form if a warm high-pressure weather system stalls in an area. The jet stream is a flow that moves air through the middle latitudes. When this shifts, it can bring a pattern of unusually warm weather into a region, creating a heat wave. Heat can be trapped by cities. If there is no rain or clouds to help cool the weather, the heat wave can linger. In humans, heat waves can lead to heat stroke, heat exhaustion, cramps, dehydration, and even death. Plants can dry up and crops can fail. There is also a greater threat of fires during a heat wave in dry areas.

Cloud formation

Clouds form when air cools and warm air is forced to give up some of its water vapor because it can no longer hold it. This vapor condenses and forms tiny droplets of water or ice crystals called clouds. Particles, or aerosols, are needed for water vapor to form water droplets. These are called condensation nuclei. Clouds are created by surface heating, mountains and terrain, rising air masses, and weather fronts. Clouds precipitate, returning the water they contain to Earth. Clouds can also create atmospheric optics. They can scatter light, creating colorful phenomena such as rainbows, colorful sunsets, and the green flash phenomenon.

Cloud types

Most clouds can be classified according to the altitude of their base above Earth's surface. High clouds occur at altitudes between 5,000 and 13,000 meters. Middle clouds occur at altitudes between 2,000 and 7,000 meters. Low clouds occur from the Earth's surface to altitudes of 2,000 meters. Types of high clouds include cirrus (Ci), thin wispy mare's tails that consist of ice; cirrocumulus (Cc), small, pillow-like puffs that often appear in rows; and cirrostratus (Cs), thin, sheetlike clouds that often cover the entire sky. Types of middle clouds include altocumulus (Ac), gray-white clouds that consist of liquid water; and altostratus (As), grayish or blue-gray clouds that span the sky. Types of low clouds include stratus (St), gray and fog-like clouds consisting of water droplets that take up the whole sky; stratocumulus (Sc), low-lying, lumpy gray clouds; and nimbostratus (Ns), dark gray clouds with uneven bases that indicate rain or snow. Two types of clouds, cumulus (Cu) and cumulonimbus (Cb), are capable of great vertical growth. They can start at a wide range of altitudes, from the Earth's surface to altitudes of 13,000 meters.



Nonstandard cloud types

Contrails, or condensation trails, are thin white streaks caused by jets. These are created from water vapor condensing and freezing the jet's exhaust particles. Contrails can be further classified as short-lived, persistent non-spreading, and persistent. Lenticular or lee wave, clouds are created by an air current over an obstacle, such as a mountain. They appear to be stationary, but are actually forming, dissipating, and reforming in the same place. Kelvin-Helmholtz clouds are formed by winds with different speeds or directions. They look like ocean waves. Mammatus clouds hang down from the base of a cloud, usually a cumulonimbus cloud. They often occur during the warmer months.

Air masses and weather fronts

Air masses are large volumes of air in the troposphere of the Earth. They are categorized by their temperature and by the amount of water vapor they contain. Arctic and Antarctic air masses are cold. Polar air masses are cool. Tropical and equatorial air masses are hot. Other types of air masses include maritime and monsoon, both of which are moist and unstable. There are also continental and superior air masses, which are dry. A weather front separates two masses of air of different densities. It is the principal cause of meteorological phenomena. Air masses are quickly and easily affected by the land they are above. They can have certain characteristics, and then develop new ones when they get blown over a different area.

Pressure systems

The concept of atmospheric pressure involves the idea that air exerts a force. An imaginary column of air 1 square inch in size rising through the atmosphere would exert a force of 14.7 pounds per square inch (psi). Both temperature and altitude affect atmospheric pressure. Low and high pressure systems tend to want to equalize. Air tends to move from areas of high pressure to areas of low pressure. When air moves into a low pressure system, the air that was there gets pushed up, creating lower temperatures and pressures. Water vapor condenses and forms clouds and possibly rain and snow. A barometer is used to measure air pressure.

Frontal systems

A cold front is a mass of cold air, usually fast moving and dense, that moves into a warm air front, producing clouds. This often produces a temperature drop and rain, hail (frozen rain), thunder, and lightning. A warm front is pushed up by a fast moving cold front. It is often associated with high wispy clouds, such as cirrus and cirrostratus clouds. A stationary front forms when a warm and cold front meet, but neither is strong enough to move the other. Winds blowing parallel to the fronts keep the front stationary. The front may remain in the same place for days until the wind direction changes and both fronts become a single warm or cold front. In other cases, the entire front dissipates. An occluded front is when a cold front pushes into a warm front. The warm air rises and the two masses of cool air join. These types of fronts often occur in areas of low atmospheric pressure.

Weather forecasting

Short and long-term weather forecasting is important because the day-to-day weather greatly affects humans and human activity. Severe weather and natural events can cause devastating harm to humans, property, and sources of livelihood, such as crops. The persistence method of forecasting can be used to create both short and long-term forecasts in areas that change very little or change slowly. It assumes that the weather tomorrow will be similar to the weather today. Barometric pressure is measured because a change in air pressure can indicate the arrival of a cold front that could lead to precipitation. Long-term forecasts based on climate data are useful to help people prepare for seasonal changes and severe events such as hurricanes.

Erosion

Erosion is the wearing away of rock materials from the Earth's surface. Erosion can be classified as natural geologic erosion and erosion due to human activity. Natural geologic erosion occurs due to weathering and gravity. Factors involved in natural geologic erosion are typically long term forces.

Human activities such as development, farming, and deforestation occur over shorter periods of time. Soil, which supports plant growth, is the topmost layer of organic material. One type of erosion is sheet erosion, which is the gradual and somewhat uniform removal of surface soil. Rills are small rivulets that cut into soil. Gullies are rills that have become enlarged due to extended water run-off. Sandblows are caused by wind blowing away particles. Negative effects of erosion include sedimentation in rivers, which can pollute water and damage ecosystems. Erosion can also result in the removal of topsoil, which destroys crops and prevents plants from growing. This reduces food production and alters ecosystems.

Deposition

Deposition, or sedimentation, is the geological process in which previously eroded material is transported or added to a land form or land mass. Erosion and sedimentation are complementary geological processes. Running water causes a substantial amount of deposition of transported materials in both fresh water and coastal areas. Examples include gravity transporting material down the slope of a mountain and depositing it at the base of the slope. Another example is when sandstorms deposit particles in other locations. When glaciers melt and retreat, it can result in the deposition of sediments. Evaporation is also considered to cause deposition since dissolved materials are left behind when water evaporates. Deposition can include the build up of organic materials. For example, chalk is partially made up of the small calcium carbonate skeletons of marine plankton, which helps create more calcium carbonate from chemical processes.

Weathering

There are two basic types of weathering: mechanical and chemical. Weathering is a very prominent process on the Earth's surface. Materials weather at different rates, which are known as differential weathering. Mechanical and chemical weathering are interdependent. For example, chemical weathering can loosen the bonds between molecules and allow mechanical weathering to take place. Mechanical weathering can expose the surfaces of land masses and allow chemical weathering to take place. Impact, abrasion, frost wedging, root wedging, salt wedging, and uploading are types of mechanical weathering.

Types of chemical weathering are dissolution, hydration, hydrolysis, oxidation, biological, and carbonation. The primary type of chemical weathering is caused by acid rain. Carbonic and sulfuric acids can enter rain when they are present in the atmosphere. This lowers the pH value of rain, making it more acidic. Normal rain water has a pH value of 5.5. Acid rain has a pH value of 4 or less.

Properties of matter

Matter refers to substances that have mass and occupy space (or volume). The traditional definition of matter describes it as having three states: solid, liquid, and gas. These different states are caused by differences in the distances and angles between molecules or atoms, which result in differences in the energy that binds them. Solid structures are rigid or nearly rigid and have strong bonds. Molecules or atoms of liquids move around and have weak bonds, although they are not weak enough to readily break. Molecules or atoms of gases move almost independently of each other, are typically far apart, and do not form bonds. The current definition of matter describes it as having four states. The fourth is plasma, which is an ionized gas that has some electrons that are described as free because they are not bound to an atom or molecule.

The following table shows similarities and differences between solids, liquids, and gases:

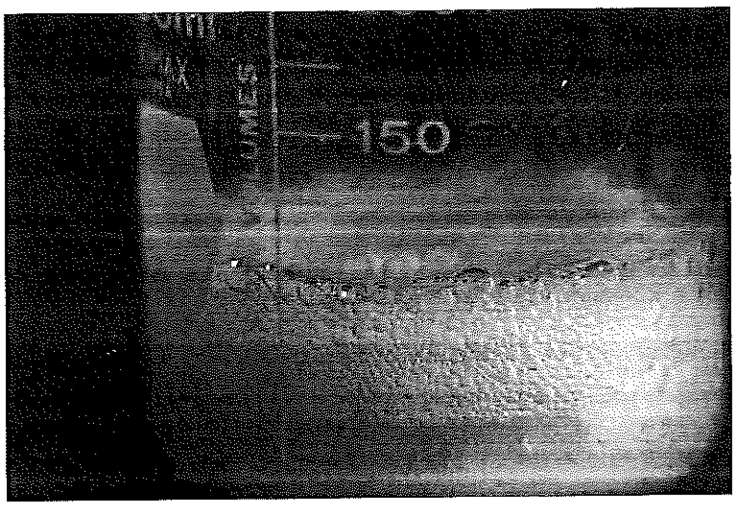
	Solid	Liquid	Gas
Shape	Fixed shape	No fixed shape (assumes shape of container)	No fixed shape (assumes shape of container)
Volume	Fixed	Fixed	Volume changes to occupy the space of the container
Fluidity	Does not flow easily	Flows easily	Flows easily
Compressibility	Hard to compress	Hard to compress	Compresses

In contrast to chemical properties, physical properties can be observed or measured without chemical reactions. These include properties such as color, elasticity, mass, volume, and temperature. Mass is a measure of the amount of substance in an object. Weight is a measure of the gravitational pull of Earth on an object. Volume is a measure of the amount of space occupied. There are many formulas to determine volume. For example, the volume of a cube is the length of one side cubed (a^3) and the volume of a rectangular prism is length times width times height ($l \cdot w \cdot h$). The volume of an irregular shape can be determined by how much water it displaces. Density is a measure of the amount of mass per unit volume. The formula to find density is mass divided by volume ($D=m/V$). It is expressed in terms of mass per cubic unit, such as grams per cubic centimeter (g/cm^3). Specific gravity is a measure of the ratio of a substance's density compared to the density of water.

Both physical changes and chemical reactions are everyday occurrences. Physical changes do not result in different substances. For example, when water becomes ice it has undergone a physical change, but not a chemical change. It has changed its form, but not its composition. It is still H_2O. Chemical properties are concerned with the constituent particles that make up the physicality of a substance. Chemical properties are apparent when chemical changes occur. The chemical properties of a substance are influenced by its electron configuration, which is determined in part by the number of protons in the nucleus (the atomic number). Carbon, for example, has 6 protons and 6 electrons. It is an element's outermost valence electrons that mainly determine its chemical properties. Chemical reactions may release or consume energy.

Reactions

Chemical reactions measured in human time can take place quickly or slowly. They can take fractions of a second or billions of years. The rates of chemical reactions are determined by how frequently reacting atoms and molecules interact. Rates are also influenced by the temperature and various properties (such as shape) of the reacting materials. Catalysts accelerate chemical reactions (decrease activation energy), while inhibitors decrease reaction rates (increase activation energy). Some types of reactions release energy in the form of heat and light. Some types of reactions involve the transfer of either electrons or hydrogen ions between reacting ions, molecules, or atoms. In other reactions, chemical bonds are broken down by heat or light to form reactive radicals with electrons that will readily form new bonds. Processes such as the formation of ozone and greenhouse gases in the atmosphere and the burning and processing of fossil fuels are controlled by radical reactions.



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Chemical equations describe chemical reactions. The reactants are on the left side before the arrow and the products are on the right side after the arrow. The arrow indicates the reaction or change. The coefficient, or stoichiometric coefficient, is the number before the element, and indicates the ratio of reactants to products in terms of moles. The equation for the formation of water from hydrogen and oxygen, for example, is $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$. The 2 preceding hydrogen and water is the coefficient, which means there are 2 moles of hydrogen and 2 of water. There is 1 mole of oxygen, which does not have to be indicated with the number 1. In parentheses, g stands for gas, l stands for liquid, s stands for solid, and aq stands for aqueous solution (a substance dissolved in water). Charges are shown in superscript for individual ions, but not for ionic compounds. Polyatomic ions are separated by parentheses so the ion will not be confused with the number of ions.

An unbalanced equation is one that does not follow the law of conservation of mass, which states that matter can only be changed, not created. If an equation is unbalanced, the numbers of atoms indicated by the stoichiometric coefficients on each side of the arrow will not be equal. Start by writing the formulas for each species in the reaction. Count the atoms on each side and determine if the number is equal. Coefficients must be whole numbers. Fractional amounts, such as half a molecule, are not possible. Equations can be balanced by multiplying the coefficients by a constant that will produce the smallest possible whole number coefficient. $H_2 + O_2 \rightarrow H_2O$ is an example of an unbalanced equation. The balanced equation is $2H_2 + O_2 \rightarrow 2H_2O$, which indicates that it takes two moles of hydrogen and one of oxygen to produce two moles of water.

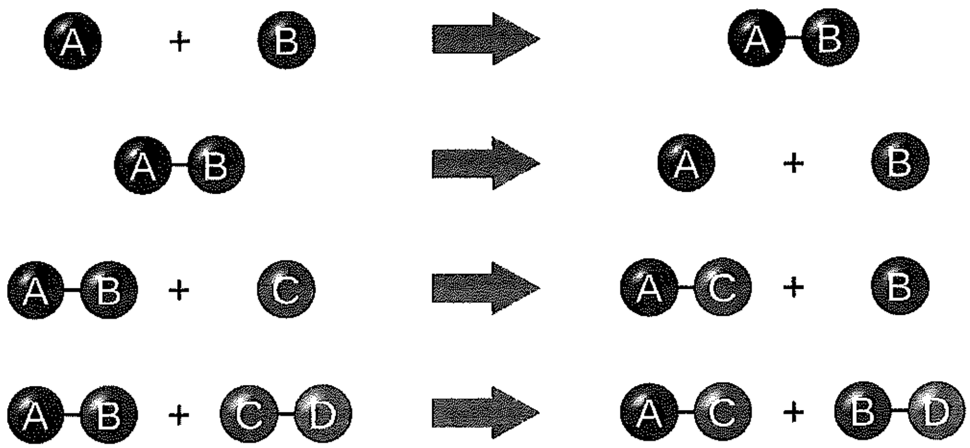
One way to organize chemical reactions is to sort them into two categories: oxidation/reduction reactions (also called redox reactions) and metathesis reactions (which include acid/base reactions). Oxidation/reduction reactions can involve the transfer of one or more electrons, or they can occur as a result of the transfer of oxygen, hydrogen, or halogen atoms. The species that loses electrons is oxidized and is referred to as the reducing agent. The species that gains electrons is reduced and is referred to as the oxidizing agent. The element undergoing oxidation experiences an increase in its oxidation number, while the element undergoing reduction experiences a decrease in its oxidation number. Single replacement reactions are types of oxidation/reduction reactions. In a single replacement reaction, electrons are transferred from one chemical species to another. The transfer of electrons results in changes in the nature and charge of the species.

Single substitution, displacement, or replacement reactions are when one reactant is displaced by another to form the final product ($A + BC \rightarrow AB + C$). Single substitution reactions can be cationic or anionic. When a piece of copper (Cu) is placed into a solution of silver nitrate ($AgNO_3$), the solution turns blue. The copper appears to be replaced with a silvery-white material. The equation is $2AgNO_3 + Cu \rightarrow Cu\ (NO_3)2 + 2Ag$. When this reaction takes place, the copper dissolves and the silver in the silver nitrate solution precipitates (becomes a solid), thus resulting in copper nitrate and silver. Copper and silver have switched places in the nitrate.

Double displacement, double replacement, substitution, metathesis, or ion exchange reactions are when ions or bonds are exchanged by two compounds to form different compounds ($AB + CD \rightarrow AC + BD$). An example of this is that silver nitrate and sodium chloride form two different products (silver chloride and sodium nitrate) when they react. The formula for this reaction is $AgNO_3 + NaCl \rightarrow AgCl + NaNO_3$.

Combination, or synthesis, reactions are reactions in which two or more reactants combine to form a single product ($A + B \rightarrow C$). These reactions are also called synthesis or addition reactions. An example is burning hydrogen in air to produce water. The equation is $2H_2\ (g) + O_2\ (g) \rightarrow 2H_2O\ (l)$. Another example is when water and sulfur trioxide react to form sulfuric acid. The equation is $H_2O + SO_3 \rightarrow H_2SO_4$.

Decomposition (or desynthesis, decombination, or deconstruction) reactions: In a decomposition reaction, a reactant is broken down into two or more products ($A \rightarrow B + C$). These reactions are also called analysis reactions. Thermal decomposition is caused by heat. Electrolytic decomposition is due to electricity. An example of this type of reaction is the decomposition of water into hydrogen and oxygen gas. The equation is $2H_2O \rightarrow 2H_2 + O_2$.



In acid/base reactions, an acid is a compound that can donate a proton, while a base is a compound that can accept a proton. In these types of reactions, the acid and base react to form a salt and water. When the proton is donated, the base becomes water and the remaining ions form a salt. One method of determining whether a reaction is an oxidation/reduction or a metathesis reaction is that the oxidation number of atoms does not change during a metathesis reaction.

Isomerization, or rearrangement, is the process of forming a compound's isomer. Within a compound, bonds are reformed. The reactant and product have the same molecular formula, but different structural formulas and different properties ($A \rightarrow B$ or $A \rightarrow A'$). For example, butane (C_4H_{10}) is a hydrocarbon consisting of four carbon atoms in a straight chain. Heating it to 100° C or higher in the presence of a catalyst forms isobutane (methylpropane), which has a branched-chain structure. Boiling and freezing points are greatly different for butane and isobutane. A rearrangement reaction occurs within the molecule.

A neutralization, acid-base, or proton transfer reaction is when one compound acquires H^+ from another. These types of reactions are also usually double displacement reactions. The acid has an H^+ that is transferred to the base and neutralized to form a salt.

Catalysts can increase reaction rates by decreasing the number of steps it takes to form products. The mass of the catalyst should be the same at the beginning of the reaction as it is at the end. The activation energy is the minimum amount required to get a reaction started. Activation energy causes particles to collide with sufficient energy to start the reaction. A catalyst enables more particles to react, which lowers the activation energy. Examples of catalysts in reactions are manganese oxide (MnO_2) in the decomposition of hydrogen peroxide, iron in the manufacture of ammonia using the Haber process, and concentrate of sulfuric acid in the nitration of benzene.

Endothermic reactions are chemical reactions that absorb heat and exothermic reactions are chemical reactions that release heat. The heat difference between endothermic and exothermic reactions is caused by bonds forming and breaking. If more energy is needed to break the reactant bonds than is released when they form, the reaction is endothermic. Heat is absorbed and the environmental temperature decreases. If more energy is released when product bonds form than is needed to break the reactant bonds, the reaction is exothermic. Heat is released and the environmental temperature increases.

An endergonic chemical reaction is one in which it takes more energy to instigate the reaction than is produced by it. An exergonic chemical reaction is one in which the net amount of Gibbs free energy is less than zero.

The collision theory states that for a chemical reaction to occur, atoms or molecules have to collide with each other with a certain amount of energy. A certain amount of energy is required to breach the activation barrier. Heating a mixture will raise the energy levels of the molecules and the rate of reaction (the time it takes for a reaction to complete). Other factors that can affect the rate of reaction are surface area, concentration, pressure, and the presence of a catalyst.

Phosphorescence and luminescence occur because energy is absorbed by a substance (charged) and light is re-emitted comparatively slowly. These processes are different from chemiluminescence, in which an excited state is created by a chemical reaction and transferred to another molecule. A glow stick is an example of chemiluminescence.

Reaction equilibrium

When a system at equilibrium is subjected to a change in the concentration of products or reactants, the system will counteract to establish a new equilibrium. This relationship is known as Le Chatelier's principle.

Consider the following system at equilibrium: $CO (g) + NO_2 (g) \leftrightarrows CO_2 (g) + NO (g)$

If NO_2 or CO (reactants) are added to the system, the result will be the formation of additional CO_2 and NO (products) until a new equilibrium is established. Conversely, if CO or NO_2 are removed from the system, the result will be the formation of additional CO and NO_2 until a new equilibrium is established.

Conversion of energy

There are many different types of energy that exist. These include mechanical, sound, magnetic, electrical, light, heat, and chemical. From the first law of thermodynamics, we know that no energy can be created or destroyed, but it may be converted from one form to another. This does not mean that all forms of energy are useful. Indeed, the second law states that net useful energy decreases in every process that takes place. Most often this occurs when other forms of energy are converted to heat through means such as friction. In these cases, the heat is quickly absorbed into the surroundings and becomes unusable. There are many examples of energy conversion, such as in an automobile. The chemical energy in the gasoline is converted to mechanical energy in the engine. Subsequently, this mechanical energy is converted to kinetic energy as the car moves. Additionally, the mechanical energy is converted to electrical energy to power the radio, headlights, air conditioner, and other devices. In the radio, electrical energy is converted to sound energy. In the headlights, it is converted to heat and light energy. In the air conditioner, it does work to remove heat energy from the car's interior. It is important to remember that, in all of these processes, a portion of the energy is lost from its intended purpose.

Energy transformations

Energy is constantly changing forms and being transferred back and forth. A pendulum swinging is an example of both a kinetic to potential and a potential to kinetic energy transformation. When a pendulum is moved from its center point (the point at which it is closest to the ground) to the highest point before it returns, it is an example of a kinetic to potential transformation. When it swings from its highest point toward the center, it is considered a potential to kinetic transformation. The sum of the potential and kinetic energy is known as the total mechanical energy. Stretching a rubber band gives it potential energy. That potential energy becomes kinetic energy when the rubber band is released.

> **Review Video: Potential and Kinetic Energy**
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Other examples of energy transformations include:

- Electric to mechanical: Ceiling fan
- Chemical to heat: burning coal
- Chemical to light: Phosphorescence and luminescence (which allow objects to glow in the dark) occur because energy is absorbed by a substance (charged) and light is re-emitted comparatively slowly
- Heat to electricity: Examples include thermoelectric, geothermal, and ocean thermal.
- Heat to mechanical: steam engine
- Nuclear to heat: Examples include nuclear reactors and power plants.
- Mechanical to sound: Playing a violin or almost any instrument
- Sound to electric: Microphone
- Light to electric: Solar panels
- Electric to light: Light bulbs

Motion and Force

Mechanics is the study of matter and motion, and the topics related to matter and motion, such as force, energy, and work. Discussions of mechanics will often include the concepts of vectors and scalars. Vectors are quantities with both magnitude and direction, while scalars have only magnitude. Scalar quantities include length, area, volume, mass, density, energy, work, and power. Vector quantities include displacement, velocity, acceleration, momentum, and force.

Motion is a change in the location of an object, and is the result of an unbalanced net force acting on the object. Understanding motion requires the understanding of three basic quantities: displacement, velocity, and acceleration.

Displacement

When something moves from one place to another, it has undergone *displacement.* Displacement along a straight line is a very simple example of a vector quantity. If an object travels from position x = -5 cm to x = 5 cm, it has undergone a displacement of 10 cm. If it traverses the same path in the opposite direction, its displacement is -10 cm. A vector that spans the object's displacement in the direction of travel is known as a displacement vector.

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Velocity

There are two types of velocity to consider: *average velocity* and *instantaneous velocity.* Unless an object has a constant velocity or we are explicitly given an equation for the velocity, finding the instantaneous velocity of an object requires the use of calculus. If we want to calculate the *average velocity* of an object, we need to know two things: the displacement, or the distance it has covered, and the time it took to cover this distance. The formula for average velocity is simply the distance traveled divided by the time required. In other words, the average velocity is equal to the change in position divided by the change in time. Average velocity is a vector and will always point in the same direction as the displacement vector (since time is a scalar and always positive).

Acceleration

Acceleration is the change in the velocity of an object. On most test questions, the acceleration will be a constant value. Like position and velocity, acceleration is a vector quantity and will therefore have both magnitude and direction.

> **Review Video: Velocity and Acceleration**
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Most motion can be explained by Newton's three laws of motion:

Newton's First Law of Motion

An object at rest or in motion will remain at rest or in motion unless acted upon by an external force. This phenomenon is commonly referred to as inertia, the tendency of a body to remain in its present state of motion. In order for the body's state of motion to change, it must be acted on by an unbalanced force.

> **Review Video: Newton's First Law of Motion**
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Newton's Second Law of Motion

An object's acceleration is directly proportional to the net force acting on the object, and inversely proportional to the object's mass. It is generally written in equation form $F = ma$, where F is the net force acting on a body, m is the mass of the body, and a is its acceleration. Note that since the mass is always a positive quantity, the acceleration is always in the same direction as the force.

> **Review Video: Newton's Second Law of Motion**
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Newton's Third Law of Motion

For every force, there is an equal and opposite force. When a hammer strikes a nail, the nail hits the hammer just as hard. If we consider two objects, *A* and *B*, then we may express any contact between these two bodies with the equation $F_{AB} = -F_{BA}$, where the order of the subscripts denotes which body is exerting the force. At first glance, this law might seem to forbid any movement at all since every force is being countered with an equal opposite force, but these equal opposite forces are acting on different bodies with different masses, so they will not cancel each other out.

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Energy

The two types of energy most important in mechanics are potential and kinetic energy. Potential energy is the amount of energy an object has stored within itself because of its position or orientation. There are many types of potential energy, but the most common is gravitational potential energy. It is the energy that an object has because of its height (h) above the ground. It can be calculated as $PE = mgh$, where m is the object's mass and g is the acceleration of gravity. Kinetic energy is the energy of an object in motion, and is calculated as $KE = mv^2/2$, where v is the magnitude of its velocity. When an object is dropped, its potential energy is converted into kinetic energy as it falls. These two equations can be used to calculate the velocity of an object at any point in its fall.

Gravitational force

Gravitational force is a universal force that causes every object to exert a force on every other object. The gravitational force between two objects can be described by the formula, $F = Gm_1m_2/r^2$, where m_1 and m_2 are the masses of two objects, r is the distance between them, and G is the gravitational constant, $G = 6.672 \times 10^{-11}$ N-m²/kg². In order for this force to have a noticeable effect, one or both of the objects must be extremely large, so the equation is generally only used in problems involving planetary bodies. For problems involving objects on the earth being affected by earth's gravitational pull, the force of gravity is simply calculated as F = mg, where g is 9.8 m/s^2 toward the ground.

The weight of an object is the force of gravity on the object, and may be defined as the mass times the acceleration of gravity: w = mg. Mass is the amount of matter an object contains. When an object falls, it will accelerate at the same speed regardless of its mass, provided that gravity is the only force working on the object. Where mass can come into play is when there is significant air resistance. The force due to air resistance is a function of the object's size, shape, and velocity, but not mass. Thus, the air resistance force on two identically sized and shaped objects of different masses will be the same, but the heavier object will not be as affected, since it requires a greater force to overcome its momentum.

Work

Work can be thought of as the amount of energy expended in accomplishing some goal. The simplest equation for mechanical work (W) is $W = Fd$, where F is the force exerted and d is the displacement of the object on which the force is exerted. This equation requires that the force be applied in the same direction as the displacement. If this is not the case, then the work may be calculated as $W = Fd\cos(\theta)$, where θ is the angle between the force and displacement vectors. If force and displacement have the same direction, then work is positive; if they are in opposite directions, then work is negative; and if they are perpendicular, the work done by the force is zero.

As an example, if a man pushes a block horizontally across a surface with a constant force of 10 N for a distance of 20 m, the work done by the man is 200 N-m or 200 J. If instead the block is sliding and the man tries to slow its progress by pushing against it, his work done is -200 J, since he is pushing in the direction opposite the motion. If the man pushes vertically downward on the block while it slides, his work done is zero, since his force vector is perpendicular to the displacement vector of the block.

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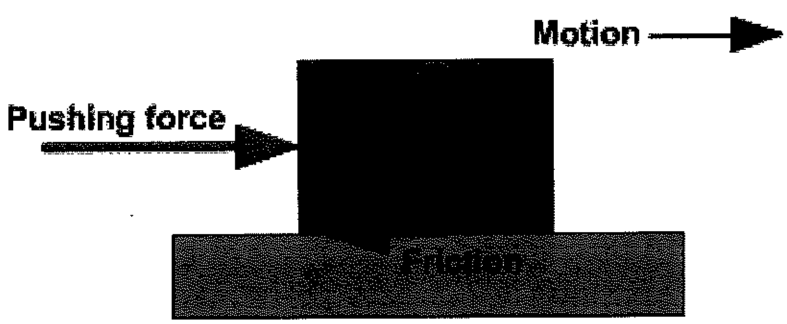
When an object is thrown upward the acceleration throughout its flight is 9.8 meters per second squared (m/s^2) downward. This is Earth's gravity (g) close to its surface. It is the acceleration of all objects when there is no resistance, such as that of air.

If an object is held stationary, there is no work performed. This is because the formula for work performed is equal to the force times distance, or displacement ($W = F \cdot d[\cos\theta]$). Displacement is a vector measurement, and there must be displacement for work to be done. If an object is being held up, forces are at work, but are canceling each other out. No work is being done.

Friction

Friction is a force that arises as a resistance to motion where two surfaces are in contact. The maximum magnitude of the frictional force (f)can be calculated as $f = F_c\mu$, where F_c is the contact force between the two objects and μ is a coefficient of friction based on the surfaces' material composition. Two types of friction are static and kinetic. To illustrate these concepts, imagine a book resting on a table. The force of its weight (W) is equal and opposite to the force of the table on the book, or the normal force (N). If we exert a small force (F) on the book, attempting to push it to one side, a frictional force (f) would arise, equal and opposite to our force. At this point, it is a *static frictional force* because the book is not moving. If we increase our force on the book, we will eventually cause it to move. At this point, the frictional force opposing us will be a *kinetic frictional force.* Generally, the kinetic frictional force is lower than static frictional force (because the frictional coefficient for static friction is larger), which means that the amount of force needed to maintain the movement of the book will be less than what was needed to start it moving.



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Density

The key property determining whether an object will float or sink in water is its density. The general rule is that if an object is less dense than water, it floats; if it is denser than water, it sinks. The density of an object is equal to its mass divided by its volume ($d = m/v$). It is important to note the difference between an object's density and a material's density. Water has a density of one gram per cubic centimeter, while steel has a density approximately eight times that. Despite having a much higher material density, an object made of steel may still float. A hollow steel sphere, for instance, will float easily because the density of the object includes the air contained within the sphere. An object may also float only in certain orientations. An ocean liner that is placed in the water upside down, for instance, may not remain afloat. An object will float only if it can displace a mass of water equal to its own mass.

Archimedes's principle states that a buoyant (upward) force on a submerged object is equal to the weight of the liquid displaced by the object. This principle of buoyancy can also be used to calculate the volume of an irregularly shaped object. The mass of the object (m) minus its apparent mass in the water (m_a) divided by the density of water (ρ_w), gives the object's volume: $V = (m-m_a)/\rho_w$.

Analysis of motion and forces

Projectile motion: occurs where an object thrown into the air near the earth's surface moves along an arched path under the effect of gravity alone

Circular motion: movement of an object in a rotating circular path

Periodic motion: motion that is repeated at recurring intervals, such as the swinging of a pendulum

Collisions

Elastic collision: collision in which the total kinetic energy between two bodies before the collision equals the total kinetic energy after the collision. An example would be a collision between two gas molecules, in which the two molecules only change direction after a collision, but not kinetic energy.

Inelastic collision: collision in which the total kinetic energy between two bodies increases or decreases after a collision. An example would be a collision in which a moving car strikes a parked car, resulting in a single body with a different kinetic energy than either of the original two bodies. In this case, kinetic energy could be lost because of friction between the tires and the road or changes in the car bodies because of the collision.

Law of conservation of momentum: for a collision between two bodies with no external forces, the vector sum of the momentums is not affected by the interaction and remains constant.

Environmental and Life Science

Reproductive systems in animals

Based on whether or not and when an organism uses meiosis or mitosis, the three possible cycles of reproduction are haplontic, diplontic, and haplodiplontic. Fungi, green algae, and protozoa are haplontic. Animals and some brown algae and fungi are diplontic. Plants and some fungi are haplodiplontic. Diplontic organisms, like animals, have a dominant diploid life cycle. The haploid generation is simply the egg and sperm. Monoecious species are bisexual (hermaphroditic). In this case, the individual has both male and female organs: sperm-bearing testicles and egg-bearing ovaries. Hermaphroditic species can self fertilize. Some worms are hermaphroditic. Cross fertilization is when individuals exchange genetic information. Most animal species are dioecious, meaning individuals are distinctly male or female.

Individuals of a species have specialized reproductive cells. These cells are responsible for meiosis, which typically results in motile spermatozoa in the male and non-motile, food-containing ova in the female. Before fertilization, the oocyte continues to develop in a follicle. In the female, human luteinizing hormone causes the follicle to break open and the oocyte to slowly move down the fallopian tube. Fertilization occurs when the two gametes fuse to form a zygote, which develops into an individual. Sperm needs to be deposited within five days of ovulation for fertilization to occur. The ovaries secrete estrogen and progesterone. The testes secrete testosterone. The placenta secretes chorionic gonadotropin.

Gametogenesis refers to the production of haploid gametes. Spermatogenesis refers to sperm production, which occurs in the testes. Oogenesis refers to egg formation, which takes place in the ovaries. It also produces a polar body.

Asexual reproduction

Asexual reproduction occurs when only one parent is responsible for reproduction. Forms of this include budding, fragmentation, parthenogenesis, and self-fertilization.

Budding: This occurs when the offspring start as a growth on the parent organism's body. Jellyfish and some echinoderms have buds that leave the parent. Other organisms, such as corals, continue to be attached and form colonies.

Fragmentation: This is similar to budding, but after maturity the individual fragments into about eight pieces. Each fragment develops into another mature individual. Some small worms reproduce using this method.

Parthenogenesis: This is also known as virgin birth because the female produces eggs that develop without being fertilized. Specific species of fish, insects, frogs, and lizards reproduce by parthenogenesis.

Self-fertilization: Some species are considered hermaphroditic, meaning individuals have both male and female reproductive parts. Fertilization can be achieved within the individual.

Early growth in humans

The stages of embryonic development are the zygote, morula, blastula, and gastrula.

- **Zygote**: diploid cell formed by the fusion two gametes during fertilization
- **Morula**: ball-like mass of 16–32 cells formed by mitotic divisions (cleavages) of the zygote
- **Blastula**: hollow, ball-like structure formed when morula cells begin to secrete fluid into the center of the morula; this is the structure that attaches to the lining of the uterus (endometrium)
- **Gastrula**: formed when cells migrate to the center of the blastula to form germ layers that differentiate to form tissues and organs

Roughly two weeks after fertilization, the embryo starts to form a yolk sac that will make blood cells, an embryonic disc, and a chorion (the placenta). By week three, the beginnings of the spinal cord, brain, muscles, bones, and face appear. After that, cardiac cells begin to beat.

Plant kingdom groupings

Only plants in the division bryophyta (mosses and liverworts) are nonvascular, which means they do not have xylem to transport water. All of the plants in the remaining divisions are vascular, meaning they have true roots, stems, leaves, and xylem. Pteridophytes are plants that use spores and not seeds to reproduce. They include the following divisions: Psilophyta (whisk fern), Lycophyta (club mosses), Sphenophyta (horsetails), and Pterophyta (ferns). Spermatophytes are plants that use seeds to reproduce. Included in this category are gymnosperms, which are flowerless plants that use naked seeds, and angiosperms, which are flowering plants that contain seeds in or on a fruit. Gymnosperms include the following divisions: cycadophyta (cycads), ginkgophyta (maidenhair tree), gnetophyta (ephedra and welwitschia), and coniferophyta (which includes pinophyta conifers). Angiosperms comprise the division anthophyta (flowering plants).

Plant phyla

Chlorophyta are green algae. Bryophyta are nonvascular mosses and liverworts. They have root-like parts called rhizoids. Since they do not have the vascular structures to transport water, they live in moist environments. Lycophyta are club mosses. They are vascular plants. They use spores and need water to reproduce. Equisetopsida (sphenophyta) are horsetails. Like lycophyta, they need water to reproduce with spores. They have rhizoids and needle-like leaves. The pteridophytes (filicopsida) are ferns. They have stems (rhizomes). Spermatopsida are the seed plants. Gymnosperms are a conifer, which means they have cones with seeds that are used in reproduction. Plants with seeds require less water. Cycadophyta are cone-bearing and look like palms. Gnetophyta are plants that live in the desert. Coniferophyta are pine trees, and have both cones and needles. Ginkgophyta are ginkos. Anthophyta is the division with the largest number of plant species, and includes flowering plants with true seeds.

Processes and systems of plants

Plants are autotrophs, which mean they make their own food. In a sense, they are self sufficient. Three major processes used by plants are photosynthesis, transpiration, and respiration. Photosynthesis involves using sunlight to make food for plants. Transpiration evaporates water out of plants. Respiration is the utilization of food that was produced during photosynthesis.

Two major systems in plants are the shoot and the root system. The shoot system includes leaves, buds, and stems. It also includes the flowers and fruits in flowering plants. The shoot system is located above the ground. The root system is the component of the plant that is underground, and includes roots, tubers, and rhizomes.

Population

Population is a measure of how many individuals exist in a specific area. It can be used to measure the size of human, plant, or animal groups. Population growth depends on many factors. Factors that can limit the number of individuals in a population include lack of resources such as food and water, space, habitat destruction, competition, disease, and predators.

Exponential growth refers to an unlimited rising growth rate. This kind of growth can be plotted on a chart in the shape of a J. Carrying capacity is the population size that can be sustained. The world's population is about 6.8 billion and growing. The human population has not yet reached its carrying capacity.

Population dynamics refers to how a population changes over time and the factors that cause changes. An S-shaped curve shows that population growth has leveled off.

Biotic potential refers to the maximum reproductive capacity of a population given ideal environmental conditions.

Relationships between and within species

The following are examples of relationships between and within species:

- Intraspecific relationships: relationships among members of a species.
- Interspecific relationships: relationships between members of different species.
- Predation: relationship in which one individual feeds on another (the prey), causing the prey to die.
- Commensalism: interspecific relationships in which one of the organisms benefits.
- Mutualism: relationship in which both organisms benefit.
- Competition: relationship in which both organisms are harmed.
- Parasitism: relationship in which one organism benefits and the other is harmed.
- Biomass: the mass of one or all of the species (species biomass) in an ecosystem or area.

Community

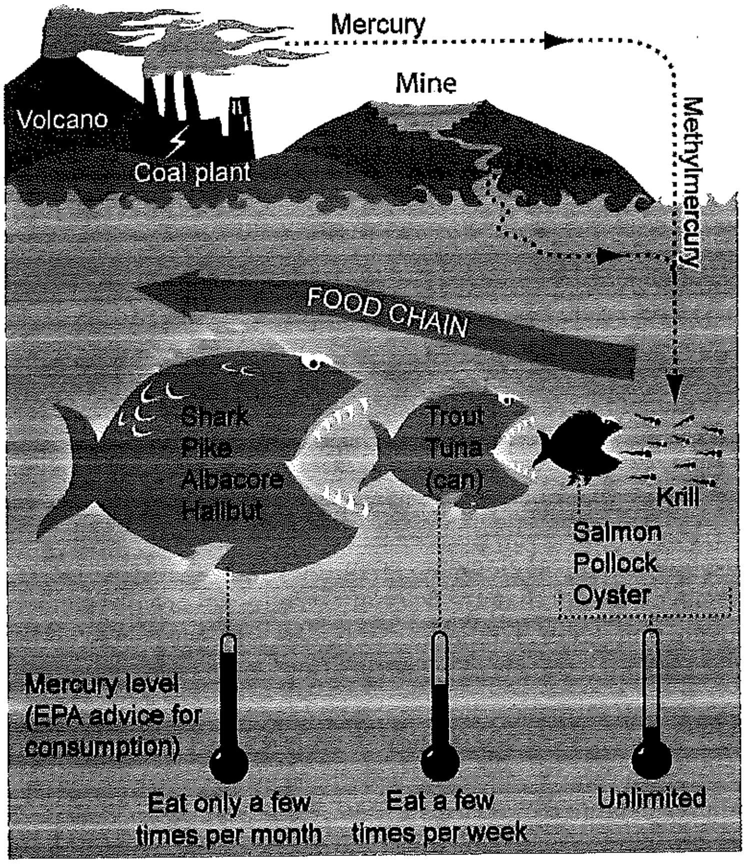
A community is any number of species interacting within a given area. A niche is the role of a species within a community. Species diversity refers to the number of species within a community and their populations.

- Biome: an area in which species are associated because of climate. The six major biomes in North America are desert, tropical rain forest, grassland, coniferous forest, deciduous forest, and tundra.
- Biotic factors: the living factors, such as other organisms, that affect a community or population.
- Abiotic factors: the nonliving factors that affect a community or population, such as facets of the environment.
- Ecology: the study of plants, animals, their environments, and how they interact.
- Ecosystem: a community of species and all of the environmental factors that affect them.

Food chains and biomagnifications

A food chain is a linking of organisms in a community that is based on how they use each other as food sources. Each link in the chain consumes the link above it and is consumed by the link below it. The exceptions are the organism at the top of the food chain and the organism at the bottom.

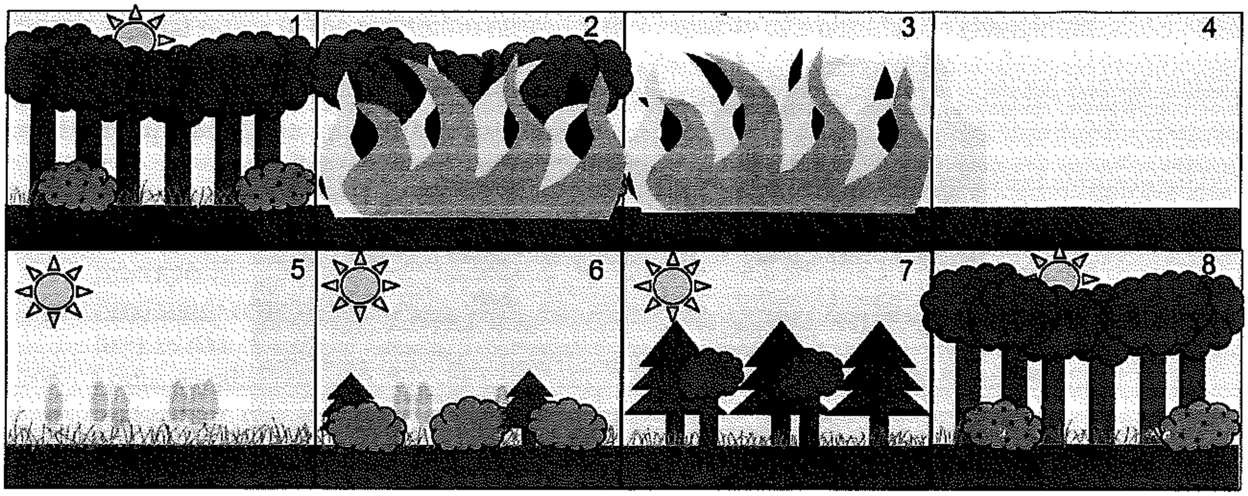
Biomagnification (bioamplification) refers to an increase in concentration of a substance within a food chain. Examples are pesticides or mercury. Mercury is emitted from coal-fired power plants and gets into the water supply, where it is eaten by a fish. A larger fish eats smaller fish, and humans eat fish. The concentration of mercury in humans has now risen. Biomagnification is affected by the persistence of a chemical, whether it can be broken down and negated, food chain energetics, and whether organisms can reduce or negate the substance.



Ecoystem stability and ecologic succession

Ecosystem stability: This is a concept that states that a stable ecosystem is perfectly efficient. Seasonal changes or expected climate fluctuations are balanced by homeostasis. It also states that interspecies interactions are part of the balance of the system. Four principles of ecosystem stability are that waste disposal and nutrient replenishment by recycling is complete, the system uses sunlight as an energy source, biodiversity remains, and populations are stable in that they do not over-consume resources.

Ecologic succession: This is the concept that states that there is an orderly progression of change within a community. An example of primary succession is that over hundreds of years bare rock decomposes to sand, which eventually leads to soil formation, which eventually leads to the growth of grasses and trees. Secondary succession occurs after a disturbance or major event that greatly affects a community, such as a wild fire or construction of a dam.



Biochemical cycles

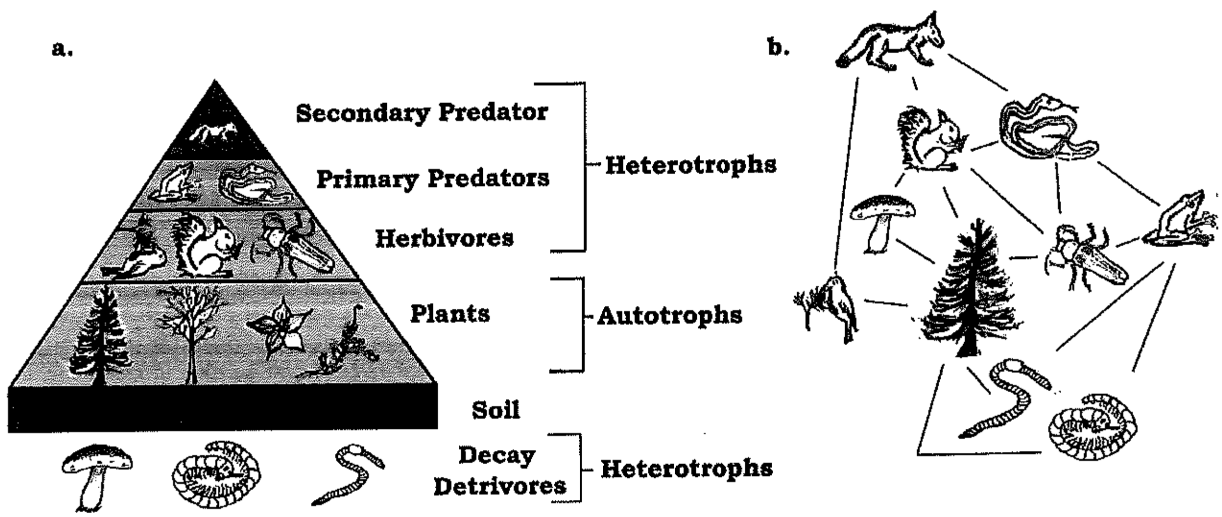
Biochemical cycles are how chemical elements required by living organisms cycle between living and nonliving organisms. Elements that are frequently required are phosphorus, sulfur, oxygen, carbon, gaseous nitrogen, and water. Elements can go through gas cycles, sedimentary cycles, or both. Elements circulate through the air in a gas cycle and from land to water in a sedimentary one.

Mimicry

Mimicry is an adaptation developed as a response to predation. It refers to an organism that has a similar appearance to another species, which is meant to fool the predator into thinking the organism is more dangerous than it really is. Two examples are the drone fly and the io moth. The drone fly looks like a bee, but cannot sting. The io moth has markings on its wings that make it look like an owl. The moth can startle predators and gain time to escape. Predators can also use mimicry to lure their prey.

Food webs

A food web consists of interconnected food chains in a community. The organisms can be linked to show the direction of energy flow. Energy flow in this sense is used to refer to the actual caloric flow through a system from trophic level to trophic level. Trophic level refers to a link in a food chain or a level of nutrition. The 10% rule is that from trophic level to level, about 90% of the energy is lost (in the form of heat, for example). The lowest trophic level consists of primary producers (usually plants), then primary consumers, then secondary consumers, and finally tertiary consumers (large carnivores). The final link is decomposers, which break down the consumers at the top. Food chains usually do not contain more than six links. These links may also be referred to as ecological pyramids.



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Natural selection, gradualism, and punctuated equilibrium

<u>Natural selection</u>: This theory developed by Darwin states that traits that help give a species a survival advantage are passed on to subsequent generations. Members of a species that do not have the advantageous trait die before they reproduce. Darwin's four principles are:

- from generation to generation, there are various individuals within a species;
- genes determine variations;
- more individuals are born than survive to maturation; and
- specific genes enable an organism to better survive.

<u>Gradualism</u>: It is the idea that evolution proceeds at a steady pace and does not include sudden developments of new species or features from one generation to the next. This can be contrasted with punctuated equilibrium.

<u>Punctuated equilibrium</u>: This can be contrasted with gradualism. It is an idea in evolutionary biology that states that evolution involves long time periods of no change (stasis) accompanied by relatively brief periods (hundreds of thousands of years) of rapid change.

Evidence supporting theory of evolution

Scientific evidence supporting the theory of evolution can be found in biogeography, comparative anatomy and embryology, the fossil record, and molecular evidence. Biogeography studies the geographical distribution of animals and plants. Evidence of evolution related to the area of biogeography includes species that are well suited for extreme environments. The fossil record shows that species lived only for a short time period before becoming extinct. The fossil record can also show the succession of plants and animals. Living fossils are existing species that have not changed much morphologically and are very similar to ancient examples in the fossil record. Examples include the horseshoe crab and ginko. Comparative embryology studies how species are similar in the embryonic stage, but become increasingly specialized and diverse as they age. Vestigial organs are those that still exist, but become nonfunctional. Examples include the hind limbs of whales and the wings of birds that can no longer fly, such as ostriches.

Rate of evolution

The rate of evolution is affected by the variability of a population. Variability increases the likelihood of evolution. Variability in a population can be increased by mutations, immigration, sexual reproduction (as opposed to asexual reproduction), and size. Natural selection, emigration, and smaller populations can lead to decreased variability. Sexual selection affects evolution. If fewer genes are available, it will limit the number of genes passed on to subsequent generations. Some animal mating behaviors are not as successful as others. A male that does not attract a female because of a weak mating call or dull feathers, for example, will not pass on its genes.

Three types of evolution

Three types of evolution are divergent, convergent, and parallel. Divergent evolution refers to two species that become different over time. This can be caused by one of the species adapting to a different environment. Convergent evolution refers to two species that start out fairly different, but evolve to share many similar traits. Parallel evolution refers to species that are not similar and do not become more or less similar over time. Mechanisms of evolution include descent (the passing on of genetic information), mutation, migration, natural selection, genetic variation, and genetic drift. The biological definition of species refers to a group of individuals that can mate and reproduce. Speciation refers to the evolution of a new biological species. The biological species concept (BSC) basically states that a species is a community of individuals that can reproduce and have a niche in nature.

Homeostasis, gene expression, transcription, translation, and cellular differentiation

Homeostasis: This describes the ability and tendency of an organism, cell, or body to adjust to environmental changes to maintain equilibrium.

Gene expression: This refers to the use of information in a gene to make a protein or nucleic acid product. Examples of nucleic acid products are tRNA or rRNA.

Transcription: This refers to the synthesis of RNA from DNA.

Translation: Synthesizing a protein from an mRNA strand.

Cellular differentiation: This is the process by which a cell changes to a new cell type.

Technology and Engineering Design

Impact of scientific and technical innovation upon living standards and productivity

Scientific and technical innovation has played a major role in enhancing productivity, increasing a society's wealth, and raising its standard of living. After a new innovation comes about, it must spread to other people and groups in order to be effective. This process is known as diffusion, and is illustrated using an s-curve, also known as a diffusion curve, which tracks an increase in revenue or productivity over time. An s-curve represents the product life of an innovation. During the early stages of product life, an innovation must establish its usefulness and experiences a very slow growth in terms of revenue and productivity. The middle stages of product life see rapid increases in growth, and the latter stages of product life involve gradual decline. Product improvements may extend the lifespan of an innovation, but it will inevitably fall off. Consequently, companies are always seeking new innovations to replace older ones.

Resource management

Resource management seeks to allocate an organization's resources in the most efficient and economical ways possible—that is, the goal of resource management is the optimization of resource usage in a project. Resources include money, employees, inventory, production, and information technology, and are allocated using a variety of processes and techniques. One such technique is resource leveling, which balances usage by eliminating inventory shortages and excesses. To avoid shortages and thereby reduce conflict, management should take care when scheduling multiple activities at the same time. If concurrent activities require more of one resource than is available or make use of the same person, they should be rescheduled. In many cases, management may be forced to delay an activity until the resource becomes available. If this activity is part of the critical path, the project may be delayed.

Stimulating competitiveness and creating new goods and services within the market

Technological innovation provides a number of benefits to the marketplace. It can introduce new products, which are simply those with which customers have no prior experience. Technological innovation can also introduce an improved or more efficient means of production or commodity handling. In many cases, these new products or means of production will open up new markets, and require the discovery of new sources of raw materials. This often stimulates the economy by creating additional competition and breaking up existing monopolies. Technological innovation is often the result of the pursuit of better quality; new market formation; new regulations; need for replacement parts or services; decreased availability of materials; increased labor costs; increased production costs; etc.

Technology and society and culture

Technology and culture have a synergistic relationship which began with the simple tools developed during the dawn of man and continues today with modern technologies such as computers and various other electronic devices. This relationship is cyclical and codependent with each party exerting influence over the other. Funding for technological development comes from two primary sources in most modern cultures and societies: Private business and enterprise, or government programs. Once new technology is developed, it influences social attitudes and beliefs, which, in turn, influence the implementation of new technology. For instance, key values and beliefs that derive from this codependence between technology and culture are the notions that human productivity should work to achieve higher levels of efficiency and that technology drives social progress. According to these beliefs, humankind is improving as long as technology is improving.

Automobile, airplane, integrated circuit, and the internet

The automobile was granted a patent in 1885. Karl Benz, who is widely regarded as the inventor of the gasoline-powered car, placed the first automobiles into production during the same year.

The airplane was developed in 1903 by Wilbur and Orville Wright. They used various principles of aerodynamics, such as drag and lift, to develop the first power and controlled flight.
The integrated circuit was developed in 1958 by Jack Kilby of Texas Instruments and Robert Noyce at Fairchild Semiconductor. It led to the development of the microchip by enabling semiconductor devices to perform the same functions as vacuum tubes. It revolutionized electronic equipment, leading to the development of personal computers, cellular phones, and various digital devices.

The internet came about with the first TCP/IP protocol, which was developed in 1983 by Robert E. Kahn and Vince Cerf.

Biotechnology

Biotechnology is the technological application of biology. It uses living organisms and bioprocesses to create products or processes, and has numerous applications in the following fields:

1. Medicine – includes drug production, gene therapy, gene testing, and pharmacogenomics (i.e. determining an individual's response to drugs based on inherited genetic traits).
2. Agriculture – includes enhancing crop yield, increasing nutritional attributes of food, improving crop durability, producing new substances in crop plants, and reducing dependence on agrochemicals
3. Biological engineering – uses physics, chemistry, and mathematics to solve life science problems.
4. Bioremediation and biodegradation – create organisms for purposes of removing environmental contamination.
5. Cloning –two main types: reproductive, which brings a fully developed life into the world, and therapeutic, which involves using stem cells.
6. Human Genome Project – seeks to discover all human genes, and create a reference sequence for the human genome.
7. Biotechnology often makes use of mathematical biology, which models complex biological processes using various types of math: graph theory, calculus, probability theory, statistics, linear algebra, abstract algebra, combinatorics, algebraic geometry, topology, dynamical systems, differential equations and coding theory

Conservation and sustainability

Conservation is the effort to reduce energy and material consumption by reducing usage and making more efficient use of existing resources. New technology can facilitate conservation in a variety of ways. Renewable energy sources (geothermal, hydroelectric energy, wind power, etc.), building techniques that take advantage of the local climate, and vehicles that consume less gas (such as hybrids) all help lower energy consumption. Real-time energy metering helps consumers to better understand the impact of their energy usage.

Sustainability determines the length of time over which an ecological system will endure. Sustainable systems are those that will remain healthy and productive for a long time. Technology is often a means of increasing energy efficiency and conserving natural resources so that the human environment can become more sustainable.

Regulating and facilitating technological development

Historically, the government has served a role not only in funding technological research but also in regulating its usage and side effects. One example of such regulation is the FDA, or Food and Drug administration. When selecting which types of research to fund, the government will choose those that offer the greatest benefit to mankind. However, the presence of different interest groups competing for resources can complicate the selection process. In reality, both the populace-at-large and special interests hold tremendous influence over governmental policy. The government also assumes a regulatory role in technological development, especially regarding the environment and the protection of ecological systems. The government is responsible for assigning liability to corporations whose products cause harm.

Material disposals, and environmental emission monitoring and control

Materials disposal is carried out using a variety of technologies and techniques:

- Incinerators – subject solid waste to the process of combustion in order to convert it into residue and gas. This generates heat, gas, steam, and ash.
- Landfills – eliminate solid waste by burying it.
- Recycling – reprocesses discarded materials (e.g., aluminum cans, glass bottles, newspapers, cardboard boxes, paper) into their constituent materials, and reuses them.
- Sustainability methods – include biological reprocessing, such as composting and anaerobic digestion, and energy recovery, which processes waste into fuel.

Environmental emission monitoring and control is performed by continuous emission monitoring systems, which use gas analyzers to test air samples for certain types of emissions, such as carbon dioxide, carbon monoxide, sulfur dioxide, mercury, etc. Federal programs use these systems to ensure compliance with emission standards, such as the acid rain program and other EPA standards.

Medical technology and agricultural technology

Medical technology includes any device, procedure, pharmaceutical, or system whose purpose is improving health, preventing sickness, and diagnosing or treating disease. Medical technology covers a vast number of healthcare products, which often make use of mathematical principles and concepts. For instance, medical imaging machines (CAT, ultrasound, etc.) and pharmacology often make use of trigonometric functions for measurement problems. Mathematical tools such as dimensional analysis are often used to calculate the correct dosage for patients.

Agricultural technology encompasses a wide array of machinery, processes, and systems designed to enhance agricultural production. Agricultural technology also makes use of mathematical principles and concepts. For instance, dimensional analyses are often used to examine complex agricultural-social economic systems. Graph theory provides a means of modeling ecology. And quadratic equations often used to solve economic problems related to agriculture.

Applications of physics to technology

The following concepts and principles of physics have been essential to the development of new technologies:

- Bernoulli's principle – states that, when the speed of an inviscid flow increases, the pressure (or potential energy) of the flow will decrease. Consequently, faster moving air creates slower static pressure and higher dynamic pressure. Carburetors and pitot tubes work on Bernoulli's principle.
- Aerodynamics – include four forces relevant to flight: thrust, lift, drag, and weight. Thrust is a reaction force explained by Newton's Second and Third Laws. When mass is accelerated in one direction, it will generate an equal force in the opposite direction. Jet engines, propeller blades, and rockets generate thrust by pushing air in the direction opposite to flight. Lift is a force that is generated perpendicular to the oncoming air flow (using Bernoulli's Principle). Airplane wings are designed to take advantage of lift (climbing, descending, banking). Drag is a force that is generated parallel to the oncoming air flow, and opposes the motion of an object. Weight is applied by gravity. In order to achieve flight, all forces must be balanced.

Applications of biology to technology

Biology includes several fields with an especially strong focus on developing new technologies. One such field is biological engineering, which attempts to emulate biological system and, thereby, develop new products or enhance existing biological systems. Biological engineering is responsible for the creation of renewable bioenergy, biocompatible materials, medical devices, diagnostic equipment, and similar technologies. A second field is molecular biology. It helped create the therapies and techniques used in gene therapy, which treats diseases by inserting, altering, and removing genes within a person's cells and tissue. Using techniques developed in molecular biology, gene therapy is capable of replacing mutated genes or even modifying and correcting mutated cells. A third field is pathology, which uses laboratory equipment to diagnose disease. Another field is biotechnology, which uses living organisms and bioprocesses to create products or processes.

Applications of chemistry to technology

An understanding of chemistry is necessary to convert raw materials—such as oil, air, water, minerals, metals, etc.—into usable and marketable materials—such as solvents, soaps, pesticides, cement, etc. The chemical industry consists of numerous businesses that use chemical processes and reactions to create and refine products. Below is a partial list of such products:

1. Petrochemicals – includes ethylene, propylene, benzene, and styrene.
2. Agrochemicals – includes fertilizers, insecticides, and herbicides.
3. Polymers – includes polyester, polyethylene, and Bakelite.
4. Fragrances/flavors – includes vanillin and coumarin.
5. Inorganic industrial compounds – includes ammonia, nitric acid, sodium hydroxide, and sulfuric acid.
6. Organic industrial compounds – includes phenol, urea, and ethylene oxide.
7. Ceramics – include silica brick and frit.
8. Explosives – includes ammonium nitrate, nitrocellulose, and nitroglycerin.
9. Oleochemicals – include lard and soybean oil.
10. Elastomers – includes polyisoprene, neoprene, and polyurethane.

Research and conceptualization

The research phase is the first phase of the engineering design process. It involves locating and examining information on a specific engineering issue or problem. It may require studying literature and documents on the topic and identifying existing solutions, costs, and market needs. Reverse engineering of similar market products is also a potential avenue of research. Common sources of research information include trade journals, governmental documents, local libraries, the World Wide Web, and interviews with subject matter experts.

The conceptualization phase is the second phase of the engineering design process. It involves identifying potential solutions for the problem using various techniques of ideation. One popular ideation technique is brainstorming, which involves rapidly thinking of and adopting solutions. Another technique is trigger word. One person says a word associated with the problem. Hopefully, this word evokes additional words and phrases that can be used to create solutions. Another technique is a morphological chart, which includes design characteristics of the problems. Engineers then propose solutions for each characteristic.

Feasibility assessment and design requirements

The feasibility assessment phase is the third phase of the engineering design process. It determines whether or not the proposed solution is possible by asking two main questions: Is the project based on an achievable idea? Is the project within the cost constraints of the organizations? These questions are best answered by an experienced engineer with good judgment. He is arguably the most important component of this phase. If the project is feasible, it is sent through the design phase.

The design requirements phase is the fourth phase of the engineering design process. It establishes the software and hardware parameters and testability, maintainability, and other key project requirements. It is carried out concurrently with the feasibility phase.

Preliminary design, detailed design, production planning and tool design, and production design

The Preliminary design phase, also known as embodiment design, is the fifth phase of the engineering design process. It defines the overall system design—including schematics, layouts, and diagrams—in a very general way. The design will change as the project proceeds, but these early diagrams will provide guidance in the early stages. Preliminary design phases leads to the detailed design phase.

Detailed design phase is the sixth phase of the engineering design process. It provides very specific and detailed specifications (solid models and drawings) on the project. Common specifications include external marking, design life, packaging requirements, operating parameters, test requirements, external dimensions, materials requirements, reliability requirements, external surface treatments, maintenance and testability information, and operating and non-operating environmental stimuli. CAD, or computer-aided design, programs are very helpful during this phase. They increase design efficiency through optimization, which decreases part volume while simultaneously maintaining quality. CAD programs can also perform the finite element method, which calculates stress and displacement. The engineer then determines whether or not these stresses and displacements conform to project parameters.

The Production planning and tool design phase is the seventh phase of the engineering design process. It establishes a plan for mass producing the product and identifies the manufacturing tools that should be used. It is during this phase that a working prototype is built and tested for standard compliance. Common tasks include material selection, production process selection, sequence of operation determination, and tool selection.

The Production phase is the eighth phases of the engineering design process. It involves manufacturing the product and conducting periodic tests of machinery.

Integrated systems and systems thinking

Integrated systems consist of numerous systems working in conjunction. Technology often consists of smaller systems combined together to form larger systems. In this way, systems are the base components of technology. Consider, for example, an automobile. It consists of numerous electronic and mechanical parts. These parts work together to create the subsystems (steering, lighting, combustion, propulsion, etc.) of which the automobile is comprised.

Systems thinking involves viewing a system as a collection of interconnected parts or processes, and then analyzing the cause and effect relationships between those parts or processes. Systems thinking is necessary when creating new products that always perform as intended.

Processes, materials, people, and capital

The following resources are required to perform technological functions:

- Processes – systematic sequences of actions through which humans create, design, invent, produce, control, maintain, and use products and systems. They are the methods through which resources are turned into products.
- Materials – include natural resources such as wood and tone; synthetic resources such as plastics, alloys, and concrete; and, mixed resources such as leather, plywood, and paper.
- People – include the manpower and labor that goes into performing some task or function related to technology. People are arguably the most important resource.
- Capital – is necessary to create products and maintain technological systems. This resource includes money and all other financial instruments.

System

A system consists of interrelated components that work together in order to bring about a certain outcome or achieve a specific goal. Systems exist in many different forms—technological, environmental, social, etc. Some systems were created through natural processes while other systems are manmade. As a core concept of technology, systems include the following topics:

- A technology system is a manmade system. It combines materials, devices, energy, structures, and information as a means of solving problems or creating products.
- Feedback occurs when output produced by a particular event or behavior influences a recurrence of the same event or behavior in the future. There are two primary types of feedback: positive feedback, which increases the occurrence of the event or behavior that produced the output, and negative feedback, which decreases the occurrence of the event or behavior that produced the output. Systems often incorporate feedback components that allow for the system to be changed or refined.

Resources

Resources are required to carry out technological activities. The key resources in technology include the following:

- Tools and machines – devices and instruments intended to extend or improve human capabilities. Tools can be handheld or motor-driven, and often perform functions such as cutting, chopping, digging, etc. Machines are structures of moving and unmoving parts that perform work. They function by changing the application of energy. Simple machines include wheels, pulleys, screws, wedges, etc.
- Processes
- Materials
- People
- Capital
- Energy
- Time
- Information

In many cases, engineers must choose between resources. This decision will be made by analyzing tradeoffs, or the advantages and disadvantages of using one resource relative to another resource. Tradeoffs may include the cost, availability, desirability, and waste associated with a particular resource.

Energy, time and information

The following resources are required to perform technological functions:

- Energy – the ability to perform work. Technological systems input energy, and though application, convert it into a specific function or product.
- Time – must be allocated for the performance of any activity. Because time is limited and is required by all technological activities, it must be used as effectively and efficiently as possible.
- Information – includes any data that has been gleaned through reading, listening, observing, researching, or consulting any number of sources. Such data need not be factual, although facts are a type of information. Knowledge is more factual and reliable than information. When being used by technological systems, information should be arranged and presented in a rational and useful way.

Requirements

Requirements are the criteria and constraints that determine the final design and development of a system or project. They are created by examining the system in terms of concept-generation, marketing, production, use, disposability, and fiscal issues. Criteria include the parameters of the system design. They encompass the elements and features that define the system and determine the manner in which it should operate. A common criterion is the level of efficiency at which the system should function. Constraints are the limits on system design. They often reflect restrictions on funding, human capabilities, space, material, time, and the environment. Constraints tend to be relative, and must be balanced against each other based on the constraint's importance in the system design. Engineers must work within the criteria and constraints of the system design.

Quality control

Quality control makes certain that products meet design requirements and customers receive functional products. It involves setting parameters for the system or product, and then making certain the system or product operates within those parameters. Quality control is an ongoing process in which the materials that enter the system, system operation, and system output are constantly evaluated against an acceptable range. Nonconformances are then identified and corrected. The parameters used by quality control are often based on tolerances and specifications created from engineering standards and marketing research, which collects and examines customer reactions, both good and bad, that influence future designs and iterations of the project.

Processes

A process is usually a routine set of procedures through which materials are input and then converted into something more useful, such as a product, a service, or even a different process. In technology and engineering, a process is focused on completing a certain project, and is often described as a set of transformations that occur between input and output. These transformations are defined by their parameters and constraints. New processes are often the result of new technologies, which are the fruits of human creation and innovation. New processes lead to new products and systems that solve problems and enhance human capabilities. We create new technologies to make our lives easier and to increase our happiness and comfort.

Optimization and tradeoffs

Optimization is a process through which designers and engineers attempt to make a product or system as efficient and functional as possible. Optimization improves the overall system by bettering the performance of specific characteristics. Mathematical models are an important component of optimization. They help engineer to test and predict possible variations in system design.

A tradeoff occurs when one characteristic is lost in exchange for another characteristic with a different set of strengths and weaknesses. When optimizing a product, engineers are often forced to make tradeoffs, and must do so with full understanding of the consequences. For instance, in order to achieve a relatively light product weight, an engineer may be forced to use weaker materials.

Quality control procedures

Quality engineers are responsible for managing, controlling, and addressing product quality. Quality engineers make use of statistical process control tools such as control charts, which identify statistical variations within a process. SPC tools help determine the specific metrics that should be monitored and the method by which they should be sampled. By following the control limits set by these tools, employees can identify nonconforming products and correct or remove them before they pass on to the next production step or the customer. Defects in the production process should be corrected as early as possible; consequently, the quality engineer will work closely with suppliers to ensure conformance and contain potential problems. Additionally, quality engineers are engaged in continuous improvement, such as Six Sigma and lean manufacturing, which seeks to reduce statistical variation and the number of nonconforming products.