

General Science Refresher Course

Scientific Investigation

1. Learning about the World

Scientific Investigation: Learning About the World

Lesson Objective

In this lesson, we will review what science encompasses, how it works, and cover some of the diversity of its fields, spanning all human knowledge.

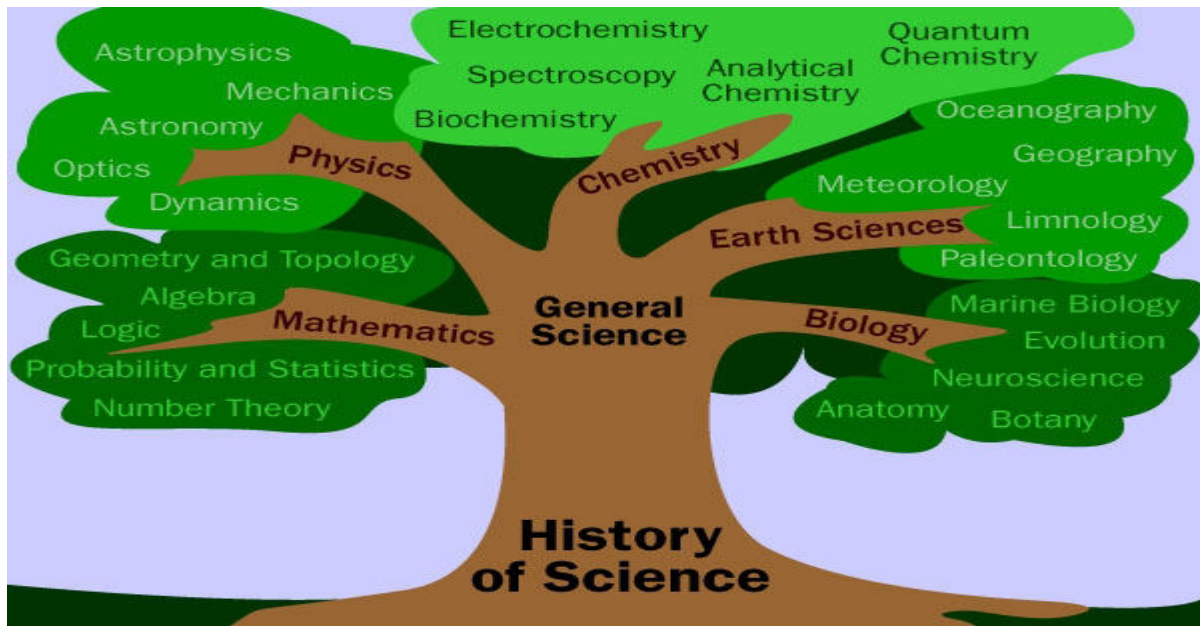
Scientific Investigation: Learning About the World

What is Science?

The word **science** comes from a Latin word that means, "to know." However, science is more than just a collection of facts and knowledge. It is **method** of observing nature and the universe, and of testing explanations for how and why things are the way they are. Scientists search for the truth. They try to uncover facts and get a better understanding of the natural world and how its parts are interrelated. Scientific knowledge and understanding are built on the principle that the universe can be explained in terms of cause and effect. Although there are many definitions of science, only two are useful in our modern understanding: empiricism and realism. According to empirical philosophy, scientific theories are objective, testable, and predictive of results that can be checked and possibly falsified through proper experimentation. On the other hand, scientific realism is more akin to identifying objects and processes; their causes, constituents, or origins; and the manner in which the causes or origins work. In short, empiricism is more about asking questions about reality; realism is more about identifying structure and cause. It may seem to be a subtle difference and the two are tightly linked in an every-day-real-world definition of science.

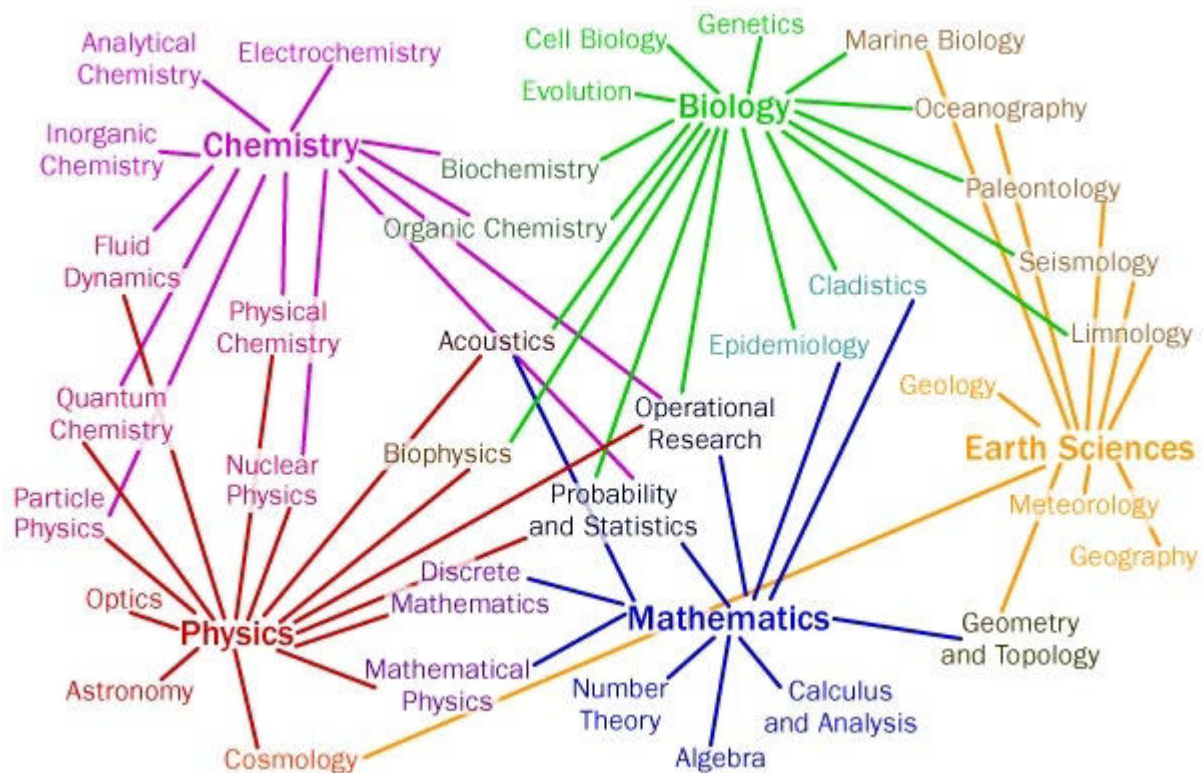
An important philosopher of science, Karl Popper, argued that verification is impossible in science and that scientific hypotheses can only be falsified. Thomas Kuhn also stated that human bias taints all observations with preconceptions that are based on the current paradigm. Kuhn argued that science involves paradigms and assumptions, and that scientific progress is mainly gained through the falsification or modification of paradigms. He also stated that the emergence of newer and more powerful paradigms occurred in a cycle that never ends. Kuhn pointed out that science has never historically proceeded as a steady accumulation of facts, but as a series of dramatic (and sometimes cataclysmic) paradigm shifts that precipitate scientific revolution.

There are no arbitrary decisions that control our lives. Storms occur not because of angry supernatural beings, but rather because a certain amount of energy from the sun has heated parts of Earth more than others. Energy flows between these places in a predictable way that follows natural laws. This flow of energy causes the storms and other atmospheric phenomena. We employ science as a powerful tool; observations are used to make predictions about how the universe works. Almost every part of our daily lives is based on scientific knowledge and its applications.



Scientific Investigation: Learning About the World

Because science covers a lot of conceptual ground people separate it into different branches of knowledge. The term *branches* might indicate that the fields of science can be shown in a tree-like diagram. However, as our storehouses of knowledge expand, a web of knowledge may display science more accurately. No matter how you prefer to visualize the complexity of science, you should realize that all of scientific progress is interrelated and there are no isolated disciplines within science — everything is connected.



Broad fields of scientific study include:

1. Biology: the study of life. This is one of the broadest disciplines of science and is significant as we learn more about ourselves and our place in the natural world.
2. Geology: the study of Earth. Geological sciences are at the juxtaposition of astronomy and Earth Sciences.
3. Chemistry: the study of elements and the interactions of their atoms.
4. Physics: the study of the physical universe and how its parts interact.
5. Mathematics: the study of numbers and shapes. Although mathematics is a field of science on its own, it is also the glue that holds the others together.

Most scientific investigations do not fall strictly within one of these classifications. There is tremendous overlap and interconnection among them. Within and between these broad fields, there are many other classifications of science. These include fields such as biochemistry and geophysics that combine concepts from two or more of the broad fields. Others, for example, botany and organic chemistry, are specialties within one of the broad fields. In addition, the principles of science are used by sociologists, economists, psychologists, and others who study human behavior. The main idea to remember is that science is a process that encompasses the whole range of causes and effects in the natural world and our systematic attempts to understand it all.

Question

Science is

- A everything we know about the universe.
- B a method for learning about the universe.
- C a collection of all observations and data.
- D biology, chemistry, geology, mathematics, and physics.

[Answer](#)

The correct answer is B. Science is a method for learning about the universe. It is more than data or a list of subjects.

Scientific Investigation: Learning About the World

So who does science anyway?

All of us know what a stereotypical “mad scientist” is. You may have pictured such a person as a middle-aged, white male with an indeterminate European accent, glasses, a beard, bad haircut, and a somewhat rumpled white lab coat. Like most stereotypes, this stereotype is far removed from reality. Science is a worldwide undertaking that involves people of all types, colors, and creeds doing many different kinds of jobs. Although many scientists work in laboratories, the settings for scientific research are diverse. Engineers, teachers, computer scientists, doctors, nurses, farmers, and even

cooks do scientific research every day. Some scientific fields, such as astronomy, actively encourage amateur observers to contribute their data, observations, and interpretations. The bottom line is that anyone can perform scientific work.

Scientific research has several purposes. In its most basic form, science is the search for greater understanding. People are curious about how things work, why the sky is blue, and whether it will rain tomorrow. Science also has a practical aspect, known as **technology**. Technology is the application of scientific knowledge to solve practical problems. Farmers, for example, use a wide variety of technologies to produce food. After early farmers observed that certain seeds grew better when the soil was loosened, they applied this knowledge to the design of the plow. Modern farm equipment now includes global positioning systems to help control precise application of fertilizer, water, and pesticides.

Modern technologies are built on the results of past scientific research that have occurred over many thousands of years. Think about all of the knowledge that went into building your car, for example. Building an engine requires an understanding of the chemistry of fuel combustion and of the materials that can handle the heat generated by internal combustion. Brakes are designed to distribute massive forces of a thousand-kilogram auto body moving at high speeds. Safety systems apply the results of biological investigations to prevent damage to human bodies during an accident. Even the process of designing an appealing shape uses the scientific study of aerodynamics and human aesthetics.

Scientific Investigation: Learning About the World

Lesson Objective

In this lesson, we will review the ethical traditions of science and the ways that scientists work to assure reliability in their investigations.

Previously we covered...

Science is a method of learning about the universe, not just a collection of facts.

Science covers and is largely responsible for the entire range of human knowledge. This diversity can be thought of as an interconnected web or as a tree of knowledge with various branches.

Technology is the application of scientific knowledge to solve practical problems.

Scientific Investigation: Ethics and conduct in science

How do I know I can trust the reports of a scientific investigation?

Because science is based on relationships between causes and effects in nature, an experiment performed under the same conditions will always yield the same results. This is the basic assumption on which all scientific investigations and scientific knowledge are built. Reproducibility of results is the core of science; while exact data will undoubtedly be slightly different; the results should be the same and show the same conclusions. When scientists report their findings to the scientific community, there is a process called peer review that entails other scientists looking at their methods and determining if their results are reproducible.

The reliability of scientific results is based on researchers following a code of ethical behavior. Elements of this code include:

- keeping accurate and truthful records of any and all results
- avoiding bias in the experiment to get the "right" result
- presenting information that allows other investigators to reproduce the experiment identically
- allowing review of results by other researchers

Accurately recording and reporting results is necessary so that an experiment can be repeated in exactly the same way by anyone. Scientific research depends on careful documentation so independent researchers can reproduce the experiment. When results are not reproducible, they cannot be accepted by the scientific community. This happened in 1989 when the results of a now-famous "cold fusion" experiment were announced. The potential new source of energy received wide coverage in the press, but when other scientists attempted to reproduce the results from the experiment, they obtained entirely different results. What happened? No one is sure exactly why the cold fusion results were not reproducible. There may have been a problem with the experimental design that was overlooked. Perhaps a second independent variable was introduced or some condition was not controlled, so that the exact procedure could not be determined. Whatever the cause of the error, the results have not been accepted as valid because they are not reproducible. Needless to say, this did nothing positive for the professional integrity of the scientists involved.

It is also important that **all** results be reported. Sometimes an experiment produces data that are not expected or appear to be inconsistent with earlier data. These inconsistencies must be recorded and analyzed just like all the rest of the data. Frequently, unexpected data leads to new questions and research directions. As a result, it is important to accurately record the exact methods used and all data obtained in an experiment. Scientists generally report their results at conferences or in scientific journals that are reviewed by other scientists. One of the problems encountered by the cold fusion researchers was that results were released to the general media prior to review by other scientists.

Perhaps the most important ethical consideration in scientific research is to avoid influencing, or biasing, the results of an experiment. [Bias](#) is the often inextricable quality of affecting the results of your experiments. Results are often skewed by the expectations of the scientists to a particular outcome. Bias can be as innocuous as accidentally avoiding running experiments when it is cold outside, but also include the blatant changing of recorded data to obtain the expected or desired result. The latter case constitutes fraud and it is a very serious breach of scientific ethics. Often times, however, bias is more subtle. If the experimenter expects a particular result, he or she may tend to accept results that support the result and reject results that do not, perhaps without any conscious realization of having done so. The design of many medical experiments prevents bias by using a "double-blind" technique. Because the results can be influenced by an expectation that a drug will work, neither the patients nor the doctors know which patients receive the real drug being tested. Because of an effect broadly termed Heisenberg's Uncertainty Principle (first developed in attempting to measure the location of electrons), we know now that there is ALWAYS bias in all human endeavors, but scientists try to minimize this bias. It is not always an easy task.

Learning About the World - How do we Use Science to Explain Things?

Scientific Investigation: Ethics and conduct in science

Lesson Objective

In this lesson, you will learn

- about techniques scientists use to design a scientific investigation
- how to evaluate an investigation
- how to tell the difference between real science and pseudoscience

Previously we covered...

Scientists have developed a tradition of ethical behavior to assure the value of results.

Accurately recording and reporting experimental results are essential in science.

Bias, whether intentional or unintentional, must be effectively eliminated from experiments.

Scientific Investigation: Ethics and conduct in science

How do you do science?

A key part of any scientific investigation is the hypothesis - a possible explanation for a phenomenon that be tested. A hypothesis is sometimes referred to as an educated guess, but it is actually more than that—a tentative explanation for something that has been observed. In the early 1600s, most people believed that all celestial bodies revolved around Earth. Nicolas Copernicus carefully observed the motions of the planets and formulated a hypothesis that the sun, not Earth, was the center of the Solar System—a heliocentric system. His hypothesis, or possible explanation, was based on observations. Of course, not everyone was immediately convinced. Other explanations of the motions of stars and planets already existed. More observations and data were needed. One observation that supported the heliocentric hypothesis was that planets sometimes appear brighter and sometimes dimmer. The relative positions of the sun, the planets, the Earth change in different ways in a heliocentric system than in a geocentric system and the observed patterns of brightness also corresponded to a heliocentric system. The fundamental change from a geocentric universe to a heliocentric solar system was a paradigm shift that brought a scientific revolution.

How do I know a good hypothesis when I see it?

A hypothesis is useful for a scientific investigation if it has certain features. First, it must make a prediction that can be tested. How does Copernicus's heliocentric universe stack up to this requirement? He could predict the positions of the planets far into the future (that could be falsified) and later observations supported the hypothesis. Second, the hypothesis must be falsifiable. If the hypothesis is not correct, there are tests or experiments that will show it to be incorrect. If the motion of the celestial bodies is not consistent with the hypothesis, it can be shown to be incorrect. In fact, parts of the Copernican hypothesis (that planets move in uniform circular motions around the sun) were later falsified. The observed motions of the planets are not consistent with these circular orbits; planets actually move in elliptical orbits around the sun. The Copernican hypothesis, although not completely correct, eventually led to an understanding of the solar system that allowed people to walk on the moon and robots to explore Mars.

Science is based on **testable hypotheses**, using the **scientific method**, and always questioning the *status quo*. Pseudoscientific fields, such as astrology, fortune telling, therapeutic touch, Intelligent Design, and studies of UFOs are generally built on a foundation of hypotheses that are not falsifiable or based on beliefs, not hypotheses. When the observations support the "hypothesis," they are presented as proof. When they do not, there is always an explanation—which cannot be tested. This is not science and there is no confusion about what is and what is not scientific.

Check your understanding of hypotheses.

Question

Which of the following could be a scientific hypothesis?

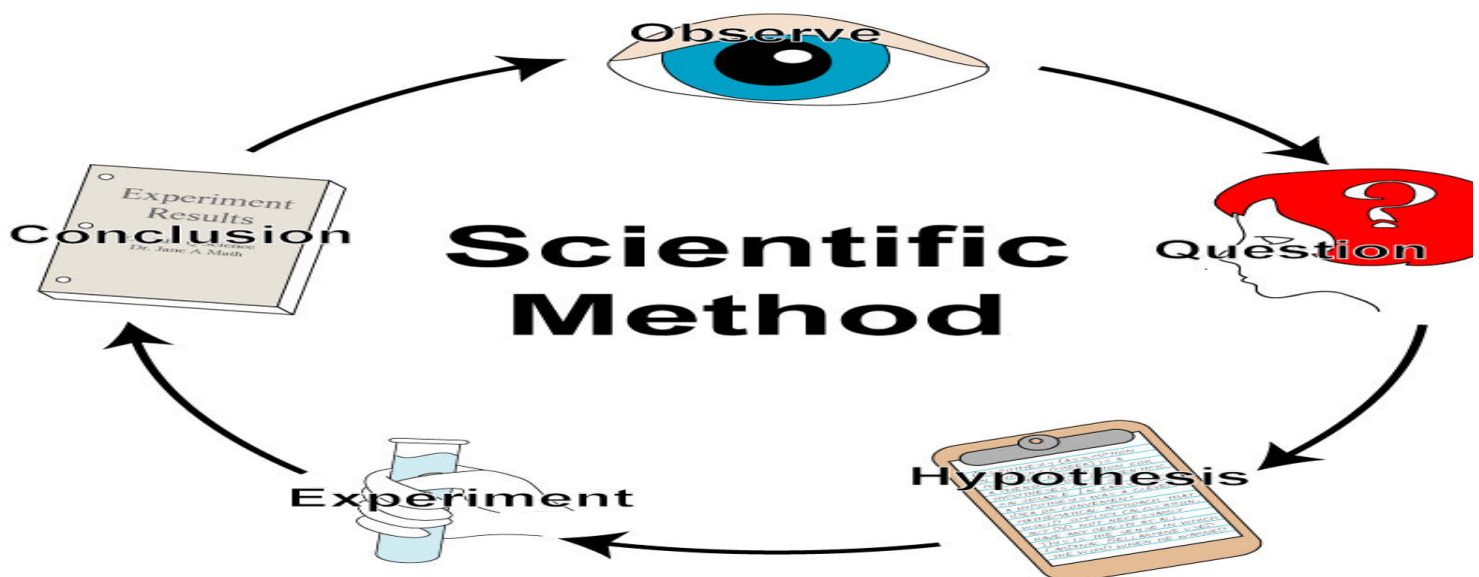
- A When a cat dies, its spirit is reborn in another kitten.
- B Dogs are better pets than cats.
- C Dogs have better hearing than cats.
- D Some people can read the minds of their pets.

✔ [Answer](#)

The best answer is C. Choice C makes a prediction that can be tested. It can also be falsified, if cats are demonstrated to have hearing that is as good as, or better than that of dogs. Choice D is not falsifiable because there is no way to prove that I don't know what my dog is thinking. (You can ask him, but he won't answer. He only communicates with me.) Choices A and B do not make testable predictions.

Scientific Investigation: Learning About the World

I have a hypothesis — now what? Forming a hypothesis is only one step of the scientific method.



The hypothesis is a tentative explanation, but it is not really useful until there are data to support it. Using prediction based on your hypothesis, you can design an [experiment](#) to test the prediction. An experiment is a set of controlled tests and observations of the results that determine whether the prediction is correct. Although an experiment can show that you were unable to disprove the hypothesis, you can never truly verify hypotheses beyond further testability. In other words, the best you can do in scientific inquiry is to NOT reject hypotheses. Skepticism always remains and empowers science to achieve hypotheses that can later become theories and perhaps even laws. More on those later.

The experiment must be designed to actually test the hypothesis, providing an answer that will support it or disprove it. For example, how can you design an experiment to test a hypothesis showing that a species of small mammals are equally likely to eat sunflower seeds and thistle seeds? If you place only thistle seeds in a feeder and count the number of small mammals that eat them, your data does not test the hypothesis. What if no small mammals show up? That could either mean that small mammals do not like thistle seeds or perhaps, that there are no small mammals in the area. In addition, it provides no data about whether they eat sunflower seeds. However, if you place two *identical* feeders side by side, one holding sunflower seeds and the other holding thistle seeds, and there are small mammals in the area, your experiment can test the hypothesis. If the small mammals spend equal time at the two feeders, the hypothesis is supported. Keep in mind that a single test does not *prove* the hypothesis to be true. If no small mammals arrive at either feeder, you still do not have useful data, because there are several possible explanations for the observation that they did not have anything to do with your hypothesis. On the other hand, if all the small mammals go wild over the sunflower seeds and ignore the thistle seeds altogether, the hypothesis is not supported by the observation.

Question

Which observation supports the hypothesis that fire ants produce a substance that is harmful to humans?

- A Ants are insects.
- B Fire ants are red.
- C Fire ant bites cause pain.
- D People are afraid of fire ants.

[Answer](#)

The Correct Answer is C. The hypothesis predicts some kind of adverse reaction, so observation C supports the hypothesis. Choices A and B are observations that are unrelated to toxicity. There are nontoxic red insects. Although people may be afraid of fire ants because they inflict pain, the fear itself is not evidence of toxicity. In fact, many people are afraid of insects that do not produce toxins.

Scientific Investigation: Learning About the World

How do I design a good experiment?

An experiment must produce unambiguous results. You can accomplish this by designing the test so that only one **variable** is changed at a time. Let's go back to the birds and their seeds. Notice that the paragraph above refers to placing different types of seed in two **identical** feeders. Why is the word "identical" italicized? There must be some reason for the emphasis. Well, what if you placed the sunflower seeds in a platform feeder and the thistle seeds in a tube feeder? Now you observe the small mammals eating sunflower seeds, but you still don't have support for the hypothesis. Why? It's possible that the animals don't have a preference for one seed over the other, but instead, a preference for one type of feeder over the other. The experiment doesn't test the hypothesis because two variables were changed. One change — the type of seed — tests the hypothesis. The other variable — the type of feeder — does not. You don't know whether your experimental results are because of one change or the other or both.

The table below shows some examples in which an **independent variable** — a factor that is controlled by the experimenter — affects the **dependent variable** — a factor that changes in response to changes of the independent variable.

Experiment	Independent variable	Dependent variable
How does temperature affect the reaction rate of a chemical reaction?	temperature	amount of reaction product forms in a given time period
How is the parent eye color related to offspring eye color in fruit flies?	color of parents' eyes	ratio of eye colors in offspring
How is the speed of an electric motor affected by the voltage?	voltage	motor speed
Which direction are tectonic plates moving?	direction of magnetic poles	orientation of magnetic materials in rock as it forms
How does the mass of an object affect the rate at which it falls?	object mass	amount of time to fall a given distance
Do all metals absorb light energy at the same rate?	type of metal	temperature of metal after a given period of exposure to sunlight

In well designed experiments, all factors, except the independent variable, should be identical in each test. For example, to test the prediction that plants grow bigger if they have more light, expose several plants to different amounts of light (independent variable) and measure growth (dependent variable). Other parameters, such as temperature, water, and fertilizer, must be the same for each plant in order to ensure that the change in the growth rate is a result of the difference in the amount of light. These factors are the **controlled variables**. In the small mammal feeding experiment, identical feeders were chosen — a controlled variable.

Question

Which of these sets of variables could be used in an experiment to test the hypothesis that different metals absorb different amounts of energy from sunlight?

- A independent — type of lighting; dependent — temperature of metal
- B independent — type of lighting; dependent — type of metal
- C independent — type of metal; dependent — temperature of metal
- D independent — temperature of metal; dependent — type of metal

✔Answer

The correct answer is C. Because you want to determine the effect on different type of metals, your independent variable (the one you change) is the type of metal. The effect on the dependent variable tests your hypothesis. The temperature of the metal is related to energy absorption. Other variable, such as type and amount of lighting and the size of the metal pieces must be controlled

Scientific Investigation: Learning About the World

After data are collected, the results of the test are analyzed to reach a **conclusion**. The conclusion may be that the experiment supports the hypothesis because the prediction is unable to be refuted. Keep in mind that this does not prove the hypothesis—it only shows that the hypothesis is not NOT true (that it might be true). An interesting thing about experiments is that the results often don't match the prediction and that's not necessarily a bad thing. The data are still useful. The scientific method is a cycle, not a linear progression. When the data do not match the hypothesis, you modify or replace your hypothesis and design a new experiment. What will you do if all of the small mammals flock to the sunflower seeds? Time for a new hypothesis: small mammals prefer sunflower seeds to thistle seeds.

Frequently an investigation not only tests the hypothesis, but leads to new questions and further investigations. While observing the small mammals, you may have noticed that the thistle feeder attracts birds. Why does one type of bird prefer one food and another prefer a different food? There may be a new hypothesis and series of experiments just waiting for the right scientist.

Question

How does the scientific method work?

- A Hypotheses are proven through experiments that clearly show that the hypotheses cannot be refuted. These become Laws of Nature.
- B Hypotheses are tested and refuted, new hypotheses are then generated to complete the cycle. Hypotheses are always falsifiable.
- C Falsifiable hypotheses are based on observations; they are tested and sometimes refuted; if they are unable to be refuted, they are taken as laws. Hypotheses are eventually proven.
- D Falsifiable hypotheses based on observations are tested; sometimes they are refuted and new hypotheses are generated; sometimes they are unable to be refuted and are tested in different ways. Hypotheses are never proven.

🟩Answer

The correct Answer is D. The scientific method is based on the testing of falsifiable hypotheses that are based on observations. If these hypotheses are shown to be untrue, new hypotheses are developed and tested. When hypotheses are unable to be refuted, they are tested in new experiments. Although we commonly assume some very well known hypotheses, they can never strictly be proven.

2. Scientific Revolutions

Scientific Investigation: Scientific Revolutions

Lesson Objective

In this lesson, you will learn about how theories are used to explain and explore the natural world, and investigate some important scientific theories.

Previously we covered...

The **scientific method** is an organized way of exploring nature.

A **hypothesis** is a possible explanation for a phenomenon.

To be useful for science, a hypothesis must be **falsifiable**.

Hypotheses are accepted, rejected, or modified based on **conclusions** derived from experimental data. Even when we accept a hypothesis, we never can prove it.

Experimental results can lead to new questions and investigations whether or not they support the hypothesis.

Scientific Investigation: Scientific Revolutions

Eureka—it worked! Now what?

A single test does not prove a hypothesis, but it can support it. Generally a hypothesis must be tested many times and under different conditions before it is generally accepted. A **theory** is an explanation of the natural world that incorporates conclusions from a number of well-tested hypotheses. Theories are not static knowledge. As new experiments and observations expand the base of knowledge, they are incorporated into the theory. For example, chemists have refined the atomic theory to account for observations about how atoms interact. In the early 20th century, a **model** was developed, showing electrons moving in fixed orbits around the nucleus, which could explain what was known about how atoms behaved. This model was incorporated into the atomic theory. Later experiments were not consistent with that model and the theory was modified. According to the current atomic theory, the model represents electrons by a "cloud" of likely positions. If new observations are not consistent with this model, the theory will be modified again. This is how science works — dissent with modification.

In common use, the words **theory** and **hypothesis** are often used interchangeably, while in science they represent very different concepts. This difference in usage has sometimes led to the misconception that a theory is a guess or belief. In science a theory is supported by a large body of evidence based on many hypotheses and it is a tool for predicting experimental results, and

understanding how the natural world works. While a theory can serve as an explanation of observed phenomena, it also serves as a starting point for new investigations into predicted phenomena. Some theories have generated many new hypotheses, expanding the reach of an entire field of science.

There are thousands or millions of theories in science, ranging from explanations of one particular phenomenon to theories that encompass entire fields of scientific understanding. Some of the most influential theories that have driven scientific research over the past few centuries include:

- atomic theory
- Big Bang
- classical mechanics and relativity
- evolution
- plate tectonics

Atomic theory

Although ancient Greek philosophers first introduced the concept of atoms, it was not a scientific theory because it was not supported by experimental data. In the early 1800's John Dalton designed experiments to test the existence of atoms as the basic units of the elements. Dalton modeled the atom as a hard ball, the basic particle of matter. Building on his work, later researchers have developed new models. According to modern atomic theory, the atom is composed of smaller charged and uncharged particles, held together by forces of attraction. Dalton's basic idea—that an atom is the smallest particle of an element—is still a key part of atomic theory. The atomic theory is the basis of all of our applications of chemistry, including all sorts of modern materials and pharmaceuticals.

Big Bang

One of the implications of Albert Einstein's theory of relativity is that the universe is expanding. This concept combined with observations that distant galaxies are moving apart at increasing speeds forms the basis of the Big Bang Theory. According to this theory, the universe began about 14 billion years ago in a sudden expansion from an extremely hot, dense phase. In the 1960s, scientists discovered the Cosmic Microwave Background (CMB)—light waves that permeate the universe. The CMB was one of the predictions of the Big Bang Theory. Today, almost all cosmologists accept the Big Bang as the best theory of the beginning of the universe. Data from the Hubble Telescope and many other space and ground-based observatories support this explanation. The theory has been used to develop an understanding, not only of the broad universe, but also the basic particles that make up all matter.

Classical mechanics and relativity

Classical and quantum mechanics are concerned with the motions and forces that cause the movement of objects. Classical mechanics was first developed more than 300 years ago through the work of Newton, Kepler, and Galileo (and others), whereas quantum mechanics is much more recent. The main scientists responsible for our progress in quantum mechanics are Bohr, Planck, and Einstein (and others). The basis of classical mechanics on mathematical explanation was a decisive stage in the development and history of science. Not simply using math in rigorous ways, classical mechanics scientists also relied on experimentation for the first time and established the formulation of quantitative predictions, and how to test them through carefully designed experiments and measurements. The main tenants of classical mechanics deal with objects on a human scale and hold for 99.99% of our everyday activities. However, the revelation of quantum mechanics was a major breakthrough for our understanding of all motion – even at the subatomic scale. Quantum

mechanics holds for energy, inertia, and the motion of all objects (including waves) and is most notable for the idea that light is a wave-particle duality. In a sense, quantum mechanics is more fundamental than classical mechanics because it provides precise explanations and predictions across all scales. Whereas there are some major holes in classical mechanics, quantum mechanics has yet to be refuted after more than a century of experimentation.

Evolution

The theory of evolution began with the introduction of natural selection in a joint 1858 paper by Charles Darwin and Alfred Russel Wallace. They both independently, and later together, assembled and collated data from their observations of plants, animals, and fossils to build the theory of evolution by natural selection. Darwin and Wallace hypothesized that evolution occurs when a trait that increases an individual's chance of successfully mating becomes more common from one generation to the next. Evolution affects population genetics and eventually leads to the emergence of new species because individual organisms acquire and pass on novel traits via inheritance. The key element of the theory is that differential survival and reproduction (based on competition for resources and/or mates) allows some organisms to pass on genetic variation to their progeny. Although the theory has been modified since Wallace and Darwin's time, natural selection remains a key concept on which our current understanding of biology, genetics, and ecology are built. The Modern Synthesis of the early 20th century has incorporated the idea of a gene as the unit of inheritance and we now understand the molecular biology of DNA replication, population and community ecology, and genetics in much greater detail. The theory of evolution is the most powerful theory in the life sciences.

Plate tectonics

In the early 20th century, Alfred Wegener noted how South America and Africa seem to fit together. He also researched the similarity of fossils at the edges widely separated continents. He proposed a hypothesis of continental drift, in which all the continents had once formed a single land mass that he called Pangaea and are now moving away from one another. Wegener's ideas were not widely accepted because he lacked an adequate explanation for the mechanism of continental drift. In the 1960s, scientist discovered evidence that supported Wegener's hypothesis. Magnetic materials in the rocks of the sea floor in the deep ocean provided evidence that the crust of Earth is made of plates that move relative to one another. This observation, as well as the results of other experiments, was combined with Wegener's continental drift in the theory of plate tectonics. Scientists have used this theory to study the prehistoric structure of the continents and to develop other theories about the internal structure and the history of the planet

Scientific Investigation: Scientific Revolutions

A **scientific law** is a statement of fact that explains a relationship in nature that is generally accepted to be true and universal. Scientific laws are based on numerous observations and tests, with no exceptions being found. Like mathematical postulates, scientific laws don't require proofs. They are accepted because of the fact that they have always been observed to be true. Scientific laws include the law of gravity, conservation of mass, and the gas laws that describe the behavior of gases. In many cases, scientific laws can be expressed as mathematical formulas.

Question

Which of the following is an established scientific theory?

- A Plate tectonics
- B Intelligent design
- C Conservation of mass
- D Internal combustion engine

👉Answer

The answer to this one is A — plate tectonics is a theory built on a number of tested hypotheses. Intelligent design is not a scientific theory because it is not falsifiable and therefore cannot be tested. Conservation of mass is a scientific law and the internal combustion engine is an example of technology.

Why is science such a powerful tool for the advancement of human endeavor?

Science is a process, not just a body of knowledge. In a broad sense, everyone is a scientist. A small child learns about the forces of gravity and friction, usually the hard way, by experimenting with toys. **Learning** by making a hypothesis, **designing** experiments to test them, **collecting** data, and **revising** the hypothesis is science. Anyone can do it because the scientific method is based on the way our brains work.

Where do we go from here?

Science is a process for discovery and it doesn't end once a question is answered. Each discovery leads to new questions. Each advance opens up new fields of research. Today's frontiers in science are built on the hypotheses and theories that directed past research. A sampling of these frontiers includes:

- nanotechnology — builds new materials at the atomic and molecular level
- biotechnology — engineers on the scale of a living cell; includes genetic engineering of DNA molecules
- agro-ecology — combines the study of natural ecosystems and social sciences to build sustainable agriculture
- information technology — develops computer systems and techniques to manage data more efficiently
- climate modeling—uses computers to build models of the complex systems of the Earth's atmosphere and oceans

Scientific Investigation: Scientific Revolutions

Lesson Objective

In this lesson, we will review the importance of measurements to a scientific investigation, how to record measurements and convert measured values between different units.

Previously we covered...

- Scientific knowledge is built on **hypotheses** and **theories**.
- Hypotheses and theories are developed based on **conclusions** drawn from data-based experiments.

- Some of the most important scientific breakthroughs in history are atomic theory, the Big Bang, classical mechanics and relativity, evolution, and plate tectonics.

Scientific Investigation: Scientific Revolutions

Although mathematics is a branch of science, it is also a key tool for nearly all scientific investigations. Because conclusions rely on reproducible data, most scientific investigations involve **measurement** of one or more physical quantities. Some attributes that can be measured include length, mass, volume, time, temperature, and number of particles. Every measurement has two components: a unit that is associated with a physical quantity, such as length or mass, and the number of units. Both parts of a measurement must be included. For example, a length of 2 is not a meaningful measurement, while 2 millimeters, 2 kilometers, 2 inches, and 2 light-years are all meaningful measurements.

Over the course of history, people have developed many different systems of measurement. For example, one distance can be expressed as 2.00 meters, 6.56 feet, 0.4 rods, or 0.00124 mile. Sharing data and experimental results is much easier, however, if everyone uses the same units.

Scientists around the world have agreed to use a metric system of measurement, based on powers of ten, known as the International System of Units (SI). The system uses fundamental units for length, time, mass, temperature, electric current, amount of a substance, and luminosity.

Name	Symbol	Quantity	Definition
kilogram	kg	Mass	This unit of mass was originally defined as the mass of one liter of water at 3.98° Celsius and standard atmospheric pressure at sea level.
second	s	Time	The second is based on an atomic clock of the transition between two levels of the ground state of the cesium 133 atom.
meter	m	Length	The unit of length was originally defined as the length of a pendulum with a half-period of one second. The meter is the length of the path traveled by light in a vacuum during a time interval of $1 / 299792458$ of a second.
ampere	A	Electrical current	The unit of electrical current is the value of the current between two conductors that, if placed 1 meter apart in a vacuum, would produce a force between these conductors equal to 2×10^{-7} newtons per meter of length. The more commonly used definition is that one ampere of current (I) is equal to a flow of one coulomb of charge (Q) per second of time (t): $I = Q / t$.
kelvin	K	Thermodynamic temperature	The unit of absolute temperature is the fraction $1/273.16$ of the triple point of water and where 0 is the absence of all motion. A temperature given in kelvins (K) is measured with respect to

			absolute zero, where molecular motion is considered to stop. It is also common to give a temperature relative to the Celsius temperature scale, with a reference temperature of 0 °C = 273.15 K, approximately the melting point of water under ordinary conditions.
mole	mol	Amount of substance	A number having a value of 6.022142×10^{23} and is also called Avogadro's number. The number of atoms or molecules in 1 mole of a substance.
candela	cd	Luminous intensity	The unit of luminous intensity is emitted by a monochromatic light source of wavelength 555 nm and that has a radiant intensity of 1/683 watt per steradian.

Units that are larger or smaller than the base unit are designated in SI by prefixes that indicate their value in different powers of ten. The table below shows the SI prefixes and their values. Note that the base unit of mass (kg) is defined as 1000 grams.

SI Prefixes

Factor	Prefix Name
10^{21}	zetta
10^{18}	exa
10^{15}	peta
10^{12}	tera
10^9	giga
10^6	mega
10^3	kilo
10^2	hecto
10^1	deka
10^0	-meter-liter-gram-
10^{-1}	deci
10^{-2}	centi
10^{-3}	milli
10^{-6}	micro
10^{-9}	nano
10^{-12}	pico
10^{-15}	femto
10^{-18}	atto
10^{-21}	zepto

Scientific Investigation: Scientific Revolutions

Other derived units, such as those for density, speed, and power are combinations of the fundamental units of the SI system. The table below lists a number of derived units and their relationship to the SI base units.

Physical quantity	SI unit	in symbols
area	square meter	m^2
volume	cubic meter	m^3
speed, velocity	meter per second	m/s
acceleration	meter per second squared	m/s^2
momentum	newton second	$\text{N} \cdot \text{s}$ or $\text{kg} \cdot \text{m} \cdot \text{s}^{-1}$
density, mass density	kilogram per cubic meter	kg/m^3
heat capacity, entropy	joule per kelvin	J/K or $\text{kg} \cdot \text{m}^2 \cdot \text{s}^{-2} \cdot \text{K}^{-1}$
molar heat capacity, molar entropy	joule per kelvin mole	$\text{J} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}$ or $\text{kg} \cdot \text{m}^2 \cdot \text{s}^{-2} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}$
specific heat capacity, specific entropy	joule per kilogram kelvin	$\text{J} \cdot \text{K}^{-1} \cdot \text{kg}^{-1}$ or $\text{m}^2 \cdot \text{s}^{-2} \cdot \text{K}^{-1}$
frequency	hertz	Hz or vps or s^{-1}
force	newton	N or $\text{kg} \cdot \text{m} \cdot \text{s}^{-2}$
electric charge	coulomb	C or $\text{A} \cdot \text{s}$
electric potential, electromotive force	volt	V or $\text{J} \cdot \text{C}^{-1}$ or $\text{kg} \cdot \text{m}^2 \cdot \text{s}^{-3} \cdot \text{A}^{-1}$
electric capacitance	farad	F or $\text{C} = \text{Q} / \text{V}$ or $C = \frac{\Phi}{V}$
electrical resistance, impedance, reactance	ohm	Ω or V / A
energy, heat, work	joule	J or $\text{N} \cdot \text{m}$ or $\text{kg} \cdot \text{m}^2 \cdot \text{s}^{-2}$
pressure	pascal	Pa or $\text{N} \cdot \text{m}^{-2}$ or $\text{kg} \cdot \text{m}^{-1} \cdot \text{s}^{-2}$
power	watt	W or $\text{J} \cdot \text{s}^{-1}$ or $\text{kg} \cdot \text{m}^2 \cdot \text{s}^{-3}$
temperature	degree Celsius	$^{\circ}\text{C}$ $^{\circ}\text{C} = \text{K} - 273.16$

Measured values can be treated just as regular numbers, added, or subtracted, but only if their units are the same. How do you work with measurements that use different units — for example (500 m + 2.3 km) **or** (6 ft – 1 m)? A conversion factor is a ratio of equivalent values that expresses a single quantity in two different units. (See SI prefixes table above.) For example, 1 km = 1000 m.

$$500 \text{ m} \cdot 1 \text{ km}/1000 \text{ m} = 0.5 \text{ km}$$

After making this conversion, you can add the first example above, as follows:

$$500 \text{ m} + 2.3 \text{ km} = 0.5 \text{ km} + 2.3 \text{ km} = 2.8 \text{ km}$$

Note that the 2.3 km can alternatively be converted to 2,300 m, yielding a sum of 2,800 m.

Using units incorrectly can have drastic effects on the results of an experiment. In 1999 NASA sent a probe, the Mars Climate Orbiter, to investigate the Martian atmosphere. After firing the rockets that were to place the probe into an orbit around Mars, the probe was lost, apparently crashing on the surface. An investigation revealed that two teams of scientists and engineers who had worked on the calculations needed to time the firing of the rockets. One team had used SI units and the other had used English units (feet and pounds). Oops.

Below are a number of sample conversion tables that are fairly straightforward, but not exhaustive. Please take some time to become familiar with the different units and understand the different and relative values (e.g., you should know that a kilogram is roughly twice as much a pound). Please note that we have not included all possible conversions — that would incorporate too many possibilities.

(English to SI)

Name of unit	Symbol	Definition	Relation to SI units
inch	in	1/36 yd	25.4 mm
foot	ft	12 in	0.3048 m
yard	yd	3 ft	0.9144 m
mile	mi	1760 yd = 5280 ft	1609.344 m
square inch	sq in	1 in ²	6.45 × 10 ⁻⁴ m ²
square foot	sq ft	1 ft ²	9.29 × 10 ⁻² m ²
acre	ac	4840 sq yd	4046.856 m ²
liter	L		1000 cm ³
cubic inch	cu in	1 in ³	16.387 mL
fluid ounce (U.S.)	Fl oz	1/128 gal (US)	29.574 mL
gallon (U.S. fluid)	gal (US)	231 cu in	3.785 L
ounce (mass)	oz	1/16 lb	28.350 g
pound (mass)	lb	7000 grains	0.454 kg
kilometer per hour	km/h	1 km/h	2.78 × 10 ⁻¹ m/s
foot per second	fps	1 ft/s	3.05 × 10 ⁻¹ m/s
mile per hour	mph	1 mi/h	0.45 m/s
standard gravity	<i>g</i>		9.81 m/s ²
joule (SI unit)	J	N·m = W·s = V·A	kg·m ² /s ²
calorie (thermochemical)	cal		4.184 J
British thermal unit (thermochemical)	BTU _{th}	1 lb/g × 1 cal _{th} × 1 °F/°C = 9.489 ÷ 9 kJ	1.054 kJ
kilowatt-hour	kW·h	1 kW × 1 h	3.6 MJ

Question

Which of the following is equivalent to 60 miles per hour?

- D 26.800 m/s

Answer

The correct answer is B. Make sure that all of the conversions are correct.
 $60 \text{ mi/hr} \cdot 1.61 \text{ km/1 mi} \cdot 1000 \text{ m/1 km} \cdot 1 \text{ hr/3600 s} = 26.8 \text{ m/s}$

Scientific Investigation: Scientific Revolutions

In addition to measurements of dimensions and time, many scientific investigations measure temperature. How should you dress if the weather report calls for a high temperature of 35° ? That depends. If the temperature is 35°F , you'll want to bundle up; if it is 35°C , light clothes are in order. If the temperature is 35K , then you are probably on the Moon, not Earth. These values correspond to the three main temperature scales in common and scientific use. You should become familiar with equivalent temperatures, including the melting and boiling points of water on the Fahrenheit, Celsius, and Kelvin scales. Another point, absolute zero, is the theoretical coldest possible temperature. Absolute zero is the starting point of the Kelvin scale.

Temperature scales

Although the Fahrenheit scale is commonly used in the United States, most of the world, including the entire scientific community, uses the Celsius scale. This scale establishes 0° as the freezing point of water and 100° as the boiling point of water, while the more precise but less useful Fahrenheit scale uses 32° F and 212° F for freezing and boiling points. The Kelvin scale is also used by scientists, particularly when they are working at very low temperatures. The standard unit of temperature change in the SI system is the kelvin (K), which is the same as 1°C . Note that the degree symbol is not used in the Kelvin scale. As with other units, conversion factors can be used to calculate equivalent temperatures in the three scales. Please see the table below.

Temperature

Name of unit	Symbol	Definition
kelvin	K	SI base unit
degree Celsius	°C	$^{\circ}\text{C} = \text{K} - 273.15$ $^{\circ}\text{C} = ^{\circ}\text{F} / 1.8 - 32$
degree Fahrenheit	°F	$^{\circ}\text{F} = \text{K} \times 1.8 - 459.67$ $^{\circ}\text{F} = 1.8 \times [^{\circ}\text{C}] + 32$

Is there a better way to write numbers?

Scientists have measured the mass of an electron with fantastic precision = 0.0000000000000000000000000000910939 kg.

Imagine using that number in a research paper several dozen times. Fortunately, there is an easier (and more concise) way to express small and large numbers. Scientific notation expresses a number as a number between 1 and 10 multiplied by a power of ten. For example, in scientific notation 500 is expressed as 5×10^2

$$500 = 5 \times 100 = 5 \times 10^2$$

For numbers smaller than 1 (1×10^0), the exponent of ten is a negative number:

$$0.125 = 1.25 \cdot 1/10 = 1.25 \times 10^{-1}$$

Therefore the mass of an electron is 9.10939×10^{-31} kg

3. Working with Uncertainty

Scientific Investigation: Working with Uncertainty

Lesson Objective

In this lesson, you will learn that every measurement has some degree of uncertainty and how to work with that uncertainty in scientific investigations.

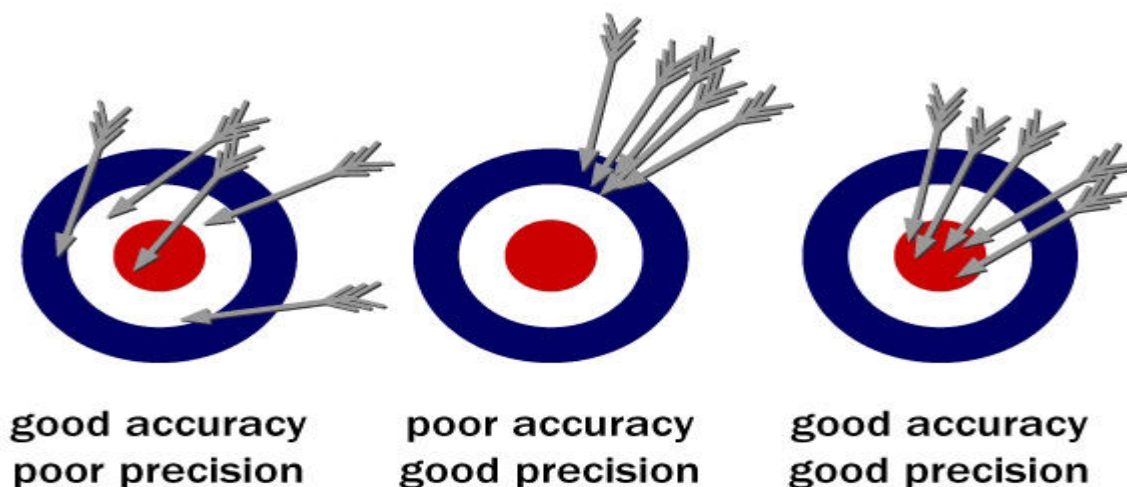
- **Previously we covered...**
- Scientific investigations rely on the precise and accurate **measurement** of an attribute.
- All measurements consist of a numerical value and a **unit**.
- Scientists use a system of units known as the **International System of Units (SI)** to ensure common ground within reproducible experiments and their results.
- **Scientific notation** simplifies the expression of very large and very small numbers.

Scientific Investigation: Working with Uncertainty

How reliable is the result?

Every measurement has some degree of uncertainty, indicated by its precision and its accuracy. **Precision** is the exactness to which a measurement can be reproduced. Using a ruler, calibrated to millimeters, you may be able to measure to a precision of one millimeter. A vernier caliper, on the other hand, may provide measurements with a precision of hundredths or thousandths of a millimeter. Even the best measuring instruments have a limit to their precision.

Accuracy is the closeness of a measured value to an accepted value. A measurement can be very precise, but if the instrument is not properly calibrated, give inaccurate readings. For example, a thermometer that is calibrated to 0.5° has a precision of $\pm 0.5^\circ$. However, if the thermometer reads 23°C and another thermometer that is known to be accurate reads 25°C , there is an inaccuracy of 2°C . The process of comparing a measuring instrument to a known standard and adjusting it to read accurately is **calibration**.



Errors can be introduced into an experiment by inaccurate or imprecise measuring instruments. They can also be introduced by using these instruments in the wrong way.

How significant are significant digits?

The precision of every measurement depends on the precision of the instrument. The two measuring scales below have different levels of precision. Using the bottom ruler, the best estimate you can make is that point is at about 2.5 units from the origin. With the top ruler, on the other hand, the measured value is clearly greater than 2.5 units and can be estimated to be 2.55 units. The recorded value uses **significant digits** to indicate the precision of the measurement. The last digit is an estimate. In the first case, you can read the value 2 and estimate the value 2.5, so the correct reading is 2.5. In the second case, an additional decimal place can be estimated, so a value of 2.55 would be recorded. If the measured point was exactly on the 2-unit mark, the bottom ruler would give a reading of 2.0, indicating two significant digits and the top ruler would give a reading of 2.00 units.

The rules for recognizing significant digits are:

- Nonzero digits are always significant — 6.89 have two significant digits.
- Zeros between nonzero numbers are always significant — 903 have three significant digits.
- Final zeros after a decimal point are always significant — 2.00 have three significant digits.
- Zeros that serve only to locate the decimal point are not significant — 0.0038 has two significant digits; 18,300 have three significant digits.

The final condition creates a problem for numbers such as 18,300 if one or more of the zeros should actually be considered significant. Scientific notation takes care of the question of the significance of zeros at the end of a number greater than 1. Remember that the value 24,000 could have 2, 3, 4, or 5 significant digits, depending on the precision of the measurement. By using scientific notation, the uncertainty is removed:

2.4×10^5 has 2 significant digits
 2.400×10^5 has 4 significant digits

Question

Which of the following correctly expresses the measured value of 0.00001030 seconds?

- A $10.30 \times 10^{-6} \text{ s}$
- B $1.03 \times 10^{-5} \text{ s}$
- C $1.030 \times 10^{-5} \text{ s}$
- D $1.03 \times 10^{-4} \text{ s}$

Answer

The correct answer is C. Scientific notation uses a number between 1 and 10 multiplied by the power of ten. Because the decimal point was moved 5 places to the right, the exponent is -5. Don't forget that the final zero is significant.

What happens to significant digits during calculations?

When you work with significant digits, ***the result of a mathematical operation can never be more precise than the least precise measurement***. It is particularly important to remember this when using a calculator to work with measured values, which generally display results in 8 to 10 digits.

You must also understand that because it is used to indicate uncertainty, the concept of significant digits applies only to measurements. Numbers used for counting, such as 4 objects, and numbers that are defined as constants, such as 10 millimeters = 1 centimeter, are considered to have an infinite number of significant digits. For example, $34.98 \text{ cm} \cdot 10 \text{ mm/cm} = 349.8 \text{ mm}$.

Scientific Investigation: Working with Uncertainty

Lesson Objective

Review mathematical concepts that are important in science and how to visualize mathematical data in charts and graphs.

Previously we covered...

- **Accuracy** and **precision** are two factors in measurement error.
- The precision of a measured value is expressed by the number of **significant digits**.

Scientific Investigation: Working with Uncertainty

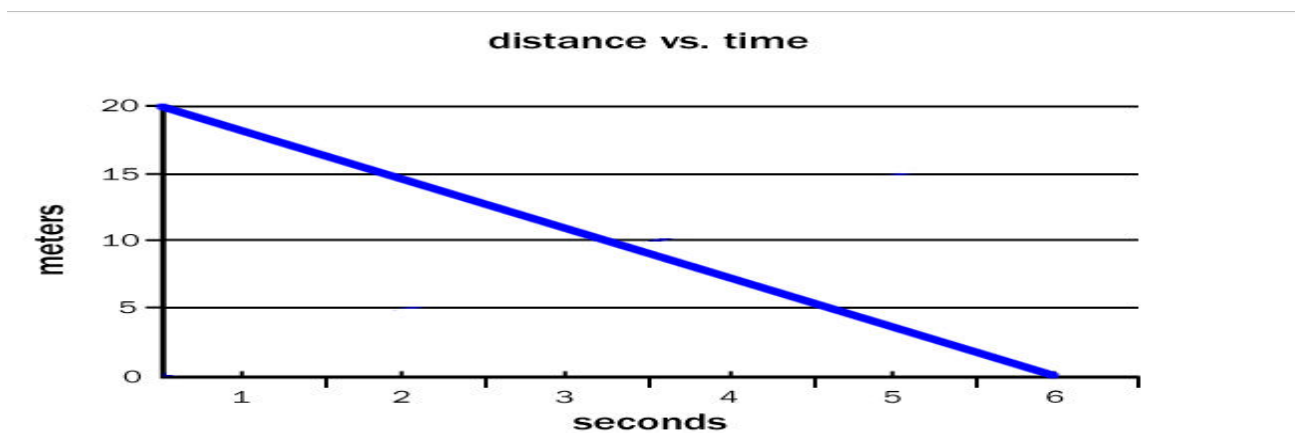
Science grows by constructing new hypotheses based on previous results, so sharing knowledge is the final step of an experiment or investigation. Peer reviews and duplication of experiments are

necessary to ensure the validity of experimental results. A scientific investigation is not very useful unless you can communicate results and conclusions to someone else. Because data is generally collected in a numerical form, tools for displaying mathematical data need to be able to condense these into a non-numerical figure or diagram, not simply a list of numbers.

There are many ways to present data in an organized form, generally using some kind of graph or table. A simple table such as this relates the dependent variable to the independent variable:

heating time (minutes)	temperature (°C)
0	45
1	68
2	88
3	100
4	100
5	100

Another way to present data is by using a graph — a visual representation of numerical relationships. One familiar type of graph is a line graph, which plots data on x and y axes. This graph below shows the distance from home versus time for a bicyclist traveling at a constant speed.



This graph shows a linear relationship between the dependent variable (distance) and the independent variable (time). This relationship can be expressed as a linear equation in the form:

$$y = mx + b$$

Where y is the dependent variable, x is the independent variable, m is the slope of the line, and b is the value of y when x is equal to zero. Notice that on this graph, the slope is negative, indicating that the distance decreases as time increases. The bicyclist started at a point 20 miles from home, represented by the y intercept. The equation represented on the graph is therefore:

$$\text{distance} = (-33.3 \text{ m/s}) (\text{time in seconds}) + 20 \text{ m}$$

There are many different kinds of graphs used to display different types of data. Depending on your audience, the subject matter, and the level of detail in the data and/or analyses, you need to choose the right way to show exactly what you want to — and get your ideas across in the simplest but most accurate manner possible. For this, we use visual representations of data

4. Presenting Data

Scientific Investigation: Presenting Data

When presenting data, our main goal is to accurately show the results and focus the attention of your reader or audience. The visual representation of data is an amazingly important aspect of science and can make or break your study. Most people are not interested in raw measurements or unanalyzed data, and we generally do not just display the raw data in an uninformative manner. We should try to display the most data with the least ink (or pixels), economically showing what we want to, but getting rid of extraneous or distracting details. Showing trends found in data can be best done by using graphs, diagrams, and charts.

Graphs, diagrams, and charts

Graphs can be the best way to display, summarize, and simplify results of data. The most basic types of graphs that are used to present data are the:

- bar graph
- line graph
- pie chart

Bar and line graphs are used to show results along a vertical (**y** axis) for a corresponding variable (such as sampling date or site) which is marked along the horizontal or **x** axis. These types of graphs can also have two vertical axes, one on each side, with two sets of results shown in relation to each other and to the variable along the **x** axis.

Bar Graph

A bar graph uses columns with heights that represent the value of the data point for the parameter being plotted. Figure 6.1 is an example of a bar graph displaying biological data, the number of frog egg clutches found per plot from April 1997 to May 1998.

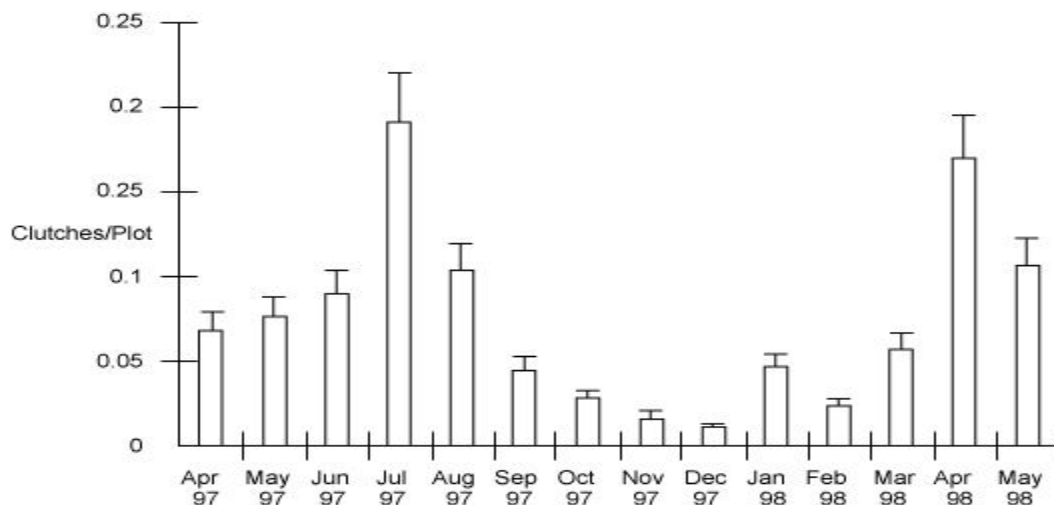


Figure 6.1

Line Graph

A line graph is constructed by connecting the data points with a line. It can be effectively used for depicting changes over time or space. This type of graph places more emphasis on trends and the relationship among data points, and less emphasis on any particular data point.

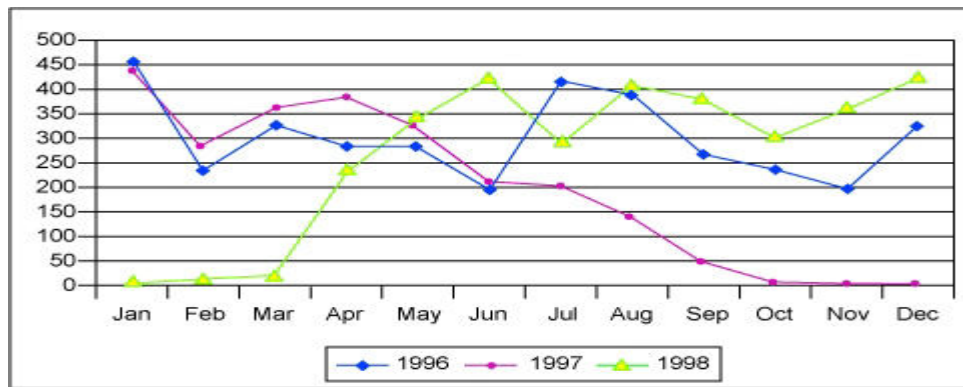


Figure 6.2: Example of a line graph used correctly to show the large impact of the 1997-1998 El Niño Southern Oscillation effect on precipitation on the island of New Guinea

Pie Chart

Pie charts can be used to compare different categories within data relative to all categories. The proportion of each category is represented by the size of the wedge or piece of the pie. Pie charts have become popular because they are useful and simple. Figure 6.3 is an example showing the relative proportions of clutches from different kinds of frogs found in the 1998 field season.

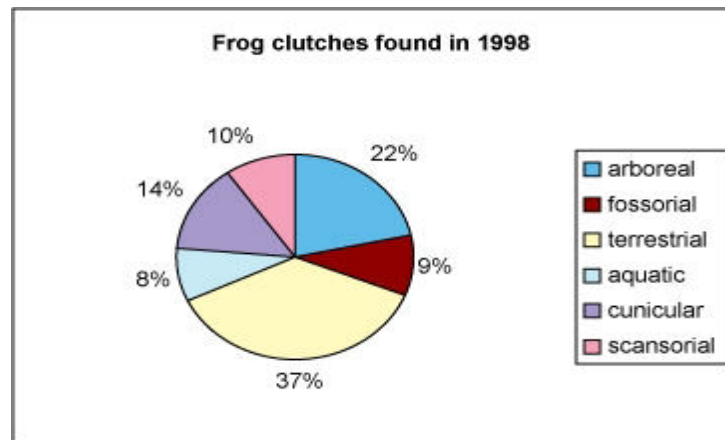


Figure 6.3 This pie chart accurately shows the different numbers of frog clutches found in 1998. Each category is a separate micro-habitat where the frogs live and lay their eggs.

Scientific Investigation: Presenting Data

Graphs, diagrams, and charts

No matter what kind of figure you use, there are some good guidelines to follow so that you can use them most effectively. Each figure should have a clear function and should be easily interpreted. Every good figure relates directly to the content and context of the subject matter. Another important thing to keep in mind is bias. Like any other part of science, bias needs to be a major concern during the presentation of results, so that no undue distortions or introduced ambiguities negatively affect the presentation of your results. It cannot be overstated that we need to ensure the accuracy of the results.

The data in a figure should be proportional to the real data, labeling should be clear and accurate, and the data should be easily interpreted from the figure directly or via the figure legend. Never overcrowd the axes of a graph or the legend of a figure. If you think there might be any possibility of misinterpreting the figure, redo it. Figures are often your best tool for relaying complex information or

large amounts of data. They are worth the extra time and effort you put into them and you should let your students appreciate this.

Try to keep it simple. A basic rule is to use the least amount of ink or pixels per/datum. The more complex a figure, the greater the chances that people will either misinterpret your data or not understand what you are trying to show.

Limit the number of parts in a figure. For example, line graphs should have fewer than five lines, pie charts should be limited to five or six wedges, and the bars of a bar graph should not be too crowded.

Consider the size of the figure you want and make the components of the figure fill the space effectively. You want the reader or viewer to be able to extract the necessary data with ease and efficiency. Figure that are too small or too crowded only make this harder and less efficient.

Create simple and short titles that adequately describe the information portrayed in the figure. Don't use acronyms or abbreviations unless you are absolutely certain that your audience will know what you mean. Use figure legends appropriately and do not try to put too much information or too little information in the legend. It should complement the figure, not detract from its effectiveness.

Question

Figures in a scientific report or presentation should

- A include abbreviations and acronyms whenever possible to ensure conciseness.
- B have many interpretations to reflect the complexity of scientific investigations.
- C be as simple as possible, informative, unambiguous, and easy to understand.
- D be complex, theory-laden, and understandable only to a few good scientists.

Answer

The correct answer is C. Figures in scientific reports need to get all the information across as simply as possible. Complex figures that include abbreviations, ambiguous interpretations, or too much noise are not useful and do not get information across to the audience

Scientific Investigation: Presenting Data

Summary Statistics

Summary statistics are extremely useful for reducing large, unwieldy data to just a few descriptive values. They can often take pages of data and turn them into a few values that can be much more quickly understood. Summary statistics are important to almost any study and include the mean, standard deviation, and number of data points (n).

In statistics we usually assume that if a parameter is measured multiple times under the same conditions, the measurements are randomly distributed around an average with more clustering around the average than further away. A graph of the frequencies of each value typically is a bell-shaped curve for normally distributed data. As you know from basic statistics, the mean and standard deviation determine the height and width of this curve.

Although both the mean and standard deviation are useful in describing most data, often in the natural sciences, real data often do not fit a normal distribution. In these cases, we have other statistics to describe the data. Many data seem to be skewed in one direction while others have a more flattened bell shape.

It is important to note that biological data, in particular, often does not follow a normal distribution because life is complex and many interdependent systems are usually affected by whatever perturbation or experimentation we attempt to force upon them. In many of these cases where the data is abnormally distributed, the mean and the standard deviation are not appropriate summaries of the statistics and we need to either transform the data or come up with better descriptors for the abnormal data..

For describing abnormally distributed data, we use statistics that still convey the information but are not overly influenced by data points at the extremes of the distribution. The median, the range, and sometimes the interquartile range are used to describe both the central tendency and the spread of the data. We know that the median is the value that is physically in the middle of the data set. The range is simply the entire range of values from the data, and the interquartile range is the difference between the value at the 75-percent level and the value at the 25-percent level. We can use another type of figure to help show abnormal data that encompasses these characteristics, called a box and whisker plot. A box and whisker plot graphically displays the mean, median, variation, skew, range, and size of the data. In some cases, you do not need to show the quartile range if the range itself is sufficient to show the skew of the data. Figure 6.4 shows how this works with data from the number of eggs in a clutch for different types of frogs.

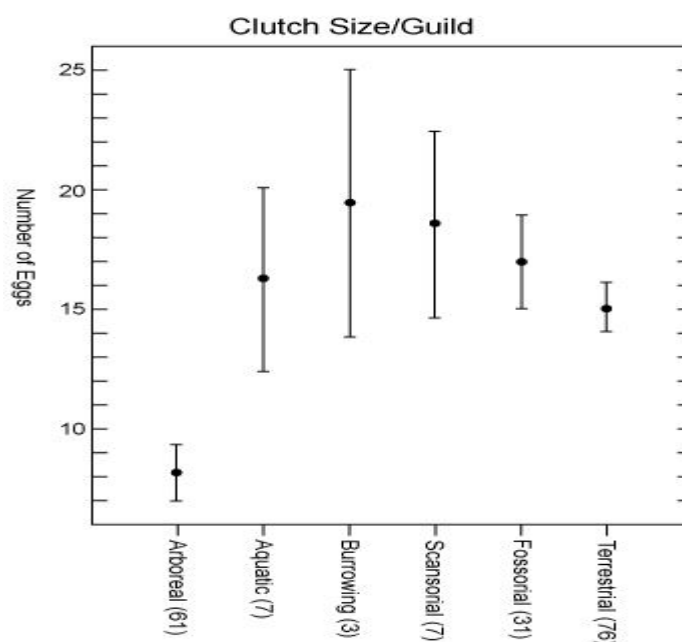


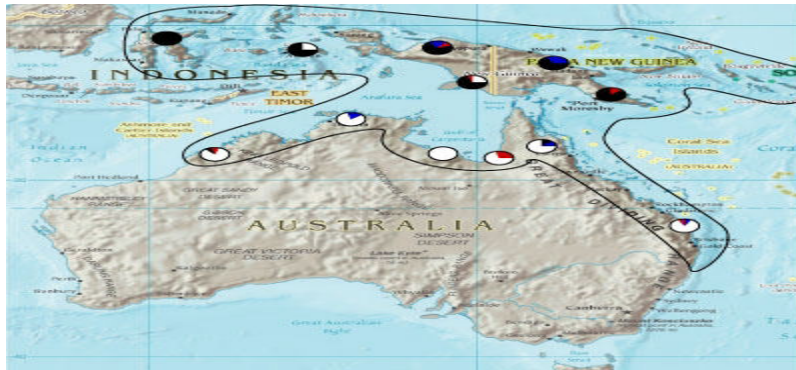
Fig. 6.4 is an example depicting the extreme values and median of the number of eggs per clutch across six different micro-habitats. This is an example where the data are not normally distributed and need to be displayed in a slightly different way.

Scientific Investigation: Presenting Data

Maps

Displaying results of your study area on a map is most often the best way to show exactly where the study took place or how the data are distributed geographically. A map should show the location of study sites in relation to a reference and also clearly show features, such as human habitations, gardens, rivers, major mountains, and other attributes important for the study.

A map should be relatively simple and show only principal features that are cogent for the study or results. The map should have enough detail and correct scale to show location of sample sites, and whatever summary information is appropriate.



Suggestions for using a map to display your data include:

- Limit the amount of information presented on the map.
- Do not put too much on a map so that it is visually complicated or difficult to read. Clearly label the map and provide a legend to interpret it.
- If you have a clear conclusion, show the conclusion on the map.

For example, if a map shows that gene frequencies are completely different on opposite sides of a large mountain range, use the information as a subtitle of the map and make sure that the map clearly shows the trend. Another good idea is to use an enlargement of the focal area on the map to adequately display the information and set the geography. You can also use different sized symbols and patterns to represent various magnitudes of the results. For example, a site with a sample size of 10 individuals could have a pie chart 10 mm wide, whereas a sample size of 90 individuals would be 90 mm in diameter. Start by finding the highest and lowest values, assign diameters and patterns to those and then fill in steps along the way.

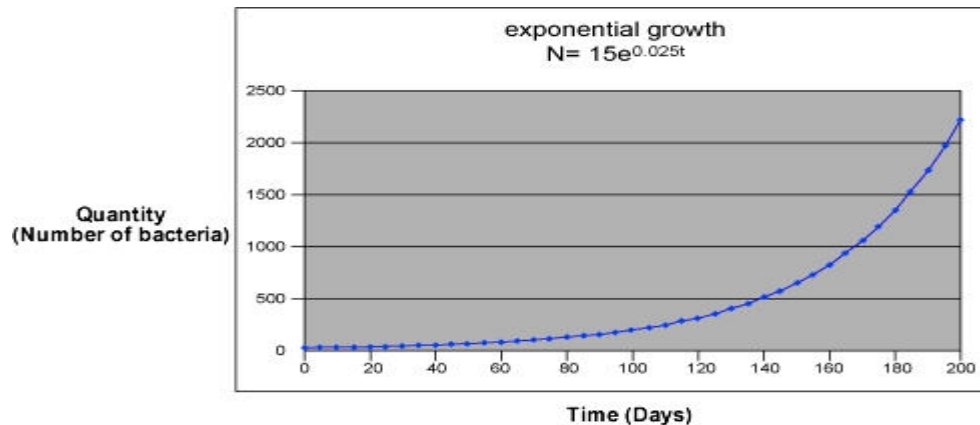
Scientific Investigation: Presenting Data

Exponential relationships

Data from an experiment does not always form a line on a graph. In some cases, the amount of y increases faster and faster as the amount of x also increases. In other words, it increases exponentially. A graph of **exponential growth** is a curve that rises increasingly faster. Exponential equations are written in the form:

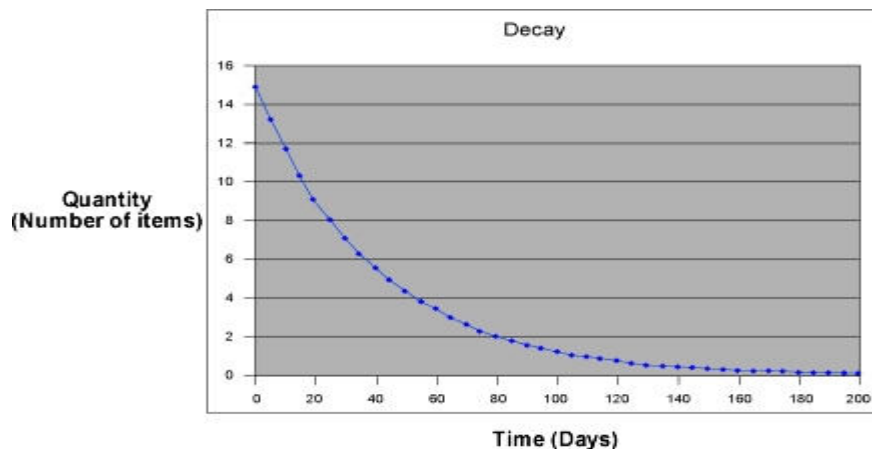
$$N(t) = N_0 e^{kt}$$

where N_0 represents the initial quantity, t represents the number of time intervals, $N(t)$ is the quantity after time t , k is a constant that is characteristic of the growth, and e^x represents an exponential function of base e .



An example of exponential growth in science is uncontrolled population growth. If a bacterial culture has an unlimited food supply, its population will increase exponentially. For example, if each bacterium produces two bacteria each day, the growth will follow the pattern: 1 on the first day, 2 on the second day, 4 on the third day, 8 on the fourth day, and so on. Other examples of exponential growth include the heat generated by an uncontrolled exothermic reaction, and the chain nuclear reaction of an atomic bomb.

When the number of objects decreases exponentially over time, the phenomenon undergoes **exponential decay**. Notice the graph of exponential decay shows an initial rapid decrease and then decreases at an increasing slower rate. Note also that the value approaches, but never crosses zero on the y axis. Examples of exponential decay include radioactive decay, in which the number of atoms of an isotope is decreased by half during a time period, known as the half-life, which is a characteristic of the particular isotope. The formula for exponential decay is: $N(t) = N_0e^{-kt}$.



Logarithmic graphs

You can see that it is easy to read values on a graph of an exponential function when the values are changing rapidly, but when the change is slow, it is almost impossible to read the change in y on the graph with any precision. When data cover a wide range of values and rates of change, a logarithmic graph is generally more useful. The values with the wide range are plotted as the base 10 logarithm of their value.

Logarithms are used to express the magnitude of exponential functions, such as the strength of an earthquake. An earthquake of magnitude 7 is 10 times as strong as an earthquake of magnitude 6; 100 times as strong as an earthquake of magnitude 5; 1,000 times as strong as an earthquake of magnitude 4; and so on. Other values expressed logarithmically are the intensity of sound and the pH of a chemical solution

Scientific Investigation: Presenting Data

Staying safe in the lab and field

- The final and still important part of doing scientific investigation is keeping yourself and others safe while you work. In many ways safety both in the laboratory and the field is a matter of common sense. It doesn't hurt, though, to repeat some of the key elements of safety. A few of the essential points include:
- Wear appropriate protective equipment, including safety glasses, gloves, snake chaps, and/or a lab coat whenever needed. Depending on the specific work you might be doing, there are many specific safety protocols and equipment for each situation. Make sure you know your safety issues and equipment thoroughly.
- Always review the reaction hazards and toxicity information for all chemicals you use and make sure you understand the possible allergens or toxic organisms you may encounter when you work in the field.
- Never eat or drink in the laboratory, but make sure you stay hydrated and protected from the sun, wind, snow, ice, or rain in the field.
- Know the location of fire extinguishers, first aid kits, and other safety equipment. Bring a first aid kit and any other specific safety equipment with you in the field.
- Clean up spills immediately and maintain a clean work area.
- Follow approved disposal procedures for all chemicals.
- Ensure that everyone you work with is also familiar and prepared for any emergency situation. A good team can save your life.

Further Reading on Scientific Investigation

Scientific Investigation: Further Reading

A Beginner's Guide to Scientific Method. (Stephen Carey): Wadsworth Publishing, 2003.

Darwin's Dangerous Idea: Evolution and the Meanings of Life. (Daniel C. Dennett): 1996.

Scientific Method, The. DVD (Educational Video Network, Inc): 2005.

Scientific Method: An Historical and Philosophical Introduction. (Barry Gower): Routledge, 1996.

Scientific Method in Practice . (Hugh Gauch, Jr.): Cambridge University Press, 2002.

Short History of Planet Earth: Mountains, Mammals, Fire, and Ice, A. (J. D. MacDougall): 1998.

Teaching the Scientific Method: Instructional Strategies to Boost Student Understanding. (Millie Blanford): Incentive Publications, 2004.

Chapter: Basic Science Core

Basic Science Core

1. The Universal Question - Where Did the Universe Come From?

Lesson Objective

In this lesson, we'll study the evidence that leads to the conclusion that the universe began with a colossal explosion called the Big Bang.

Previously we covered...

In the previous lesson we reviewed what science encompasses, how it works, and covered some of the diversity of its fields, spanning all human knowledge.

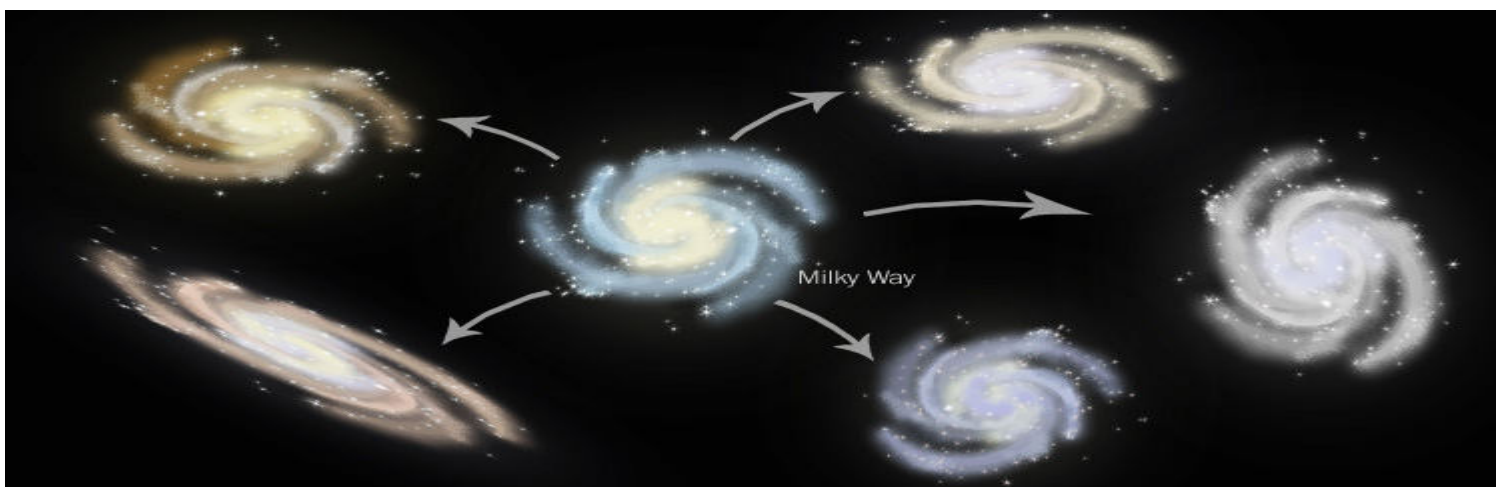
Also we learned that technology is the application of scientific knowledge to solve practical problems.

Basic Science Core - The Universal Question - Where Did the Universe Come From?

The Big Bang

There is significant evidence that the universe was created in a **Big Bang** event. The generally accepted and most common scientific theory that explains the origin of our universe is that there was an explosion that took place about 14 billion years ago.

This explosion took place at the moment the universe began – starting from something about the size of a grain of sand and ending up as the universe as we now know it. There is significant evidence to support this theory. Scientists agree that the universe is currently expanding and thinning out. We know from the law of the conservation of mass, the total mass of the universe is constant, so all the matter of the universe must have been closer together at one time. This suggests that an explosion may have started the matter that became galaxies moving away from each other. From any place in the expansion, all other places appear to be moving away from each other at speeds proportional to their distances from the place of observation. The Big Bang theory also implies that the universe has a finite age, equal to the length of time since the big bang explosion.



Most galaxies appear to be moving away from the Milky Way galaxy, and in general particles appear to be moving away from each other as the universe continues to expand.

Astronomers can measure how fast the universe is expanding and the approximate distance to the furthest stars from **parallax** measurements. From this, they can calculate roughly how long the universe has been expanding to assess its age. Based on measurements of how fast distant galaxies are moving away from us and from measurements of the cosmic background radiation, astronomers estimate that the universe is about 13.7 billion years old

Basic Science Core - The Universal Question - Where Did the Universe Come From?

More evidence for the Big Bang

Edwin Hubble, an American astronomer, made an important discovery in the 1920s that also helped give more credence to the Big Bang theory. Hubble studied the spectra of many galaxies moving away from each other and found a way to determine how fast our galaxy was moving, and in what direction it was moving relative to other galaxies. He discovered that with very few exceptions, all galaxies were moving away from each other simultaneously. Hubble noticed an important relationship between the speed of a galaxy and how far away it was from us. He used the Doppler shifts in the galaxies' light to arrive at this relationship known as **Hubble's Law**: The faster a galaxy is moving away from us, the farther away it is from us.

If the Big Bang theory is accurate, we would expect to find evidence that the universe is still spreading apart today just as it began doing billions of years ago. All observations from telescopes have been unable to refute this central tenet of cosmology and astronomy. We might also expect evidence of excess energy left over after the massive explosion. This, too, has been observed in every case where data are sufficient to make such a test.

What will happen to the universe in the distant future? One possibility is that the universe will continue to expand, as it is doing now, with its stars eventually using up all of their fuel and burning out like old light bulbs, making the universe a cold and dark place. Another possibility is that the universe will eventually stop expanding and start to implode. This would pull all the galaxies back together into a very dense black hole (like a recoiling rubber band) to result in a reverse of the Big Bang.

Question: What does Hubble's Law state?

- A The mass of the universe is constant.
- B The closer a galaxy is to us, the faster it is moving away from us.
- C The faster a galaxy is moving away from us, the farther away it is from us.
- D The universe is expanding and thinning out.

✔Answer

The correct answer is C. The faster a galaxy is moving away from us, the farther away it is from us. Although some of the other examples may be true, none are the definition of Hubble's Law

Basic Science Core - The Universal Question - Where Did the Universe Come From?

Galaxies

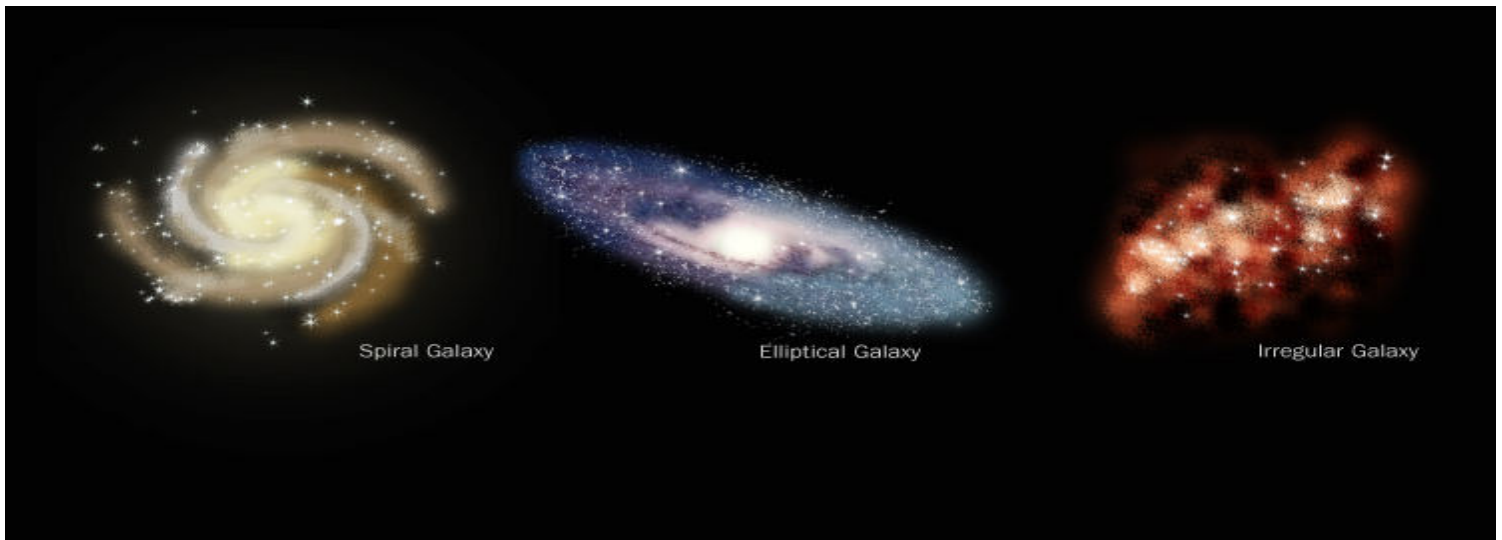
Previously we covered the Big Bang theory and the origin of our universe. We also know that the universe contains an enormous number of galactic clusters, each full of billions of galaxies made up of stars, solar systems, planets, errant dust, rocks, and gas clouds held together by their own gravity. There are billions of galaxies in the universe with the largest galaxies containing trillions of stars. It is hard to comprehend just how massive the universe really is – it is probably beyond human understanding. But you get the idea.

There are several different configurations that galaxies can have. The most common are spiral, elliptical, and irregular.

Spiral galaxies are shaped like a flat disc or pinwheel (like our Milky Way galaxy), with a bulge in their center, and arms that spiral outward. Many bright young stars, dust, rocks, and gas make up the spiral arms. The youngest stars are found at the tips of the spiral arms. Very few new stars form in the denser central bulge. Many spiral galaxies have a barrel-shaped region of stars and gas that passes through the center of the galaxy, perpendicular to the main axis. These galaxies are called barred-spiral galaxies.

Elliptical galaxies are galaxies with a rounded or egg-shape to their central region, and without spiral arms or protrusions of any type. Although billions of stars are contained in elliptical galaxies, there is much less gas and dust between the individual stars. Because there is relatively little dust and gas (the stuff stars form from), there are fewer young stars in an elliptical galaxy than a spiral galaxy, for example.

Irregular galaxies are galaxies that have no regular spiral or elliptical shape. Irregular galaxies are typically much smaller than spiral or elliptical galaxies and have much more dust and gases, so they have a much higher concentration of bright, young stars.



Major types of galaxies: Spiral, Elliptical, and Irregular

There are also bright but very distant objects (ten billion years old or more) that look much like stars. “Quasi” means “something like” in Latin and hence, these objects were named quasi-stellar objects which became **quasars**.

Further study has revealed that quasars are very young, active galaxies with giant black holes and large amounts of gas around the center. As the gas heats up from the extreme friction in the dense gravity, the quasar heats up and shines brightly.

Question: What is the configuration of an elliptical galaxy?

- A An elliptical galaxy is a galaxy without spiral arms and with more of a round- or egg-shaped center region.
- B An elliptical galaxy is a galaxy that has no regular spiral or elliptical shape.
- C An elliptical galaxy is a galaxy shaped with a bulge in its center and arms that spiral outward in a pinwheel.
- D An elliptical galaxy is a galaxy that has a bar-shaped region of stars and gas that passes through its center.

👉Answer

The correct answer is A. Although the other answers define configurations of other types of galaxies, elliptical galaxies are without spiral arms and have a rounded center region

Basic Science Core - The Universal Question - Where Did the Universe Come From?

The Milky Way Galaxy

Our solar system is located in one of the arms of a spiral galaxy about halfway from the center of the galaxy to the outer edge. Some evidence now exists that our galaxy may actually be a barred-spiral galaxy. But the shape of the Milky Way galaxy depends on from where it is viewed. If you could view it from its side, it would look like a thin disk with a large bulge in its center. If viewed from the top or bottom you would see a typical spiral shape. The spiral shape cannot be seen from Earth because our solar-system's vantage point is inside one of the galaxy's spiral arms.

When we observe the Milky Way, we usually are looking toward the center of the galaxy, about 25,000 light-years away. We know its shape because we can study the center with X-rays, infrared radiation, and radio waves which are not blocked by the dust and gas as much as visible light.



Our Galaxy, the Milky Way and our approximate location within it.

2. Stars

Basic Science Core: Stars

Formation of stars

Stars do not last forever; they are born, have a (relative to humans) long life, and usually fade out or transform into another kind of object. All stars and galaxies initially form from a **nebula**, a large volume of gas and dust. When enough gas and dust contract from gravity, a star can begin to form. At this early stage of development, when the contracting clouds of dust and gas contain enough mass to eventually form a star, the fledgling star is known as a **protostar**.

A star is “born” when the density of the contracting gas and dust causes intense heat and pressure, enough to start a **nuclear fusion** reaction. Recall that nuclear fusion occurs when individual atoms combine to form heavier atoms and in the process, release tremendous amounts of energy. In most stars, hydrogen atoms combine with other hydrogen atoms to become helium atoms.

The composition of most stars is about 73% hydrogen, 25% helium, and 2% of other elements with atomic numbers up to, but not exceeding, that of iron.

The lifetime of a star depends on its mass. Although you would assume that a star with a large mass would have a longer lifetime than a star with a smaller mass, the opposite is true. Stars with smaller masses have longer lifetimes than more massive stars. You know intuitively that a small car can drive farther (run longer) than a large car on a single tank of gas. If smaller cars have smaller gas tanks how can they drive longer on a tank of gas? Simple; small cars also have smaller, much more fuel-efficient engines, and smaller cars weigh less than larger cars. On the other hand, a large car with a larger gas tank requires a bigger, engine which will burn gas faster. Using the same analogy for stars, even though small stars have less mass (fuel) to use, they use it more slowly than larger stars and have much longer life spans.

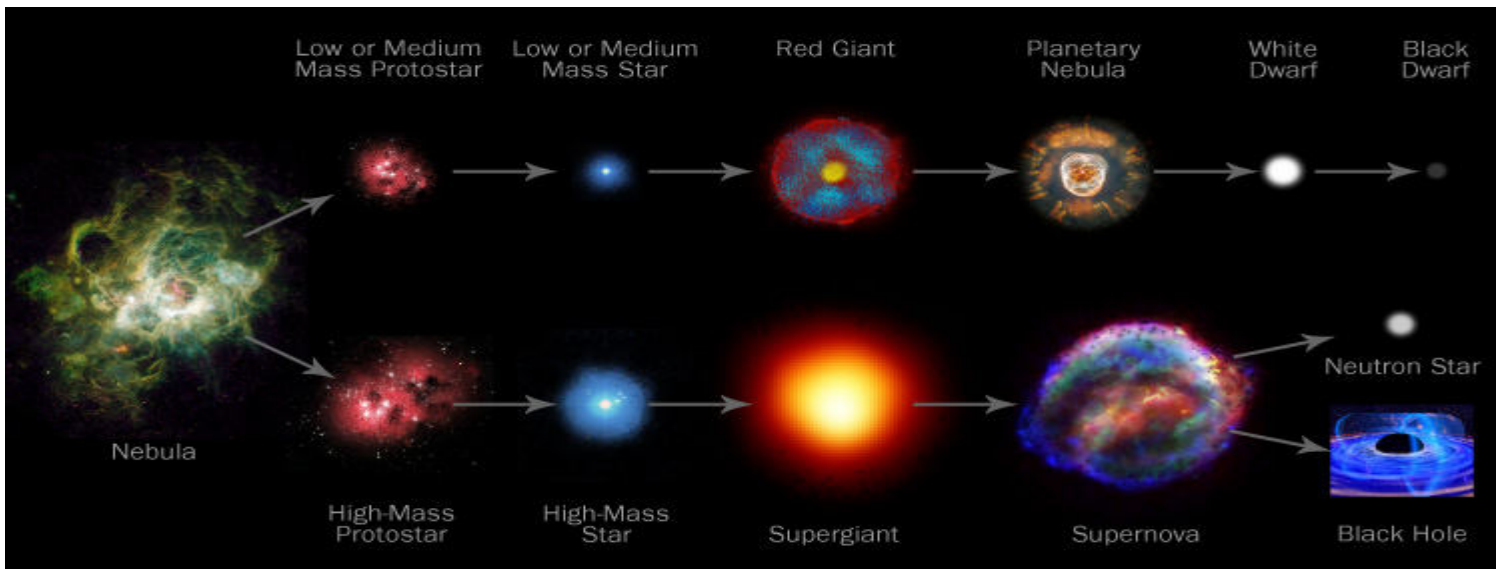
Basic Science Core: Stars

Death of a star

Stars go through a life cycle, eventually dissolving or transforming into another type of celestial body. When a star approaches the consumption of all its fuel, its outer gases expand as the central core shrinks. At the time of death (when a star runs out of fuel to burn), the original mass of the star will determine if it becomes a **red giant** or a **supergiant**. Both of these transformed stars can evolve in different ways and become black holes, neutron stars, or black dwarves.

Stars of low to medium mass, such as our sun, require billions of years to consume all their fuel. As they start to use up all the fuel, their outer layers expand and they become red giants. Eventually, as their outer regions grow larger and drift further out into space, forming a glowing cloud of gas called a planetary nebula. The core of the star that is left behind has a bluish-white color and cools to become a white dwarf.

White dwarfs are relatively small (about the size of the Earth) but they are very dense, having similar mass as our sun, but with a small volume. This gives white dwarfs a density about one million times the density of the sun. A tablespoon full of this material would have as much mass as a 20-story building on Earth. Having no fuel, white dwarfs glow faintly from leftover energy, and after billions of years, eventually stop glowing and become **black dwarfs**.



Life history of stars and other celestial bodies depends on their original mass.

Basic Science Core - Stars

Unlike the life cycle of a low- to medium-sized star, the life of a more massive star ends quickly in a brilliant catastrophic explosion. When a supergiant consumes all its fuel, it collapses into its core, creating a tremendous increase in heat and pressure within the core. The immense heat cannot easily radiate away causing the star to suddenly explode, becoming much larger and millions of times brighter. This can happen in a matter of a few hours and the explosion is called a **supernova**. After the supernova phase, much of the star's original material expands into space, probably to become part of another nebula or protostar.

Some of the material from a star is left behind when a supergiant explodes and may form a **neutron star**. A neutron star is the remains of a star that once was very massive. They are even smaller and denser than white dwarfs, and while they can contain up to three times the mass of our sun, they can have a diameter as small as 24 km – the size of a typical city. These are truly massive and dense objects.

Question: Stars with a relatively small mass have what type of lifespan compared to more massive stars?

- A Short, because larger nearby stars absorb smaller stars.
- B Short, because they consume fuel (mass) at a very fast rate.
- C Long, because they have less internal gravity to pull mass into a black hole.
- D Long, because they consume fuel (mass) at a very slow rate.

✓Answer

The correct answer is D. Small stars have long life spans. Larger stars live shorter and more intense lives, comparatively.

Basic Science Core: The Earth

The Sun

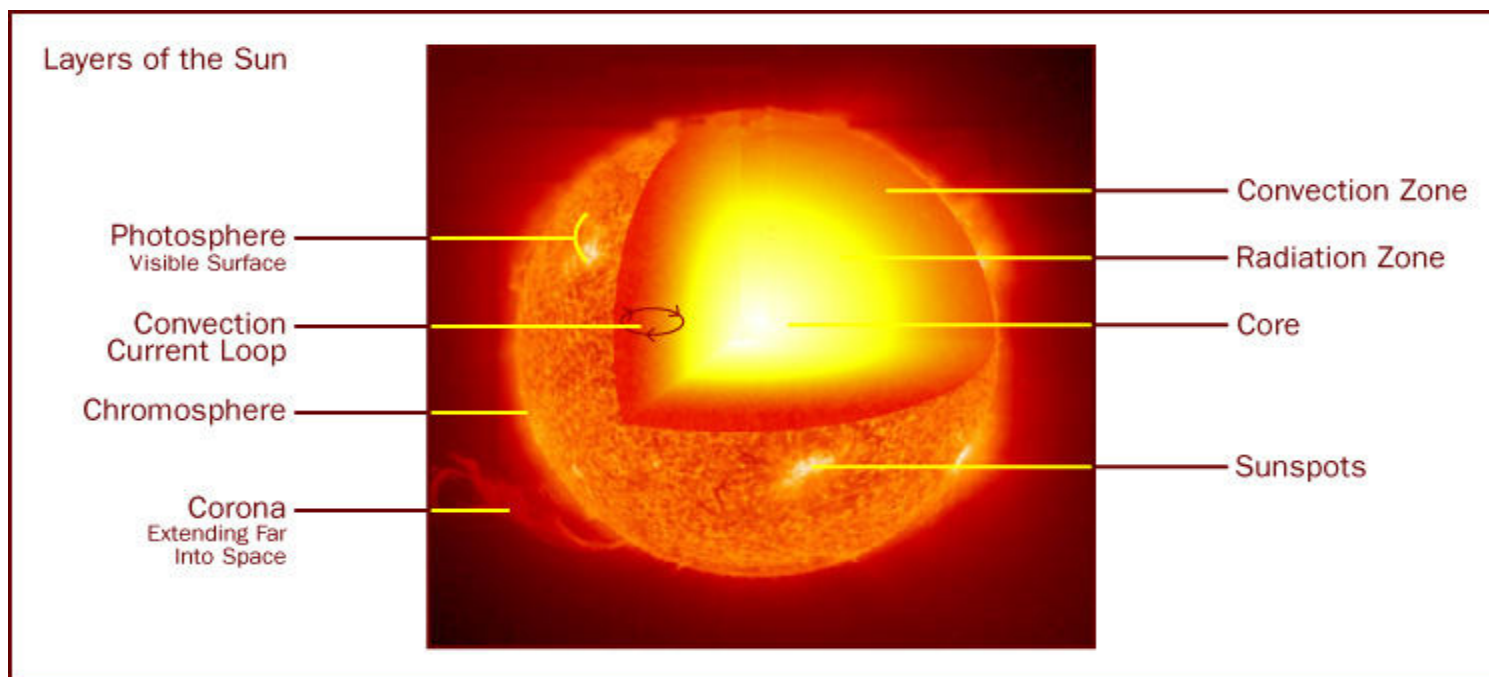
The sun, like all stars, does not have a solid surface. It is a big ball of gas atoms in what is called the plasma state of matter; they are atoms that have their electrons stripped away. Similar to Earth, however, it does have an interior and an atmosphere. The sun's interior consists of the core, the radiation zone, and the convection zone.

The sun's core is where all the energy is produced. This energy is not generated by burning fuel but rather by the process of nuclear fusion, where hydrogen atoms combine to form heavier elements (usually helium) along with a tremendous release of energy. The mass of the helium produced is less than the mass of the hydrogen atoms consumed, and the difference in mass is transformed into energy.

The energy produced in the core migrates to the next layer of the sun, the **radiation zone**, which is the middle layer of the sun's interior and the region of dense gas where energy is transferred into electromagnetic radiation. The radiation zone is extremely dense and it can take more than 100,000 years for energy to move through it.

The **convection zone** is the outer layer of the sun's interior where hot gases rise from the bottom of the convection zone. These hot gases gradually cool as they reach the top of the convection zone, only to sink again, heat up again, and form loops of gas that are transported toward the sun's surface.

The sun's atmosphere consists of three layers: the photosphere, the chromosphere, and the corona. The photosphere is the innermost layer of the sun's atmosphere and is considered to be the visible surface of the sun. It is made up of gases because the sun does not have a solid surface. The chromosphere is the thin middle layer of the sun's atmosphere that is usually not visible because of the bright glare from the photosphere. The chromosphere can only be seen during a total solar eclipse when the moon blocks the light from the photosphere. Then, the reddish glow of the chromosphere just above the photosphere can be seen. The corona is the outermost layer of the sun's atmosphere, which extends about one- and-a-half million km into space from the sun's surface.



Question: What is the sun's photosphere?

- A It is the innermost layer of the sun's atmosphere made up of gases, since the sun does not have a solid surface.
- B It is the middle layer of the sun's interior made of very dense gas where energy produced in the sun's core is transferred in the form of electromagnetic radiation.
- C It is the thin, middle layer of the sun's atmosphere.
- D It is the outermost layer of the sun's atmosphere, extending about one-and-a-half million km into space from the sun's surface.

✔ **Answer**

The correct answer is A. The other answers are defining other parts of the Sun.

3. The Earth

Basic Science Core - The Earth

Lesson Objective

In the next lesson, we will review the make-up of our planet and the different layers of the Earth and its atmosphere.

We will also look at the Earth's attributes and review the concepts of latitude and longitude on the Earth's surface.

Previously we covered...

We just finished covering the life cycle of stars.
We also looked at the layers of the sun.

Basic Science Core: The Earth

Our Earth System

The Earth is divided into four main components or spheres: the **lithosphere**, the **hydrosphere**, the **atmosphere**, and the **biosphere**. Each sphere is a part of the larger system and all the parts are interconnected, working together as a whole. Any change in one sphere causes changes in one or more of the other spheres. Matter and energy constantly move from one sphere to another. For example, the water system cyclically moves water and energy from the oceans, to the atmosphere, the land, and back to the oceans. The sun supplies almost all of the energy for Earth's processes, both biotic and abiotic. For example, the sun supplies the energy to keep the water cycle in constant motion. The sun's heat and light energy is transferred to the Earth via radiation, a method in which energy can travel through space. The sun's radiation warms the surface of the Earth and provides the light energy for green plants. The remainder of the energy is a much smaller amount by comparison. It comes from the Earth's interior and is transferred into Earth's system primarily through volcanic eruptions.

All the systems of Earth are interlinked and interdependent. Earth's solid rocky layer is called the lithosphere. Earth's water bodies (rivers, oceans, lakes, and ice) form the hydrosphere; the oceans affect the temperature of the atmosphere, and flowing rivers shape the topography of the lithosphere. All habitats for living organisms on Earth, whether in air, in water, on land, or underground, form the biosphere. Plant growth constantly changes the surface of the lithosphere and gases expelled by plants affect the atmosphere. Storms in the atmosphere bring rains that change the surface of the lithosphere. The outermost sphere of the Earth is called the atmosphere and consists of the mixture of gases that surrounds the planet. All spheres are tightly interrelated and constantly affect each other.

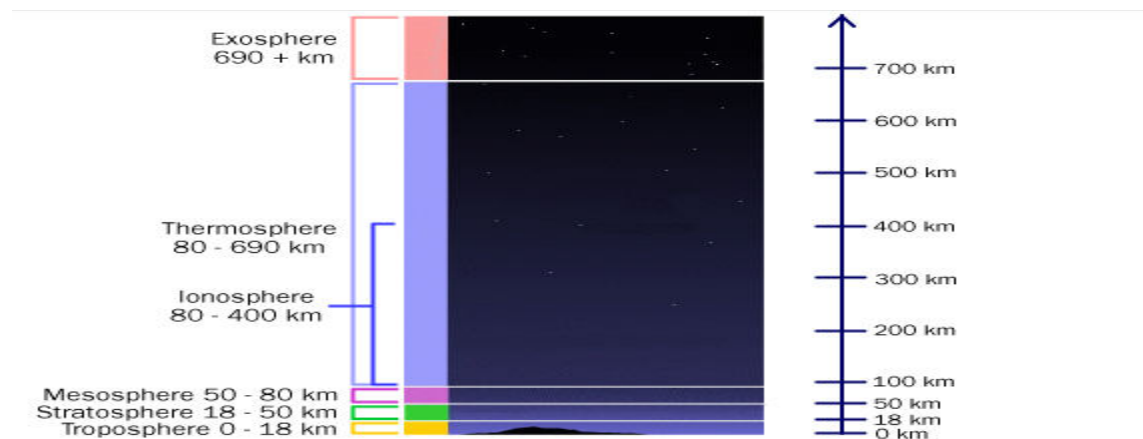
Basic Science Core: The Earth

Above the Earth's Surface

Surrounding the Earth's surface is an envelope of gases called the atmosphere. Earth's atmosphere is made up mostly of a mixture of nitrogen, and oxygen, smaller amounts of carbon dioxide, hydrogen and inert gases, some liquids and their vapors and solids. The most abundant gas in the atmosphere is nitrogen, which accounts for approximately 78% of the air we breathe. The next most abundant gas in the atmosphere is oxygen, which accounts for 21% of our air. The remaining 1% of the atmosphere is made up of (in decreasing order) argon, carbon dioxide, neon, helium, methane, krypton, and hydrogen. The atmosphere is relatively thin, only extending a few hundred kilometers above the Earth's surface.

The atmosphere supports the conditions for life on Earth, making the Earth suitable for living things. Just like all the other 'spheres,' the atmosphere is constantly changing with gases being exchanged between and among the different Earth systems. The atmosphere also traps water and heat near the surface of the Earth. The heat held near the Earth makes it possible for water to exist as a liquid and provides the temperature ranges suitable for life, as we know it. The atmosphere promotes a stable environment by preventing excessive solar radiation from reaching the Earth and protects the Earth's surface from most meteor impacts.

The atmosphere is comprised of a series of four main layers of different temperatures: the **troposphere**, the **stratosphere**, the **mesosphere** and the **thermosphere**. The thermosphere is further divided into the ionosphere and the exosphere.



Basic Science Core: The Earth

In sequence from the ground up, the first layer is the troposphere. Living things exist in this layer and it is where all weather occurs. The troposphere extends upward from ground level up to about 12 kilometers above the surface of the Earth. While the troposphere is the thinnest layer of the atmosphere, it contains almost all of the mass of the atmosphere because heavier atoms congregate closer to the Earth because of the influence of gravity. The temperature is the highest at the bottom of the troposphere and decreases about 7°C for every kilometer of altitude. At the top of the troposphere, the temperature levels out at about –60°C.

The stratosphere is the next layer above the troposphere and extends upward about 50 kilometers. It contains the ozone layer and is the layer that absorbs the most ultraviolet radiation. The lower regions of the stratosphere are the same temperature as the top of the troposphere. Surprisingly, as the higher the layer the warmer the temperature. This is because when ozone absorbs energy from the sun heat is generated, thus warming the surrounding air.

The mesosphere is the third layer of the Earth's atmosphere. It is the layer that protects the Earth's surface from being struck by most meteoroids. When you see a shooting star, you are seeing a trail of hot gases glowing in the mesosphere. The mesosphere is marked by a reversal of temperatures, getting colder as altitude increases. In the outer mesosphere, temperatures drop to –90°C.

The thermosphere is the fourth and outermost layer of Earth's atmosphere. The thermosphere extends upward from 80 kilometers above Earth's surface, gradually blending into outer space. The air in the thermosphere is very thin and hot, due to a reversal of temperatures in these layers. The air in the thermosphere can reach 1,800°C because this is the first layer to be penetrated by sunlight, and nitrogen and oxygen molecules convert this energy into heat.

The thermosphere is divided into two layers: the ionosphere and the exosphere. The ionosphere goes from about 80 kilometers to 400 kilometers above the Earth. The molecules in the ionosphere become ions, electrically charged by the sun's radiation. Ions are efficient at reflecting radio waves and are responsible for the propagation of radio waves back to Earth. The ***aurora borealis*** also occurs in the ionosphere. The outer layer of the atmosphere is the exosphere, and it extends from about 400 km above Earth's surface thousands of km, essentially blending into outer space. Cellular phone calls and television pictures are relayed by communication satellites that orbit in the exosphere.

Basic Science Core: The Earth

Below Earth's Surface

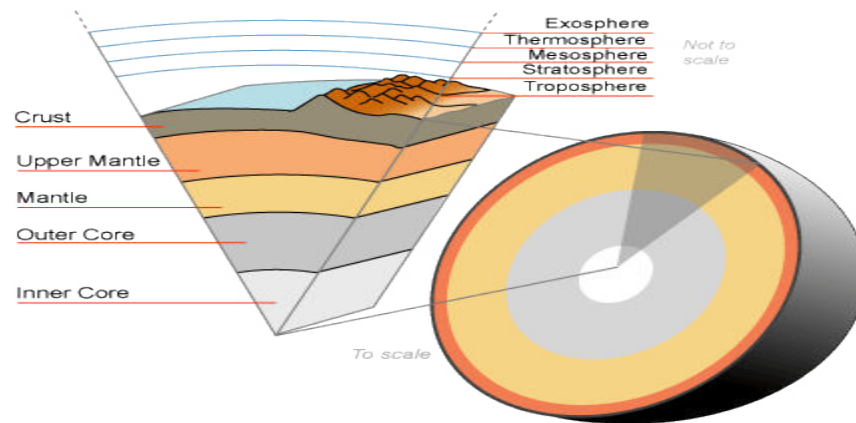
The three main layers of the lithosphere of Earth are its crust, mantle, and core. These layers are very different from each other in size, composition, pressure, and temperature.

The crust is a layer of rock that forms the outer physically hard surface of the Earth. It includes the ocean floor, continental soils, rocks, and mountains. The crust can be thought of as the paper-thin skin on an onion. The crust is thinnest under the oceans and thickest under mountains. The crust averages 5 to 40 km thick and can be a maximum of about 71 km thick under the tallest mountains. The Earth's crust is mostly composed of basalt and granite.

Earth's mantle is located just underneath the crust. The mantle consists of very hot rock and consists of two layers: the lithosphere and the asthenosphere. Together, these layers are over 3,000 km thick. The lithosphere is the top-most rigid layer of the mantle that averages about 75 km in thickness.

Immediately below the lithosphere is the asthenosphere, which is hotter and under higher pressure than the lithosphere and therefore is a little less solid than the rock above. Visualize plates of the lithosphere 'floating' on a very dense, fluid-like asthenosphere. Below the asthenosphere is Earth's core.

The core is a very dense concentration of mostly iron and some nickel. It consists of two parts: a solid inner core and a liquid outer core. These two layers are 35,000 km thick. The outer layer of the core is molten metal and it surrounds the inner core, which is a dense sphere of solid metal. Extreme pressure within the inner core compresses atoms of iron and nickel so much that they cannot form a liquid. Both layers are primarily made of the iron and nickel but scientists have recently determined that oxygen, sulfur, and silicon are also present.



Earth Layers

Basic Science Core: The Earth

Magnetic Field

Since we know that the Earth's core consists of two parts, a solid inner core and a liquid outer core, scientists currently think that movement in the liquid outer core is responsible for the Earth's magnetic field. A compass points northward because the Earth acts as a huge magnet. The compass needle aligns itself with the magnetic field of the Earth, slightly off of true geographical north in most cases. The northern magnetic pole of the Earth is located about 1,770 km away from the true North Pole, somewhere in the Hudson Bay region of northern Canada. The southern magnetic pole is located south of Australia. The difference between where a compass points and the true geographical pole is known as **magnetic declination**.

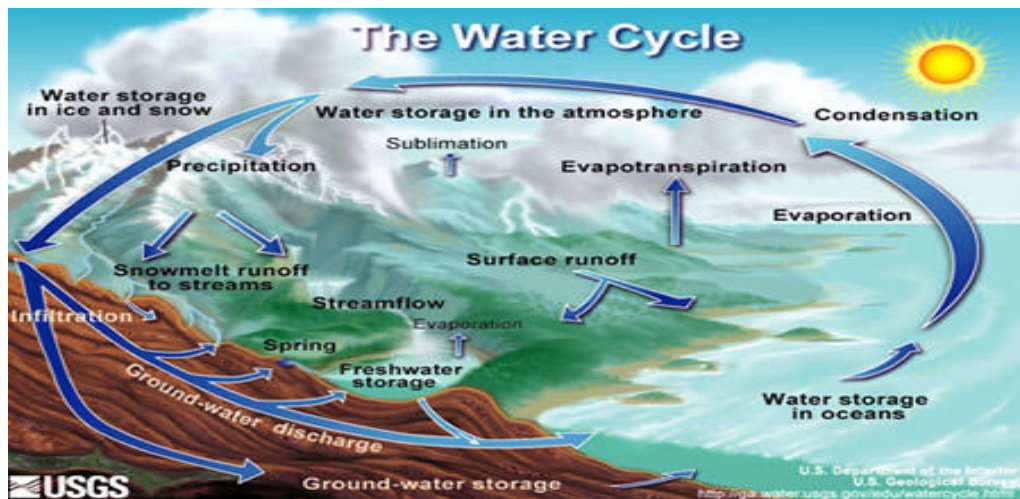
It is not known exactly why the Earth has a magnetic field of such strength. The configuration of the Earth's magnetic field is like that of a strong bar magnet placed near the center of the Earth. But the Earth is not a magnetized piece of iron, like the bar magnet we are all familiar with. The liquid part of Earth's core is simply too hot for the individual atoms to remain aligned in a magnetic conformation. So why is the Earth basically a magnet? Scientists currently believe that movements in the liquid core cause charged particles to move (a moving charge creates a magnetic field), looping within the Earth to create its magnetic field. The convection currents of the core may also be affected by the rotation of the Earth, and this may add to the Earth's magnetic field.

Basic Science Core: The Earth

Earth's Water Cycle

The Earth's surface is covered by more than 70% water. Earth differs from all other known planets because of water, which is largely responsible for life on Earth. Water on Earth today (like energy and mass) is the same that was here many years ago; it is recycled over and over in the water cycle.

The water cycle is a continuous process in which water moves from the atmosphere to various bodies of water, in land and living things, and then back to the atmosphere, completing the cycle. The water cycle has three main components (evaporation, condensation, and precipitation) and is primarily driven by the sun's energy.



Basic Science Core: The Earth

During evaporation, water is transformed from a liquid (in oceans, lakes, rivers, and soil) to a gas, or water vapor. Plants aid in evaporation by drawing water from their roots and releasing it through their leaves as water vapor (a process called evapotranspiration). **Condensation** is the transformation of water vapor back to liquid form by any of a series of ambient changes (temperature, pressure, etc.) that help it change state. For example, water vapor is often carried upward on thermal currents, and cools dramatically at higher altitudes, condensing into liquid water. Molecules of condensed water collect together on tiny dust particles in the air to form clouds. As more and more water vapor condenses, the drops of water in the clouds become larger, and then finally too large to stay in the cloud. Eventually the larger drops fall back to Earth as precipitation in the form of rain, snow, sleet, or hail. The precipitation falls all over Earth, some directly back to the oceans or lakes, but the water that falls on land may soak into the ground or simply run off the surface and find its way back into rivers, lakes, and oceans where the process starts all over again.

Question: What source of energy keeps the Earth's water cycle running?

- A The core of the Earth
- B The sun's radiation

- C The Earth's gravitational field causes water to run downhill after it condenses into clouds and falls to the Earth as precipitation
- D The living things that generate oxygen, which combines with hydrogen to form water

✔Answer

The correct answer is B. Nearly all processes on Earth have the Sun's radiation as their primary source

Basic Science Core: The Earth

Earth's Rocks

A key process on the Earth's surface is rock formation. First, let's get reacquainted with rock types. Rocks are classified according to their origin and composition. There are three main types of rock: igneous, sedimentary, and metamorphic.

Igneous rock forms during the cooling process of Earth's magma or lava. It may form on or beneath the surface, from lava eruptions. Igneous rock that formed from lava on the Earth's surface is called extrusive rock, the most common of which is basalt. Basalt is also the most common rock on Earth and forms much of the ocean's floor. Igneous rock that formed when magma hardened beneath the Earth's surface is called intrusive rock. The most abundant intrusive rock on Earth is granite, which helps to form many mountain ranges.

Sedimentary rock is made when particles of other rock, plant or animal remains are compressed for long periods of time. Most sedimentary rocks are formed by erosion, deposition, compaction, and cementation. Sedimentary rocks are easily identified because they usually have layers of different sediments that are readily apparent. Many fossils are found in sedimentary rock.

Metamorphic rock forms when existing rock is altered by pressure or heat under the surface of the Earth. Sometimes forces deep within the Earth push rock down toward the mantle where pockets of magma rising through the crust provide additional heat that can produce metamorphic rock. The deeper underground, the more pressure there is on the rock. Under high temperature and pressure, the minerals in one kind of rock can be changed into other minerals forming metamorphic rock.

Basic Science Core: The Earth

Radiometric Dating

While most atoms are stable and do not change over time, some are unstable and break down over time, releasing particles and energy in a process called **radioactive decay**. It is the process in which atoms of one element break down to form another element. This decay takes place naturally in most igneous rock and can be used by scientists to determine the age of the rock. As radioactive elements in the rock decay over long periods of time they change the composition of the rock. The rate of decay of any radioactive element is constant – and is referred to as the element's **half-life**. When one-half of a radioisotope's original mass has decayed to a lower energy state, that period of time is called the element's half-life. To effectively date a substance, scientists simply compare the ratio of the unchanged forms versus the changed forms of the element. The most prevalent radioactive

element with a half-life appropriate to the age of most rocks is carbon-14 (written in scientific notation: ^{14}C , a relatively unstable isotope) and its ratio to carbon-12 (^{12}C , a more stable isotope of carbon).

Carbon-14 dating is most useful in dating materials from plants and animals that are less than 50,000 years old. This is because carbon-14 has a half-life of 5,730 years. After every 5,730 years, the amount of carbon-14 remaining in a rock or fossil is cut in half. For this reason, it cannot be used to accurately date ancient fossils after approximately 10 half-lives (50,000 years), because the amount of remaining carbon-14 becomes too small to measure accurately. For much older dating, materials with longer half-lives (such as potassium-40 with a half-life of 1.3 billion years) are used to accurately measure the age.

Question: Why is carbon-14 radioactive dating not appropriate for determining the age of materials approximately one billion years old?

- A Materials approximately one billion years old never had carbon-14 in them originally.
- B Carbon-14 has a half-life of over 57 million years, so after one billion years of radioactive decay, there wouldn't be enough decay to measure accurately.
- C Carbon-14 has a half-life of 5,730 years and after one billion years of radioactive decay, there wouldn't be enough carbon-14 left to measure accurately.
- D The potassium-40 in materials approximately one billion years old destroys carbon-14 so it cannot be measured.

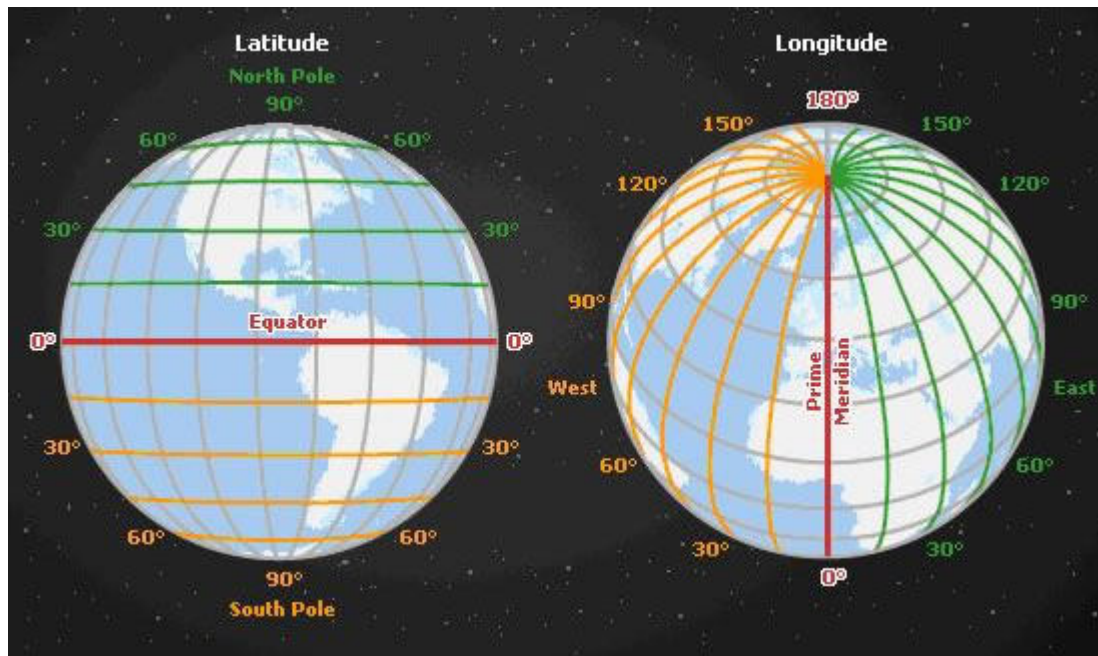
✔Answer

The correct answer is C. All carbon on Earth exists as a ratio of different isotopes, carbon-14 being one of the easiest to measure because of its relative ratio in most carbon-bearing substances (due to its half-life).

Basic Science Core: The Earth

Earth's Latitude & Longitude

The most common way to accurately describe the location of places on the Earth is by using the lines of latitude (in degrees north or south of the equator) and longitude (in degrees east or west of the prime meridian). This system provides a grid that can be used to locate any place on the Earth's surface. The figure below shows the lines of latitude and of longitude.



Latitude and longitude enable us to describe the location of everything on our planet. Latitudes divide the Earth into two hemispheres at the Equator, the Northern and the Southern Hemispheres. Lines of latitude are parallel to each other. Longitudinal divides, on the other hand, are not parallel and meet at the poles. Longitude divides the Earth into hemispheres along the Prime Meridian and the International Date Line.

Between the equator and each pole are 90 evenly spaced parallel lines, or degrees, about 112 km apart. The degrees come from the angle the line of latitude makes between the equator and the center of the Earth.

As the Earth rotates on its axis, any given location on the Earth's surface comes in and out of exposure to sunlight, causing day and night. If this location is tilted toward the sun, the period of daylight is longer because it receives the sun's rays more directly than if the location was tilted away from the sun. If Earth's axis was not tilted, day and night at all locations on the Earth would always be 12 hours long. At the poles where latitude is at maximum summer is three months of daylight and winter is three months of darkness. On the equator, however, days and nights remain about 12 hours long throughout the year.

Longitude is measured east or west of the prime meridian and there are 360 degrees of longitude that run from north to south, meeting at the poles. Like latitude, degrees of longitude are spaced about 112 km apart at the equator. As lines of longitude approach the poles, however, they become closer together. Each degree of longitude is defined by the angle it makes with the prime meridian and the center of the Earth.

The 360 degrees of rotation (also in longitude) correspond to twenty-four hours in a day on the Earth. There are 24 separate time zones of 15 degrees (each 1 hour) around the Earth. Because the circumference of the Earth is about 35,420 km, each 1-hour zone corresponds to a little less than 1,475 km (35,420 km divided by 24 hours). Since the continental contiguous United States are 4,800 km across and each hour represents a little less than 1,475 km, we have four time zones across most of the country (pacific, mountain, central, and eastern).

4. Physics: The Basic Principles

Lesson Objective

We will review the concepts of force, inertia, mass, weight, and the three laws of motion first developed by Sir Isaac Newton.

Previously we covered...

We previously covered concepts concerning the Earth sciences and our understanding of how the universe began. The Big Bang theory is the most likely explanation with scientific evidence for the genesis of our universe. It hinges on the idea that our universe expanded out of a tiny primeval fireball and that this expansion continues as galaxies today still move farther away from each other.

Physics: The Basic Principles

Force and inertia

The foremost Italian scientist, Galileo, successfully eliminated the notion that a force was necessary to keep an object moving by introducing the notion of inertia. His observations paved the way for Newton to formalize the laws of motion, and he is often credited as the Father of physics.

To start us off let us review some terminology. In physics, a force is a push or pull. For example, a push or pull on an object would be considered to be a force. When one object pushes or pulls on another object, both objects exert an equal but opposite force on each other. Friction is the force caused by irregularities in the surfaces of the objects that are in contact and moving relative to one another. Any two objects, no matter how smooth they are, have some frictional force between them when they are moving relative to one another. If there was no such thing as friction, a moving object would need no force whatsoever to remain in motion. Objects in a vacuum theoretically move without friction.

Question

When a rocket engine ignites on a launching pad, what can be determined about forces acting on the rocket ship?

- A The launching pad exerts a force on the rocket ship equal and opposite to gravity.
- B The force of gravity acting on the rocket ship is overcome by the force generated by burning the rocket fuel.
- C The two forces act in the same direction.
- D The force on the rocket ship exactly cancels the force of gravity.

✔Answer

The correct answer is B. In order for the rocket to launch into space, it must overcome the gravitational force of the Earth acting on its mass. The burning rocket fuel expelled out the back of the rocket causes a forward thrust that is greater than the weight of the rocket and the air friction acting on it. Hence the rocket accelerates upward.

Physics: The Basic Principles

Mass and Weight

How can two objects with the same mass have different weights? The terms weight and mass are often used interchangeably and thus are often confused with each other. We think that a heavy object contains a lot of matter, but this is not always true. We often determine the amount of matter in an object by weighing it on a scale. This is not an accurate method to determine an object's mass. Mass is more fundamental than weight; because mass is the measure of the *amount of matter* in an object and depends only on the number and kind of atoms in the object. Weight, on the other hand, is a measure of the gravitational force acting on an object. There are places where a massive object has no weight as in space, hence weight depends on an object's location – Earth is by far the most common location considered when weight is discussed. That is why we often confuse the terms weight and mass.

Mass is the measure of the amount of matter in an object and weight is the force exerted by gravity on an object. A person has the same mass at all times, no matter where the person is located. However, the weight of the person can change drastically depending on where the person is. A person weighs more at sea level than he/she does on top of a mountain because the pull of gravity is greater at sea level (closer to the center of the Earth) than it is on the top of a mountain. Similarly, a person weighs more on the Earth than he or she does on the Moon because the force of gravity on Earth is greater (about 6 times) than that on the Moon.

Question

What is the difference between mass and weight?

- A Weight is a measure of the amount of matter in an object and mass is the force exerted by gravity on an object.
- B The mass of an object varies depending on how far the object is from the center of the Earth.
- C Mass is a measure of the amount of matter in an object and weight is the force exerted by gravity on an object.
- D The mass and weight of an object do not depend on where the object is located.

Answer

The correct answer is C. It is important to understand that mass never changes, whereas weight is simply the gravitational force exerted on a mass.

Physics: The Basic Principles

Newton's First Law of Motion

By the time he was twenty-four years old, Sir Isaac Newton had developed the three laws of motion, the cornerstone of all of physics.

Newton's First Law of Motion states that every object at rest will remain at rest, and any object in motion will remain in motion (in a straight line at a constant speed) unless acted upon by an outside force.

In other words, an object tends to remain in its state of motion or non-motion unless a non-zero force acts upon it. A book on your desk, for example, is in a state of rest unless it is moved in some way. Now consider if the book was in motion on your desk. Let's say you exerted a quick force on your book trying to slide it off the end of your desk. Most likely, the book would come to a stop before it fell off. This is because of a large frictional force between the book and the desk. The moment you let go of the book, it is in motion and tries to stay in motion, but because of the outside force of friction that acts on the book after you let go, it stops. Now imagine you took your book to the arcade and slid it across an air hockey table. The book would slide easily across the table in a straight line, probably hitting the side before it stops because there is less friction.

Whether an object is in motion or not, it resists any change to that state of motion. This is called inertia, the tendency of an object to resist any change in its motion. Newton's first law of motion is also called the law of inertia. Some objects have more inertia than other objects. For example, if you try to push an elephant and then try to push a beetle, you quickly realize that the elephant is much harder to push because it is more massive (i.e., it has more mass). Likewise, when you try to stop an elephant, it is much harder to stop than the beetle. The greater the mass of an object, the greater its inertia, and the greater the force needed to change its motion.

Physics: The Basic Principles

Newton's Second Law of Motion

Acceleration describes the rate at which the velocity of an object changes $a = v / t$. We also know that if we apply a non-zero force to an object, its state of motion changes. The most popular sport in the world gives us a great example. Consider a soccer ball at rest. Apply a force with your foot and it starts to move. Since the ball was not moving before you kicked it, it accelerated, or changed its velocity. The ball accelerates each time you kick it; force causes acceleration. It is also important to remember that velocity, unlike speed, includes both speed and direction. Hence an object that changes direction at a constant speed is also accelerating.

Now if you kick the soccer ball and kick the goal post, you will find that the ball accelerates and moves easily, while the goal post is much harder to accelerate and move by applying a force. Now, kicking goal posts is not recommended, but it makes a good example for the observation that for any given force (e.g., your kick), the acceleration produced in another object (e.g., the ball or the goal post), is inversely proportional to the mass of that object. Newton came up with one of the most important laws of nature ever proposed, the Second Law of Motion, which states: When a non-zero force is applied to a body, that body is accelerated in the direction of the applied force at a rate directly proportional to the applied force and indirectly proportional to the mass of the body. In equation form, the second law is:

$$a = \frac{F}{m}$$

Or, more commonly:

$$F = ma$$

Question

If a force of 2000 Newtons is applied to a 1,000 Kg car, what is the car's acceleration?

- A 2,000,000 m/s²
- B 0.5 m/s²
- C 1,000 m/s²
- D 2 m/s²

Answer

The correct answer is D and can be obtained by dividing the force by the mass.

Physics: The Basic Principles

Newton's Third Law of Motion

Newton also realized that force is not just a single entity, but is an interaction between two objects. Suppose you pound a nail into some wood with a hammer. You strike the nail with the hammer and the nail goes into the wood because of the force exerted on the nail by the hammer. That is only half of the story. What stopped the hammer from moving? The nail actually exerted a force on the hammer to stop its motion. So there was an interaction of two forces: the hammer on the nail, and the nail on the hammer.

Newton realized that forces come in pairs, which brought him to his third law of motion. Newton's Third Law of Motion states that when one object exerts a force on another object, the second object exerts an equal and opposite force on the first object. The key idea here is that each force is a part of a system and for every action there is an equal and opposite reaction.

It is important to emphasize here the concept of action/reaction *pairs*, meaning *two* objects. If object A acts on object B, then the reaction is object B acting on object A. The reaction is never caused by a third object. For example, if a 150 pound person is standing on a floor, Earth's gravity is exerting a downward force of 150 pounds on the person. The reaction to that force, required by Newton's third law, is the person's gravity pulling up on the Earth with a force of 150 pounds. These forces (Earth on person and person on Earth) form an action reaction pair. The floor also exerts an upward force of 150 pounds on the person, but that is *not* the reaction to the Earth pulling the person down. Not all equal and opposite forces form the action reaction pairs required by Newton's third law

Physics: The Basic Principles

The Universal Law of Gravitation

We all know how objects fall to Earth because of gravity, and that gravity is what holds water in a glass. Gravity is the main interaction between objects. Newton made key observations about how gravity behaves between all objects. He discovered that gravity is universal – it exists everywhere, between all objects, and it depends on the masses of the objects and the distance between them.

Newton's Universal Law of Gravitation states that all objects attract all other objects with a force that is proportional to the product of the mass of the objects, and is inversely proportional to the square of the distance between them. Stated in equation form, this law is:

$$F \propto \frac{m_1 m_2}{d^2}$$

Newton recognized that the greater the masses of two objects, the greater the force of attraction between them. Moreover, the closer the two objects are to each other, the greater the force of attraction –by the square of that distance.

Newton also realized that all objects in the universe are affected by gravity and their gravitational forces act everywhere in the universe, not just on Earth. The force that makes an apple fall to the ground is the same force that keeps the planets in orbit around the sun and is also the same force that would allow a leaf in California to attract and potentially come into contact with a feather in New York (if there were no other forces like friction or objects in the way to prevent that from happening, no matter the object's sizes or locations). Nonetheless, the attractive force between the leaf and the feather (and ALL objects everywhere) is still there. Most of the time, however, this force is only great enough to be noticed when at least one of the objects is massive.

Now imagine a man flying in a hot air balloon 20 meters above the ground. Is the force of attraction between the man and the center of the Earth the same as when he stands on the Earth? No. The force of attraction between the man and the center of the Earth (his weight) when he is standing on the ground is more than when he is in the hot air balloon 20 meters high.

The fact that gravity is inversely proportional to the square of the distance between the objects in questions is the key here. When the man is standing on the ground, the distance between him and the center of the Earth is less than when he is 20 meters high in the hot air balloon. His mass and the Earth's mass are the same whether he is up in the balloon or not. Because he is farther from the center of the Earth when he is up in the balloon, the force between him and the center of the Earth is less than when he is on the ground. This difference in force is very slight because the difference in distance is very slight, but it does exist. However as the distance between the man and the earth increases, the weight of the man decreases, eventually leading to "weightlessness" of astronauts in space.

Question

Which one of the following equations correctly describes the mathematical nature of the law of universal gravitation?

A $F \propto m_1 m_2 d^2$

B $F \propto \frac{d^2}{m_1 m_2}$

C $F \propto \frac{m_1 m_2}{d^2}$

D $F \propto \frac{1}{m_1 m_2 d^2}$

✔[Answer](#)

The correct answer is C. Gravitational force is best described as the product of the masses of the objects divided by their distance squared.

Physics: The Basic Principles

Conservation of Momentum

Momentum is the characteristic of a moving object that makes it difficult to stop. Consider a bicycle moving at 1 km per hour and a train moving at 1 km per hour. The train has the most momentum and is much harder to stop because it has so much more mass than the bicycle: or consider two identical automobiles, one of them is moving at 1 km per hour and the other automobile is moving at 100 km per hour. The faster moving automobile has more momentum and is much harder to stop because it has a higher velocity. So momentum has something to do with both mass and velocity. The momentum (p) of an object is defined as the product of the mass (m) and velocity (v) of the object, or:

$$p = mv$$

Question

What is the momentum of a 50 Kg object traveling at 25 m/s?

- A 1,250 Kg-m/s
- B 250 Kg-m/s
- C 2,500 Kg-m/s
- D 75 Kg-m/s

✔[Answer](#)

The correct answer, A, is obtained by multiplying the mass of the object by its velocity.

Physics - The Basic Principles

Momentum and Newton's third law of motion lead us to another fundamental law of nature, the Conservation of Momentum. The Law of Conservation of Momentum states that in the absence of external forces, the momentum of a system is conserved – it never changes. Obviously, there is an intimate relationship between inertia and momentum.

The momentum of a system never changes unless it is acted on by outside forces. An isolated system will always have the same momentum before an interaction as it does after the interaction. Use this fact to help answer the following question.

Question

A 1,000 Kg automobile moving with a velocity of 50 m/s collides with another 1,000 Kg automobile at rest, and they get stuck together from the impact. Immediately after the collision (and ignoring the effects of friction), how fast will the two automobiles be traveling?

- A 0 m/s
- B 25 m/s
- C 40 m/s
- D 50 m/s

Answer

The correct answer is B. Multiplying the masses and the velocities before the collision and setting them equal to the product of the masses and velocities after the collision, the equation for the speed of the two automobiles together gives 25 m/s. Answer A is incorrect since the momentum before the collision was not zero.

5. Physics: Work

Lesson Objective

Now we will investigate forces acting over distances and work.

Previously we covered...

The previous sections discussed forces, masses, and velocities. We reviewed the concepts of inertia, momentum, force, and their interactions with objects' masses.

Physics: Work

Work

The scientific definition of work is the product of the force applied to an object multiplied by the distance the object is moved under the influence of the force.

In equation form,

$$\text{Work} = \text{Force} \cdot \text{Distance}$$

or

$$W = F \cdot d$$

If you carry a 50 kg box up one flight of stairs, you have done work on the box because you applied a force to it and moved it a distance. If you carry the same box up two flights of stairs, you have done twice the amount of work because you applied the same force but over twice the distance. Similarly, if you carried a 100 kg box up one flight of stairs, you would do the same amount of work as you did carrying the 50 kg box up two flights of stairs. This is because the product of the forces and distances was the same for both situations.

Question

If a 70 N force is applied to an object and raises it 2.0 m vertically, what amount of work was performed on the object?

- A 35 N-m
- B 68 N-m
- C 72 N-m
- D 140 N-m

✓Answer

The correct answer is D. The work performed is equal to the force multiplied by the distance

Physics: Work

Energy

Energy is an inherent quality of every system in our universe – it is all around us. In physics, we describe energy as the amount of work needed to change the state of a system. This could mean changing a substance from a solid to a liquid, changing the volume of a substance, or the total pressure of a system. Although energy is easily transferred from one form to another, it is never lost or gained.

There are two fundamental types of energy, potential (PE) and kinetic (KE). When you carried the boxes up the stairs, the work you performed gave the boxes the ability to do their own work. You exerted a force and gave the boxes potential energy. If you dropped the boxes from where you carried them, they would fall, gain velocity, and could do work of their own; they would transform their potential energy into kinetic energy. Look at the equations and their units below and you will see that work and energy are exactly the same quantities.

$$\text{Work} = F \cdot d = \text{N} \cdot \text{M} = \text{Joule}$$

$$\text{KE} = \frac{1}{2} m \cdot v^2 \text{ or } = \text{Kg} \cdot \text{M}^2/\text{s}^2 = \text{N} \cdot \text{M} = \text{Joule}$$

$$\text{PE} = m \cdot g \cdot h \text{ or } = \text{Kg} \cdot \text{M} \cdot \text{M}/\text{s}^2 = \text{N} \cdot \text{M} = \text{Joule}$$

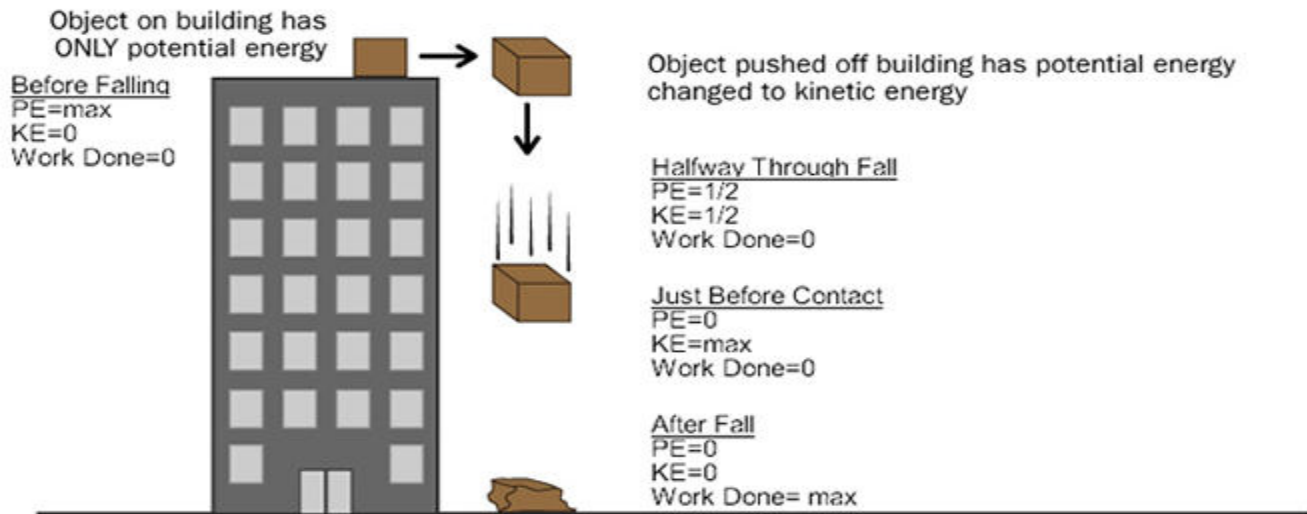
Physics: Work

Conservation of Work and Energy

The Law of Conservation of Work and Energy states that energy cannot be created or destroyed in a closed system. It can be transformed from one form into another, but the total amount of energy is always the same. Stated in equation form this becomes:

$$(\text{KE} + \text{PE} + \text{Work})_{\text{before an event}} = (\text{KE} + \text{PE} + \text{Work})_{\text{after an event}}$$

If you lift up the 50 kg box, you do work and give it potential energy by virtue of its position relative to the gravitational force of the Earth. If you drop it, the potential energy is converted into kinetic energy, and when the box hits the ground, the kinetic energy is transferred to the ground. But where did the kinetic energy of the box go? The crumpled box just sits there on the ground. It has no ability to do work and it is not moving. Where did the energy go? The energy did not disappear. The energy went into crumpling the box, changing the state of physical materials by breaking literally billions of molecular bonds, and to literally warming up the ground, albeit just a little. All energy is conserved.



Basic Science Core: Machines

Simple Machines

Simple machines help us perform work by distributing the components of work into smaller parcels. A machine lets you do work in a more efficient manner and in less time. Using a machine requires the same amount of work as not using the machine, but the machine changes the way in which you perform the work. Using a machine makes your work easier by changing one or more of the following factors: the force you exert, the distance over which you exert the force, and/or the direction you exert force. If you use a machine to exert less force, for example, it will increase the distance involved in your work.

If you need to move a 50 kg box up to a high shelf, it is much easier to push it up a ramp than to lift it straight up. If the length of the ramp was twice the distance up to the shelf, you would only have to exert half the force of lifting the box, but you would have to push it up the ramp for twice the distance as you would lifting it. Using a machine makes your work easier, but it does not reduce the amount of your work.

You can also use a machine to apply a greater force than you could do by yourself, but you will have to exert a force over a longer distance. When you use a hammer to pry a nail out of a piece of wood, for example, your hand moves a much greater distance than the nail moves when it comes out. You

actually generate a much greater force over a short distance (a tightly stuck nail moved a short distance) by applying less force over a greater distance

Basic Science Core: Natural Forces

The Basic Forces of Nature

All forces in nature can be classified into four basic kinds, each with a different relative strength. They are (listed in order of weakest to strongest):

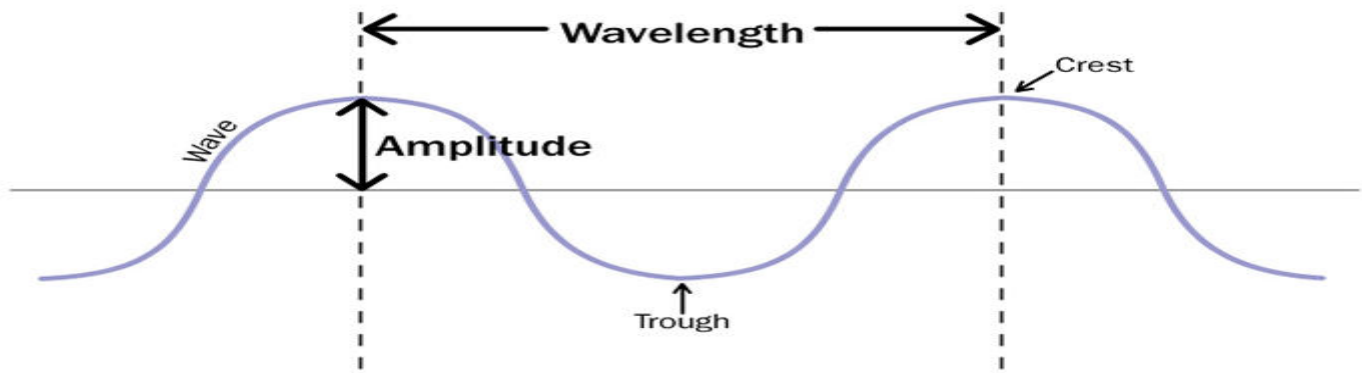
1. gravitational force
2. electromagnetic force
3. weak nuclear force
4. strong nuclear force

Gravity is one of the two forces that dominate our everyday lives and is probably the most common force that everyone recognizes. Electromagnetism is the other dominant force in our everyday lives. The electromagnetic force acts between all particles that have electric charge. It is attractive for oppositely charged particles, and repulsive for particles of the same charge. The electromagnetic force is the 'glue' that holds atoms, molecules, and chemical substances together. The electromagnetic force is generally responsible for all forces involved when atoms interact. The weak nuclear force is most commonly seen in the beta decay of radioactive particles and named because it is relatively weak (10^9 times less than that of the strong nuclear force) and limited to distances smaller than an atomic nucleus. The strong nuclear force is the strongest of all forces and it is 'glue' that holds the protons and neutrons together in the nucleus of an atom. Although two protons (both being positively charged) repel each other via the electromagnetic force, the strong nuclear force overcomes the repulsive force within an atom and holds the nucleus together. Even though it operates at very short distances (within the nucleus of an atom), it is incredibly strong relative to the other fundamental forces.

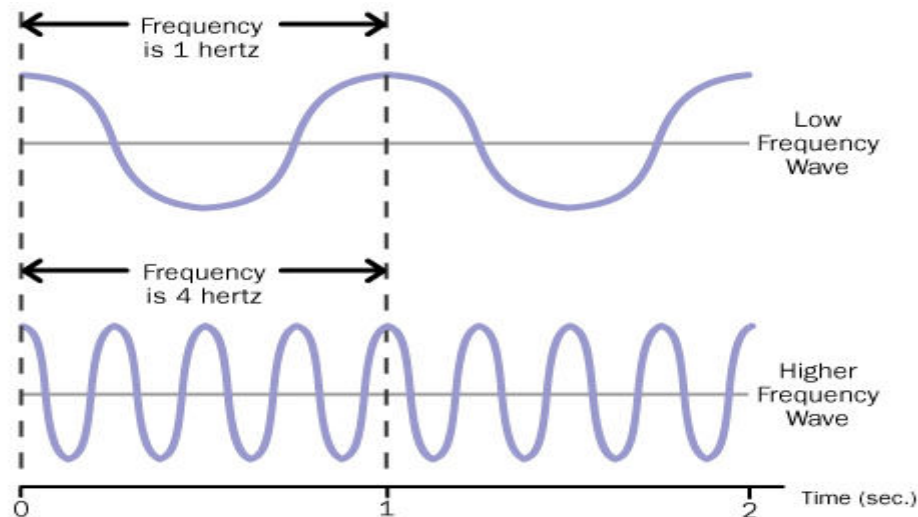
Physics: Wave Mechanics

Waves

Most of the information we receive gets to us in the form of a wave (sound waves, light waves, radio waves, etc.). Some waves travel through physical materials, and the material through which a wave travels is called a medium. Waves that require a medium to travel through are called mechanical waves. A mechanical wave is a particle disturbance that transfers energy from one place to another without changing the medium through which it travels. However, not all waves require a medium. Light waves travel from the sun through the vacuum of space to the Earth. Waves that do not require a medium to travel through are called electromagnetic waves. The basic properties of waves are wavelength, frequency, amplitude and speed.



The maximum distance the medium moves above or below its rest position when a wave passes by is called the amplitude. The more energy a wave has the more amplitude it has. Waves travel in a series of repeating vibrations. The distance between the maximum heights of successive waves is the wavelength. The frequency of a wave is the number of complete waves that pass by a given point per unit time. If one wave passes by a point every second, the frequency of the wave is 1 vibration per second VPS or more commonly, 1 Hertz; named after Heinrich Hertz, the great German physicist who was the first to show that electromagnetic waves exist.



Different waves travel at various speeds. If you see a lightning strike, you see the light immediately because light is an electromagnetic wave, which does not need medium through which to travel; and compared to sound has a relatively high frequency and short wavelength. Some time after you see the lightening, you hear the thunder. That is because the sound waves created by the lightning are mechanical waves that travel much more slowly than light because they must travel through a medium, air. Sound waves, when compared to light, have a relatively low frequency and long wavelength. The speed, frequency, and wavelength are all related to each other by the formula:

$$\text{Speed} = \text{Frequency} \cdot \text{Wavelength}$$

Assuming the medium does not change, the speed of a wave is constant. For example, sound waves in air (of the same temperature and pressure) all travel at the same speed. If the speed of a wave is constant and the frequency increases, the wavelength decreases by the same proportion.

Question

What is the speed of a water wave on a lake that has a wavelength of 0.5 M and frequency 2 hertz?

- A 4 m/s
- B 2.5 m/s
- C 1 m/s
- D 1.5 m/s

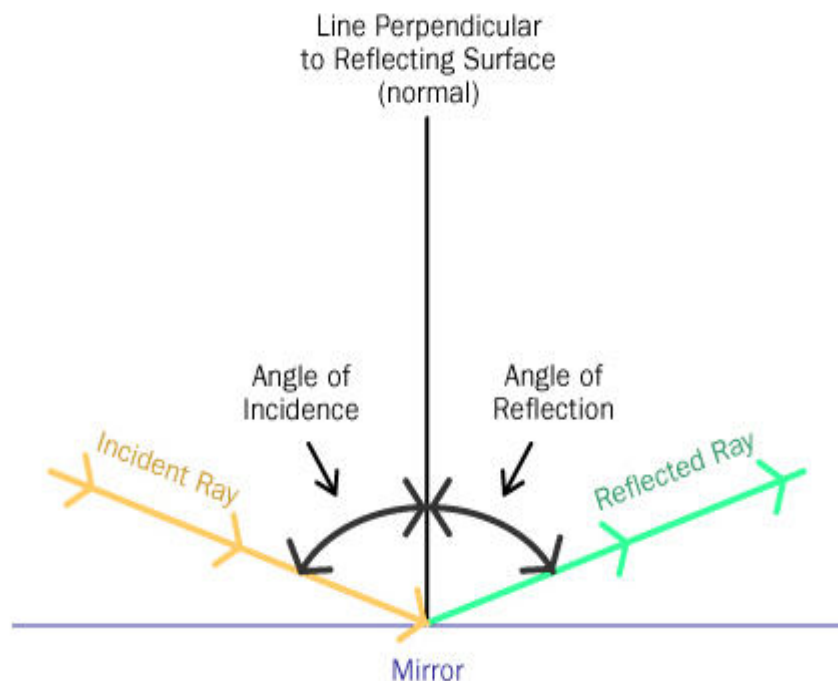
Answer

The correct answer is C. The speed of the wave is the product of 0.5 m and 2 Hertz, or 1 m/s.

Physics: Wave Mechanics

Wave Interactions I: Reflections

Waves interact with objects in their way, which can sometimes change their speed. The interaction between a wave and an impenetrable surface it strikes is called reflection. Examples of reflections of waves are the echo in a canyon or seeing yourself in a mirror. All waves behave according to the law of reflection so when a wave reflects from a surface, there is the incoming or incident wave and the outgoing, or reflected wave. The angle of the incident wave is called the angle of incidence while the angle of the outgoing wave is called the angle of reflection. The law of reflection states that the angle of incidence equals the angle of reflection.



Question

When light strikes a mirror, the light reflects off the surface. The angles of the incoming light and the reflected light are always

- A equal to each other.
- B different from each other.
- C add up to 90 degrees.
- D add up to 180 degrees.

✓Answer

The correct answer is A. The law of reflection states that the angle of incidence equals the angle of reflection. Although it is possible for the angles to add up to 90 degrees, it is not always the case. Under normal circumstances, it would be impossible for the angles to add up to 180 degrees

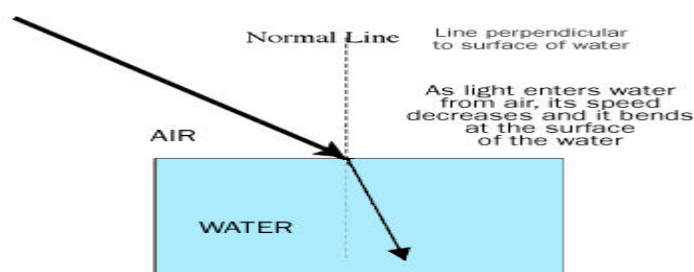
Physics: Wave Mechanics

Waves Interactions II: Refraction

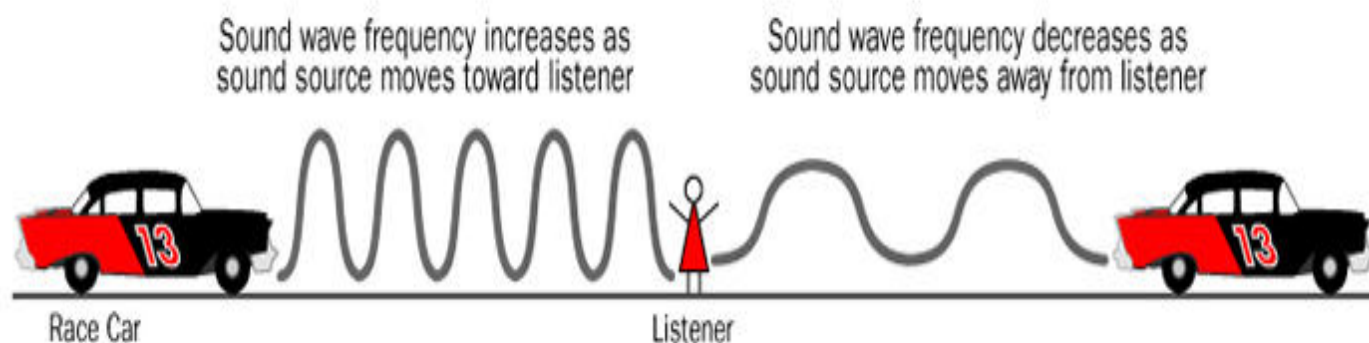
Have you ever driven slightly off the edge of a road only to notice that when the car wheels come just off the pavement your car suddenly turns slightly? This happens because the first wheel to hit the soft shoulder of the road slows down while the other wheels stay the same speed. This change in speed between different wheels causes a change in direction. As in the example, when the speed of a wave changes while passing from one medium into another, the direction of the wave changes. This is called refraction. Refraction is the change in direction of a wave due to a change in its velocity.

The Law of Refraction states that when a light wave enters a new optically transparent medium at an angle other than perpendicular, one side of the wave changes speed before the other side, causing the wave to change direction (or bend relative to a stationary object). However, refraction does not always occur when a wave changes media. When a wave moves from one medium into another, the wave bends, but only if it enters the new medium at an angle that is not perpendicular to the surface.

Refraction is not so important a phenomenon with mechanical waves as it is with light where it is responsible for image formation by lenses, the eye, cameras, etc. Bending of mechanical waves occurs when mechanical waves encounter a barrier in which there are openings or when they move along the side of a physical barrier. The waves slow because of friction and they change their direction of motion.



Another interesting characteristic of waves is that they seem to change their frequency depending on the motion of the wave source. You may know this but may not realize why. Think about the sound of a race car zooming by you. Have you noticed that you heard the pitch of the sound change as the car approached you and change again as the car zoomed away from you? You heard the frequency change from a high-pitched whine to a low-pitched rumble. The motion of the sound source (the race car) causes this phenomenon. This change in frequency caused by the motion of the wave source is called the Doppler Effect. Imagine the sound waves emanating from the race car much like the ripples in water from a pebble dropped in it. As the car approached the listener, the distance between repeating parts of each wave (wavelength) were compressed, causing more of them to be compressed in a shorter time. This caused an actual increase in the frequency of the sound. As the car went away from you, the distance between repeating parts of each wave (wavelength) was stretched out, causing fewer of them to occur in a certain time. This caused an apparent lowering of the frequency of sound.



Perhaps more interesting is that the frequency of the sound does not really change – it appears that way for the observer, but the frequency does not actually change at the source. The frequency of the sound heard depends literally on where you are listening. Any one who hears the race car approaching will hear a higher frequency sound than when the car is moving away. Yet the race car driver hears a constant frequency of sound. This happens for light as well. Although we just discussed an example of the Doppler shift in mechanical waves, see if you can answer this question about the Doppler shift in light waves (note that increasing the wavelength of a light wave changes its color toward a more blue color).

Question

According to the Doppler Shift, what happens to starlight seen on the Earth when that star is moving away from the Earth?

- A It increases in frequency.
- B It decreases in wavelength.
- C It increases in wavelength.
- D It decreases in amplitude.

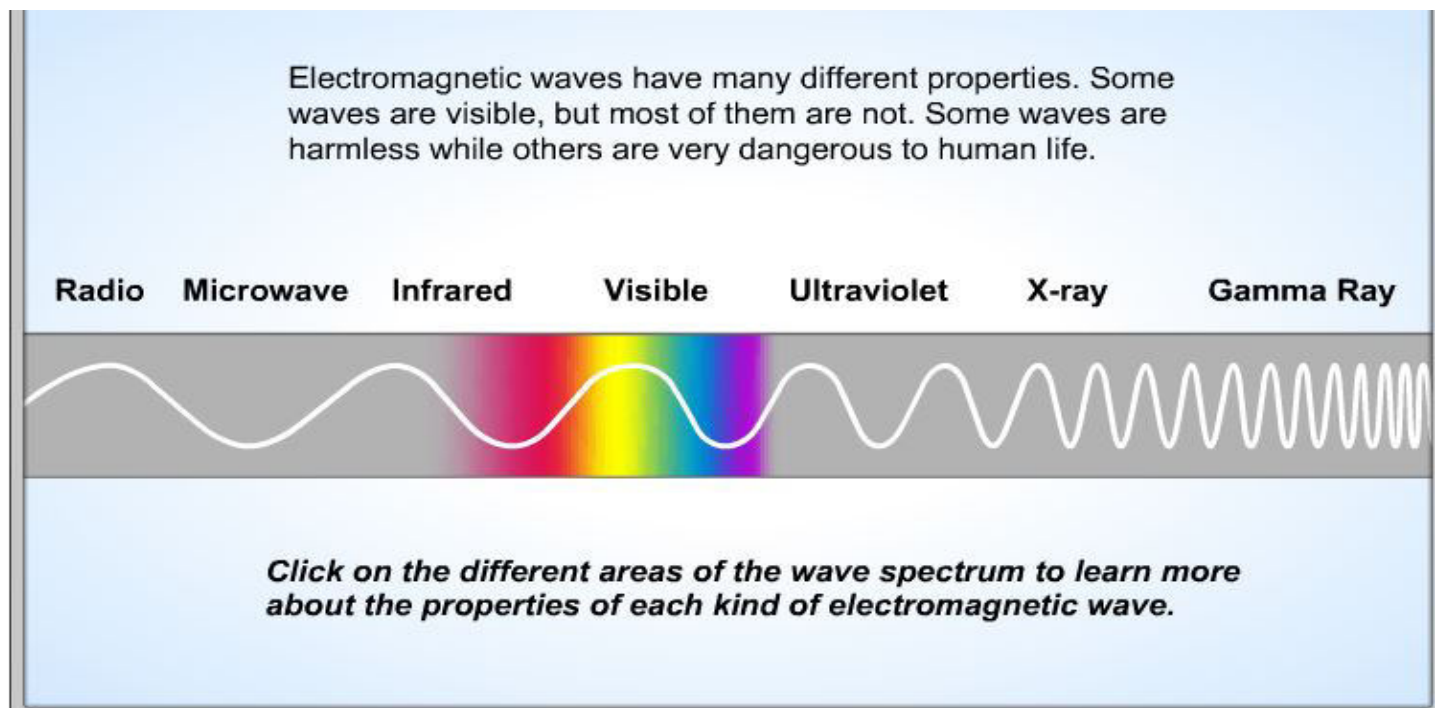
✓Answer

The correct answer is C. A Doppler Shift in starlight arriving at the Earth is the increase in wavelength of an individual color within a star's light and the decrease of frequency of the waves. The star's motion away from the Earth causes the wavelengths of its light to increase over what they are at the source. The increase in wavelength can be accurately used to measure the speed that the star is moving away from the Earth and how far away the star is from the Earth

Physics: Electromagnetic Spectrum

The Electromagnetic Spectrum

Electromagnetic radiation is wave energy that has both electric and magnetic aspects. The spectrum of possible types of electromagnetic radiation is quite broad and includes all of the ways in which humans communicate. There are radio waves, microwaves, infrared rays, visible light, ultraviolet rays, X-rays, and gamma rays, listed in order of increasing frequency. These electromagnetic waves are all around us all the time, but the only wavelengths our eyes sense is what we are most familiar with – visible light. Only a very small part of the electromagnetic spectrum is visible light.



Radio

Radio waves are the longest waves of the electromagnetic spectrum. We use radio waves to broadcast radio, television, and cellular phone signals. Radio waves are also used to peer deep into space.

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Microwave

We use microwaves to cook and heat food in a microwave oven. Microwaves are particularly useful for transmitting information because these wavelengths can penetrate rain, smoke, and clouds. The Doppler weather radar uses microwaves to chart the location of cloud formations, helping meteorologists report on current weather conditions.

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Visible

Visible light waves are the only wavelengths in the electromagnetic spectrum that we can see. The longest visible light waves are those of the color red, and the shortest are those of the color violet. The color of an object is the color of the wavelength reflected by the object. All other wavelengths are absorbed. Wavelengths in the visible light range of the spectrum are used in satellite and telescopic imagery.



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Ultraviolet

Ultraviolet radiation can be dangerous to humans. The sun emits ultraviolet radiation that causes sunburn. Ultraviolet light can also be very helpful to humans, especially in the field of astronomy. The famous Hubble telescope captures fantastic images of deep space by collecting ultraviolet radiation from heavenly bodies.

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X-ray

X-rays were discovered quite by accident in 1895 by German scientist Wilhelm Conrad Roentgen. X-rays are, of course, used today to study the internal structures of living creatures. Many objects in space, such as neutron stars and black holes, emit x-rays that we collect using x-ray satellites.

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Gamma Ray

Gamma rays have the shortest wavelength of any wave on the electromagnetic spectrum. Gamma rays are created by radioactive atoms and in nuclear explosions. Gamma rays can kill living cells, making them very dangerous. Doctors use this to their advantage, using gamma rays to kill cancerous cells. Many objects in space emit gamma rays. Massive unexplained bursts of gamma ray energy sweep across the universe from an unknown source, happening at least once a day. Scientists are studying these gamma ray bursts, hoping to find clues to the origin of our universe.

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Electromagnetic waves with frequencies lower than visible light are radio waves, microwaves, and infrared waves (thermal). Waves with higher frequencies than visible light are ultraviolet rays, X-rays, and gamma rays. The waves with higher frequencies have higher energy, and hence, the more hazardous they can be.

Radio waves and microwaves are used for the broadcasting of information and entertainment through the atmosphere. Microwaves are also used to cook food and create cellular telephone transmissions. Infrared waves are known for their heating capacity. Infrared waves are just below the visible-light part of the spectrum, and although you can feel infrared waves, you cannot see them. Common uses are heat lamps and infrared cameras that can detect heat. Continuing down the spectrum, visible light ranges in both wavelength and frequency. The lowest frequency visible light is red. As the frequency increases the color of the light changes to orange, yellow, green, blue, and violet. All the different frequencies (colors) in the white light refract (change speeds) differently and bend at different angles causing a rainbow to form.

Ultraviolet waves have high enough frequencies (and energy) to be hazardous. In small quantities, they are used in the human body to produce vitamins and increase the amount of epidermal melanin. However, excessive exposure causes sunburn, eye damage, and changes in tissues and organs (including cancer). X-rays have still higher energy, easily penetrating soft tissue in a human body (but not through bone), allowing doctors to see bony formations inside the body and to diagnose and treat many health problems. X-rays are more dangerous than ultraviolet waves and thus must be used sparingly – which is why you probably get dental X-rays only once a year and wear a heavy lead apron to prevent exposure to the rest of your body. X-rays are also used in industrial engineering applications such as looking for cracks in the steel supports of a concrete and steel structure.

Gamma rays are the shortest wavelengths and the highest frequencies (and energy). Because they are the highest energy waves, they have the highest penetrating power on the electromagnetic spectrum, and are the most powerful. Because of the penetrating nature and the tissue damage that

comes along with it, gamma rays are used to kill cancer cells within the body and are carefully focused as much as possible to not impinge on nearby healthy tissue.

Question

As the wavelength of electromagnetic waves decrease, what happens to the frequency and the energy?

- A The frequency increases and the energy increases.
- B The frequency decreases and the energy decreases.
- C The frequency decreases and the energy increases.
- D The frequency increases and the energy decreases.

Answer

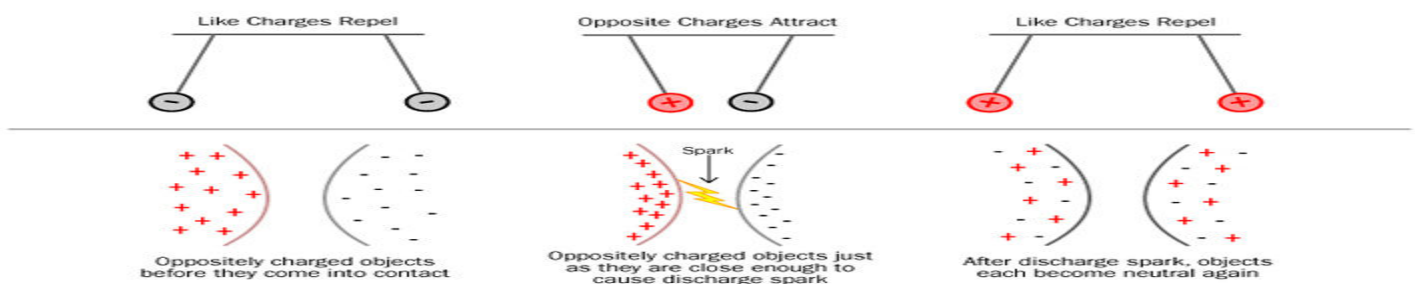
The correct answer is A. As the wavelength of electromagnetic waves decrease, the frequency increases, because $\text{speed} = \text{wavelength} \cdot \text{frequency}$. The speed of an electromagnetic wave is a constant (under most conditions) and therefore the wavelength and frequency are inversely proportional to each other. Also, as frequency increases, energy increases.

Physics: Electrostatics

Electric Charge and Static Electricity

Have you ever pulled a blanket out of your clothes dryer to find a sock stuck to it? What is holding them together is the force of electric charges.

We have previously learned that protons and electrons have opposite charges, and that protons are positive and electrons are negative. When two protons come close together, they push each other apart. The same is true for two electrons. However, if an electron and a proton come close together, they attract each other. They attract each other because they have different charges and in nature, opposite electric charges attract each other. They do so with an electrostatic force. Every electric charge has an electric field extending around it; an invisible region where the object's electric force is exerted on other charged objects, without the two objects coming into contact. When a charged object is placed within the electric field of another charged object, it is either attracted or repelled depending on the type of charge. The strength of an electric field depends on the distance from the object. The greater the distance from the charged object, the weaker the electric field becomes.



Most objects have no overall or net electric charge meaning they are neutral, neither positive nor negative. Therefore, there are no electric fields around neutral objects. However, some neutral objects can become charged. While protons are tightly bound in an atom's nucleus, the outer electrons can easily be moved away from their atoms. An object becomes charged when it loses or gains electrons – negatively charged if it gains electrons or positively charged if it loses electrons. Such charges do not move or flow – they are static. The accumulation of this kind of charge on an object is called static electricity.

Static electricity on an object does not stay there forever. It discharges. Electrons move from or to charged objects in such a way as to remove the charge on the objects (make them neutral again). When two oppositely charged objects come into close proximity or contact, they discharge in the form of a spark of electricity. You have probably felt the effects of this yourself. Lightning is a dramatic example of static discharge. During thunderstorms air and water droplets swirl violently and water droplets become charged. To restore their neutral condition, electrons move from an area of excess negative charge to an area of excess positive charge and produce an intense spark such as lightning. Some lightning reaches the ground because negative charges at the bottom of storm clouds may give the ground a positive charge. Electrons will jump from the clouds to the Earth's surface, producing a giant spark.

6. Life in Review

Basic Science Core: Life in Review

Lesson Objective

Next, we will go over the basics of the biological sciences and get ready for more in-depth reviews into all of the major disciplines of science. Our first topics will deal with how scientists organize the diversity of living organisms and how everything in biology can be best conceptualized in the context of evolution.

Previously we covered...

In the last lesson, we reviewed some of the major topics of physics, including the four of its fundamental fields: mechanics, energy, waves, and the electromagnetic spectrum.

Basic Science Core: Life in Review

Classification of Life

When we observe the natural world, one of our innate abilities is to classify things and organize them into groups. It is how our brains work as hunters and gatherers. In order to survive as long as we have, natural selection has shaped our abilities and behaviors. One of our most remarkable abilities is to classify things into meaningful categories. This is one of the few things that humans can do better, more effectively and more efficiently, than computers.

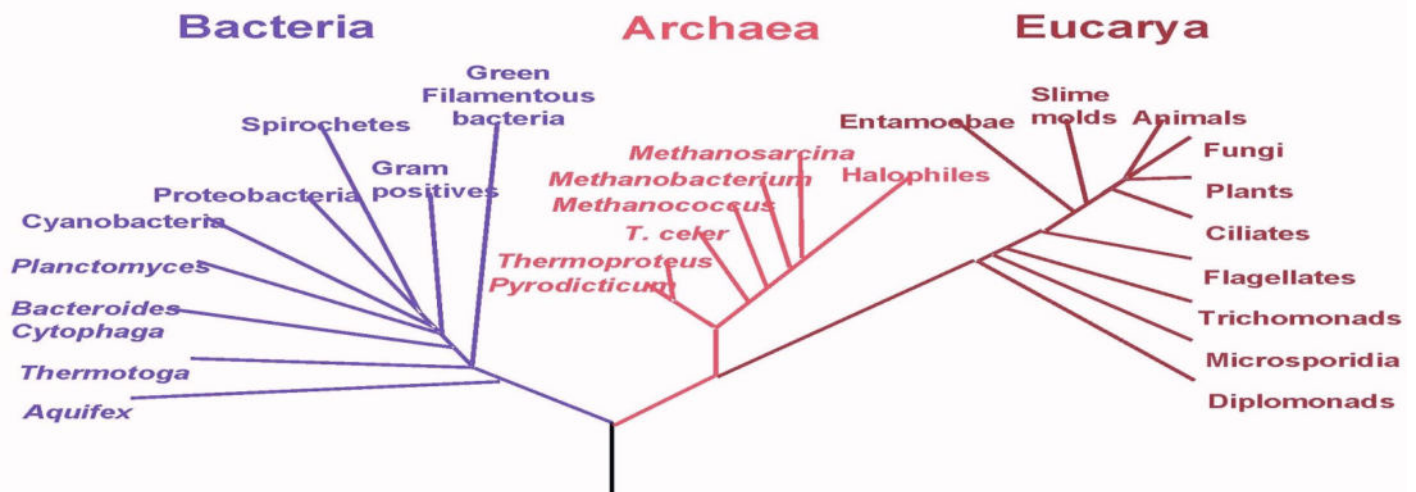
Biologists use a classification system to organize all living things into groups based on the organisms' evolutionary relationships. This also makes them easier to study and understand. Biologists use a hierarchical system of roughly eight groups to classify organisms.

Group	Effective size	Example
Domain	Largest – there are only three known Domains of life	Eukarya
Kingdom	Used to be the largest with at least seven categories	Animalia
Phylum	Extremely broad	Chordata
Class	Recognizably related	Mammalia
Order	Small and familiar	Primates
Family	Most understood	Hominidae
Genus	Tightly related	Homo
Species	Smallest groups of a single kind	sapiens

A three-domain system of classification is the most commonly used system in modern biology and is based on nucleotide sequencing in RNA molecules that may have the most information about how life evolved on Earth. The three domains are **bacteria**, **archaea**, and **eukarya**. All known organisms fall into one of these categories.

Basic Science Core: Life in Review

Phylogenetic Tree of Life



Bacteria are all around us all the time. Members of the domain bacteria are prokaryotes, whose cells lack a nucleus (a dense area that contains nucleic acids – chemical instructions for the cell's activities). Archaea are tiny organisms that thrive in some of the most extreme habitats found on Earth, from geothermal vents, where hot gases and liquids spew from ocean floors through volcanic fissures to colder, acidic, or highly alkaline waters. Biologists believe that these harsh conditions are similar to those of ancient Earth and give more evidence that these organisms may have been some of the first life on our planet. Eukaryotes are organisms that contain cell nuclei and are classified further into protists, fungi, plants, and animals. Protists are any eukaryotic organism that cannot be classified as an animal, plant, or fungus and are a mixture of different, potentially unrelated, organisms. Fungi have cellular walls, use spores to reproduce, and feed by absorbing food.

Mushrooms, mold, and mildew are all fungi. Plants are multi-cellular, autotrophic eukaryotes that live on land and in both fresh and salt water. In addition, plants are autotrophs; that is they can manufacture sugars from sunlight and water. They provide the original food for all the heterotrophs on the planet. The plant phylum includes a great variety of organisms. Some plants produce flowers while others do not. Some plants, such as trees, can grow very tall while others, like mosses, never grow more than a few millimeters in height. All animals are multi-cellular eukaryotes and are heterotrophs. Animals have different adaptations that allow them to locate food, capture, eat, and digest it. Animals live in extremely diverse environments and can have complex behavioral adaptations that we find fascinating because humans are also animals.

Question 1: What is the proper order of the classifications of life beginning with domain?

- A Domain, class, order, phylum, kingdom, family, genus, and species.
- B Domain, kingdom, phylum, class, order, family, genus, and species.
- C Domain, kingdom, order, class, family, phylum, genus, and species.
- D Domain, order, family, kingdom, phylum, class, genus, and species.

✔Answer 1

The correct answer is B.

Question 2: What are the three domains in which all organisms are classified?

- A Bacteria, archaea, and species.
- B Bacteria, phylum, and eukarya.
- C Fungi, archaea, and eukarya.
- D Bacteria, archaea, and eukarya.

✔Answer 2

The correct answer is D. Bacteria, archaea, and eukarya are the three domains that encompass all know life.

Basic Science Core: Evolutionary Concepts

Darwin and Wallace

In all of human history, one of the most important and powerful scientific theories is that of evolution. Evolution is the process by which organisms acquire and pass on traits that were not present previously. This change-through-time is generated by inherent variation and mediated by natural selection. When Charles Darwin and Alfred Russel Wallace co-founded the theory of evolution through natural selection, they were well aware of the controversy. But the evidence was

overwhelming, even back in 1858. Both men had spent large amounts of time exploring the tropical rainforests and islands of the world. Darwin mostly explored South America and the Galapagos Islands from aboard the **Beagle**, while Wallace actually lived and worked for extensive time periods across South America and the Indo-Malaysian archipelago. Between the amazing field observations and data collected by these two outstanding natural historians, there was ample evidence to form the ideas that have led to our current understanding of evolution.



Wallace and Darwin first published a joint work in 1858 that laid out the scientific establishment of the theory, while the more famous and popularized version came out in a large tome by Darwin the next year. Although it was not immediately embraced by the scientific community, the theory of evolution has become one of the most powerful paradigms in all human endeavors. Later, during the 1930s, a group of scientists furthered the idea of evolution by combining it with Gregor Mendel's work on heredity to create the modern synthesis. In this new and improved version of evolution, the idea that genes are the fundamental unit of inheritance added a crucial bit of information about how evolution really worked — at the molecular level. With this mechanism, evolution came to mean the change in allele frequency in a population over time and could be explained through four main processes: migration, mutation, natural selection, and genetic drift.



Basic Science Core: Founders of Evolution

Outstanding in their field

In the mid 1800's, Charles Darwin and Alfred Russel Wallace were exploring some of the most diverse ecosystems on the planet. Both scientists had uncanny abilities to categorize and theorize about the origin and maintenance of the tremendous diversity they were witnessing. Both men came up with ideas about natural selection, speciation, and the fundamentals of evolution. Observations included the sheer diversity of living things, the remains of ancient organisms, and the characteristics of organisms on islands versus their mainland counterparts (the Galapagos Islands for Darwin and the Indo-Malaysian islands for Wallace). These observations led them both to separately, and then together; develop one of the most important scientific theories of all time — the theory of evolution.

After returning to England, Darwin compared Galapagos organisms to organisms that lived elsewhere, and found many similarities and differences. He found that plants and animals were almost identical in the Galapagos as they were in South America. However, as he studied his observations more closely, he found important differences, too. He theorized that some of the organisms in the islands must have come from the mainland, perhaps blown out to sea during a storm or set adrift on a fallen log. Once they reached the islands, they reproduced for many years and the offspring, while very similar, developed differences from their mainland relatives.

The most obvious differences Darwin noticed were the sizes and shapes of bird's beaks on the various islands of the Galapagos. An examination of birds from different islands and the South American mainland revealed that the birds had slightly different beak sizes and shapes. The differences in the beaks of birds in different locations seemed to show interesting patterns: there were classes of beak size and shape that each island seemed to share. Moreover, each island seemed to not only have similar bird beak adaptations in different species, but each island's species were slightly different from every other island's and the mainland's species. Darwin hypothesized that these differences in beak shape and size were adapted to best obtain food that was available in various environments and that the differences were variations on a theme, all coming from a common ancestor.

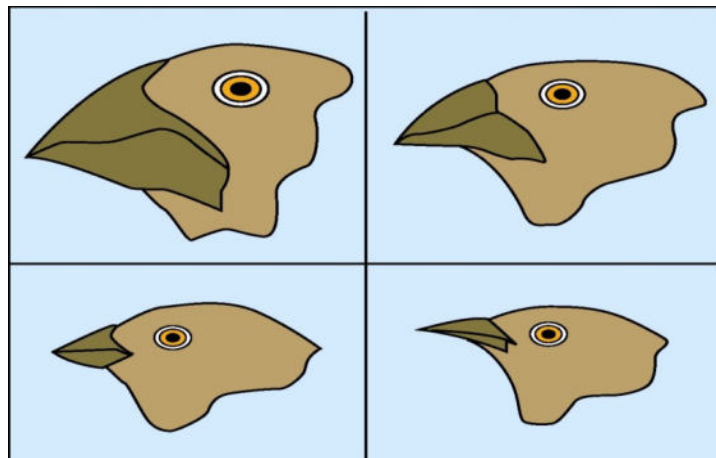


Figure 1. Darwin made observations of different bird beaks like these, each adapted to food availability for the different species.

Basic Science Core: Natural Selection

Evolution

Darwin reasoned that plants and animals that arrived on the Galapagos Islands encountered conditions that were different from those they experienced on the mainland, and must have evolved over many generations to become better adapted to their new surroundings. While Darwin was realizing the implications of these findings, another naturalist, Alfred Russel Wallace, was in the midst of one of the most important field expeditions of all time. Unlike Darwin, whose careful and meticulous fieldwork was synergized by months of contemplative research and theorizing back home in England, Wallace was more cavalier with his thinking while in the field. For many years after his trip around the world, Darwin continued to think about what he observed and was shocked to learn that Wallace had come to the very same conclusions, while in the Indo-Malay archipelago. While Darwin refined his theory based on countless observations made 15 years earlier, Wallace was publishing the first papers on the idea of natural selection. Finally, after many letters back and forth, the pair decided to jointly publish a paper that demonstrated how evolution, whose primary mechanism was natural selection, was a gradual change in a species over long periods of time. Although Darwin gets most credit for the theory of evolution through natural selection, both he and Wallace came to the same conclusions based on tropical fieldwork.

Question: What is the building block of change that helps a species survive and reproduce in its environment?

- A Evolution
- B Adaptation
- C Variation
- D Selection

✓Answer

The correct answer is C. While the other choices are viable parts of the evolutionary process, variation is the primary building block that allows natural selection and adaptation to affect change over time. If there were no variation in the first place, natural selection would have nothing to work with - and evolution wouldn't occur

Basic Science Core: Life in Review

Natural Selection

Darwin and Wallace proposed an explanation of how evolution occurs in nature. In 1858, they proposed that evolution occurs by a process of natural selection. Natural selection limits unsuitable variations that can be passed on to the next and future generations. Organisms that have successful variations are more able to pass on their genetic material (for whatever reason) and become "selected" naturally.

Wallace and Darwin identified many factors that can affect natural selection. They knew that most organisms produced many more offspring than could survive on the available resources. Among these numerous offspring will be variation — they are not only different from each other, but also different from their parents. Any variation that can enable certain organisms to out-breed others will be advantageous in passing on those traits. For example, if an organism is able find food faster in their environment, that may enable an organism to be more able to mate successfully, so that trait (ability to find food faster) will be passed on. Another example: one organism might have a color that protects it from predators better than the coloration of another organism. Competition is common among members of the same species when food and other resources are limited. The important factors that must accompany a biological system in order for natural selection to act, are inherent variation, some sort of competition, and differential mating success based on whatever factors are acted upon by natural selection.

7. Integrating the Sciences

Basic Science Core: Integrating the Sciences

Lesson Objective

In this lesson, we will review different facets of science to show how integrating knowledge gained from different types of science can enable a more meaningful and complete understanding of our universe. We will use surface area, volume, and mass as a way to integrate physics and biology.

Previously we covered...

We have reviewed one of the more important ideas in biology: The evolutionary process. The theory developed by Charles Darwin and Alfred Russel Wallace.

Basic Science Core: Physical Limitations

Biophysical Properties

The relationships between surface area, volume, and mass are an integral aspect of the physical properties of all biological systems. A primary law of how organisms relate to their environment has a lot to do with their size, surface area, and mass. Examples are; the limits of certain body types, organs, and cells. The table below shows how the volume of an object increases relative to surface area and length. The table also shows that as the length of a side increases the surface area increases as the square, and the volume increases as the cube of the linear dimension.

Side Length, Surface Area, and Volume of a Cube

Side length	Surface area : face	Surface area : solid	Volume
(units)	(square units)	(square units)	(cubic units)
1	1	6	1
2	4	24	8
3	9	54	27
4	16	96	64
5	25	150	125

To extrapolate, if the length increases by a factor of three, the volume will increase 27 times. In biological systems, this becomes important to the physics of how and why natural selection acts on certain characteristics. In very simple terms, it really is all about surface area.

Question: Let us assume there is a mutation in a population of insects that affects body size by a factor of two. If one of these double-sized insects stepped on a scale, how much more would the mutated animal weigh than the non-mutated version? Assume that volume and mass are directly proportional.

- A No more weight
- B Twice the weight
- C Four times the weight
- D Eight times the weight

👉Answer

The correct answer is D. We know that when a linear dimension of an object doubles, its volume increases by the cube. Since the cube of two is eight, the mutated animal would weigh eight times as much as the non-mutated animal. Decreasing the ratio of surface area to volume by making the object larger, enables living organisms to accrue certain benefits, like being able to maintain a constant body temperature with less calorie investment than smaller organisms. Their larger volume contains more heat and the rate at which they lose heat is proportionate to their relatively smaller surface area. Hence, they are able to keep warm more easily than physically smaller animals. Think of how and why surface area to volume ratios can be integral aspects of the development of organ systems, like our digestive, reproductive, respiratory, and circulatory systems. Think of why there are limits to the sizes of organisms. Could this also be related?

Basic Science Core: Observing the Past

Fossils

The obvious integration of geology and biology is the remains of organisms that have died, but left clues about their characteristics in behind. Paleontologists have used fossil records to determine how organisms have changed over time through evolution. Paleontologists study fossils and make comparisons to extant organisms (living today).

Fossils are usually formed in sediments whose lowest (oldest) sediments are deposited first with newer layers laid down on top of the older layers. Thus, fossils located in lower layers of rock are considered to be older than fossil layers closer to the surface. The rocks in which fossils are formed (or the fossils themselves) usually contain carbon-14, a slightly radioactive element that decays over time into a more stable isotope, carbon-12. Scientists measure the ratio of these two isotopes to determine how old the rock is where the fossil is found.

Basic Science Core: Continuation

Reproduction

Since organisms have limited lifetimes, they must reproduce in order to continue the species. Most animals and plants reproduce sexually. Sexual reproduction is the process in which an offspring develops from the fusion of two gametes (a male's sperm cell and a female's egg cell). The gametes contain the characteristics of each parent and when they fuse, they pass certain traits such as size, shape, color, or ability to fight disease onto the offspring. Each offspring resulting from sexual reproduction exhibits a combination of characteristics from both parents. Each gamete is haploid, meaning that the gamete contains half the number of chromosomes as the parent. This division of genetic material to be passed on is mediated by the process of meiosis. During meiosis, the chromosome pairs separate and are distributed to different daughter cells. The resulting gametes have half as many chromosomes as the other cells in the organism. When gametes combine, each contributes half the normal number of chromosomes, thus each offspring receives the normal number of chromosomes — half from each parent.

Some organisms reproduce asexually as well as sexually. Asexual reproduction is the process in which a single organism produces an offspring identical to itself. There are many examples in nature when organisms reproduce asexually. Sometimes environmental factors may be important in determining when an organism reproduces asexually. At other times, when an organism has enough energy, it may reproduce sexually. The ability to reproduce sexually is thought to add variability, and the potential for selection to affect traits can help organisms adapt to their environment faster. This could mean the difference between survival and extinction.

Basic Science Core: Selective Choices

Selective Breeding and Artificial Selection

Selective breeding is the process of selecting organisms with desirable traits to be parents of the next generation. As farmers and animal domesticators, humans have excelled at selecting both crop plants and animals (for food and work) through time. Excellent examples are the sweet potato, corn, rice, cows, chickens, and pigs. Two common selective breeding techniques that have been used to mold better plants and animals are inbreeding and hybridization.

Inbreeding involves crossing two individuals that have similar characteristics and/or may be closely related. For example, suppose a male and a female chicken are plump and have grown to maturity very quickly. The male and female chickens are inbred and their offspring will probably have the same desirable traits. Inbred organisms have alleles that are very similar to their parents and are genetically very similar to each other and their parents. Because of this similarity, inbreeding increases the probability that organisms will inherit alleles that lead to genetic disorders such as hip problems common with many breeds of dogs. This is called inbreeding depression and is one of the deleterious aspects of inbreeding.

Hybridization involves crossing two genetically different individuals. The resulting offspring is intended to have the desirable traits of both parents. For example, a farmer may cross corn that produces many kernels per cob with corn that is drought resistant, with the goal of growing drought-resistant corn that also produces numerous kernels per cob. Although this is an excellent idea in theory, there are often complications that prevent getting only the best characteristics from each parent.

Basic Science Core: Engineering Choices

Genetic Engineering

Genetic engineering is not necessarily a high-tech laboratory activity. As mentioned above, humans have been genetically engineering both plants and animals for centuries in the process of selective breeding and artificially selecting specific traits they deemed important and beneficial. Today, however, we are getting much better at selecting the exact properties we want plants and animals to have. Scientists have developed other powerful techniques for producing organisms with desirable traits, where genes from one organism are transferred into the DNA of another organism. In addition to producing new plants and animals, genetic engineering can produce medicines and improve food crop quality and yield.

Another interesting and very promising new technology involving genetic engineering is bioremediation. In a non-polluted environment, microorganisms are constantly at work breaking down organic matter. If an organic pollutant such as oil has contaminated this environment, some of the microorganisms would die, while others capable of eating the organic pollution would survive. Bioremediation works by providing these pollution-eating organisms with fertilizer, oxygen, and other conditions that encourage their rapid growth. These organisms would then be able to break down the organic pollutant at a correspondingly faster rate. In fact, bioremediation is often used to help clean up oil spills. Because it harnesses the power of living organisms to help solve environmental problems, it has become extremely valuable as tool for environmental protection.

Bioremediation provides a technique for cleaning up pollution by enhancing the same biodegradation processes that occur in nature. Depending on the site and its contaminants, bioremediation may be safer and less expensive than alternative solutions such as burning or burying the pollutants. It also has the advantage of treating the contamination in place so that large quantities of soil, sediment or water do not have to be dug up or pumped out of the ground for treatment.

Question: The process of selecting organisms with desirable traits to be parents of the next generation is called?

- A Selective Breeding
- B Sexual Reproduction
- C Meiosis
- D Inbreeding

Answer

The correct answer is A. Selective Breeding is the process of selecting organisms with desirable traits to be parents of the next generation. Sexual reproduction is the process in which an offspring organism develops when two sex cells (a male's sperm cell and a female's egg cell), meiosis is the process of dividing the genetic material of an organism into a haploid gamete, and inbreeding is the crossing two related individuals that have similar characteristics.

Basic Science Core: Basics of Heredity

Mendel's Work with Heredity

Heredity is the passing of physical characteristics from parents to offspring. In the mid-nineteenth century (at the same time as Wallace and Darwin's theory of evolution), Gregor Mendel wondered why different pea plants had different characteristics, such as how tall they grew or why some had different color seeds. Mendel observed that sometimes pea plants had the same traits as their parents and sometimes they did not. Mendel experimented with over 28,000 pea plants to understand the process of heredity, which ultimately laid the foundation for the study of genetics. Mendel developed a method by which he could cross-pollinate pea plants that had different traits. In one experiment, Mendel crossed purebred tall plants with purebred short plants, and found that all offspring of the first generation were tall — that the shortness trait seemed to disappear.

Trait	Phenotypes	
Seed shape	 Round	 Wrinkled
True Breeding - crossed to itself produces only itself		
Seed color	 Yellow	 Green
Pod shape	 Inflated	 Constricted
Pod color	 Green	 Yellow
Flower color	 Purple	 White
Flower and pod position	 Axial (on stem)	 Terminal (at tip)
Stem length	 Tall	 Dwarf

When the first generation of plants (f1) was full grown, he allowed them to self pollinate to produce the next generation (f2) and found that about three-fourths of the plants were still tall but approximately one-fourth short — that the shortness trait seemed to reappear even though none of the parents were short. So, he determined that only one form of a trait appeared in the first generation

but that in the second generation, the trait that earlier had disappeared had reappeared in about 25% of the plants. Mendel reached several conclusions. He reasoned that individual factors or sets of “genetic information” must control the inheritance traits in the plants and that these factors exist in pairs — one from each parent. He also realized that one factor in the pair can sometimes mask, or hide, the other factor.

Today, we use the word gene for the factors that control a trait. We also use the word allele for different forms of a gene. The gene that controls the height in the pea plants, for example, has one allele for tall plants (T) and one allele for short plants (t). Mendel’s discovery of genes and alleles changed scientist’s ideas about heredity. Before Mendel, most people thought the traits of an individual were simply a blend of the parent’s characteristics (i.e., if a tall plant were crossed with a short plant, that the offspring would all have medium height). Mendel’s experiments showed that parent’s traits do not simply blend in the offspring; instead, traits are determined by individual, separate alleles inherited from each parent.

Unfortunately, none of Mendel’s conclusions were realized as such important breakthroughs at the time. Gregor Mendel never knew how important his discoveries would be to a new synthesis of evolutionary theory that was developed well after Wallace and Darwin shared their views with the world. Fortunately for us, however, the modern synthesis of evolutionary theory has withstood the tests of time, innumerable experiments, and was strengthened by the integration of this new knowledge about the units of heritability.

8. Biogeography

Basic Science Core: Biogeography

Lesson Objective

In this lesson, we will cover some of the basics of biogeography, another example of how different scientific disciplines can be more fully integrated to gain a deeper understanding of our world.

Previously we covered...

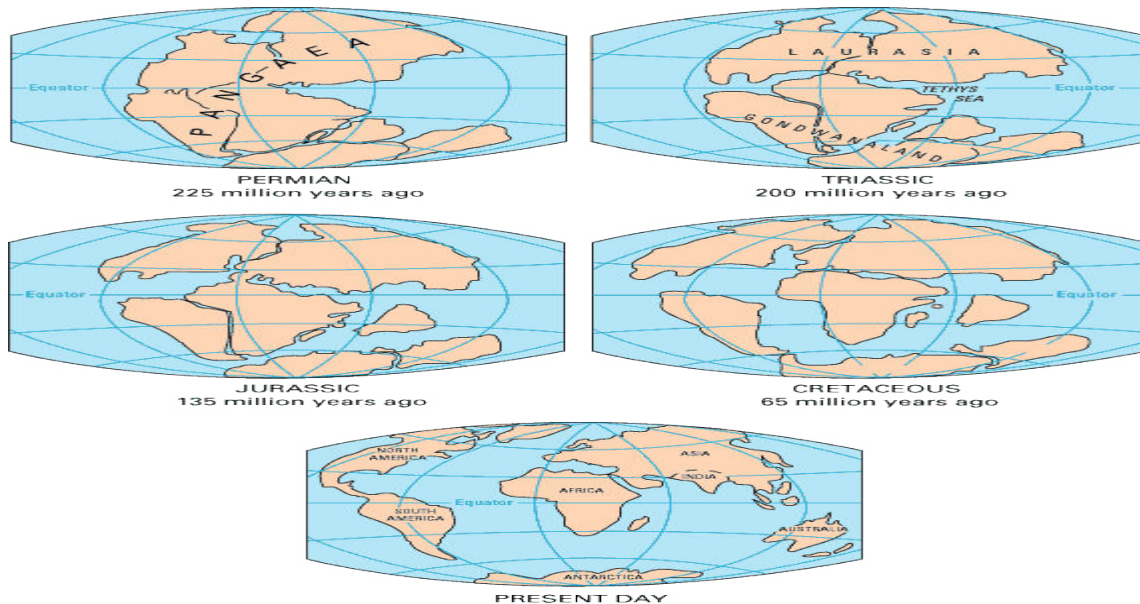
We reviewed some of the concepts of how evolution operates, namely natural selection. We also showed how humans have used evolutionary change to affect changes in our food crops and domesticated animals through many generations. Lastly, we showed how a field like horticulture was extrapolated to ask questions about inheritance that eventually led to a new breakthrough in the theory of evolution. We reviewed how Gregor Mendel’s pea plant experiments led to the discovery of a gene as the unit of heritability.

Basic Science Core: Biogeography

Continental Movements & the Distribution of Plants and Animals

In addition to studying the intrinsic characteristics of species themselves, biologists also try to understand what led to the distribution of species we see on Earth today. The major factor that has affected how species are distributed is the motion of the Earth’s continents via plate tectonics.

The figure below shows how much the continents have moved over the past 250 million years or so. About 250 millions years ago, all of today's continents were part of a single large land mass called Pangaea. Over time, they have slowly drifted into their present day locations.



Continental drift has a great affect on the distribution of species. Australia, for example, drifted away from other land masses at least 55 million years ago and carried the organisms that lived there along with it, effectively isolating them. Organisms from the other land masses were prevented from getting to the isolated island and for this reason, kangaroos, koalas, and other species unique to Australia developed in isolation.

The movement of organisms from one location to another is called dispersal. Causes of dispersal are wind, water, and living things. Many animals move from location to location on their own, but plants and small organisms usually need assistance. Winds can disperse seeds, spores of fungi, and very tiny organisms. Similarly, organisms that can float, swim, or cling to floating material are also dispersed by water. Some organisms can be dispersed under their own power or by other living things. For example, birds may eat berries in one location, fly to another, and deposit the seeds elsewhere in its waste. Plant burs can easily hitch rides on most animals and go everywhere the animal does. Humans have the largest affect on dispersing organisms. Human travel around the world accounts for such dispersal, some of which is intentional as when the Europeans took corn and tomato plants from central and South America back to Europe. Sometimes, human dispersal is unintentional as when insects, snakes, toads, or germs are carried to new places by an airplane traveler, in a ship's ballast water, or other human transport. Several species that were transported to other locations by such means and survived in those new locations are called exotic species. They can often become problematic for the native species.

The same species are not located in all areas of the world due to limitations on their dispersal such as physical barriers, competition, and climate. Physical barriers such as water, mountains, and deserts are difficult for many organisms to cross. For example, once Australia became isolated from the other continents, the ocean acted as a barrier to dispersal. When an organism enters a new area, it must compete for resources with the species already there. To survive, the new organism must find its own niche and if it cannot, competition is a barrier. Climate differences also limit dispersal. For example, the top of a mountain has a very different climate that the base. The base may be warm and dry allowing low bushes and cactus to thrive, part of the way up the mountain may be cooler and wetter, allowing large trees to thrive, while the top of the mountain may be very cold and windy, with thinner

air, allowing only short, hardy plants to survive. Places with similar climates tend to have species that occupy similar niches. For example, most continents have large, flat, grassy plains that support various grazing animals. In North America, the large grazing mammals of the grasslands are bison; in Africa, they are wildebeests and antelopes; and in Australia, they are kangaroos — all grazers, originally isolated by continental drift.

Basic Science Core: Energy in Living Systems

Energy Flow in Ecosystems

Just as all the pieces in a puzzle all have individual roles in making the final picture, all organisms have an individual role in the movement of energy through its ecosystem. An organism's energy role is determined by how it obtains its energy and interacts with other organisms. Each organism in an ecosystem fills the role of a producer, a consumer, or a decomposer.

The sun provides most of the energy to most ecosystems. Some organisms such as plants, algae, and some bacteria, capture the sun's energy and store it as food energy for later use. Other organisms living near the deep sea vents utilize other forms of non-solar energy, and are able to live that way. Most organisms store food energy as fat or other biomolecules for later use. This kind of energy is called potential energy —or food energy stored and held for later use by an organism. The stored energy has a chemical potential for providing energy at a later time, much like potential energy in a physical-science application. Organisms use the stored energy from the sun to convert water and carbon dioxide from the environment into food (sugar) molecules via photosynthesis, and consume the energy to live. The energy being actively used by a plant or animal is called kinetic energy, much like energy of motion in a physical science application.

Living organisms follow the same rules of physics that all living and non-living objects do. With regards to energy, every organism is governed by the laws of thermodynamics. Thermodynamics is a study of the interaction between heat (thermo) and energy (dynamics).

The first law of thermodynamics states that energy cannot be created nor destroyed. This law applies to the chemical processes in all organisms. It says that the total energy of a system of an organism and its surroundings stays the same, although the form of the energy may change or the system may gain or lose energy to the surroundings. If an organism has stored energy, that energy may be used to produce heat energy in the organism as it moves or performs some task, and that expended energy in turn is released to the organism's surroundings. Although energy has been transformed from one form to another, the total amount of heat between the organism and its surroundings always stays the same.

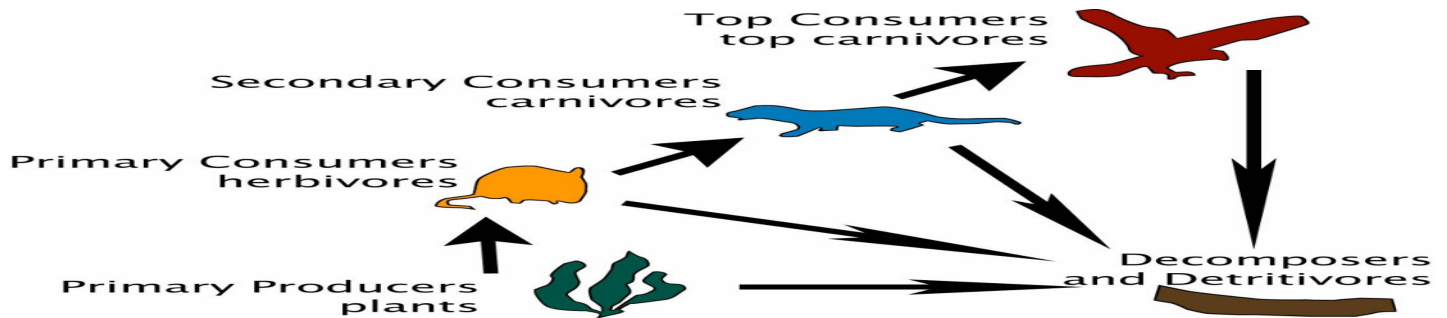
The second law of thermodynamics states that randomness in the universe always increases. This law means that all molecules will keep moving randomly until they reach a stable configuration. For example, gas molecules keep moving from organisms, cells, and everything in the universe, trying to achieve stable balance — even if the molecules must be chaotic (random) for a while.

An organism that makes its own food is called a producer. Producers provide all the food within an ecosystem. In some ecosystems, producers obtain energy from sources other than sunlight. One such ecosystem is found in the rocks deep beneath the ground. Some bacteria produce their own food by using the potential energy in hydrogen sulfide gas.

Some members of an ecosystem cannot make their own food and instead must feed on other organisms for energy. They are called consumers. Consumers are classified by what they eat. Plant eaters are called herbivores, such as caterpillars and deer. Consumers that only eat other animals

are called carnivores, such as spiders and tigers. Consumers that eat plants and animals are called omnivores, such as many birds, bears and most humans.

In an ecosystem consisting only of producers and consumers, the raw materials of life would remain locked up in wastes and the bodies of dead organisms. Luckily, there are organisms that take care of this problem and are called decomposers. Decomposers break down wastes and dead organisms and return the raw materials to the ecosystem. Decomposers are the recyclers of nature. While they obtain food for themselves, they also return broken down food molecules to the environment that can be reused by other organisms. Examples are mushrooms and bacteria.

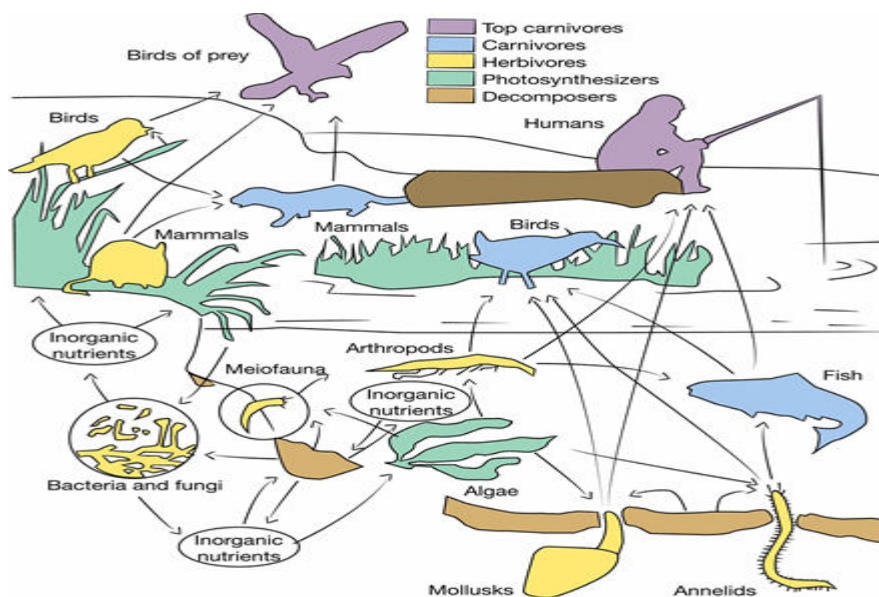


Basic Science Core: Chains and Webs

Food Chains and Food Webs

The energy that enters most ecosystems from sunlight is converted to food molecules by producers and then eaten by the consumers. Finally, decomposers recycle it. The movement of this energy through an ecosystem is commonly shown in food chains and food webs.

A food chain shows only one path through which energy moves through an ecosystem. You do not eat only one thing every day and neither do most organisms. Most producers and consumers are part of many food chains simultaneously. Many overlapping food chains within one ecosystem are called a food web.



Just as food chains overlap and connect to form food webs, food webs overlap and connect also. While a seagull may eat a fish at the ocean, it might also fly well inland and eat a mouse in a field,

thus linking two and easily more food webs. Most of the world's food webs interconnect, resulting in a global food web

Basic Science Core: Human Systems

Human Body Systems

The stomach, heart, brain, and lungs are all organs in the human body. An organ is a structure that is made of different kinds of tissue; these tissues perform a specific function or group of functions. There are four types of tissue in the body: muscle, nerve, connective (bone), and epithelial (skin). Each organ performs a specific function and all work together in one large system.

The major organ systems that make up a human body are:

1. The circulatory system that transports nutrients, gases (such as oxygen and CO₂), hormones and wastes through the body.
2. The digestive system that breaks down food and absorbs nutrients.
3. The nervous system that relays electrical signals through the body. The nervous system directs behavior and movement and, along with the endocrine system, controls physiological processes such as digestion, circulation, etc.
4. The skeletal system that provides support for the body, to protect delicate internal organs and to provide attachment sites for muscle tissue.
5. The endocrine system that relays chemical messages through the body. In conjunction with the nervous system, these chemical messages help control physiological processes such as nutrient absorption, growth, etc.
6. The muscular system that provides movement. Muscles work in pairs to move limbs and provide the organism with mobility. Muscles also control the movement of materials through some organs, such as the stomach and intestine, and the heart and circulatory system.
7. The respiratory system that provides gas exchange between the blood and the environment. Primarily, oxygen is absorbed from the atmosphere into the body and carbon dioxide is expelled from the body.
8. The excretory system that filters out cellular wastes, toxins and excess water or nutrients from the circulatory system.

9. Subatomic Biology

Basic Science Core: Sub-Atomic Biology

Lesson Objective

We will review the importance of some of the sub-atomic properties in chemistry that are relevant in biological systems. This becomes especially important when we think about how water fits into the biological picture.

Previously we covered...

We have reviewed some disparate fields of biology in order to get an idea of the breadth of the discipline. Biology encompasses living systems and what affects them, from biogeography, to organ systems within our bodies, to the sub-atomic properties of the elements that make up living tissues.

Basic Science Core: Sub-Atomic Biology

Valance Electrons and Bonding

Electrons do not orbit the nucleus like planets. Instead, electrons can be anywhere in a cloud-like region around the nucleus. The "cloud" symbolizes where electrons are likely to be found. An electron's movement is related to its energy level, or the specific amount of energy it has. Electrons of different energy levels are likely to be found in different places, lower energy electrons close to the nucleus and higher energy electrons farther away from the nucleus.

An atom's valence electrons are those electrons that have the highest energy level and are held most loosely, furthest from the nucleus of an atom. The number of valence electrons in an atom of an element determines many properties of that element, including the ways in which the atom can bond with other atoms. Atoms with five, six, or seven valence electrons become more stable when this number increases to eight. Similarly, atoms with one, two, or three valence electrons can lose electrons and become more stable. When these two types of atoms combine, electrons are transferred from one atom to another, making the atoms more stable and able to bond tightly together in an ionic bond. The chemical bond formed when two atoms share electrons is called a covalent bond. A strong, stable bond is formed when the total number of shared valence electrons equals eight. Covalent bonds usually form between atoms of non-metals, whereas ionic bonds usually form between a metal and a non-metal.

Question: Valance electrons are found in

- A the inner most orbits around the nucleus.
- B the outer most orbits around the nucleus.
- C randomly in all orbits around the nucleus.
- D the nucleus of an atom.

✔Answer

The correct answer is B. An atom's valence electrons are those electrons that have the highest energy level and are held most loosely, furthest from the nucleus of an atom. One of the most important features of an element's reactivity is how many valence electrons (or space for donations) are available to form bonds with other atoms.

Basic Science Core: Sub-Atomic Biology

The Importance of Water

Covalent bonds hold the hydrogen and oxygen atoms together in a water molecule. In covalent reactions, the atoms have an electrical charge (for example, positive or negative), but they do not give or take electrons. Instead, the atoms share electrons, which essentially cause one of the atoms to have a more positive charge and the other to have a more negative charge. In water, the oxygen is a bit more negative, and the hydrogen atoms are a bit more positive. The opposite charges cause the

hydrogen atoms of one water molecule to be pulled toward the oxygen atom of other nearby water molecules, creating a strong non-covalent bond to hold the water together. This strong bond, which is called a hydrogen bond, makes it difficult to boil or freeze water, which is important because a living organism contains so much water. The covalent bond strength means that water is a stable molecule; it is very hard to pull the oxygen and hydrogen of a water molecule apart into its constituent, the atoms. Although water contains covalent bonds, the characteristics of boiling and freezing water are a result of its network of hydrogen bonds, not its covalent bonds.

Further Reading in Basic Science Core

Basic Science Core: Further Reading

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Chemistry

1. Tools of the Trade: the Periodic Table

Chemistry: Tools of the Trade: the Periodic Table

Lesson Objective

In this lesson, we will be reviewing the properties of the periodic table and the patterns of the elements displayed therein. The material will concentrate on empirical characteristics of the elements that are reflected by their valence electrons.

Previously we covered...

We have covered an extensive (but not exhaustive) review of the main disciplines of the sciences: scientific investigation, physics, chemistry, Earth science, and biology. The last lessons concentrated on the chemical and physical aspects of biology.

Chemistry: Tools of the Trade: the Periodic Table

Development of the table

The first periodic table that ordered the elements based on their atomic weight was developed by Dmitri Mendeleev, a Russian chemist, in the 1860s. Mendeleev predicted the existence of previously unknown elements and paved the way for modern chemistry. In the 1860's he knew:

- that elements were made of small indivisible particles called atoms
- all **atoms** of an individual **element** have the same properties including **mass**.
- atoms can combine in whole number ratios to form **compounds**.

Mendeleev probably wrote the properties of elements known at the time on placards and arranged them in similar groups to discover that they were repeating, or periodic, thus the name of the table today, the periodic table. Where there were elements missing, he left room for elements that were yet to be discovered. One of the most striking patterns reveals an **octet** arrangement, or that certain characteristics of the elements repeat every eight elements. We know today that the observed properties of the elements are determined by their outermost **electron cloud** or shell, which has been described as the rule of **octet rule**.

Today, the **periodic law** is based on the number of **protons** in the nucleus of an element or the **atomic number**, not the **atomic mass**. The atomic number of the elements is the number of the protons in the nucleus of that element and is the method by which the periodic table is constructed. The atomic mass is the number of protons and neutrons in the nucleus. There are only a couple of places on the table where there is a discrepancy between the atomic mass and the atomic number. These stem from the nature of **radioactivity** when elements are unstable and have a short half-life. Remember that sub-atomic particles are too small to be seen — even with the most powerful microscopes in use today — and finding evidence for these particles requires sophisticated measurement techniques and equipment like particle accelerators. Nevertheless, the table organizes elements in a very systematic way that is invaluable to chemists and the basic arrangement first suggested by Mendeleev is still valid today.

The periodic table is an important tool for all scientific endeavors. Understanding the significance of Groups IA through VIIIA is the key to the rest of the periodic table. The increasing Group A number corresponds to the increasing number of valence (outer) electrons. Group VIIIA elements all (except

He) have 8 valence electrons, hence the rule of octet. Helium (He) is such a small atom that only two electrons have room to fit so near the nucleus and fill the outer shell. The elements in Groups IA and IIA easily lose electrons to become positive ions. The tendency to lose electrons easily identifies elements that are commonly called metals. Group IIIA elements tend to lose electrons but not as readily as the Group IA and IIA elements. They often combine with other atoms by sharing electrons. The elements in Group VIA and VIIA easily gain electrons to become negative ions. The tendency to gain electrons easily identifies elements that are commonly called non-metals. The Group V elements tend to gain electrons, but not as readily as Groups VIA and VIIA. They too often combine with other atoms by sharing electrons. The Group IVA elements invariably combine with other atoms by sharing electrons. They do not readily transfer electrons. The Group B elements have more complicated electron structures and will be discussed shortly.

Chemistry: Tools of the Trade: the Periodic Table

Properties of the elements in the table

Many of the elements in the table were named according to characteristic properties or sources for where they were found. For example, gold comes from the Latin term *aurum* meaning “shining dawn” which references its appearance. Phosphorus comes from Greek meaning “light bearer,” which is appropriate considering it is the main ingredient in match heads that spontaneously ignite with enough friction. Helium came from the Greek word *helios* that means “the sun” which is composed of helium and hydrogen. Moreover, several elements have been named after where they were first discovered or synthesized (e.g., Ytterbium, Yttrium, Berkelium, Lutetium, Americium, Dubnium, Germanium, and Scandium — just to name a few).

The periodic table organizes the elements in such a way that even someone unfamiliar with the substances can predict reactions (with both reactivity and composition) of the resulting compounds from the reaction; a significant advantage to having to be familiar with each individual substance. Now would be an excellent time to reacquaint yourself with the periodic table.

Chemistry: Tools of the Trade: the Periodic Table

Elemental groups

An elemental group is simply the vertical column of that element in the periodic table. There are 18 groups in the standard periodic table and they each correspond to the shared characteristics of those elements, based mainly on their shared number of valence electrons.

Beyond the 18 different groups, there are also classifications that are sometimes more meaningful and carry broader characteristics across more elemental groups. For example, there are nine basic classes of elements using this method:

- **Alkali metals**
- **Alkaline Earth metals**
- **Rare Earth metals**
- **Transition metals**
- **Post-transition metals**
- **Metalloids**
- **Non-metals**
- **Halogens**
- **Noble gases**

Alkali metals

The alkali metals are the elements in Group 1A on the periodic table (all the elements in the first column excluding hydrogen H): lithium (Li), sodium (Na), potassium (K), rubidium (Rb), cesium (Cs), and francium (Fr). With a single electron in their outermost or valence shell, these elements are some of the most reactive with other elements. Hence, they are rarely found in their pure elemental forms in nature. If or when they are in their pure forms, they tend to be extremely volatile and potentially dangerous. They are all, low-density silver gray metals that are relatively soft. They react with water to form very basic hydroxides and also with halogens to form ionic salts. They lose their valence electrons most easily of all the elements. This lowest energy-state in losing an electron causes them to form positively charged ions. Thus they form ionic substances with those elements that readily gain electrons.

Hydrogen is not an alkali metal because it occurs naturally as a diatomic gaseous molecule and removal of its single electron requires considerably more energy than that for the alkali metals.

Alkaline Earth metals

With two electrons in their valence orbit, the alkaline Earth metals are the elements in Group 2A (the second row from the left) of the periodic table: beryllium (Be), magnesium (Mg), calcium (Ca), strontium (Sr), barium (Ba), and radium (Ra). The alkaline Earth metals were named for their placement between the alkali metal oxides and the rare Earth metal oxides. These elements are also silver in color, low-density, soft metals, but they do not react as readily with halogens and water as the alkali metals. In this class, beryllium is the exception since it does not react with water and its halides are covalent compounds. Otherwise, this is a cohesive class of elements.

Rare Earth metals

The rare Earths (lanthanides and actinides) are often the elements usually put in a separate section below the periodic table and share many properties that make them difficult to tell apart. The common properties for the lanthanides and actinides include similar coloration (silver, white, or gray), high luster, and good electrical conductivity. As a group, they also have very few differences in solubility and reactivity. The elements of the lanthanide series are the 15 rare Earth elements from lanthanum to lutetium (atomic numbers 57 through 71) on the periodic table. The actinide series encompasses the 15 chemical elements that lie between actinium and lawrencium (atomic numbers 89 - 103) on the periodic table. Although actinides are chemically similar to the lanthanides, the actinides are radioactive. Some actinides with higher atomic numbers are not found in nature and have extremely short half-lives.

Transition metals

These are the 39 elements in the very middle of the periodic table (in rows 3 through 7) that form at least one ion with a partially filled *d* electron orbit (except for zinc and scandium). The properties of the transition elements are the result of their ability to contribute valence electrons in a variety of ways the other elements do not.

Post-transition metals

The post-transition metals are the metallic elements in the right hand side of the periodic table, occurring between the metalloids and the transition metals in rows 3-5: aluminum (Al), gallium (Ga), indium (In), tin (Sn), thallium (Tl), lead (Pb), and bismuth (Bi). These elements are usually soft at

room temperature and they have relatively low melting and boiling temperatures. They are also more electropositive than the transition metals, but less than alkali metals and alkaline Earth metals.

Metalloids

The metalloids are the elements sandwiched between the post-transition metals and the non-metals in rows 3-7 on the periodic table: boron (B), silicon (Si), germanium (Ge), arsenic (As), antimony (Sb), tellurium (Te), and polonium (Po). They share common features of ionization and reactivity and generally have intermediate properties between metals and non-metals.

Non-metals

Even though the non-metals are fewer in number than other groups, they play a major part of life on Earth. Non-metals are highly electronegative and gain electrons more readily than they give them up. The non-metals are the halogens, the noble gases, and hydrogen (H), carbon (C), nitrogen (N), oxygen (O), phosphorus (P), sulfur (S), chlorine (Cl), and selenium (Se). Most non-metals are found in the upper right hand side of the periodic table (except for hydrogen in the uppermost left). Non-metals are generally either insulators or semiconductors and usually form ionic bonds with metals by gaining electrons. Many non-metals (hydrogen, nitrogen, oxygen, fluorine, chlorine, bromine, and iodine) are diatomic, and most of the rest are otherwise polyatomic.

Halogens

The halogens are the highly reactive elements in Group 7A of the periodic table: fluorine (F), chlorine (Cl), bromine (Br), iodine (I), and astatine (At). These elements usually form diatomic molecules in their natural form and require one electron to fill their outer electron orbits. Hence, they have a strong tendency to form negative ions (referred to as halide ions) and salts (known as halides). These elements have increasing melting and boiling points and decreasing electronegativity as you move down the row. Because halogens are highly reactive, they can be quite dangerous. For example, chlorine and iodine are commonly used as disinfectants in drinking water, swimming pools, and many surfaces we want to be sterile. We primarily utilize chlorine both internally (as an ion, chloride is involved in many biological processes and important molecules) and externally as a disinfectant.

Noble gases

The noble gases are the chemical elements in group 8A, on the right side of the periodic table: helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe), and radon (Rn). The noble gases are also known as inert gases since they are not usually re-active during most chemical reactions. Their full electron shells make the inert gases highly unreactive except under extreme heat and pressure. They have very low melting and boiling points.

Chemistry: Tools of the Trade: the Periodic Table

Metals, non-metals, and metalloids

Generally the arrangement in the periodic table provides a clear delineation of metals and non-metals, which can be explained by the atomic structures of the elements. Although we just went over the major classes of elements, most of the elements on the periodic table are metals and they are characterized by:

- easily lose valence electron(s) to make the valence shell complete

- having shiny reflective surfaces
- conducting electricity and heat
- being ductile and malleable
- existing as a solid under normal conditions (except for mercury)
- being soluble in water as positive ions

Elements on the far right side of the periodic table are non-metals and have the following characteristics:

- easily gain valence electron(s) to make the valence shell complete
- they have non-lustrous sheen but a variety of colors
- solids are brittle (and both hard and soft)
- they are poor conductors of heat and electricity
- they exist as negative ions in a solution

Elements in between metals and non-metals on the table have intermediate characteristics. For example:

- Silicon and germanium are valuable as semiconductors in computer chips.
- Antimony looks like a metal (lustrous and shiny) but it is brittle and is a poor conductor of heat and electricity.
- Many of these elements have no set patterns of reactivity and depend on the characteristics of other elements in the compounds they form.

SCREEN SHOTS

Chemistry: Tools of the Trade: the Periodic Table

Using common oxidation numbers based on group

Elements in each group tend to have a common stable **oxidation number** that can be used to predict **reactions**. For example, Group 1 elements can be thought of as having an oxidation number of +1 because these elements commonly lose one electron to become more stable. Group 2 can be thought of as having an oxidation number of +2 because these elements commonly lose two electrons to become more stable. Group 3 can be thought of as having an oxidation number of +3 because these elements commonly give away three electrons to become more stable. Group 4 can be thought of as having an oxidation number of + or -4 because these elements commonly gain or lose four electrons to become more stable, depending on what other element it reacts with. Group 5 can be thought of as having an oxidation number of -3 because these elements commonly gain three electrons to become more stable. Group 6 can be thought of as having an oxidation number of -2 because these elements commonly gain two electrons to become more stable. Elements in group 7 gain one electron to become more stable and are said to have an oxidation number of -1.

To predict how elements will react, simply determine the whole number ratio required to make an algebraic sum of zero. Since negative one and positive one have an algebraic sum of zero, these elements tend to bond with each other to form stable compounds, such as sodium chloride $\text{Na}^{+1} + \text{Cl}^{-1} \rightarrow \text{NaCl}$. Sodium chloride is much more stable than sodium or chlorine are individually, and the combination is the common substance known as table salt. Any compound that has an algebraic sum of zero based on sum of the oxidation numbers of its elements has the potential for reacting and can be predicted based on its location on the periodic table.

Barium chloride, BaCl_2 is an example where barium has the oxidation number of +2 and chloride -1 meaning that it requires two -1 ions or (two chloride ions) to balance a single +2 ion, barium, for an algebraic sum of zero. Barium chloride is a common salt used to defrost roads in the wintertime. Carbon dioxide, CO_2 is an example where carbon has an oxidation number of +4 and oxygen has an oxidation number of -2. Carbon dioxide is the gas that is produced as a waste product in the process of cellular respiration in all living things. Carbon will even bond with itself very tightly to form the hardest pure substance known, which is a diamond. Chemists' first theories were based on simple observable proportions such as these to determine the relationships on the periodic table without a complete understanding of why these proportions were observed.

Chemistry: Tools of the Trade: the Periodic Table

Using energy levels based on period

Today, we understand that the periodic table summarizes both the chemical and physical properties that are based on atomic structure. As the distance from the center of the nucleus increases, the complexity of the arrangement of the electrons around the nucleus increases. This can also be identified by the distance from the top of the periodic table or row. For example, the difference between lithium (element number 3) and sodium (element number 11), is that sodium has one more shell or layer of electrons than lithium. They both have one electron in their outermost shell (because they are in group number one making them very reactive), but because the second shell of electrons has more volume to occupy as a function of distance from the center of the atom ($V = \pi \cdot r^3$), there is the potential for a more complex arrangement in space to find an electron within that space. Sodium is more stable than lithium but reacts in the same proportion as lithium with other elements.

The difference between helium (element number 2) and neon (element number 10), is that neon has one more shell of electrons than helium. The properties of the two elements are similar — colorless, odorless gases — but the additional shell of electrons means neon also has more protons in the nucleus which more strongly hold onto the electrons.

2. Quantum Mechanics - Electron configurations and orbital diagrams

Chemistry: Quantum Mechanics - Electron configurations and orbital diagrams

Lesson Objective

We are now going to review the electron orbits, their shapes, and distribution on the periodic table. This will set the stage for understanding the different kinds of reactions and bonds that occur among elements, molecules, and compounds.

Previously we covered...

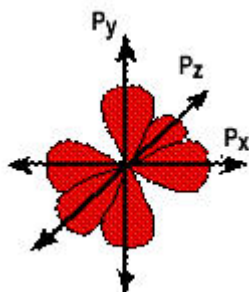
In the previous lesson, we reviewed the periodic table, its history and development. We know that Mendeleyev, the great Russian chemist, was an excellent predictive scientist who was able to foresee the discovery of dozens of elements before they were formally recognized. We also reviewed the nine main classes of elements (alkali metals, alkaline Earth metals, the rare Earths, transition metals, post-transition metals, metalloids, the non-metals, halogens and noble gases), the 18 groups of elements, and their constituent properties.

Chemistry: Quantum Mechanics - Electron configurations and orbital diagrams

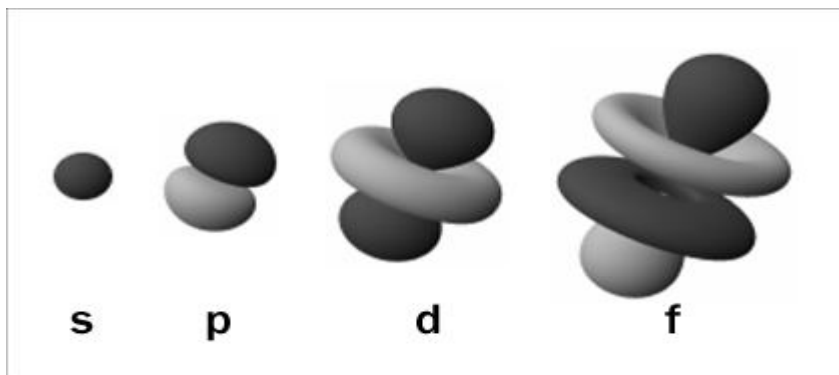
Orbital shapes

Quantum mechanics describes the probability for finding an electron within the specific dimensional spaces described by Schrödinger's wave equations. The area in which there is a probability for finding an electron is called the orbital space. The orbital space-shapes, called orbital configurations are described by mathematical equations which predict the possibility for finding an electron in that space. **Only two electrons can ever occupy any orbital.**

Electrons fill spaces near an atom based upon the energy required by an electron to maintain its position. The spaces requiring the least energy are filled first while those spaces requiring more energy are filled last; similar to pouring water into a glass. The lower potential energy position is the bottom of the glass, and as water continues to be poured the water rises into a position of higher potential energy. The lowest energy orbitals are called the *s* orbitals. The *s* orbitals are spherical in shape. Since only two electrons can ever occupy any orbital, the first *s* orbital is full when it has two electrons in it. This also corresponds to the element He, which you notice, is at the end of row 1. The next row begins filling orbitals by using the spaces that require the least energy first, *s* orbitals require the least energy, and so the first orbital in the second row is an *s* orbital. There are eight elements in the second row and each element must have all of its electrons placed in space. The second energy level (row two) beginning with lithium, contains two types of orbitals *s* and *p*, where the *p* orbitals resemble a dumbbell shape with orientations that are physically as far separated from one another as possible. The three *p* orbitals are designated by X, Y, and Z which represent the three perpendicular axis. Each *p* orbital can hold 2 electrons meaning the total number of electrons in the *p* orbit is 6. The two electrons in the *s*, plus the six electrons in the *p* orbital give a total of eight electrons, the rule of octet. The three *p* orbitals are shown below.



In the third energy level, beginning on the row with sodium, there are three possible orbital space shapes, *s*, *p*, and *d*, with the *d* orbital resembling the *p* orbital but occupying less space. The final shape which shows up on the fourth energy level, beginning on the row with potassium, is an *f* orbital which is still more complex but occupies less space than the *d* orbital.



The main idea is that the larger the atom, the more complex the probability for finding an electron within a given space, and the greater the options for electrons existing in different energy clouds.

Chemistry: Quantum Mechanics - Electron configurations and orbital diagrams

Orbital shapes and location on the periodic table

The periodic table not only has relationships within the horizontal rows (periods) but also within the vertical rows (or groups). The first two vertical columns, groups 1A and 2A, are elements whose **s orbitals** are filled. For any given orbital, it requires two electrons (with opposite spins) to fill the orbital space. For example,

- Hydrogen, in period 1A, has one energy level with one electron in an s orbital.
- Helium, also in period 1A, has one energy level with two electrons in an s orbital with opposite spins.
- Lithium has two energy levels and is located in period 2. The first energy level has two electrons with opposite spins (just like helium) but has an additional energy level with only one electron in the outermost shell.
- Following the pattern, beryllium has the same electron configuration that lithium has with one additional electron which must have an opposite spin. If you travel down the table you will see the same patterns.
- Cesium has six energy levels (period 6A) with one electron in an s orbital in the outer most level. Its inner levels are exactly the same configuration as xenon, the element before cesium, with the additional electron residing in the outermost s orbital.

Each atom of an element has one more electron than the previous element and a regular pattern for where that electron can be found. Within the increasingly complex three-dimensional spaces that these electrons occupy, electron configuration can be determined fairly readily by simply locating the element on the periodic table

Chemistry: Quantum Mechanics - Electron configurations and orbital diagrams

Elements in vertical columns (groups) 3A through 8A fill their *p* orbitals. Remember that you can have a *p* orbital on the *x* axis, the *y* axis, or on the *z* axis (all being able to hold 2 electrons with opposite spins). For example, an atom of the element nitrogen has two energy levels with two electrons in the first energy level (in an s orbital), two electrons in the second energy level (in an s orbital), and three electrons in *p* orbitals in the second energy level, one in the *x* direction, one in the *y* direction, and one in the *z* direction. Remember the energy requirement. Once an electron occupies a space in one of the *p* orbit lobes, that lobe has a higher energy requirement for new electrons than a completely un-occupied lobe.

Locate the atoms of elements whose energy levels contain **d orbitals**, also known as the transitional elements. These orbitals are more complex than the *p* orbitals with five different possible orientations. The complexity of the electron arrangement accounts for properties of the elements such as iron, copper, nickel, and zinc, which can exist in many different oxidation states. Iron is a common metal that not only changed the history of man (the Iron Age), but also was responsible for an industrial boom in American history, beginning with the growth of the railroad in the 1860's and peaking one hundred years later. One of the most reliable measures of a country's national economy was its steel production throughout much of this period. The electron arrangement of iron makes it perfect for alloying in various ratios for its industrial uses, and also ideal as the central atom in hemoglobin, responsible for carrying oxygen in many animals. The *d* orbital arrangement of electrons in an element such as iron is what gives it the unique characteristics for its reactions in nature.

The most complex orbitals are the **f orbitals** they have seven different orientations. These elements are located on the periodic table —see if you can find them. These elements are commonly unstable, many of them are radioactive, and some do not even exist in nature, having only been synthesized in particle colliders. Two of the most commonly known elements in this group are uranium and plutonium, both naturally occurring. The potential uses of these very complex elements are a constant source of anxiety in world politics because of their unique and dangerous characteristics. One kilogram of plutonium 239 can be converted to produce about 22 million kilowatt hours of heat energy.

Chemistry: Quantum Mechanics - Electron configurations and orbital diagrams

How do we know this?

Keep in mind that these areas for finding electrons with the greatest probabilities are based on mathematical equations, and to even confirm that an electron did exist in a location, required hitting it with another electron to knock it out of the space. **Heisenberg's uncertainty principle** was based on this relationship. To measure the existence of the electron required changing the physical structure of the atom he tried to measure. This idea of simply measuring something that changed what you are trying to measure has been extended to other areas of science as well. The German chemist Werner Heisenberg won the Nobel Prize in 1932 for his contributions to atomic structure, and his uncertainty principle is an important contribution for all scientists. Being aware of your bias (the fact that you always affect what you are studying) is critical to elegant experimental design. This has obvious implications across all of the scientific fields that require experimentation to test hypotheses. Understanding that simply studying something involves an inherent change to the system can be an important breakthrough.

3. Bonding and Atomic Structure

Chemistry: Bonding and Atomic Structure

Lesson Objective

Now we will turn to the atomic structure, an atom's stability, and one of the best ways to show electron distribution, with a Lewis dot structural diagram.

Previously we covered...

We have reviewed the essential nature of electron orbits and their role in determining many of the fundamental differences between the classes and groups of elements and how they interact.

Chemistry: Bonding and Atomic Structure

Stability

Atoms tend to arrange themselves in a way that is most stable, or at the lowest energy, in accordance with entropy. The periodic table is arranged in such a way to help us predict reactions based on atomic structure and the shared characteristics of groups of elements that share a set number of valence electrons. Most elements don't exist in their pure forms as they are depicted on the table because they are reactive with other elements and substances. An interesting exception can be found

in group 8A containing helium, neon, argon and the other noble gases. These elements at the end of each row are so stable that it is difficult to make them react under any conditions. These elements have full electron configurations in their outermost energy level orbits with no empty spaces (rule of octet again), and hence, no potential for picking up or sharing electrons belonging to other elements. For this reason, they are called inert and are the most stable elements in their pure elemental forms.

Outside of these noble gases, different elemental groups vary in how stable they are in their pure forms, or how easily they form compounds with other elements. On the other end of the spectrum, for example, are the alkali metals and the halogens, two groups that are extremely reactive, almost never existing in their pure elemental forms in nature. These two groups have an electron to donate or have room to gain one electron from another atom. For this reason, these two groups are often found with each other as ionic substances and with most other elements.

Chemistry: Bonding and Atomic Structure

What part of atoms is not stable?

Atoms have three basic types of subatomic particles: **electrons**, **protons**, and **neutrons**.

- Electrons are negative, have almost no mass, and are located on the outer margins of the atom and believed to be in constant motion around the nucleus, like bees around the mouth of a hive. Sometimes they can even leave the atom if they find something more attractive. We calculate that they exist in cloud-like orbits around the nucleus of the atom. They are symbolically referred to as “e (-)”.
- Protons are positively charged particles, are very massive compared to electrons (about 1,826 times heavier), and are located in the nucleus of the atom. The number of protons is the critical feature of the atomic number of an element and is distinguished by the symbol “p (+)”.
- Neutrons have no charge, are considered equal in mass to a proton (they are slightly more massive), and are also located in the nucleus of the atom. They are designated by the symbol “n”.

The nucleus is the very dense and positively charged center of the atom. The electrons are negatively charged existing clouds about the nucleus to balance the atom. For an atom to **bond** to another atom, it must somehow share or transfer electrons with or to a neighboring atom. Electrons are the keys to reactivity between elements, primarily because they are negatively charged and are attracted to the positively charged nuclei of the two atoms. Some bonding is called **ionic** because the electrons physically move from one nucleus leaving behind a positive ion, to another nucleus creating a negative ion. The two oppositely charged ions then come together to form ionic substances. **Covalent** bonding occurs when neither atom gains or loses electrons. The electrons are shared by the atoms involved in the reaction. Ionic bonds require large amounts of energy to break, although most ionic substances easily dissolve in water with electrons remaining with the non-metallic atom. Covalent bonds — where the electrons are shared equally by both atoms, are more easily broken.

Let's look at some simple examples with familiar substances in order to understand bonding and compounds better. If you examine the electron configuration of hydrogen (element number 1 & atomic number 1), you will find it to be the simplest of atoms with one s orbital containing one electron. For hydrogen to be most stable, it must find another electron to have the configuration similar to helium. Helium has two protons and two electrons equally balancing a positive and negative charge. But hydrogen has only one proton so it doesn't have the potential to hold two electrons like helium does. So if another atom of hydrogen happens to come by with its lone electron, the two atoms can share the pair of electrons making them both more stable. The resulting compound H₂ has an equal

attraction for the pair and thus is said to “share” electrons. Chemists label this type of bond as covalent meaning they have an equal valence or attraction for the negative charge. Hydrogen is an excellent example of an element that forms diatomic molecules with itself in order to reach a more stable electron distribution. Try to think of other elements that do this readily (hint — almost our entire atmosphere is comprised of diatomic molecules).

Chemistry: Bonding and Atomic Structure

Hydrogen can also bond to oxygen (element number 6) and will form the substance water, formula H_2O . Oxygen has two energy levels. The innermost level has the same configuration as helium, which has great stability. The outermost layer is lacking two electrons to have the stability that neon has with a full outer shell. So with the need for two electrons, each of two hydrogen atoms can share its one electron to make a stable configuration with oxygen, and at the same time make a stable configuration for itself similar to helium. Because oxygen has 6 protons (six times more positive charge than hydrogen) the shared pair of electrons is pulled a little closer to the oxygen than the hydrogen, which has one proton. While this is still considered to be a covalent bond, it is called polar covalent because the electrons are not equally attracted to both of the atoms in the bond.

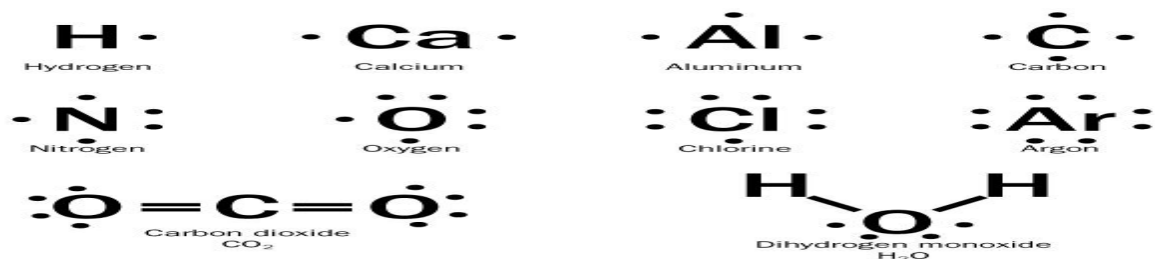
Hydrogen can also bond to chlorine, element number 17. Chlorine has 17 protons and 17 electrons. The first energy level has a stable configuration similar to helium and is very stable. The second energy level has a stable configuration similar to neon and is also very stable. But the third energy level needs only one electron to have the stability of argon (one of the noble gases). Hydrogen can bring its single electron to the partnership, but when this bond occurs, the pull on the electrons is very strong towards the chlorine atom. In fact, it is so strong that in water, the two atoms will separate and the electrons will go with the chlorine atom to form an ion. An ion is simply an atom with a charge — or a different number of electrons than protons. In this case, chlorine has 17 protons, but 18 electrons, thus it is negatively charged. It is now called a chloride ion, (Cl^-). But it is more stable than it was uncharged. The hydrogen that has now lost its electron is also an ion but it is positively charged (H^+). That is why this type of bonding is labeled ionic because it often forms ions when the bond is broken. This substance, HCl , is responsible for the activity that occurs in your stomach (also known as stomach acid) and is one of the most important biological acids, or H^+ donors.

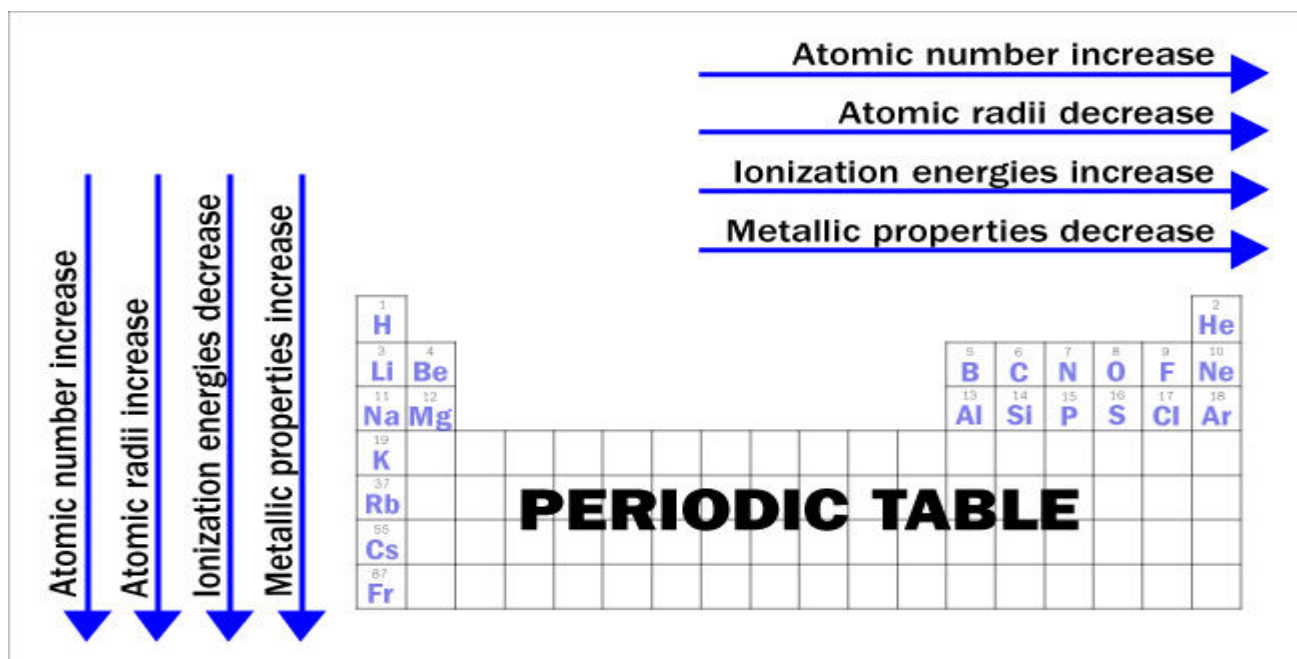
So an element can form any kind of bond, depending on what other elements are interested in the same electrons in the vicinity. All elements can shift electrons to gain stability and the most stable configurations are those with a full outer shell similar to the noble gases in group 8A.

Chemistry: Bonding and Atomic Structure

Electron dot structures

An American Chemist, Gilbert Newton Lewis, devised a simple way to demonstrate the octet rule using what are known today as **electron dot structures**. The dots come from the number of electrons that exist in the outermost shell.





4. Formulae and Naming Compounds

Chemistry: Formulae and Naming Compounds

Lesson Objective

In the next lesson, we will review the rules of chemical nomenclature and why we use them. At the end of this lesson, you should be able to name most inorganic chemicals, compound, or material.

Previously we covered...

We have just covered the materials having to do with the atomic structure, the stability of atoms, and the most useful way to demonstrate electron distribution, the Lewis dot diagram. We also synergized these concepts to help understand the important trends of chemical properties on the periodic table, making it an important and powerful tool.

Chemistry: Formulae and Naming Compounds

New properties require new names

When elements combine to form compounds, the resulting substances have new chemical and physical properties. For example:

- Sodium is a soft, silvery, reactive toxic metal that can ignite spontaneously in air.
- Chlorine is a diatomic toxic green gas that is very irritating to the lungs.
- But when sodium combines with chlorine in a one to one ratio, it forms sodium chloride, or table salt, an absolutely essential nutrient in our diets. Its appearance is neither green nor metallic but a cubic crystalline substance that easily dissolves in water.

Chemistry: Formulae and Naming Compounds

How does a formula symbolize a substance?

Chemists use a shorthand notation for easily symbolizing the ratio of atoms to one another. Each **symbol** begins with a capital letter. Some, but not all, have additional lowercase letters. For example:

- Sodium chloride's formula is NaCl and is understood to be bonded in a one-to- one ratio — one sodium atom for every atom of chlorine.
- Water (H₂O) is understood to have two hydrogen atoms bonded to one oxygen atom.
- Barium chloride (BaCl₂) is understood to have two chlorine atoms bonded to one barium atom.

The order of the symbols usually follows the order on the table, that is, the one closest to the left on the table is the one written first in a compound.

Naming compounds is a systematic process. The International Union of Pure and Applied Chemistry (IUPAC) is an organization dedicated to making clear and consistent rules for naming and solving problems of common language for complex chemical compounds. Since every substance has its own set of properties, it is very important to have such a consistent naming system. Without these naming

consistencies, the combinations and permutations of different compounds would exceed our ability to realistically name or even discuss them.

Chemistry: Formulae and Naming Compound

Naming binary ionic compounds

Generally, the binary (two different element) ionic compounds are named with the element farthest to the left on the table first (which is usually the least **electronegative**), and the element farther to the right, second. Using the previous example, sodium chloride follows this idea. Or you can say that the most metallic element comes first and the least metallic element comes second. Iron oxide (commonly known as rust) is an example of a compound where you might recognize the metal as the first part of the name and the non-metal as the second part. In both cases the second part of the name has a different ending (-ide). Using this rule, what would you call a compound formed from sulfur and aluminum? If you immediately thought aluminum sulfide you would be right. The single negative element always ends in “-ide”.

Question: What is the name of the binary ionic compound made from two atoms of chlorine and one atom of barium?

- A Chloric baride
- B Chloric barium
- C Barium Chloride
- D Barium Chlorium

✔Answer

The correct answer is C, barium chloride, since barium is a metal and chlorine is a non-metal. D is incorrect because you do not change the suffix of an element to match its compound material. Some elements (transitional elements) have more than one common oxidation state and the IUPAC has recommended that these elements include a roman numeral to indicate their oxidation state. For example, a more correct name for rust is iron III oxide, to indicate that iron is in the +3 oxidation state in that compound. The old naming system would call that compound ferric oxide. Cupric oxide would indicate copper II oxide. To avoid confusion, the new naming system identifies the oxidation state by using a Roman numeral in the name.

Chemistry: Formulae and Naming Compounds

What about compounds that have more than two elements?

Ternary compounds often contain oxygen along with two other elements. Oxygen is the most commonly reacted element on the table and can bond with just about anything. Often oxygen will be found in what is known as a polyatomic ion, or a group of non-metals bonded to non-metals, that exist as a very stable charged complex. An example of this is a sulfate ion which is made of one sulfur atom and four oxygen atoms (SO_4^{-2}). If aluminum bonds to sulfate, the resulting formula would look like this: $\text{Al}_2(\text{SO}_4)_3$. Because aluminum's oxidation number is +3 and sulfate's oxidation number is -2, there are three sulfate ions for every two aluminum atoms for an algebraic sum to equal zero. ($3 \cdot -2$

= - 6 and $2 \cdot +3 = + 6$). There are many types of polyatomic ions and most of them include oxygen. The naming of these compounds follows the same pattern as a binary compound, which is the name of the positive element, aluminum, first, then the name of the negative ion, sulfate, second.

Question: What is the proper name of a compound made from one atom of hydrogen, one atom of carbon, one atom of sodium, and three atoms of oxygen?

- A Hydrocarbon tetroxide
- B Hydrosodium oxide
- C Sodium hydronate
- D Sodium hydrogen carbonate

👉Answer

The correct answer is D, but the compound (NaHCO_3) is also called sodium bicarbonate, or more commonly, baking soda. The other possibilities either do not incorporate all the elements (Na, C, O, and H), or do not follow the nomenclature rules of naming complex compounds whereby the metal is listed first. A major hint is that the carbonate ion (CO_3) needs to have its own name independent of the metal and hydrogen that come before it.

Chemistry: Formulae and Naming Compounds

What about compounds with special properties dissolved in water?

Some substances have unique properties when dissolved in water and thus have their own naming system. We refer to these as acids. Because of the nature of the water molecule, there are two pairs of unshared electrons that exist on the oxygen atom. These are perfect for attracting a hydrogen ion that has lost its electron to a strongly electronegative element such as chlorine. Remember that for hydrogen to exist in a stable state it needs two electrons or the same configuration as helium. So in a water solution the free floating hydrogen ions are attracted to the electron pairs in water molecules. These solutions are responsible for characteristics of acids, like sour taste, low pH, and the ability to change an indicator dye such as litmus from blue to pink.

H⁺ hydrogen ion (no electrons)

..

H: O: water molecule

..

H

A hydrogen ion bonded in this way to a water molecule is also known as a hydronium ion.

Naming acids is systematic as well.

- Binary compounds use “hydro ____ ic” and depend on the second element
 - HCl is named hydrochloric acid
 - HF is named hydrofluoric acid
 - H₂S is named hydrosulfuric acid
- Ternary compounds omit the “hydro” prefix and are named by the central atom
 - H₂SO₄ is named sulfuric acid
 - PO₄ is named phosphoric acid
 - HClO₃ is named chloric acid

There are additional rules for naming acids with different numbers of oxygen atoms. Some theories even label substances as acids that don't have hydrogen and don't have to be dissolved in water, but these are not the most common or recognized naming schemes. The IUPAC details these additional naming schemes. The most traditional theory of acids and bases first proposed by Svante August Arrhenius, a Swedish chemist who won the Nobel Prize in 1903, is based on hydrogen ions in water solutions.

Chemistry: Formulae and Naming Compounds

What about compounds that are not ionic?

Non-metals will often bond to other non-metals in a way where the electrons are shared and separate ions are not formed. These compounds are called molecules and also use a prefix naming system to identify the ratio of atoms which may exist in a variety of proportions. For example,

- CO is called carbon monoxide
- CO₂ is called carbon dioxide
- SO₃ is called sulfur trioxide

Prefixes for naming molecules (covalently bonded):

Mono 1

Di (2)

Tri (3)

Tetra (4)

Penta (5)

Hexa (6)

Hepta (7)

Octa (8)

Nona (9)

Deca (10)

Chemistry: Formulae and Naming Compounds

A final note

Remember, the reason that elements bond with other elements is to form a more stable state and there is a wide variety of possibilities with the 118 elements on the table. Using the most common oxidation numbers based on electron configuration patterns makes the table a useful predictive tool.

5. Reactions and Stoichiometry

Chemistry: Reactions and Stoichiometry

Lesson Objective

We are now going to review the four different kinds of reactions and how to balance a chemical equation. At the conclusion of this lesson, you should be able to identify and describe any reaction and effectively balance both sides of a chemical reaction.

Previously we covered...

We have reviewed the chemical naming rules and how to name any chemical, compound, or material based on a few important nomenclature protocols. This is a basic skill that will serve us well in the next lessons.

Chemistry: Reactions and Stoichiometry

Reactions

With our knowledge of atomic structure and, since elements are known to bond in regular, predictable patterns in whole number ratios, there are a number of quantitative relationships that can be determined using information from the periodic table.

A conveniently measured amount of any element that equals the mass in grams of that element is called a **mole**. One mole of hydrogen weighs 2 grams. One mole of chlorine weighs 70 grams. Just like a dozen equals twelve, a mole equals Avogadro's number of atoms or 6.02×10^{23} . 6.02×10^{23} molecules of hydrogen would weigh 2 grams. An equal number of chlorine molecules would weigh 70 grams. Chlorine is much heavier than hydrogen because it has more protons and neutrons. A similar analogy is that a dozen bowling balls would weigh more than a dozen golf balls. A mole is simply a very large number of atoms. You need a very large number of atoms to be able to measure something you can see, like a teaspoon of salt. The **coefficient** is given to determine the number of moles in the balanced equation. Using these mole ratios, you can substitute the grams for atomic mass units and calculate relative masses for reactants and products.

Here are some simple examples of the gram atomic weight for one mole of different common compounds.

Carbon dioxide: CO₂

One mole (C) 12 grams + One mole (O₂) 32 grams = 44 grams

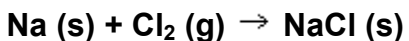
Water: H₂O

One-half mole (O₂) 16 grams + One mole (H₂) 2 grams = 18 grams

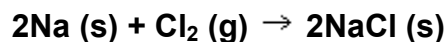
Chemistry: Reactions and Stoichiometry

Balanced equations and chemical reactions

There are four basic types of chemical reactions. The first is the simplest and is known as synthesis, or a composition reaction. This type of reaction combines two or more substances to form at least one new compound. One example has already been given which is when sodium metal, a solid, combines with chlorine gas to form sodium chloride. The reaction can be symbolized in the following way:

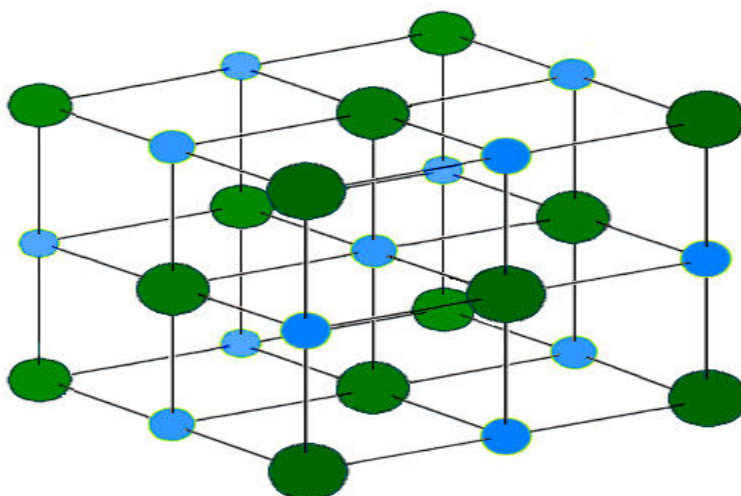


The reactants are on the left hand side of the arrow and the product(s) is (are) on the right. It can be read to mean that the reactants, sodium and chlorine, will react to form a single product, sodium chloride. In the chemical equation above, the (s) stands for solid, and the (g) stands for gas which indicates which state of matter the substance is in. Sometimes the arrow is read as “yields”. As you look at this equation, the natural question to ask is why are there three atoms on one side of the equation and only two atoms on the other? What happened to the extra chlorine atom? Good question. This equation is not a balanced equation, and matter doesn't just disappear and appear. A more accurate way to correctly represent this reaction is as follows:



This can be understood by saying that two sodium atoms combine with one diatomic chlorine molecule to form two ionic units of sodium chloride.

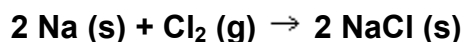
Another aspect of chemical reactions is the physical properties of compounds, or how atoms and molecules fit together. If we look at the crystal structure of NaCl, we notice that it is a closely packed cube.



The sodium chloride crystal structure has each atom with six of its nearest neighbors in an octahedral geometric pattern. Na ions are in light blue and Cl ions are darker green for contrast.

All reactions are simply rearrangements of matter in more stable ways. New matter is never created, and no matter is ever destroyed. This is known as the **law of conservation of matter**; matter can neither be created nor destroyed, but matter simply changes form.

sodium + chlorine → sodium chloride



2 moles + 1 mole = 2 moles

$$2(23 \text{ amu}) + 2(35 \text{ amu}) = 2(58 \text{ amu})$$

$$46 \text{ amu} + 70 \text{ amu} = 116 \text{ amu}$$

$$116 \text{ amu} = 116 \text{ amu}$$

Using the atomic weights from the periodic table, you can see that two sodium atoms weigh 46 atomic mass units. One chlorine molecule weighs 70 atomic mass units. Two units of a sodium chloride crystal weigh 116 atomic mass units. The total mass of the reactants must equal the total mass of the product.

Chemistry: Reactions and Stoichiometry

A second type of chemical reaction is known as a decomposition reaction. This is where a compound is broken down into two or more simpler parts. One example is the electrolysis of water. Water can be broken down into its constituent elements, hydrogen and oxygen with the addition of electricity. The equation looks like this:

water → hydrogen + oxygen



2 moles → 2 moles + 1 mole

$$2(18 \text{ grams}) = 2(2 \text{ grams}) + 32 \text{ grams}$$

$$36 \text{ grams} = 4 \text{ grams} + 32 \text{ grams}$$

Based on these quantitative relationships you can predict that 36 grams of water will yield 4 grams of hydrogen gas and 32 grams of oxygen gas. The lowercase (l) stands for liquid, which is what the state of water is in the reaction.

Question: If carbon has a molecular weight of 12g and oxygen has a molecular weight of 16g, what does a mole of carbon dioxide weigh?

- A 28g
- B 40g
- C 44g
- D 58g

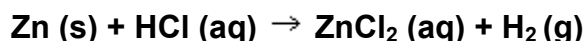
✓Answer

The correct answer is C, 44g. Since one mole carbon combines with two moles of oxygen to form two moles of carbon dioxide, the weight of a mole of this gas would be $12 + 16 + 16 = 44\text{g}$.

Chemistry: Reactions and Stoichiometry

A third type of reaction is called a **single replacement reaction**. This is where a more active element will replace a less active element in a compound. One example is when the metal zinc is dropped into a solution of hydrogen chloride to generate hydrogen gas. The equation would look like this:

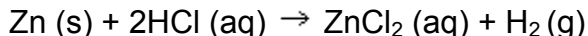
zinc + hydrogen chloride $\rightarrow$ zinc chloride + hydrogen



The (aq) stands for aqueous, which means that the substance is dissolved in a water solution. Can you determine what coefficients are missing to make the equation a balanced one?

If you thought a 2 needed to be in front of the reactant HCl, you would be right. How many moles of zinc would be needed to react with 2 moles of hydrogen chloride to form 1 mole of aqueous zinc chloride?

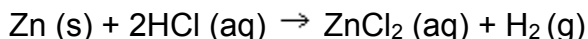
You are correct if you thought the answer was one. One mole of zinc will react with 2 moles of aqueous hydrogen chloride to form one mole of zinc chloride and one mole of hydrogen gas.



Question: If you started this reaction with 65 grams of zinc, how many grams of hydrogen would you expect to make?

✓Answer

If your answer was 2 grams, you are correct!



1 moles + 2 moles $\rightarrow$ 1 moles + 1 mole

$$1(65 \text{ grams}) + 2(36.5 \text{ grams}) = 1(136 \text{ grams}) + 1(2 \text{ grams})$$

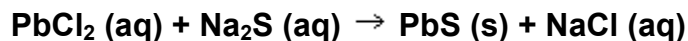
$$138 \text{ grams} = 138 \text{ grams}$$

Chemistry: Reactions and Stoichiometry

A fourth type of reaction is known as a **double replacement reaction**. These often occur when two soluble reactants are dissolved in water and one of the products is not soluble. These insoluble products drop out of solution as a precipitant and can make the solution appear cloudy. One example is when lead chloride and sodium sulfide are dissolved in water; a precipitant forms known as lead

sulfide. This substance is believed to be the “snow” that precipitates on the surface of Venus. The reaction can be written as follows:

Lead chloride + sodium sulfide $\rightarrow$ lead sulfide + sodium chloride



Question 1: Using the unbalanced equation above, determine what coefficients are missing to make the equation balanced.

- A 2 in front of the NaCl and 2 in front of the PbS
- B 2 in front of the PbS
- C 2 in front of the NaCl
- D The equation is already balanced.

 **Answer**

Question 2: How much will two moles of NaCl weigh in grams?

- A 94g
- B 116g
- C 124g
- D 136g

 **Answer**

To summarize the four basic types of reactions:

- $A + B \rightarrow AB$ composition
- $AB \rightarrow A + B$ decomposition
- $A + BC \rightarrow AC + B$ single replacement
- $AB + CD \rightarrow AD + CB$ double replacement

Chemistry: Reactions and Stoichiometry

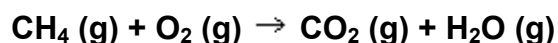
Oxidation reactions

Oxygen is a common component of the Earth's atmosphere and therefore is readily available to react with most elements and compounds on Earth. With its relatively small size and high electronegativity, oxygen participates in a large number of chemical reactions. One special type of reaction that is a combination of two basic types of reactions (composition and single replacement) is called an

oxidation reaction, first named because oxygen was the most common element to be observed in this type of reaction. Other electronegative elements are observed to react in the same manner.

Let's take a common example of an oxidation reaction with a molecule of methane, CH₄. Methane is also known as natural gas, or swamp gas. This gas is flammable because it reacts in the presence of a spark with oxygen and produces a flame. Natural gas stoves make use of this reaction for heating and cooking.

methane + oxygen → carbon dioxide + water



Question: Is this a balanced chemical equation? What coefficient(s) are needed to make this equation follow the law of conservation of mass?

🔍 **Answer**

Question: How many grams of carbon dioxide gas would be produced from reacting two moles of oxygen with methane gas?

🔍 **Answer**

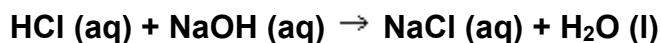
Oxidation reactions are the basis for respiration in all living things because most organic molecules can be oxidized to produce energy. Proteins, lipids, and carbohydrates can all be used as fuels similar to the methane in this example. Oxidation reactions are essential for life on Earth to exist.

Chemistry: Reactions and Stoichiometry

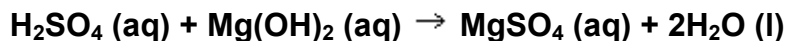
Neutralization reactions

One very common type of a double replacement reaction occurs when an acid and a base react to form a salt and water. Examples are given below:

hydrochloric acid + sodium hydroxide $\rightarrow$ sodium chloride + water

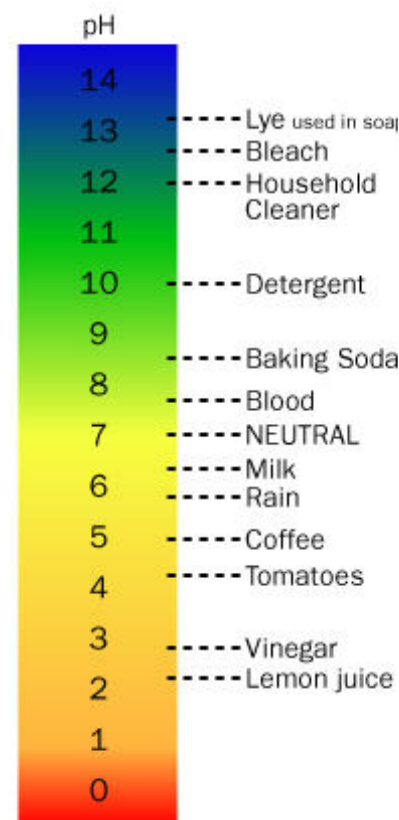


sulfuric acid + magnesium hydroxide $\rightarrow$ magnesium sulfate + water



An equally strong acid and base will produce a neutral solution of salt water. The acidity of solutions can be of varying strengths and can be measured by what is called the pH. A solution will be labeled an acid if the pH is less than 7, a base when the pH is greater than 7, and neutral when the pH equals 7.

The pH is defined as the negative log of the hydrogen ion ($[\text{H}^+]$) or hydronium ion ($[\text{H}_3\text{O}^+]$) concentration depending on what source you use. Remember that hydrogen ions are really just bare protons (positively charged nuclei) that are attracted to the lone pair of electrons in water molecules. The nature of this relationship determines the strength of the acid in water because some substances tend to give up more $[\text{H}^+]$ in water than others.



6. Physical Chemistry

Chemistry: Physical Chemistry

Lesson Objective

We are now going to review the important components at the juncture between physics and

Previously we covered...

We have now reviewed the four different kinds of reactions and how to balance a

chemistry on a macro scale. These include the concepts of motion, collisions, temperature, and pressure. At the end of this lesson, we will have a better understanding of how the physical properties of a system affect chemical properties and reactions.

chemical equation. We covered all the material we needed to know in order to identify and describe any reaction and effectively balance both sides of a chemical reaction.

Chemistry: Physical Chemistry

Random motion and collisions

All particles of matter are in constant random motion because of the energy present in the environment on Earth. We associate this energy with temperature, an average measure of the kinetic energy of particles. When the temperature increases, the average kinetic energy increases, and the amount of random motion also increases. This seems apparent when we observe steam billowing out of a boiling pot of water, or the movement of smoke directly over a fire. Similar to the way that energy is translated when one pool ball hits another pool ball; atomic sized particles also collide with each other and translate that motion between and among particles. When a particle hits the bottom of a thermometer, that movement is transferred to the atoms of mercury in the tube. More collisions mean that the mercury rises higher. The height of the mercury is a way for us to have a relative idea of how many particles are banging against the bulb of the thermometer.

Cold is not the opposite of heat; it is the absence of heat, or the reduction in the amount of random motion. Only at absolute zero (0 Kelvin, -273 ° Celsius, or -459.67° Fahrenheit) does motion theoretically come to a complete stop (Note: Kelvin is not measured in degrees). This is the temperature where there is zero kinetic energy. Since this is colder than any place found naturally on Earth, it is beyond the range of common experience and probably only exists theoretically or in the farthest reaches of the universe. We could never measure absolute zero simply because our presence (or instrumentation) would make the energy of the system greater than zero.

Particles in motion move from areas of higher concentration to areas of lower concentration. This is called diffusion and is part of the idea of entropy. This can be observed when a candle is lit and the aroma slowly moves across the room. Eventually, the concentration of all molecules will become equally distributed, and a sample of air in a closed space will be the same no matter which part of the space was sampled. The rate at which this occurs depends on the temperature of the space. At higher temperatures this equilibrium occurs more rapidly due to the increased speed of the molecules.

Chemistry: Physical Chemistry

Thermal energy and state of matter

The first law of thermodynamics states that the energy of the universe is constant. Energy is neither created nor lost but it can change form. Kinetic energy is the energy of motion that can be observed in physical states of matter. In solids, vibrational energy exists, but the particles are not free to completely move past each other, due to the potential energy stored in the bonds holding the atoms together. In liquids, the particles are free to flow past each other and are at a higher kinetic energetic

state than in solids. In a gas, the particles are moving so rapidly that the atoms are many thousands of times more distant from each other than in a liquid.

Chemistry: Physical Chemistry

Temperature and heat flow — latent heat

Temperature is a measure of the average speed of the particles measured in degrees. Heat is a measure of the transfer of energy required to increase the temperature of a given substance, and depends on the amount and characteristics of the substance in question. Heat is measured in units called calories. When a substance changes state, it will release or absorb energy, but will not change temperature. Although this seems a bit counterintuitive, it makes sense. Realize that it takes energy to change state (**e.g.**, from liquid to gas) and that while more heat may be applied, the energy is used to change state, not increase temperature. Boiling water at sea level is always going to be 100 ° C; never more, never less. The energy required to change states is called latent heat energy. This can be observed as an ice cube melts. The temperature of the ice cube will remain constant (near 0 ° Celsius) but the ice will turn to water because heat energy is giving the molecules energy to break free from the fixed position. Heat always flows from where it is to where it is not. This is the fundamental phenomenon that drives everything from volcanoes to hurricanes

Chemistry: Physical Chemistry

Particles bumping into each other

Any time a new substance is formed, when the kinetic energy of collisions activates the potential energy of the substance, bonds may be broken or formed. This formation of bonds occurs to form something more stable if energy is given up. Reactions that release energy are called exothermic. Examples of exothermic reactions include:

- The explosion of dynamite
- Burning of gasoline
- Oxidation of sugar in the mitochondria of cells (burning calories)

Endothermic reactions require energy to make bonds and usually result in a substance that is less stable. These are reactions that often feel cold when they happen because the products have more energy than the reactants, and need an input of energy, usually in the form of heat.

For example:

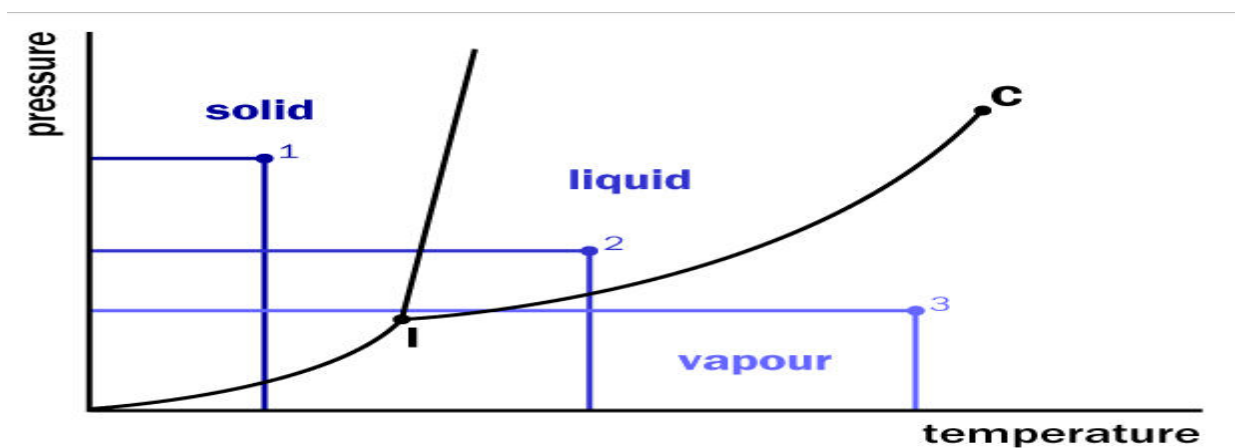
- Photosynthesis takes carbon dioxide and water to make sugar and oxygen (sugar has 4 calories per gram)
- Water can be separated into hydrogen gas and oxygen gas, but it requires a large amount of energy (endothermic) to do this.

Chemistry: Physical Chemistry

Temperature and pressure both affect the states of matter

When the pressure increases, it pushes the particles closer together. When the temperature increases, energy increases, making more random motion available to move particles farther apart.

Temperature and pressure can be varied to change many pure forms of matter into different states. Below is a graph that represents all three forms of matter at different temperatures and pressures.



- At higher pressures and low temperatures, substances tend to be solids.
- At medium temperatures and pressure the same substance may exist as a liquid.
- Higher temperatures and low pressures produce a gas.

The triple point (labeled I) is the point where a substance can exist in all three states and is a unique thermodynamic equilibrium to each substance. For example, ice can evaporate (to become a gas) in your freezer without ever being a liquid. Leave an ice cube out to observe for a week in the freezer and you will see. Dry ice, (solid carbon dioxide) also evaporates to become a gas at room temperature. Skipping the liquid state is often called sublimation. The nature of the substance determines the temperature and pressure required for phase changes. The Critical point, (labeled C), denotes the temperature at which pressure cannot overcome the energy available to the particles and the substance cannot be compressed into a liquid at that temperature. The normal melting point is the temperature under normal conditions (one atmosphere of pressure) when a substance changes from a solid to a liquid. The normal boiling point is the temperature under normal conditions (one atmosphere of pressure) when a substance changes from a liquid to a gas.

7. Gas Laws, Ideal Gas, and Kinetic Molecular Theory

Chemistry: Gas Laws, Ideal Gas, and Kinetic Molecular Theory

Lesson Objective

We will continue to discuss the important components that link physics and chemistry by looking at gas laws and the characteristics of gases.

Previously we covered...

We have begun to review the juncture between physics and chemistry on a macro scale, including the motion, collisions, temperature, and pressure.

Chemistry: Gas Laws, Ideal Gas, and Kinetic Molecular Theory

Why gas laws, but not solid or liquid laws?

Because gas particles have a relatively large distance between them, the volume can vary depending on temperature and pressure. Solids and liquids don't have enough distance between the particles to

change volume appreciably. Gas laws provide a means to predict pressure, volume, or temperature given the other two variables. Firefighters use this principle when entering a burning room to quickly extinguish the flames and check for victims. In a hot, closed room, a small amount of water will quickly expand as it turns to steam, to squeeze out the available oxygen which knocks down the flames. Water can expand over a thousand times in volume. Popcorn pops because the tiny bit of water in the kernel expands with such force that the kernel pops. Pressure, temperature, and volume are important variables to understand when working with gases

Chemistry: Gas Laws, Ideal Gas, and Kinetic Molecular Theory

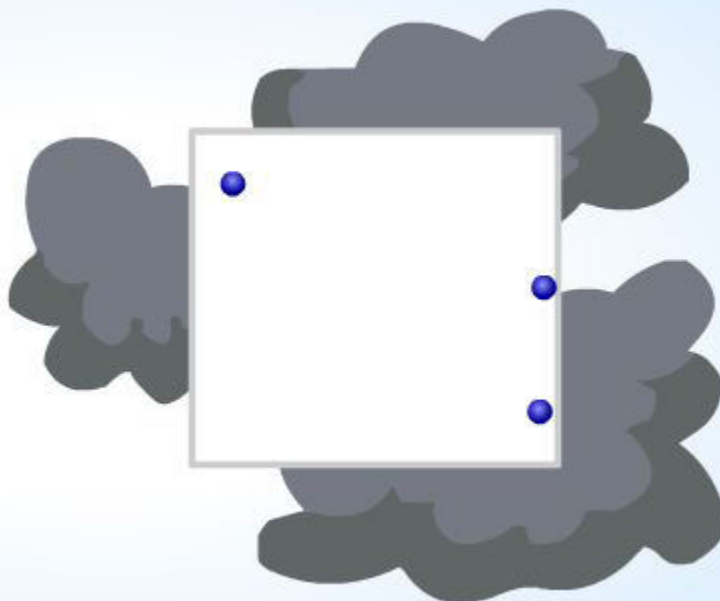
Variable relationships

With a gas, an increase in pressure will result in a decrease in volume. Take a balloon to the bottom of the pool and watch what happens. A decrease in pressure will result in an increase in volume. That's why, when a balloon rises, it eventually will burst because the pressure decreases as it climbs higher in the atmosphere and the volume expands. This type of relationship is called an inverse one because as one variable increases the other variable decreases. Robert Boyle, a British chemist, first described this relationship. Please explore these ideas further in the interactive module on Gas Laws.

Ideal Gases

A gas is a phase of matter, like liquid and solid. A gas does not occupy a set amount of space.

An Ideal Gas is a theoretical gas that has particles that have little to no mass. The collisions between the particles in an ideal gas are elastic, which means there is no loss of energy when particles collide with each other or with the walls of the container that the gas is in.



Boyle's Law

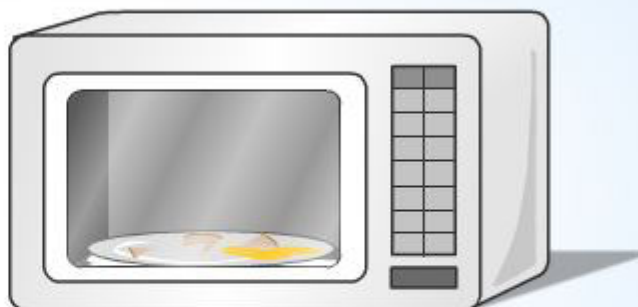
In the mid 1600's Robert Boyle studied the properties of a gas when the Temperature is held constant. He observed that the product of the pressure and the volume for an ideal gas is observed to be nearly constant. This became known as Boyle's Law. In other words, when you increase the pressure, the volume decreases.



$$P_1 \cdot V_1 = P_2 \cdot V_2$$
$$P \cdot V = \text{constant}$$

Gay-Lussac's Law

In the late 1800's Joseph Louis Gay-Lussac studied the relationship between the pressure and temperature in gases, keeping other properties constant. He discovered that the pressure of a gas is directly proportional to its temperature. In other words, Gay-Lussac's Law states that when the temperature of a gas is increased, keeping all other properties constant, the pressure increases.



$$P_1/T_1 = P_2/T_2$$
$$P/T = \text{constant}$$

Charles's Law

Jacques Charles, a French scientist in the early 1800's performed experiments to improve the performance of hot air balloons. In his experiments he kept the properties of the gas constant, except for the temperature and volume. Charles's Law states that the volume of a gas is proportional to the temperature, when the pressure and the amount is kept constant. In other words, when you increase the temperature, the volume increases.



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

Combined Gas Law

The Combined Gas Law combines Boyle's Law, Charles's Law and Gay-Lussac's Law. This law states that the product of the pressure and the volume of a gas, divided by the temperature is constant.

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

Avogadro's Law

In the early 1800's, the Italian scientists Amedeo Avogadro discovered that gases of the same volume at the same temperature and pressure, contain the same number of molecules. This number later became known as avogadro's number: 6×10^{23} . In other words, Avogadro's law states that there is a direct relationship between the amount of a gas, in number of moles and the volume, keeping pressure and temperature constant.



$$\frac{V_1}{n_1} = \frac{V_2}{n_2}$$
$$\frac{V}{n} = \text{constant}$$

Ideal Gas Law

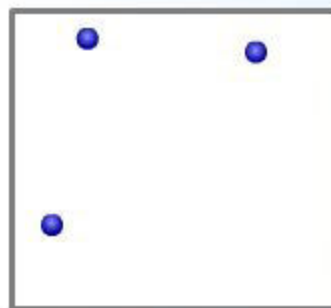
The equation $pV = nRT$, also called the Universal Gas Equation or the Ideal Gas Law, can be derived from the combined gas law and Avogadro's Law. P is the variable for the pressure measured in atmospheres, V is for volume measured in liters, n is the variable for the number of molecules also measured in moles. R is the gas constant, also sometimes referred to as the Universal Gas Constant, relating the pressure and volume of a quantity of gas to the absolute temperature, equal to 8.314 joules per Kelvin or 1.985 calories per degree Celsius.

$$PV = nRT$$

Kinetic Molecular Theory

The basic Kinetic Molecular Theory is a theoretical molecular model, that explains the behavior of gases. It is based on several assumptions:

1. Gases contain molecules that are in constant, random motion. These molecules collide with each other and the walls of the container that the gas is in.
2. These collisions are elastic, which means that when the molecules collide with each other or the walls of the container there is no loss of energy.
3. The gas molecules occupy no space.
4. The forces between the molecules are negligible.



Chemistry: Gas Laws, Ideal Gas, and Kinetic Molecular Theory

With a gas, an increase in temperature will result in an increase in volume. Take a balloon outside in the sunshine. Watch what happens to the size of the balloon. Now take it and put it in the refrigerator. What happens? This relationship is called a direct relationship because both variables do the same thing. As one variable increases the other increases and vice versa. A French chemist named Jacques Charles who loved to fly hot air balloons first described this relationship. This graph always produces a straight line characteristic of any direct proportion.

In addition to these variables, it was determined by the Italian, Amedeo Avogadro, that under similar conditions, equal volumes of gases contain the same number of molecules. This principle led to the measurement discussed previously, the mole. One mole of any gas at standard temperature (273 K) and standard pressure (1 atmosphere) will occupy 22.4 liters of volume and contain $6.02 \cdot 10^{23}$ molecules. This very large number, $6.02 \cdot 10^{23}$, is also called Avogadro's number.

Chemistry: Gas Laws, Ideal Gas, and Kinetic Molecular Theory

The physical characteristics of all gases

The particles of a gas move rapidly and are far apart, relatively speaking. Because of these two facts the interaction of the particles with each other is minimal compared to liquids and solids and therefore acts similarly to each other no matter what gas we are observing. Chemists use what is called an ideal gas equation that is a useful predictor. It was determined that the ratio of the pressure and volume to the number of moles and temperature always resulted in the same ratio. This ratio is called the ideal gas law constant, or R. The relationship is written:

$$pV = nRT$$

Where p = pressure, V = volume, n = number of moles, and T = temperature. The ideal gas law constant, R , is 0.08206 L-atm/mol-K. Using this constant proportion, the properties of most gases can be calculated given three of the four variables. This estimation is not as accurate at lower temperatures or higher pressures because of the interaction between the particles at closer distances and lower energies. Nonetheless, it is an extremely useful equation that holds for most everyday gas interactions

8. Reaction Rates

Chemistry: Reaction Rates

Lesson Objective

Now we will cover the rates of reactions and what affects them, namely, temperature, pressure, surface area, catalysts, and various characteristics of the reactants in the system.

Previously we covered...

In the previous lesson, we reviewed the concepts of the ideal gas, the gas law, and molecular kinetics.

Chemistry: Gas Laws, Ideal Gas, and Kinetic Molecular Theory

Rates of change

The very nature of chemistry is concerned with how substances change over time. This change over time is an aspect of kinetics called reaction rate. As the masses of reactants in a given reaction decrease, the masses of products increase. For a reaction like dynamite exploding, this may seem like a trivial exercise in quantifying a process, but most reactions are not as dramatic or complete as dynamite exploding. Many reactions in the human body are maintained in a steady state within an equilibrium by virtue of these factors. Blood sugar metabolism, controlled by insulin, is one such example.

Reaction rates depend on many factors:

- Concentration
- Temperature
- Particle size or surface area
- Reaction mechanism
- Catalysis
- Nature of the reactants

Reaction rates decrease as the concentration of the reactants decreases. If there are fewer particles to interact, the chance that those particles may come in contact diminishes. As the product particles accumulate, they also get in between potential reacting particles and this also decreases the rate of the reaction.

Generally, as the temperature increases, the increase in resulting particle motion increases the chances for particles to collide and interact. An increase in temperature usually increases reaction rates. An exception to this is with gases. Sometimes the increase in temperature will create greater

distances between particles, unless there is a constant or increasing pressure to keep the distances between particles constant.

The greater the surface area of a reactant, the more easily it will have access to the other reactant. For example, powdered solids react more readily than large chunks of a solid. Many reactions proceed more quickly in water because the ions are separated and available for interaction, whereas in the solid dry form, they are ionically bonded together. In general, the smaller the particle size and more access it has to the other reactant the greater the potential for interaction.

Some reactions have mechanisms that require more than one reactant to be present for successive steps to take place. Or multiple successive steps may be required to completely change one reactant into one product. The rates of these reactions depend on the rate-limiting mechanism that is specific to the individual reaction. These cannot be predicted easily and require actual experimentation to reveal the individual mechanisms. These types of reactions are often encountered with molecular or organic compounds.

Many of these complex reactions can be speeded up tremendously using catalysts. Most biochemical reactions that occur in living systems have a number of catalysts that tightly regulate the speed of reactions with feedback systems. These include cascades of reactions that are signaled at the surface of a cell and ultimately regulate gene expression, to allow the cell to adapt to changing conditions. One example is the reaction that occurs when you have fever that results in the production of many millions of rapidly dividing white blood cells that protect the body against infection.

Chemistry: Gas Laws, Ideal Gas, and Kinetic Molecular Theory

Determining the rate of reaction

The average rate of reaction for a given period can be determined from the slope of the line on a graph in which concentration is plotted against time. The equation can be stated as:

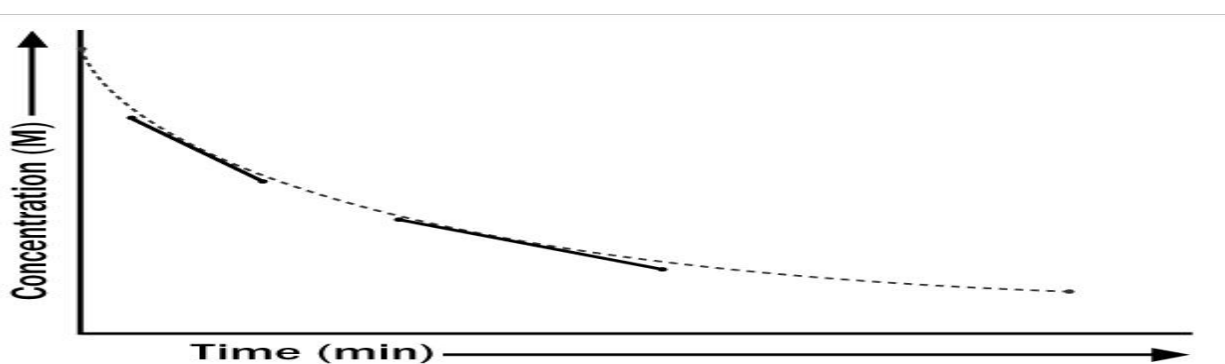
$$\text{Reaction Rate} = K [A]^n [B]^m$$

K = Reaction Constant

A = Reactant & B = Reactant

n & m = Order Number (Superscript number)

You can see from this graph that the slope of the line changes as the availability of the reactants changes. The first solid line indicates a more rapid reaction than the second solid line in the graph.



Chemistry: Gas Laws, Ideal Gas, and Kinetic Molecular Theory

A catalyst can be thought of as a tunnel through a mountain of activation energy. Because of the specific structures in the catalyst, reaction mechanisms can proceed with less energy. This can greatly influence the reaction rate. One example that is used industrially (and borrowed from bacteria) is protease. This enzyme breaks down protein and is added to many laundry detergents to facilitate the removal of stains in clothing. Bacteria use proteases as a weapon in their arsenal to defeat other bacteria, destroy structural proteins in hosts, or regulate reaction rates at the site of infection.

9. Oxidation and Reduction

Chemistry: Oxidation and Reduction

Lesson Objective

In this lesson we will look at oxidation and reduction reactions.

Previously we covered...

We have reviewed the basics of reaction rates and what determines how they change across different conditions of a system.

Chemistry: Oxidation and Reduction

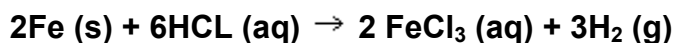
Electrons will travel

Oxidation and reduction reactions are among the most common and important of all chemical processes. Photosynthesis and respiration, combustion of fuels in automobile engines, and the reactions of metal bridges to acid rain are all the result of the movement of electrons from a source to a destination. Anytime you can move particles from one place to another, there is the potential for useful work as a result. These reactions are the basis for how batteries function and the resulting production of a direct current.

Chemistry: Oxidation and Reduction

Acids and metals

If you examine a box of cereal, you will observe that it includes a reasonable serving of the recommended daily amount (RDA) of iron. Believe it or not, this iron is almost always in the form of powdered iron filings. A simple experiment is to take a bowl of cereal, pour milk over it (or water), and simply stir it with a white clean, plastic-covered magnet. In about 10 minutes, you will collect a noticeable amount of what looks like cast-iron-skillet filings. Iron is magnetic, so as the cereal softens in the solution, the iron is freed from the cereal matrix and is attracted to the magnet. What happens to that iron when it is dumped into the solution of acid in your stomach?



Two iron atoms give 3 electrons each to 6 hydrogen atoms, which then share a pair of electrons between them to have a stable configuration similar to helium. A total of 6 electrons were exchanged. The iron atoms that have a +3 charge (because they now have 3 more protons than electrons) are

attracted to the three chloride ions that have a -1 charge. The iron is said to be oxidized because it has lost electrons. The chlorine has been reduced because it has gained electrons. All the electrons lost are gained by another substance and the iron in the oxidized form can be picked up by hemoglobin to carry oxygen in the blood. Without this transformation, iron cannot perform that duty.

10. Solutions

Chemistry: Solutions

Lesson Objective

Now we are going to cover the chemistry of solutions, including some electrochemical concepts.

Previously we covered...

In the last lesson we took a quick look at oxidation and reduction reactions.

Chemistry: Solutions

What is a solution?

A solution is a combination of two or more pure substances equally dispersed throughout the solution. Using the common example of salt water, the solvent is the water, the solute is the salt and the saltwater combination is the solution. If the solution has dissolved all the salt it can dissolve, it is called a saturated solution. If more salt can be dissolved, it is called an unsaturated solution. Sometimes, a solution can hold more than a saturated solution but a change in temperature or a seed crystal can precipitate the solution. These unstable solutions are called supersaturated. Only under certain changes such as a gradual cooling with no vibrations can a supersaturated solution be achieved.

Sometimes solution processes can be endothermic or exothermic. If the attraction of the solute for the solvent releases energy, it can become highly exothermic. An example of this would be dissolving an acid in water. These solutions get very hot. If the attraction of a solute for a solvent requires energy, such as ammonium nitrate in water, the temperature of the solution decreases and is endothermic. Instant heat packs and cooling packs use this principle to achieve the desired temperature simply by mixing an aqueous salt in water

Chemistry: Solutions

Not all solvents dissolve all substances

Water is considered to be the universal solvent, but it is chemically a polar solvent. This means that the molecules have the electrons shifted slightly to one side in the bond between the hydrogen and oxygen. Because this shifts the electron density to one side, a polar molecule is more positive on one side and less positive or more negative on the other side. Its' polarity allows water to dissolve ionic substances that have positive and negative ions, such as sodium chloride. The positive part of the water molecule is attracted to the chloride ions and the negative part of the water molecule is attracted to the sodium ions. In terms of solutions, the phrase "like dissolves like" holds true. Water can also dissolve other polar substances, such as ethanol, C_2H_5OH .

Examples of nonpolar solvents are gasoline, kerosene, oils, and waxes. These substances don't dissolve in water. However, they dissolve in each other. Crude oil is really just a naturally found, complex mixture of hydrocarbons from which methane, propane, butane, and octane are simply dissolved components.

Chemistry: Solutions

How do you know how much solute is dissolved in a solution? One crude way is to examine the density. As more particles dissolve in a solution, the solution becomes denser. That is why ships sail higher on salt water than fresh water (and it is easier to float in the ocean than in the swimming pool). More precise ways to measure the concentration are as follows:

- Molarity: the number of moles of solute per liter of solution
- Molality: the number of moles of solute per kilogram of solution
- Percent composition: the number of grams of solute per 100 grams of solution
- Parts per million: A unit of concentration often used when measuring very dilute levels of pollutants in air, water, body fluids, etc. One ppm is 1 part in 1,000,000. The common unit **mg/liter** is equal to ppm.

Chemistry: Solutions

Why do they put salt on the roads in the wintertime?

Some properties of solutions don't depend on the substances dissolved but are simply a result of the number of separate particles in the solution. These are called colligative properties.

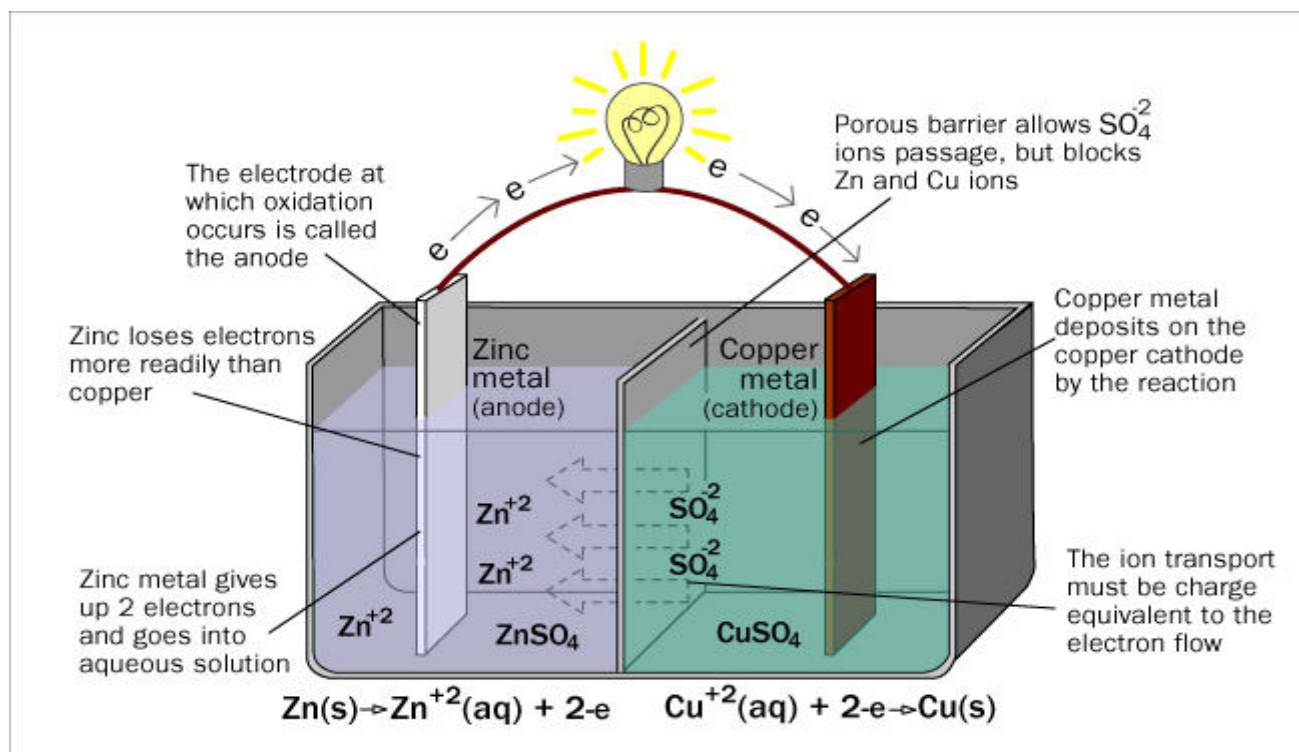
One of these properties is freezing point depression. If one dissolves a number of particles in a solution, this interferes with the ability of the water molecules to line up properly as the temperature drops and particle motion slows down. Because the particles are in between the water molecules the temperature must be much lower to turn the liquid into a solid. This is the principle behind the salt placed on icy roads.

Another property is boiling point elevation. A saltwater solution boils at a higher temperature than a pure water solution. This is because the salt particles interfere with the water molecules

Chemistry: Solutions

Electrochemical cell

As described earlier, electrochemical cells (batteries) are applications of oxidation and reduction, or redox reactions. As electrons flow from less electronegative elements to more electronegative elements, via ionic solutions, a current can be achieved. Look at the diagram below. Electrons travel from the zinc to the copper plate. These extra electrons supply the copper sulfate ions of copper with the electrons to become elemental copper and plate, onto the copper cathode. The sulfate ions travel to the anode to pick up the zinc atoms that have lost two electrons to become zinc ions. This supports the electron flow through the cell. This flow has the ability to do work such as light up a light bulb or produce heat.



11. Nuclear Fission & Fusion

Chemistry: Nuclear Fission and Fusion

Lesson Objective

In this lesson, we are going to cover the main aspects of nuclear fission and fusion, including isotopic and radioactive concepts.

Previously we covered...

We reviewed the chemical properties of solutions in the last lesson, including the chemistry of electrochemical cells (aka batteries).

Chemistry: Nuclear Fission and Fusion

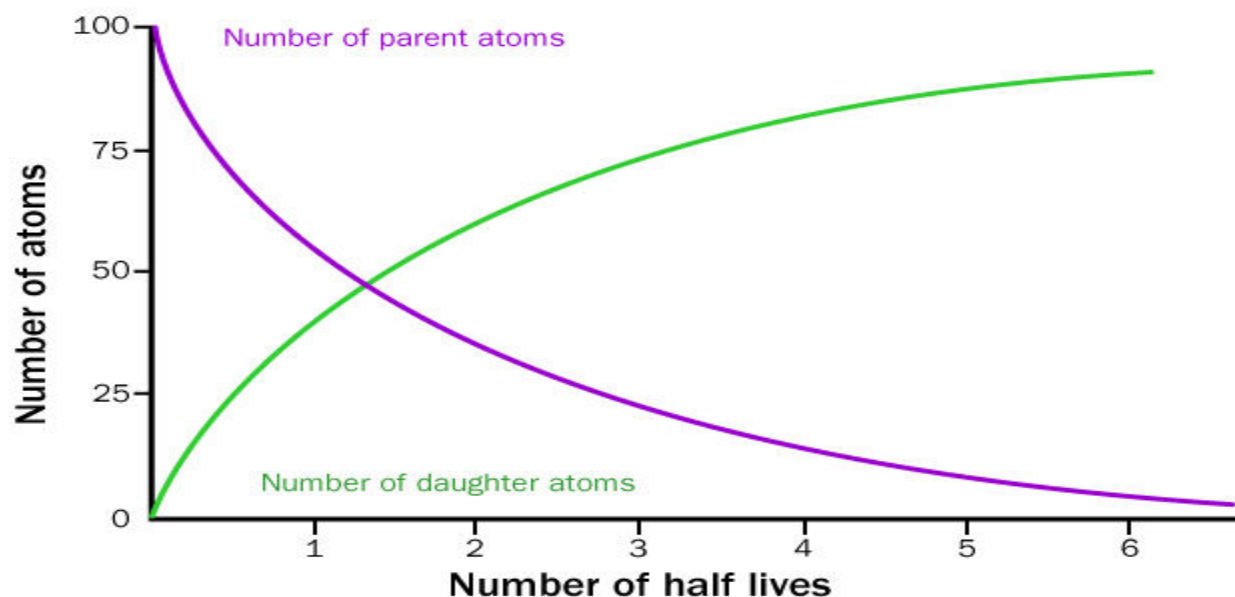
What is an isotope?

All of the chemical reactions that we have discussed have involved only the exchange of electrons on the outside of the nucleus. Elements with the same number of protons but different number of neutrons (such as tritium, deuterium, and protium — are all forms of hydrogen having one proton and three, two, and one neutron respectively) are called isotopes. Sometimes elements with unstable nuclei (due to larger numbers of protons and neutrons) can lose nuclear particles that change the number of either protons or neutrons in the nucleus. These are called radioactive elements because a large amount of energy is usually released as the nucleus loses mass. As the nucleus decays, the atoms of one element are transformed into the atoms of another element. This is called natural transmutation. For elements greater than number 83, this produces isotopes that are radioactive, also known as radioisotopes.

Chemistry: Nuclear Fission and Fusion

Radioactive decay

Radioactive elements follow a predictable rate of decay based on their known half-life. These reactions are similar mathematically to the rate of reaction discussed earlier. As the parent atoms decrease, the daughter atoms increase proportionally.



There are two types of nuclear reactions:

- Fission: the energy contained in the heavy nucleus of the atom overcomes the forces that bind the nucleus together. Uranium and Plutonium are common elements used in nuclear reactors that make use of this process.
- Fusion: the energy released when two light nuclei fuse to form a heavier nucleus. The sun's energy is a result of these type reactions where hydrogen atoms combine to form helium.

Further Reading in Chemistry

Chemistry: Further Reading

Periodic Table and Trends

Mendeleev and The Periodic Table (Primary Sources of Revolutionary Scientific Discoveries and Theories Series) (Katherine White): 2004

A Well-Ordered Thing: Dmitrii Mendeleev and the Shadow of the Periodic Table (Michael D. Gordin): 2004

The Complete Idiot's Guide to Chemistry (Ian Guch): 2003

Quantum Mechanics

Schaum's Outline of Quantum Mechanics (Eliahu Zaarur, Phinik Reuven): 1998

Introduction to Quantum Mechanics (2nd Edition) (David J. Griffiths): 2004

What Is Quantum Mechanics?: A Physics Adventure (Transnational College of LEX Staff-Editor): 1995

Primer of Quantum Mechanics (Physics) (Marvin Chester): 2003

Molecular Bonding and Structure

Chemical Bonding Models, Volume 1, Molecular Structure and Energetics (J. F. Liebman-Editor, et. al.): 1986

Structure and Bonding (Basic Concepts In Chemistry) (Jack Barrett): 2002

Bonding and Structure of Molecules and Solids (D. G. Pettifor): 1995

Chemical Reactions and Stoichiometry

Chemistry for Dummies (John T. Moore): 2002

Chemical Kinetics: The Study of Reaction Rates in Solution (Kenneth A. Connors): 1990

Chemical Kinetics and Reaction Dynamics (Paul L. Houston): 2001

Fundamentals of Chemical Reaction Engineering (Mark E. E. Davis, Robert J. J. Davis): 2002

Electrochemistry

Analytical Electrochemistry (Joseph Wang): 2000

Modern Electrochemistry 2A: Fundamentals of Electrodics (John O'M. Bockris, et. al.): 2001

Modern Electrochemistry 1: Ionics (John O. Bockris, et. al.): 1998

Solution Chemistry

Basic Gas Chromatography (Harold M. McNair, James M. Miller): 1998

Gas Laws

Molecular Collision Theory (M. S. Child): 1996

Nuclear Chemistry

Shaum's Outline Of General, Organic and Biological Chemistry (George Odian, Ira Blei): 1994

Chapter: Earth Science

1. The History of the Earth

Earth Science: The History of the Earth

Lesson Objective

In this lesson, we are going to explore geologic time and a technique used to measure the age of the Earth.

Previously we covered...

The Earth is one of nine planets in our solar system.

The Earth's crust is broken into plates that float on a molten layer called the mantle in a process called plate tectonics.

Plate tectonics are responsible for volcanism, earthquakes, and mountain building at plate boundaries.

The number of protons contained in the nucleus differentiates chemical elements.

Earth Science: The History of the Earth

The Data are in the Strata

Go outside and pick up a rock. Take a close look at it. You can determine the rock's volume, mass, color, and texture easily. Using laboratory methods, you could even determine the rock's chemical composition. But how could you determine the age of the rock? Would this rock be as old as the Earth or would it be younger? Could this rock's age give you a clue to the history of our planet?

For a very long time, geologists examined rock and sediment layers on the sides of hills, in deep canyons, or on the sides of mountains all over the world. Upon inspection, it is easy to assign a relative order to the geologic events that laid down these layers. The sandstone on the bottom came first, then later the layer of limestone, and much later the clay layer, and so on. The basic concepts of a geologic time scale began late in the 17th century when scientists correctly deduced that each rock strata represented a different geologic time period.

Earth Science: The History of the Earth

During the 18th century, scientists realized that they could not read rock strata as simple layers because geological processes deep in the earth complicate the layer order. Strata once on the ocean floor millions of years ago could now be on the top of a mountain. It can be distorted, eroded, or tilted long after it was deposited. Rock strata deposited at the same time in different parts of the world can vary greatly in composition. Clearly, marking distant geologic times by types of rock strata in layers only gives part of the picture.

By the 19th century, geologists began to classify strata according to the types of fossils found within it. This made it possible to identify similar strata on different continents if they contained the same kinds of fossils. These observations lead to the development of the relative geologic time scale. However, the actual age of these rock strata and fossils they contained remained a topic for heated debate for many decades. It wasn't until after the discovery of radioactivity in the late 1890s, that a method would be developed to determine the absolute age of rocks, fossils, and other material found

in any rock strata. This tool would give geologist what was needed to date rock strata and to develop a chronology of the Earth's history

Earth Science: The History of the Earth

The Geologic Time Scale

Geologists have known for some time that the entire history of the Earth is preserved in the strata. There you can easily see the clues to the geological and biological processes of ancient times. The geologic time scale displayed below was developed over a long period of time and was most recently updated in 2004 by the International Commission on Stratigraphy.

Eon	Era	Period	Ended MYA*
Phanerozoic	Cenozoic	Neogene	Now
		Paleogene	23
	Mesozoic	Cretaceous	65
		Jurassic	140
		Triassic	205
	Paleozoic	Permian	245
		Pennsylvanian	290
		Mississippian	325
		Devonian	355
		Silurian	415
		Ordovician	440
		Cambrian	495
Proterozoic	Neoproterozoic	Ediacaran	542
		Cryogenian	630
		Tonian	850
	Mesoproterozoic	Stenian	1000
		Ectasian	1200
		Calymmian	1400
	Paleoproterozoic	Statherian	1600
		Orosirian	1800
		Rhyacian	2050
		Siderian	2300
Archean	Neoarchean		2500
	Mesoarchean		2800
	Paleoarchean		3200
	Eoarchean		3600
Hadean			3800

Earth Science: Absolute Dating of Earth Materials

The accepted age of the Earth (and the rest of our solar system) is about 4.6 billion years. This age is computed through a number of different methods. Unfortunately, the age of the Earth can not be determined from terrestrial rocks since they have not been able to withstand the effects of a volatile planet such as Earth.

The Earth is a vibrant and thriving planet whose surface is completely reworked through the process of plate tectonics every 500 million years or so. New rock structures are constantly being forged and brought to the surface through our planet's dynamic geological machine. This means that it would be almost impossible to find rocks on the Earth's surface that date back to 4.5 billion years. The processes of weathering and erosion compound this problem.

The most common method for determining the age of rocks is radioactive dating. Radioactive isotopes change into stable isotopes through the process of radioactive decay. This process changes the total number of protons in the nucleus and thus changes the isotope through time. This is commonly referred to as an object's isotopic signature. The time it takes for half of the radioactive materials in a sample to decay into another isotope is called the half-life. Carbon-14 is a well known isotope that has a half-life of 5730 years.

Earth Science: The History of the Earth

Carbon-14 dating is very useful for archeologists wanting to date an ancient artifact or to paleontologists wanting to determine the age of a fossil. Over time, carbon-14 decays into nitrogen-14. The amount of carbon-14 that is left in a sample is an indication of the age of the sample. Although carbon-14 can be used to determine the age of materials up to 40,000 years old, this is too short of a time span to be useful in determining the age of the Earth.

This table lists some of the many radioactive isotopes with half-lives longer than carbon-14.

Radioactive Isotope	Decay Product	Half-Life
Uranium-238	Lead-206	4.5 billion years
Uranium-235	Lead-207	704 million years
Thorium-232	Lead-208	14 billion years
Rubidium-87	Strontium-87	48.8 billion years
Potassium-40	Argon-40	1.25 billion years

Earth Science: The History of the Earth

Several radioactive dating methods based upon isotopes with long half-lives are used to determine the age of rocks. These methods reveal that the oldest rocks on Earth date from between 3.8 and 3.9 billion years. Most of the rocks dated were metamorphic. The radiological information stored in these rocks is reset or lost due to the heat and pressures of formation inside the Earth.

Some sedimentary rocks that have been dated included minerals in their structure as old as 4.1 - 4.2 billion years. To find older rocks, we must look towards extraterrestrial sources. The Earth formed at the same time and from the same materials as the rest of the solar system. If we can collect

extraterrestrial rocks and date them, we could find rocks older than the Earth that could give us a clue to Earth's age.

Every year the earth is bombarded by tons of meteorites. Meteorites come from comets and asteroids, which are made of the leftover material from which the planets formed. The surfaces of comets and asteroids are not subject to the same geological and erosion processes which affect rocks on the Earth's surface. This means that the rocks on comets and asteroids remain relatively unchanged from the time of the solar system's formation.

Earth Science: The History of the Earth

This table shows the age of several meteorites tested using radioactive dating methods.

Meteorite Sample	Radioactive Dating Method	Age of Meteorite (billion years)
Allende	Ar-Ar	4.53 +/- 0.03
Guarena	Ar-Ar, Rb-Sr	4.45 +/- 0.07
Olivenza	Ar-Ar, Rb-Sr	4.51 +/- 0.11
Saint Severin	Ar-Ar, Rb-Sr, Sm-Nd	4.46 +/- 0.12

These samples (as well as other meteorite samples) show that the average age of meteorites hover around 4.5 billion years. But what about rocks collected from another extraterrestrial site? From 1969 to 1972, the Apollo moon missions collected several hundred pounds of moon rocks. Many of these lunar rock samples (especially those collected during the Apollo 16 and Apollo 17 missions) also dated to around 4.5 billion years. Since we know that the Earth formed out of the same material and at about the same time as all of the other objects in the solar system, then the age of the Earth must be about 4.5 billion years.

2. The Atmosphere - An Ocean of Air

Earth Science: The Atmosphere - An Ocean of Air

Lesson Objective

In this lesson, we will explore the composition of our atmosphere. We will also take a look at the role water and heat energy play in climate and weather.

Previously we covered...

The **geologic time scale** developed as a relative scale based upon observations of rock strata.

The age of terrestrial rock strata has been determined by radioactive dating methods.

These methods use naturally radioactive isotopes with known half-lives to determine the age of rocks.

The age of the Earth is 4.5 billion years old based upon measuring the age of extraterrestrial sources such as meteorites and moon rocks that formed at the same time as the Earth.

Earth Science: The Atmosphere - An Ocean of Air

It's All About Gas

Our atmosphere is a delicate life-giving blanket of air. This air surrounds us all of the time. It goes from the ground at our feet to hundreds of miles over our heads. We are confined to our environment of air just like fish are confined to their environment of water. We can feel air as we move through it or as it moves around us so we know that it is a physical material. Air is a tasteless, odorless, and for the most part, invisible gas.

Earth Science: The Atmosphere - An Ocean of Air

What Gases Are Found in Air?

Air is a mixture of gases. The table below lists the major gaseous components of our atmosphere.

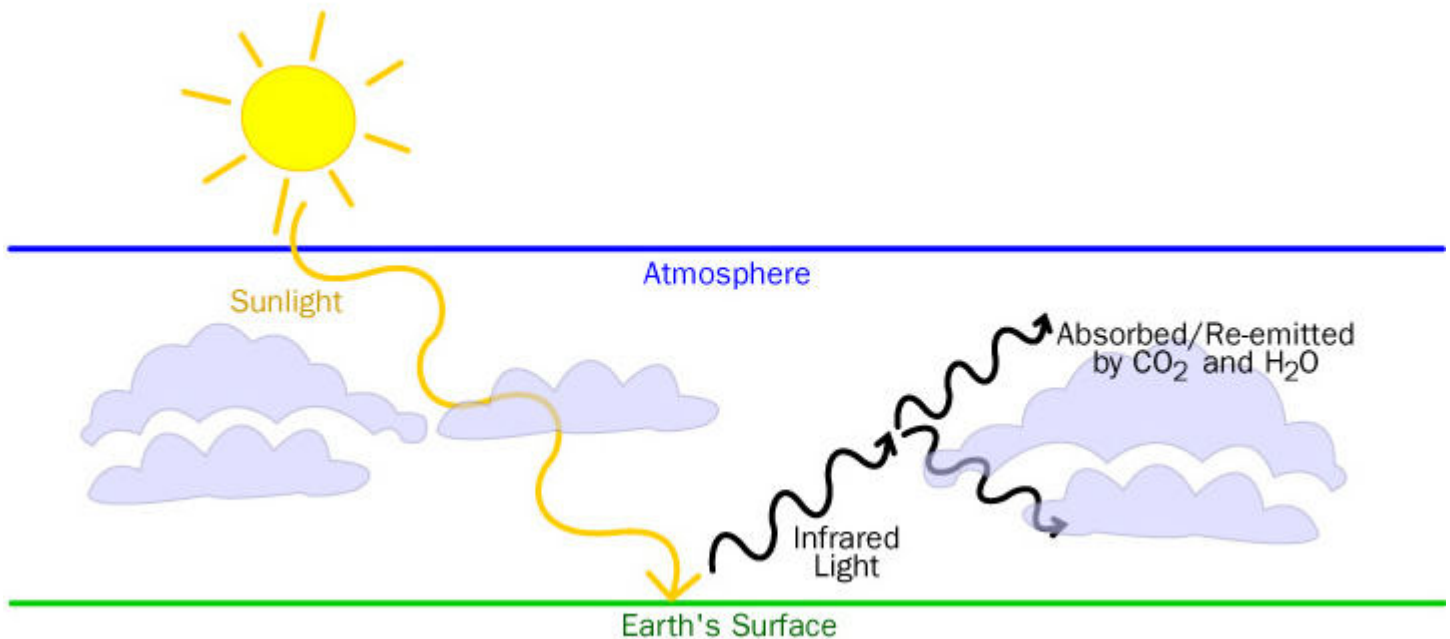
Gas	Symbol	Volume
Nitrogen	N ₂	78.084%
Oxygen	O ₂	20.947%
Argon	Ar	0.934%
Carbon Dioxide	CO ₂	0.033%
Neon	Ne	18.2 parts per million
Helium	He	5.2 parts per million
Krypton	Kr	1.1 parts per million
Sulfur dioxide	SO ₂	1.0 parts per million
Methane	CH ₄	2.0 parts per million
Hydrogen	H ₂	0.5 parts per million
Nitrous Oxide	N ₂ O	0.5 parts per million
Xenon	Xe	0.09 parts per million
Ozone	O ₃	0.07 parts per million
Nitrogen dioxide	NO ₂	0.02 parts per million
Iodine	I ₂	0.01 parts per million
Carbon monoxide	CO	trace
Ammonia	NH ₃	trace

You probably noticed that the majority of the gas in our atmosphere is nitrogen. In fact, the gases nitrogen, oxygen, argon, and carbon dioxide combine to make up 99.998% of the volume of the atmosphere.

Earth Science: The Atmosphere - An Ocean of Air

Carbon Dioxide and Water in the Atmosphere

Carbon dioxide and water are greenhouse gases. These gases get this classification because of their ability to trap heat in the atmosphere. Sunlight traveling through the atmosphere is absorbed by the Earth's surface. It is then re-emitted as infrared radiation into the lower atmosphere where it is absorbed by carbon dioxide and water vapor. This infrared radiation is re-emitted and absorbed many times over by carbon dioxide and water, which warms the lower atmosphere.



Earth Science: The Atmosphere - An Ocean of Air

Several atmospheric studies indicate that carbon dioxide concentrations are increasing in our atmosphere. Since 1958, the observatory on top of the extinct volcano Mauna Loa in Hawaii has taken daily measurements of the carbon dioxide concentrations in the atmosphere. The study conducted there indicates that the concentration of carbon dioxide in the atmosphere has increased by an average of 1.4 parts per million by volume annually. Human activities, natural processes, or (most likely) a combination of the two may be causing this increase in carbon dioxide.

Increased atmospheric carbon dioxide is a concern because global temperatures tend to increase as levels of 'green house' gases increase. Ocean water absorption and photosynthesis will continue to be major processes that help to moderate the concentration of atmospheric carbon dioxide.

Water vapor is a small but climatologically significant component of our atmosphere. Contained mostly in the lower atmosphere, water vapor concentrations vary widely depending upon geography and climate. In a desert region, the concentration of atmospheric water vapor could be almost as low as 0% most of the time. The same thing can be said about the climate at the poles. The air in these cold regions is very dry with extremely low concentrations of water vapor. The maximum amount of atmospheric water vapor that can be found in any climate is 4%. Areas with this high concentration of water vapor are typically tropical areas.

Earth Science: The Atmosphere - An Ocean of Air

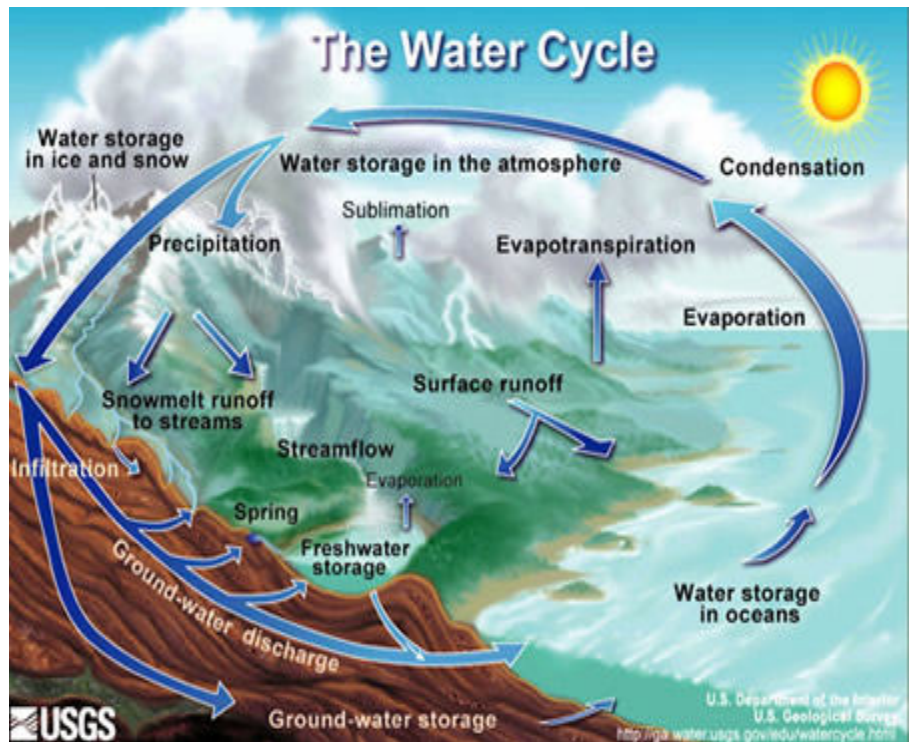
The Water Cycle

Weather phenomena such as clouds, precipitation, thunderstorms, and hurricanes are produced by the exchange of heat energy in the atmosphere through the condensation and evaporation of water. These same processes are responsible for transporting liquid water from the earth's surface into the atmosphere and back again through the water cycle.

On average, a single water molecule can be in the atmosphere about one week before it is returned to the surface through precipitation. The concentration of water at any given time in the atmosphere is called humidity. Humidity can be referred to as relative humidity, specific humidity, or absolute humidity. If we were able to instantly condense the annual average amount of water vapor in the atmosphere, we would only collect about 25 millimeters in our gauge. However, if we could collect the average precipitation that collects annually around the world, our gauge would overflow the one-meter mark. This gives you an indication of the amount of water that is processed annually through the atmosphere by the water cycle.

The water cycle not only circulates water through the atmosphere, but it also does the same thing with energy in the form of heat. To illustrate this, let's follow one kilogram of water into the atmosphere. Each kilogram of liquid water that absorbs sunlight gains 2260 kilojoules of energy to make the transition to water vapor. This water vapor would probably stay close to the surface if it were not for convection in the atmosphere. Convection currents carry water vapor to higher altitudes.

As our kilogram of water vapor gains altitude, it expands and cools. This process is referred to as an adiabatic process since the cooling that occurs is a result of the expansion and subsequent drop in pressure due to the gain in altitude. The rate at which it expands and cools depends upon the conditions present in the atmosphere at that time. When this kilogram of water vapor cools down to the dew point, it begins to condense on dust particles in the atmosphere forming clouds. The act of condensation releases 2260 kilojoules of energy into the surrounding atmosphere. If the one-kilogram sample cools enough to form ice crystals, it can release an additional 2842 kilojoules of heat energy into the atmosphere. This heat energy is what drives the various forms of weather phenomena we experience.



3. A Short History of the Atmosphere

Earth Science: A Short History of the Atmosphere

Lesson Objective

The focus of this lesson is to discuss the theory of the formation of our atmosphere.

Previously we covered...

The air in our atmosphere is a mixture of different gases

Nitrogen, oxygen, argon, and carbon dioxide combine to make up 99.998% of the volume of the atmosphere.

Carbon dioxide and water vapor are major greenhouse gases that help to moderate heat in the atmosphere.

Atmospheric water vapor is replenished constantly by the water cycle.

The water cycle also delivers heat energy to the atmosphere.

Earth Science: A Short History of the Atmosphere

Where did the atmosphere come from?

Our atmosphere evolved over a period of billions of years. The atmosphere we have today is very different from the atmosphere of the very young Earth. That atmosphere would be as alien to us as the atmosphere of another planet. In fact, it is by studying the atmospheres of other worlds in the solar system that we have a good idea about the evolution of our atmosphere. The geological, chemical, and biological processes that shaped our planet controlled this evolution.

Earth Science: A Short History of the Atmosphere

The Earliest Atmosphere

4.6 billion years ago, the early Earth was surrounded by an atmosphere of mostly hydrogen and helium. These gases came from the cloud of material from which the solar system formed. Given the Earth's distance from the newly forming sun, this atmosphere may have also contained numerous hydrogen compounds such as ammonia, methane, and water vapor. This atmosphere was not destined to stick around very long. Hydrogen and helium are lightweight gases. These gases were gradually lost to space because the gravitational pull of the Earth was too weak to hold an atmosphere made of hydrogen and helium. This early atmosphere was depleted within the first 100 million years. However, during this time, processes were already at work that would lead to the next atmosphere.

Earth Science: A Short History of the Atmosphere

Water and Carbon Dioxide enter the Atmosphere

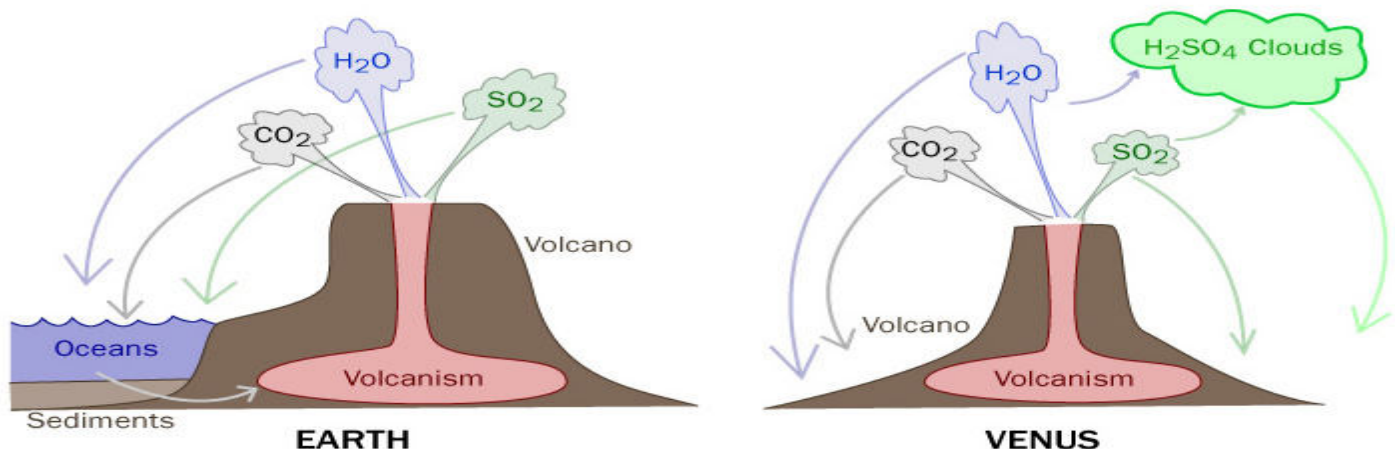
During the formation of our planet, many different gases were delivered to our world through collisions with comets and asteroids. These gases became trapped inside our planet and were eventually released through geological processes such as volcanoes and steam vents. The gases vented through these processes are listed in the table below.

Volcanic Gas vented on Early Earth	Percentage by Volume
Water Vapor (H_2O)	79%
Carbon Dioxide (CO_2)	12%
Sulfur Dioxide (SO_2)	7%
Nitrogen (N_2)	1%
Hydrogen (H_2)	0.5%

The large amount of water vapor that was vented eventually fell back to the surface. This water collected on the surface and became the first rivers, lakes, and oceans. In the previous lesson, we learned that water and carbon dioxide are greenhouse gases. So we can assume that the global climate was much warmer at this time than it is today. A good model of this early atmosphere is the planet Venus. The atmosphere of Venus is composed of 96% carbon dioxide. This abundance of a greenhouse gas contributes to Venus' surface temperature of 485°C (almost 900°F !).

Earth Science: A Short History of the Atmosphere

The same volcanic processes that helped to shape Earth's early atmosphere were also at work on Venus with one exception. Venus did not receive the abundance of water that the Earth received. The presence of bodies of water on the surface of the Earth became instrumental in absorbing much of the carbon dioxide from the atmosphere. This trapped carbon dioxide eventually became bound into the ocean sediments and over billions of years became locked into carbonate sedimentary rocks such as limestone. Over time, some of this ancient carbon is released back into the atmosphere as carbon dioxide through volcanism where it is once again absorbed by the oceans and other processes.

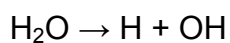
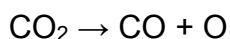


Earth Science: A Short History of the Atmosphere

Oxygen Becomes a Component of the Atmosphere

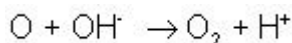
Our atmosphere today is rich in oxygen. Oxygen is a very important gas that sustains animal life on this planet. However, the early atmospheres of Earth did not have much oxygen. The story of how oxygen levels increase in our atmosphere is a story of sunlight and plant life. All of the oxygen in the early atmosphere was bound up in the molecules of carbon dioxide (CO₂) and water (H₂O).

Long before there was a protective **ozone layer**, strong ultraviolet light pierced the atmosphere all the way to the surface. The energy of this ultraviolet light was absorbed by carbon dioxide and water. These molecules were broken apart by photolysis. Carbon dioxide was broken down to carbon monoxide and atomic oxygen while water was broken down to atomic hydrogen and a hydroxyl ion. This atom of hydrogen would escape into space.



Earth Science: A Short History of the Atmosphere

The atomic oxygen from the breakdown of carbon dioxide would eventually interact with the hydroxyl ion from the breakdown of water. This reaction resulted in atomic hydrogen and molecular oxygen. The hydrogen from this reaction would also escape into space leaving behind oxygen gas.



Photolysis was a slow process that probably only yielded about 1% of the atmospheric oxygen. The abundance of oxygen we have today in our atmosphere was made possible by plant photosynthesis. However, before photosynthesis could happen, primitive life had to be protected from ultraviolet light. The process of photolysis increased the levels of oxygen in the upper atmosphere. Sunlight there acted upon it to form ozone. This ozone layer became a protective shield that blocked most of the harmful ultraviolet radiation from the sun. This made it possible for prokaryotic life such as cyanobacteria to develop photosynthesis as a metabolic process. This primitive photosynthesis contributed to an increase in atmospheric oxygen that made it possible about 2 billion years later for eukaryotic life to evolve.

Earth Science: A Short History of the Atmosphere

Photosynthesis in eukaryotes was much more efficient and oxygen levels continued to climb. However, much of this oxygen was robbed from the atmosphere by the abundance of dissolved iron in the ocean. This iron easily bonded to oxygen removing it from the atmosphere and storing it in red sedimentary layers. Once the majority of the iron was removed from the oceans through this process, atmospheric oxygen began once more to steadily increase. About 400 million years ago, vascular plant life began to inhabit dry land. These plants, and their descendants, contributed the majority of the oxygen in the atmosphere. Today, plant photosynthesis is responsible for maintaining the atmospheric oxygen concentration of 20%. Without the process of photosynthesis over billions of years, we would not have the oxygen we need to breath.

4. The Layers of the Atmosphere

Earth Science: The Layers of the Atmosphere

Lesson Objective

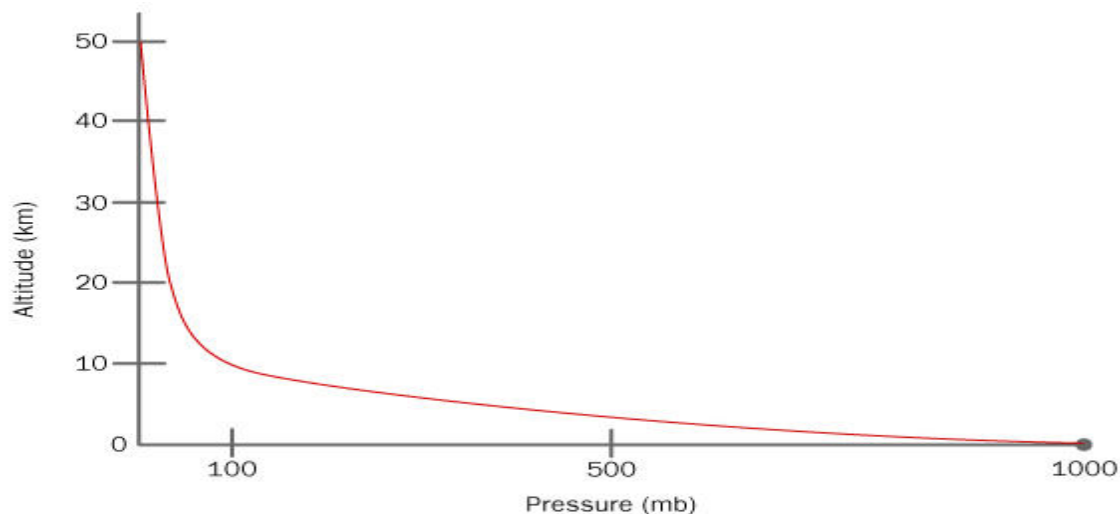
The purpose of this lesson is to explore the various layers of the atmosphere, focusing on the pressures and temperatures at different altitudes

Earth Science: The Layers of the Atmosphere

The Weight of Air

As you stand on the surface of the Earth, your body bears the weight of a column of air that stretches upwards for several hundred kilometers. The weight of this air column pushes equally on every square inch of your body exerting a pressure in every direction. This pressure results from the constant collisions of air molecules against your body. The force of the atmosphere above is weighing down these air molecules.

Air pressure at sea level is measured to be 1 kilogram per square centimeter (14.7 pounds per square inch). This means an air column pressing on 1000 square centimeters (which is a little over one square foot) would weigh one ton. This air pressure at sea level is defined as one atmosphere (1 ATM). As you move upwards through the atmosphere, the density of air molecules around you decreases. There is also less air above you as you gain altitude. In response, air pressure also decreases with altitude. At an altitude of about 50 kilometers, the atmospheric pressure is just above 0.0009869 atmospheres. At this altitude, you are above 99.9% of the bulk of the atmosphere.



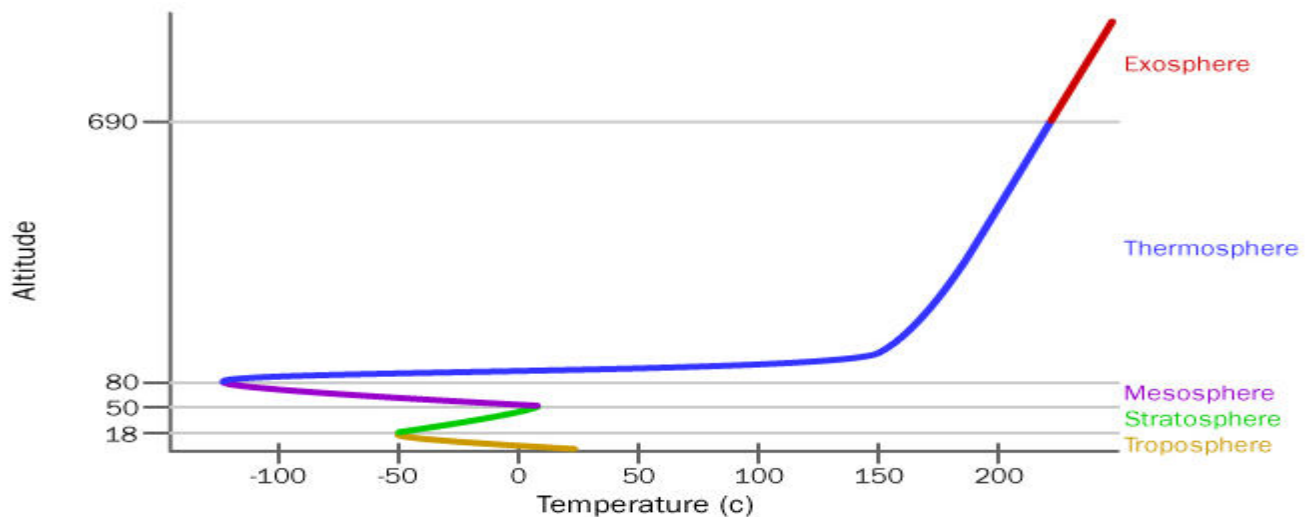
Earth Science: The Layers of the Atmosphere

Air Temperature defines the Layers of the Atmosphere

Air temperature is mostly controlled by the absorption of solar energy. This energy is transferred as heat to the atmosphere by the interactions of the greenhouse gases carbon dioxide and water, and at

higher altitudes by ozone. The following table lists the various layers of the atmosphere. The boundaries for each layer are defined by the change in atmospheric temperature that happens there.

The Layers of the Atmosphere		
Atmospheric Layer	Change in Temperature/Altitude	Altitude Boundaries
Troposphere	Decreases	0 - 11 km
Stratosphere	Increases	11 - 50 km
Mesosphere	Decreases	50 - 80 km
Thermosphere	Increases	80 - 500 km
Exosphere	Increases	500 - 10,000 km



5. Measuring & Forecasting the Weather

Earth Science: Measuring & Forecasting the Weather

Lesson Objective

The objective of this lesson is to learn some of the basics about the science of measuring and forecasting the weather.

Earth Science: Measuring & Forecasting the Weather

What's the weather like today?

Meteorology is the science of measuring and forecasting the weather. It is easy for us to take our modern meteorologists for granted and to be upset with them when their forecasts do not work out. However, in many ways meteorology is a young science that is maturing all the time as more data is collected and technology improves. Today, meteorological forecasting is a multimillion-dollar industry that affects the lives of everyone on the planet.

Perhaps the most important key to weather forecasting is data collection. The practice of setting up weather stations to collect information goes back several centuries. This data, collected over a long period of time, can be used to make models, look for trends, or to investigate different types of weather phenomena. The table below lists common meteorological instruments that you would find in a weather station and the type of data that they collect.

Weather Instrument

Thermometer
Barometer
Anemometer
Hygrometer
Rain Gauge

Data Collected

Temperature
Air Pressure
Wind Speed and Direction
Humidity
Precipitation

Earth Science: Measuring & Forecasting the Weather

While traditional ground-based weather stations still play an important role in collecting data, meteorologists also take to the skies for their data. Weather balloons carry instruments to high altitudes to give a vertical picture of the atmosphere on a given day. This information is important because it gives the meteorologist information about the condition of the atmosphere at high altitudes that might affect low altitude air masses and our weather. Aircraft also play a role in gathering data from higher altitudes or from places that are not accessible any other way. For example, when forecasters are watching hurricanes, aircraft fly into the eye of the storm to conduct visual observations as well as to drop instruments to measure temperature, wind speeds, and pressure.

Going still higher, weather satellites in geostationary orbit keep a constant watch over the entire surface of the Earth. These satellites are equipped with cameras and instrumentation that can watch global cloud formations, air temperatures, and atmospheric moisture amounts over long periods of time. Perched high above the earth's surface, these weather satellites can record long term climatic changes as well as keep a watchful eye on approaching hurricanes and dangerous thunderstorms.

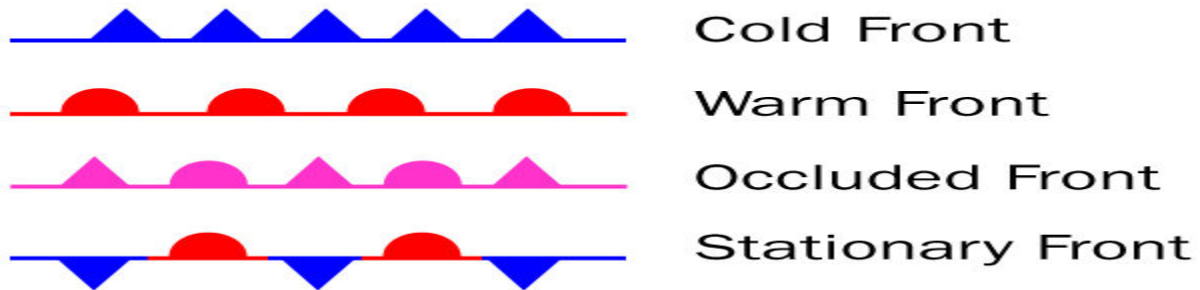
Another important tool in weather monitoring and forecasting is Doppler radar. Computer advances have improved the data that can be derived from radar systems. In a typical Doppler radar operation, microwaves are beamed into an approaching storm. These microwaves are reflected back to the radar dish providing information such as wind speed, direction, and relative amounts of precipitation. Due to the many observations of weather spotters and the data they collect, analysis of Doppler radar imagery has improved greatly. Meteorologist can analyze these Doppler radar images in real time to locate where wind, rain, hail, and tornados are located within a complex thunderstorm. These tools have already saved many lives by providing advance warning to communities in the path of dangerous storms.

Earth Science: Measuring & Forecasting the Weather**What's the weather going to be like tomorrow?**

The business of weather forecasting is based upon analyzing trends. A number of climate and weather models have been developed over the years that assist the meteorologist in making a forecast. However, it is often up to the meteorologist to make professional judgments when the models give widely differing projections.

Weather maps play an important role in forecasting. These maps show the interactions and movements of warm and cool air masses over a wide area. The place where warm and cool air masses come together is called a front. These fronts are often where dramatic weather such as thunderstorms can happen. When a warm air mass is advancing and overtaking a cool air mass, the boundary is called a warm front. If a cool air mass is advancing and overtaking a warm air mass, the boundary region is referred to as a cold front. If the warm and cool air masses collide and neither air mass is overtaking the other, then the front is called a stationary front. If a cold air mass overtakes

and replaces cool air mass at the surface with warm air above, the front is called an occluded front. A cold occlusion occurs when a cold air mass slides under a cool air mass at the surface. A warm occlusion happens with a cool air mass rides over the top of a cold air mass at the surface. The following symbols are used to plot the positions of fronts on weather maps.



Earth Science: Measuring & Forecasting the Weather

The mechanism that makes air masses move is wind. Knowing how to predict wind patterns is an important part of predicting the motion of air masses. In order to do this, meteorologists plot regions of air pressure on weather maps. Lines called isobars connect areas of similar air pressure. When isobaric lines are close together on a chart, this indicates a rapid change in air pressure. A rapid change in air pressure results in an increase in wind and subsequent motions of air masses. Prevailing winds always blow from areas of high pressure to areas of low pressure.

A weather map with a completed set of isobars can reveal a number of standard weather patterns. A curved set of isobars that encircles an area of low pressure usually indicates a depression with the wind moving around its center in a counterclockwise direction (northern hemisphere). If a set of curved isobars is found to wrap around an area of high pressure it indicates the presence of an anticyclone. In the region of an anticyclone, the winds move in a clockwise direction (northern hemisphere). An open V-shape set of close isobars with low pressure inside will mark a trough while N-shaped close isobars with high pressure will indicate a high pressure ridge.

6. Clouds & Weather

Earth Science: Clouds & Weather

Lesson Objective

The purpose of this lesson is to learn the names of different cloud formations and the type of weather they indicate.

Previously we covered...

Meteorology is the science of measuring and forecasting the weather.

Barometers, weather maps, weather satellites, thermometers, anemometers, hygrometers, weather balloons, and computer models are used to acquire and process vast amounts of data in real time to forecast weather.

Dynamic weather usually happens along fronts where warm and cool air masses interact.

Isobars are lines of equal pressure on a weather map. They can be used to locate areas of wind and other wind phenomena

Earth Science: Clouds & Weather

Reading the Skies

***Red sky at night, sailor's delight. Red sky in the morning, sailor's warning.
Mackerel sky and mare's tails, makes a sailor furl his sails.***

A sailor's life and livelihood were affected by the weather in the days of sailing vessels. Sailors have a long tradition of weather sayings that are easy to remember and that are based upon practical observations of weather phenomena. Farmers also have weather sayings that have been passed down through the generations. These sayings indicate that our ancestors regarded weather information and the potential to predict the weather as practical knowledge. Although these old sayings sound quaint and simple, they do contain pearls of wisdom that are still useful today. Most are based upon observations of types of cloud formations. The table below lists various types of cloud formations and the weather that they indicate.

Cloud Name (symbol)	Type	Alt. (km)	Description	Weather Indicator / Appearance
Cirrus (Ci)	high	+5	thin, wispy, made of ice crystals	Associated with fair weather.
Cirrostratus (Cs)	high	+5	thin, sheet-like, halo around sun & moon	Possible bad weather in 12/24 hours.
Cirrocumulus (Cc)	high	+5	rounded white puffs, found in rows, "mackerel sky"	Unsettled weather may be on the way.
Alto cumulus (Ac)	mid	2-5	shallow, puffy, wave-like, made of ice and water	Can appear in early morning or late evening.
Altostratus (As)	mid	2-5	grayish/blue-gray, can uniformly cover the sky, sun can be seen but no halo	Usually seen in advance of storms.
Nimbostratus (Ns)	mid, vert.	0.5-5	dark gray, wet-looking, sun completely blocked	Produce light to moderate precipitation over a large area.
Stratus (St)	low	>2	uniform grayish cloud covering whole sky, no precipitation, called fog on the ground	Fog, drizzle, or mist if low enough.
Stratocumulus (Sc)	low	>2	Low, lumpy, puffy, found in patches or rounded masses	Drizzle, or light rain, passage or approach of worse weather.
Cumulus (Cu)	low	>2	cotton balls or cauliflower	Slightly developed means fair weather, moderately developed bring possible precipitation.
Cumulonimbus (Cb)	vert.	2-23	towering appearance, anvil-shaped top	thunderstorms

7. Solar Radiation & the Atmosphere

Earth Science: Solar Radiation and the Atmosphere

Lesson Objective

The purpose of this lesson is to explore how our atmosphere interacts with the spectrum of electromagnetic radiation that bombards it from the Sun.

Earth Science: Solar Radiation & the Atmosphere

Without the influence of the sun, our planet would be a barren, frozen, wasteland. Each day, 1367 Watts / square meter of solar energy hit the top of the atmosphere. Almost 30% of this solar energy will be reflected and scattered back into space (6% by the atmosphere, 20% by clouds, and 4% by the Earth's surface). About 19% will be absorbed by the atmosphere while the remaining 51% will be absorbed at the Earth's surface.

Sunlight is a composition of many different wavelengths of light in our visible spectrum, but mostly wavelengths of energy we cannot see. Our Sun actually produces all of the wavelengths of the electromagnetic spectrum. However, due to its surface temperature of 6000°C, the peak visible wavelength emitted by the Sun is 540 nanometers or in the yellow-green part of the visible spectrum, which is why the sun "appears" yellow.

Only certain parts of the electromagnetic spectrum can pass freely through our atmosphere while other forms of radiation are blocked completely. The table below shows the various forms of electromagnetic radiation that are blocked, absorbed, or transmitted by the atmosphere.

Electromagnetic Radiation	Interaction with Atmosphere	Mechanism that makes this possible.
Gamma Rays	Absorbed	Blocked by ozone and ordinary oxygen.
X-Rays	Blocked	Blocked by ozone and ordinary oxygen.
Ultraviolet Rays	Partially absorbed	Absorbed by ozone.
Visible Light	Transmitted	The atmosphere is transparent to visible light.
Infrared Light	Partially absorbed	Absorbed by carbon dioxide and water, the same greenhouse gases that help to warm our planet.
Microwaves	Blocked	Blocked by water and carbon dioxide.
Radio Waves	Transmitted	The atmosphere is mostly transparent to radio waves.

8. The Earth's Water

Earth Science: The Earth's Water

Lesson Objective

In this lesson, we will explore the physical and chemical nature of water on our planet.

Earth Science: The Earth's Water

Natural Resources, Conservation, and Pollution

Our world contains many natural resources that we use to survive and some that we consume in the pursuit of our modern lifestyles. Air, water, and plant and animal life are all natural resources that we utilize in order to live. Rocks, minerals, and fossil fuels are examples of natural resources that we exploit to power our world and make technology possible. Wealth and status in the world economy is often determined by a nation's access to natural resources. These resources can be classified as renewable, inexhaustible, and non-renewable.

Renewable resources are, as the name implies, resources that can be renewed, usually through careful management or conservation. Most of the renewable resources used in the world today come from plant and animal material. Our food supply relies on numerous renewable resources. As long as the rate at which we extract living material for our food supply is the same as the rate that it is replenished, we need not worry about the future of this type of resource. However, history provides many examples of situations where demand exceeds supply and a food resource was exhausted. In many nations, conservation laws are enforced and agricultural methods are followed to insure the future availability of food resources. Some of the renewable resources used by our society go toward the production of items such as clothing and housing. Cotton grown in the southern United States has provided a renewable resource used to make clothing and other material for many years. Timber harvested from carefully managed forests can provide the raw materials to supply materials for future construction.

Earth Science: The Earth's Water

Saltwater and Freshwater

The vast majority of the hydrosphere (approximately 97.5%) is composed of salt water. The salinity of salt water, also called seawater, is about 3.5% on average. This means that roughly 35 grams of salts can be extracted from one liter of seawater. Of these salts, sodium chloride is the most common. Seawater also contains a wide variety of other chemical compounds. The following table shows the percentage by mass of elements that are commonly found in seawater.

Composition of Seawater by Element (percentage mass)

Oxygen	85.7
Hydrogen	10.8
Chlorine	1.9
Sodium	1.05
Magnesium	0.1350
Sulfur	0.0885
Calcium	0.04
Potassium	0.0380
Bromine	0.0065
Carbon	0.0026

Earth Science: The Earth's Water

One theory concerning the origins of salt in seawater dates back to the 18th century. The original thought was that salt and other minerals were delivered to the oceans by rivers after having been washed away by erosion and by leaching out of the ground. However, this was just half the story. Most of the salt in seawater has very ancient origins. Shortly after the formation of the oceans, sodium began to leach from the ocean floor. At the same time, hydrochloric acid was released from both volcanoes into the atmosphere and hydrothermal vents on the ocean floor. Sodium and chlorine combined in the prehistoric ocean to form sodium chloride, becoming the most abundant element in seawater.

The process through which sodium was leached from the ocean floors is no longer active in our oceans today. Although the oceanic leaching process no longer occurs, the salinity of the oceans has been stable for millions of years. This is because both chemical and geological processes are constantly recycling salt. Salt collects in sedimentary layers on the ocean floor. Eventually, these sedimentary layers are pushed under the continental masses at subduction zones by plate tectonics. The trapped salts in these layers make their way back to the surface through leaching and other processes, and are ultimately washed back into the sea.

All of the water in the hydrosphere contains some salt. Freshwater is defined as water that contains less than 0.5 parts per thousand of dissolved salts (by mass). By this definition, only about 2.5% of the world's water supply is classified as freshwater. Glaciers and the polar ice caps currently store almost 95% of our planet's freshwater supply. The remaining freshwater can be found in lakes, rivers, streams, aquifers, and in the atmosphere. Freshwater collects in reservoirs from precipitation of water vapor and through melting snow and ice

9. Water on the Move

Earth Science: Water on the Move

Lesson Objective

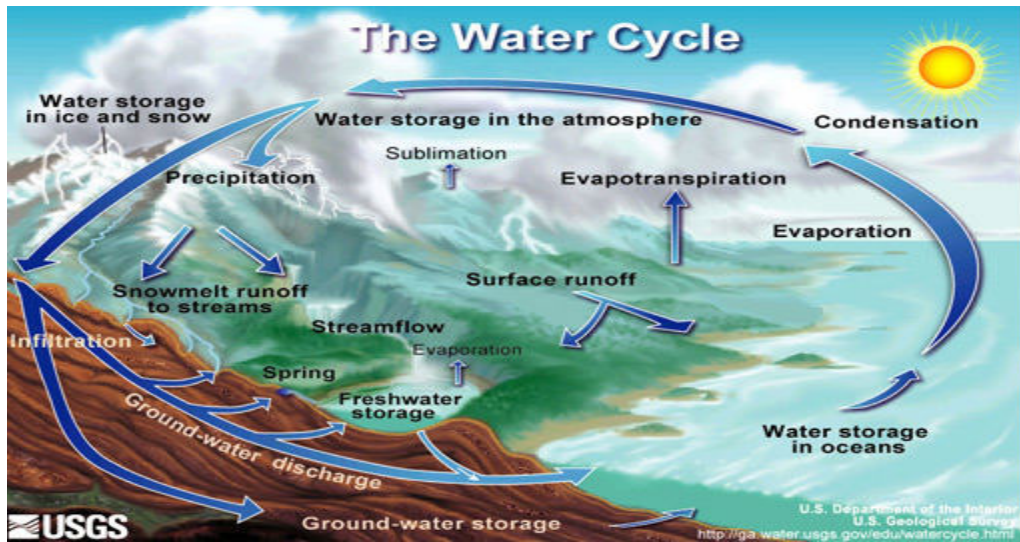
The purpose of this lesson is to discuss the hydrologic cycle and its role in moving water from land to sea and back again.

Earth Science: Water on the Move

Hydrologic Cycle

The hydrologic cycle is a combination of many different processes that circulate water through the hydrosphere. Most of the processes involve water's ability to change its physical state (solid, liquid, or gas) at a variety of atmospheric temperatures and pressures. The hydrologic cycle involves continuous water interactions between the atmosphere, land, underground, and through plant life on the surface. Crucial to this cycle is the availability of places to store large amounts of water, such as

aquifers, lakes, and oceans. The mechanisms that drive the hydrologic cycle are evaporation, transpiration, sublimation, condensation, precipitation, infiltration, discharge, and runoff.



Earth Science: Water on the Move

Most of these hydrologic processes involve cycling water through the atmosphere (evaporation, condensation, precipitation, etc.). However, processes that occur below and above the surface of the Earth carry the vast majority of water in the hydrologic cycle. The movement of groundwater is controlled by the nature of the rocks and sediment around and through which the water passes. The ground's ability to store water is determined by the porosity of rocks and soil near the surface. Sandstone is known for storing water, but generally speaking, soil is very porous and therefore has a great capacity to store water. However, the amount of water that penetrates the soil is determined by the soil's permeability. Soil that is mostly composed of loosely packed material will permit a great deal of water to pass through it. However, the more densely packed the material becomes; the less permeable the soil is going to be and the harder it becomes for water to move through it. The permeability of certain rocks and sediments makes it possible for large movements of water deep underground. For the most part, this flow of groundwater is very slow (on average about 14 meters per year). Groundwater can also collect in underground reservoirs called aquifers. Aquifers form in areas where sand, gravel, and other types of loose sedimentary rock are common. Water from an aquifer can be discharged naturally by springs or by man-made wells.

Large-scale movements of water and ice across the continent cause erosion and is responsible for many kinds of eroded features. U-shaped valleys are commonly found in northern latitudes. These valleys formed when glaciers cut deep grooves into the surface as they advanced and retreated across the landscape during the ice ages. Glaciers are large masses of ice that form during long periods when the climate allows more snow to accumulate in winter than melts in the spring. The accumulations of snow compress into ice over time. Gravity pulls on the glacier as the weight of the ice increases, causing it to move slowly downhill. As these glaciers move, they erode the landscape with tremendous force, picking up large amounts of sediment and sometime very large rocks. When the glacier melts, these sediments and rocks are deposited sometimes hundreds of miles from their starting place. Melting glaciers contribute a great deal of freshwater to runoff on most continents. A recent concern has also focused on glaciers which contain millions of tons of methane frozen in their cores. As glaciers melt, they release what are called greenhouse gasses, creating potentially massive amounts of methane to be released into the atmosphere.

Earth Science: Water on the Move

Melting ice, snow, and precipitation from high altitudes flows down hill, forming small mountain streams. These mountain streams combine with other streams at lower altitudes and eventually become part of large tributary systems that feed into major rivers moving across a continent. Under the influence of gravity, water in streams, creeks, and rivers cut deep channels into the surface. This erosion process is responsible for moving millions of tons of sediment towards the sea. As water transports these sediments across the continent, deposits can form natural levees and flood plains that can alter a river's course over time. River and streams can occasionally overflow their banks in times of heavy rains and large snow melts. At these times, flood waters can further erode the landscape causing **sheetwash** and **rill** formation. When the river finally meets the sea, sediment carried for hundreds of miles by the river is dumped into the ocean in a fan-shaped formation called a delta. If the river has existed for a sufficient period of time, the sediment dumped in the river delta can form a complex of islands. Over time, these river sediments can slide down the continental shelf and collect on the ocean basin inside deep sea trenches.

10. The Oceans

Earth Science: The Oceans

Lesson Objective

The purpose of this lesson is to explore the topography and hydrology of the oceans.

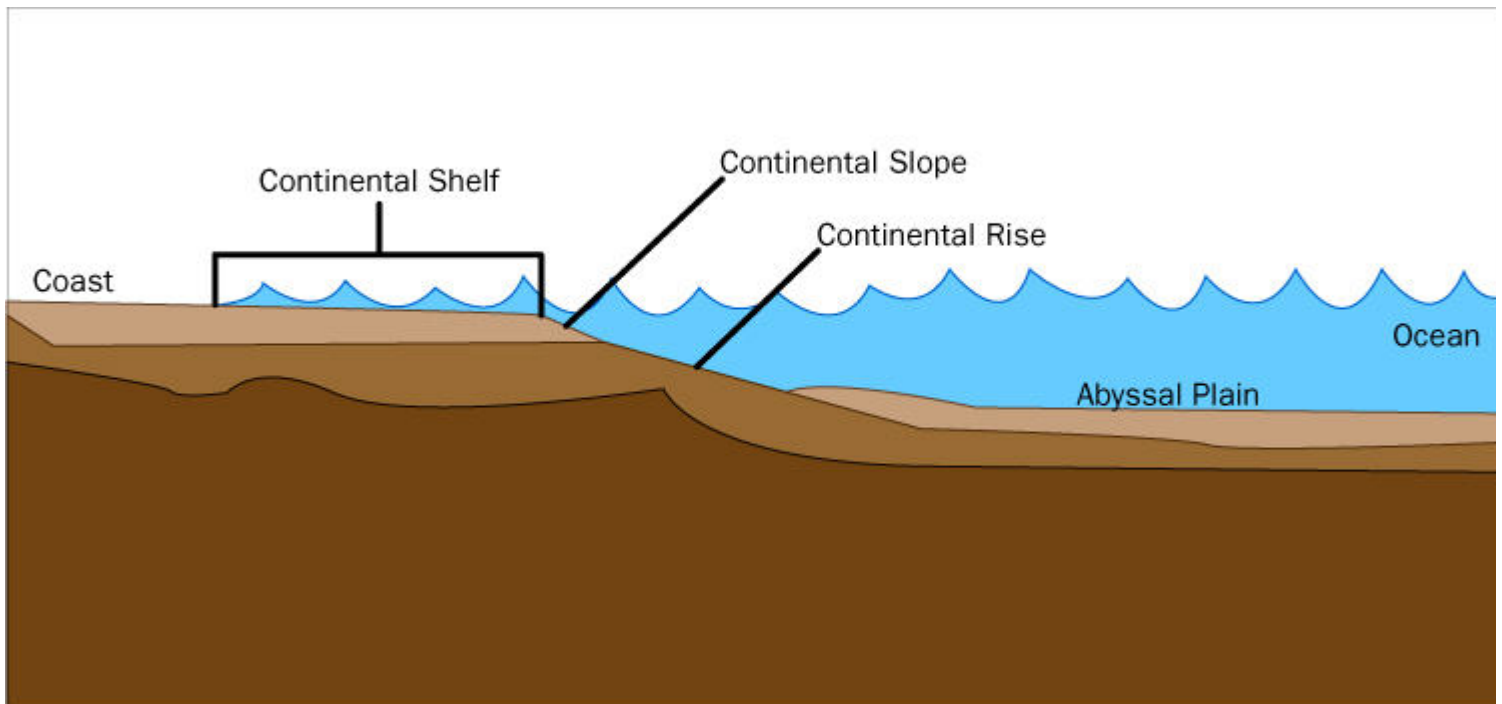
Earth Science: The Oceans

Ocean Floor Topography

The World Ocean is a large interconnected body of seawater that contains the majority of water in the hydrosphere. Divided by continents and other geographic features, the World Ocean is a combination of five major oceans: the Pacific Ocean, the Atlantic Ocean, the Indian Ocean, the Arctic Ocean, and the great Southern Ocean. The World Ocean covers more than 361 million square kilometers of the Earth's surface and contains almost 1,370 million cubic kilometers of water. That is a lot of water! Because of water's properties as an energy-storing agent, this amount of water is probably the single most important regulator of our planet's climate.

An ocean can be described geologically as an area of the Earth's crust that is covered by deep water. For much of human history, the depths of the ocean were completely unknown territory, hidden from view by huge amounts of water. Today, we live at a time when the ocean floor has been mapped in great detail by technology such as sonar and by measuring minute gravitational fluctuations. The topography of the ocean floor reveals many geographic features that are identical to those found on land, such as mountains, plains, and valleys.

Earth Science: The Oceans



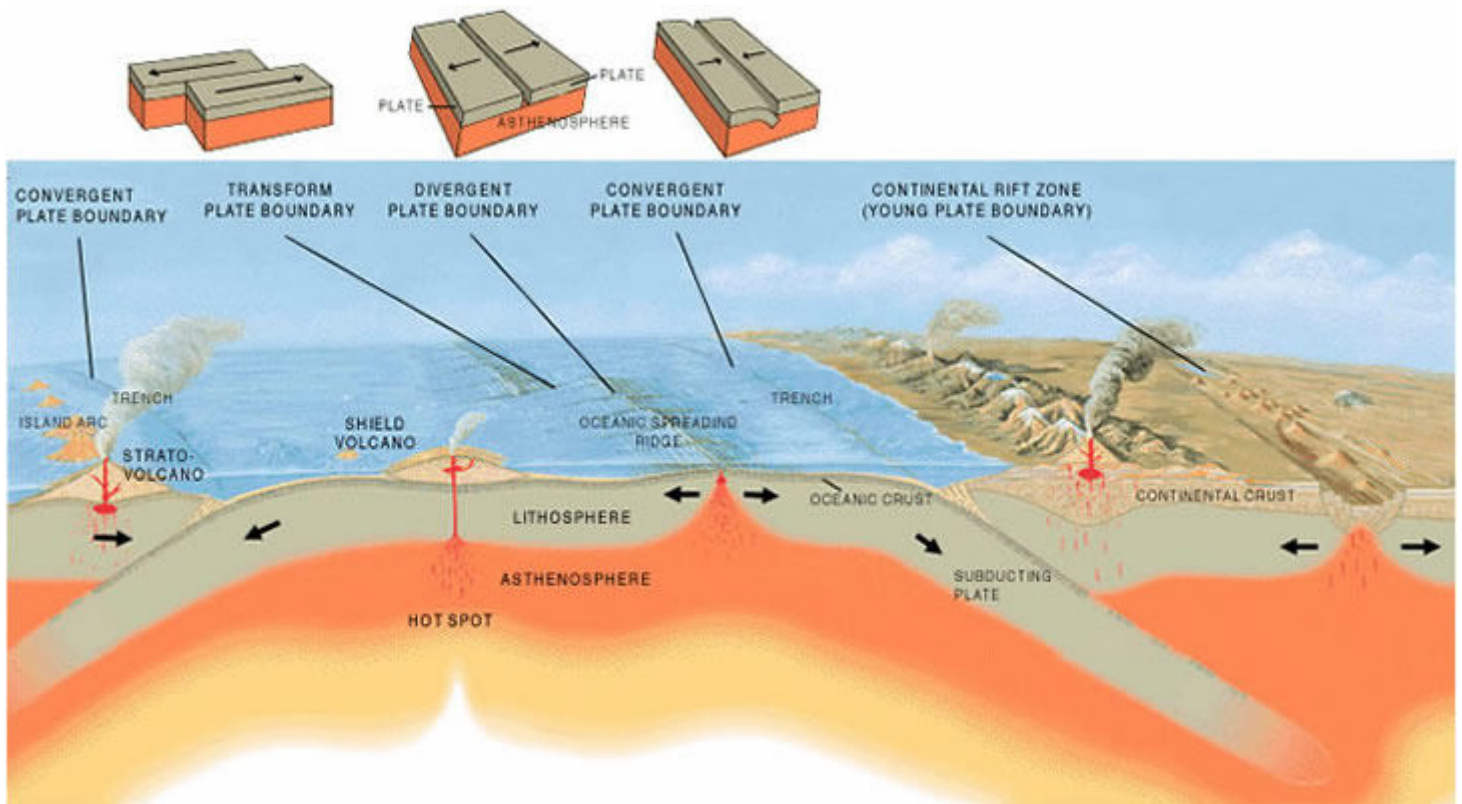
The continental shelf

Where a continent meets the sea is a region called the continental shelf. The depth and area of the continental shelf varies with location. The continental shelf ends in a sloped area called the continental slope. This gently sloped area sometimes ends with a more steeply sloped region called a rise. Canyons below the ocean scar many continental slope regions. These V-shaped canyons are often carved by strong ocean currents or by undersea earthquakes. The continental slope eventually levels out into the ocean basin.

The topography of the ocean basin varies across the floor of the ocean. Extending from the edges of the continental slope are the abyssal plains. These relatively flat regions range at depths from 3 to 6 kilometers below sea level. The abyssal plains are found in all major oceans and normally extend across the ocean floor to the mid-oceanic ridges. The abyssal plains are composed of sedimentary accumulations and decomposing organic material. Much of the Atlantic Ocean basin is abyssal plain, and is markedly more so than in the Pacific Ocean. One of the reasons for this is that most of the world's rivers empty into the Atlantic Ocean, but this difference also arises from the Pacific Ocean basin, which is ringed with trenches that collect sediment from river flows.

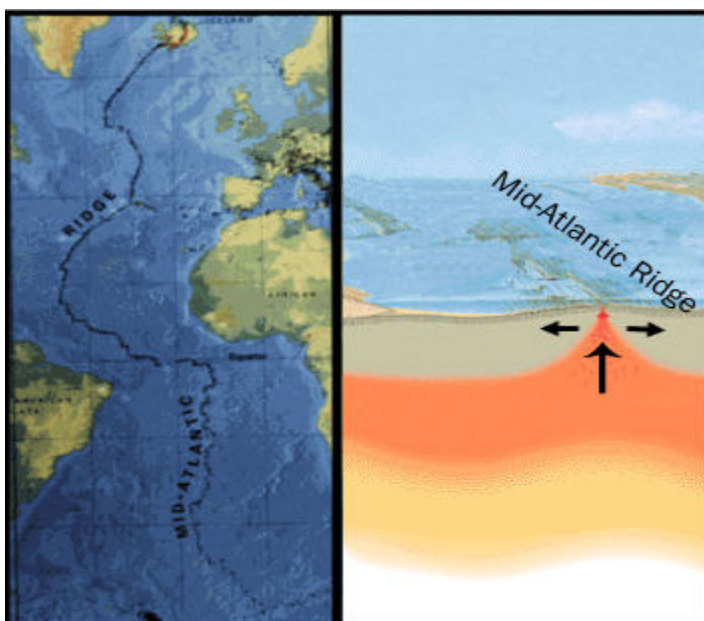
Earth Science: The Oceans

Trenches are created by the action of plate tectonics. For example, the Pacific plate (also called the Pacific basin) moves westward, underneath the Eurasian plate. It is in this kind of subduction zone that you find trenches. Trenches are the deepest features found in oceans. The deepest trench in the world is the Marianna Trench in the Pacific Ocean, at a depth of almost 11,000 meters.



Trenches are found in subduction zones formed by convergent boundaries (where plates slide toward each other).

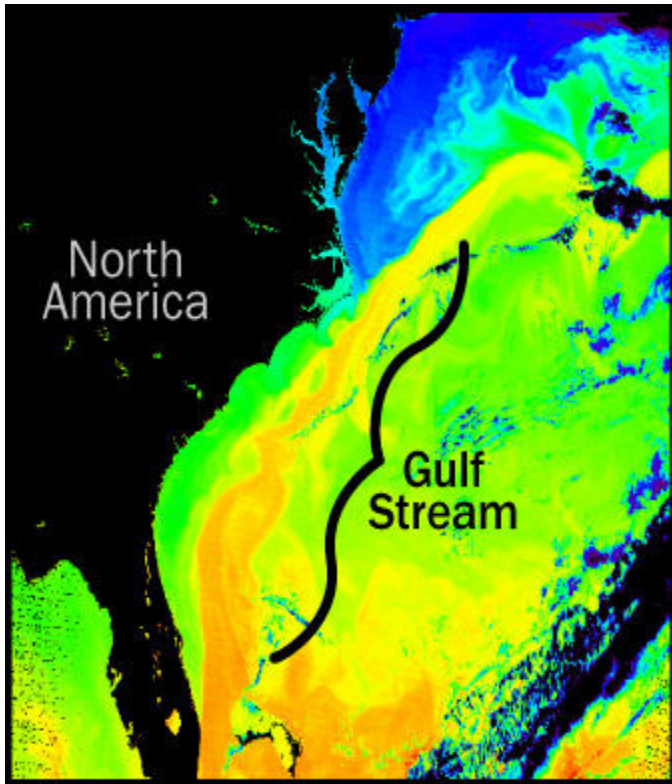
The collisions of undersea crustal plates also build mountains on the ocean floor similar to those above sea level. However, the largest underwater mountains are built through volcanic eruptions. These seamounts are produced when mounds of volcanic material build-up and poke up from the ocean depths to form island chains. The best example of this is the string of Hawaiian Islands. The Islands are still being made as the Pacific plate slides westward across a volcanic hot spot in the Earth's crust, leaving behind a curved trail of islands.



Mid-ocean ridges are examples of divergent plate boundaries (where two plates spread apart).

Another plate tectonic feature found on the ocean floor is the mid-oceanic ridge. In the 18th century, Benjamin Franklin and others proposed that the continents of Africa and South America were joined together in the distant past. It was not until the 20th century that this idea was shown to be correct when sonar measurements confirmed the existence of a spreading fissure in the Earth's crust under the Atlantic Ocean. Magma arose from the depths to fill this crack in and solidified. Eventually the pressure built up, causing the surrounding area to rise and buckle. This continued to form other magma-filled cracks and bordering mountain ranges.

In effect, it would seem that the ocean floor is spreading out from the middle of the Atlantic Ocean. The continents on both sides of the Atlantic Ocean have been moving away from each other at the rate of 5 centimeters per year for the past 20 million years.



Earth Science: The Oceans

Ocean Circulation

The topography of the ocean floor plays an important role in the movement of water across the globe. Other factors that influence the circulation of water include surface currents, deep ocean currents, and the tides. Surface currents move horizontally across the uppermost layers of the ocean. These layers are well mixed by wind, rain, and other weather phenomena. Wind is the primary mechanism that drives surface currents. Other contributing factors of ocean currents are the Earth's rotation and the location of landmasses.

Earth Science: The Oceans

Surface currents distribute heat energy through the oceans and around the globe, which in turn helps to moderate the global climate. The current patterns in the northern hemisphere typically rotate in a clockwise direction while those in the southern hemisphere rotate counter-clockwise. Ocean current systems transport warm water from the equator towards the poles. As this warm water flows near a continent, it influences the coastal climate. The weather on the eastern United States is influenced by the warm Gulf Stream, which causes the coastal climate to be warmer on average. The opposite is the case for the western coast of the United States. The west coast climate is moderated by the cool North Pacific current that brings cold water down from the north towards the equator, resulting in a cooler coastal climate.

Deep ocean currents are huge vertical movements of water that start as a sinking of very cold water at the poles. This water sinks because it becomes colder and saltier at the poles, causing its density to increase. These dense waters move slowly outward from the poles (mostly from the north Atlantic) and across the bottom of the ocean. This circulation of deep, dense water is somewhat like a conveyor belt that transports huge amounts of water from the cold polar regions to other parts of the

World Ocean. When these waters become warm again, they rise towards the surface and bring valuable nutrients to microscopic sea life (e.g., phytoplankton). Upwelling currents create a similar effect near continental boundaries.

11. Resources & Hazards

Earth Science: Resources & Hazards

Lesson Objective

The purpose of this lesson is to discuss some of the natural resources and potential hazards associated with living on the planet Earth.

Previously we covered...

...the many important facets of the water cycle, and water's important history, origin, and role in the hydrosphere.

Earth Science: Resources & Hazards

Natural Resources, Conservation, and Pollution

Our world contains many natural resources that we use to survive and some that we consume in the pursuit of our modern lifestyles. Air, water, and plant and animal life are all natural resources that we utilize in order to live. Rocks, minerals, and fossil fuels are examples of natural resources that we exploit to power our world and make technology possible. Wealth and status in the world economy is often determined by a nation's access to natural resources. These resources can be classified as renewable, inexhaustible, and non-renewable.

Renewable resources are, as the name implies, resources that can be renewed, usually through careful management or conservation. Most of the renewable resources used in the world today come from plant and animal material. Our food supply relies on numerous renewable resources. As long as the rate at which we extract living material for our food supply is the same as the rate that it is replenished, we need not worry about the future of this type of resource. However, history provides many examples of situations where demand exceeds supply and a food resource was exhausted. In many nations, conservation laws are enforced and agricultural methods are followed to insure the future availability of food resources. Some of the renewable resources used by our society go toward the production of items such as clothing and housing. Cotton grown in the southern United States has provided a renewable resource used to make clothing and other material for many years. Timber harvested from carefully managed forests can provide the raw materials to supply materials for future construction.

Earth Science: Resources & Hazards

The United States has a diverse energy production portfolio. The table below lists the types of fuels consumed in the production of electrical energy in our country.

Electrical Generation by Fuel Type Consumed	
Coal	52.3%
Nuclear Energy	21.7%

Renewable Energy	12.1%
Natural Gas	10.7%
Residual Fuel	1.8%
Electrical Imports	1.2%
Distillate Fuel	0.8%

Soil, water, and air are other examples of inexhaustible natural resources. While these resources seem to exist in an unlimited supply, human activities that pollute or deplete these resources are still a cause for serious concern. For instance, fossil fuel combustion releases poisonous chemical compounds such as carbon monoxide into the atmosphere. Chemical and organic pollutants from industry can taint drinking water. A significant percentage of drinking water is wasted each year in activities such as watering lawns, filling swimming pools, and flushing toilets. Conservation measures have been in place for many years to ensure the availability of clean soil, water, and air for future generations. As stewards of the environment, society must continue to attempt to reduce pollution and conserve our natural resources.

Earth Science: Resources & Hazards

With each passing year, our society's demand for electrical energy increases. Therefore, it is crucial to find other resources that can provide uninterrupted energy for the future. Many decades ago, nuclear energy promised a future of clean unlimited energy. Currently, nuclear energy is unpopular because radioactive waste products usually do not break down for thousands of years. Nuclear energy claimed to be an inexhaustible energy supply. However, there are other examples of inexhaustible energy resources that are environmentally friendly. Wind, solar, hydroelectric, and geothermal energy are all examples of inexhaustible natural resources. These types of resources help to reduce fossil fuel demand and provide energy through processes that do not create pollution. Oil, however is still necessary for the plastics we use today.

Classes of Plastics			
Number	Symbol	Name	What is it used for
1	PETE	Polyethylene Terephthalate	2 liter bottles, mouthwash bottles, boil-in-bag pouches
2	HDPE	High Density Polyethylene	Milk jugs, trash bags, detergent bottles
3	V Vinyl or PVC	Polyvinyl Chloride	Cooking oil bottles, meat packaging
4	LDPE	Low Density Polyethylene	Grocery bags, produce bags, food wrap, bread bags
5	PP	Polypropylene	Yogurt containers, shampoo bottles, straws, diapers
6	PS	Polystyrene	Coffee cups, take-home boxes, egg cartons, meat trays
7	OTHER	Made from a combination of different kinds of plastics	Thousands of different things.

Earth Science: Resources & Hazards

Hazards & Disasters

While natural resources are used to build a society's infrastructure, natural disasters threaten to destroy it. A natural disaster occurs as the result of a natural phenomenon that can cause wide scale property damage and loss of human life. Sometimes the magnitude of the natural disaster depends upon how a society is able to cope with the event. Technologies have been employed over the years in an attempt to lessen the impact of a natural disaster. Buildings that absorb the vibrations from earthquakes, flood control measures such as levees and dams, and tornado shelters are all examples of ways society has developed to prepare for hazards. The table below lists some common natural disasters and the mechanisms of each that cause damage.

Natural Disaster	Mechanisms for Destruction
Blizzard	Large snow accumulations, high winds, and poor visibility
Earthquake	Vibrations, dangerous structural damage, landslides, and fires
Flood	High water and rushing water
Forest Fire	Fire and smoke
Thunderstorm	Lightning, wind, hail, rain, and tornado
Hurricane	Wind, rain, damaging surf, and flooding
Ice Storm	Ice buildup
Tsunami	Damaging surf and flooding
Volcanic Eruption	Nuees ardentes, lava flows, phreatic eruptions, gas emissions, lahars, and pyroclastic flows

12. Astronomy and Cosmology

Earth Science: Astronomy and Cosmology

Lesson Objective

Next, we will review the basic facets of astronomy, including tools of the trade, our solar system, and the age of the universe.

Previously we covered...

In the last lesson, we reviewed the hydrosphere, oceans, natural resources and pollution.

Earth Science: Astronomy and Cosmology

Tools of the trade – Instruments

The difference between astronomy and other sciences is that with astronomy, you cannot hold in your hands what you want to study. There are exceptions of course because there are meteorites, moon rocks, and the evidence from space probes, but for the most part, evidence is indirect when it comes to **galaxies, stars, planets, and asteroids**.

Most of the evidence comes from telescopes that use the **electromagnetic spectrum** which is composed of several forms of electromagnetic energy or electromagnetic waves:

Visible light - The form of electromagnetic waves that can be detected by the human eye. Using telescopes that reflect and refract light, astronomers have produced most images from ground and space based telescopes. Charge coupled devices (CCD's) revolutionized these observations.

Radio waves - Radio telescopes are large radio receivers that look somewhat like large satellite TV antennas and they are designed to receive radio waves from astronomical objects. In New Mexico is one of the world's premiere radio astronomical observatories, the VLA, which stands for the "very large array." There are 27 dishes, each measuring twenty five meters across and mounted on railroad tracks.

Ultraviolet - Since the atmosphere filters out most of the UV spectrum, these instruments have to be above the atmosphere in satellites containing ultraviolet telescopes.

Infrared (heat) - Special detectors designed to detect infrared radiation can be mounted on optical telescopes, which then become infrared telescopes. They can be ground or space based.

X-rays and gamma rays - There are no ground based instruments because the atmosphere filters even more x-rays than UV. X-ray and gamma ray observations must be done from space.

All forms of electromagnetic waves travel at a rate of 300,000 km/s (or 186,000 miles per second). At that rate, light can make 7 trips around the equator of the earth in one second. Light defines distance in space units: a light year is the distance light travels in one year. The closest star (besides our sun) is Proxima Centauri – 4.3 light years away (or 26 trillion miles).

Cosmology is the scientific study of the origin and evolution of the Universe. Evidence suggests that the universe began with a big bang. Edwin Hubble's 1929 observation that galaxies were moving away from us provided the first clue that led to the Big Bang theory. Many other observations since confirm this.

The Big Bang theory predicts that the light elements (hydrogen, helium, lithium, and beryllium) were fused from protons and neutrons in the first few minutes after the Big Bang because of the intense heat. These elements are abundant throughout the universe. Heavier elements are all synthesized in stars. As stars die, they turn helium into carbon, oxygen, silicon sulfur and iron. Heavier elements are produced and blasted back into space through supernova explosions.

The early universe was very hot. The cosmic **microwave** background radiation is thought to be the remnant heat leftover from the Big Bang.

Earth Science: Astronomy and Cosmology

Universal Age

Various astronomers estimate that the Big Bang occurred between 12 and 24 billion years ago. This number varies by source because of the error that must be considered with the method of calculation. The most recent estimates are closer to 12 or 13 billion years. For comparison:

- Solar System is thought to be about 4.5 billion years old
- Humans have existed for 1 or 2 million years.

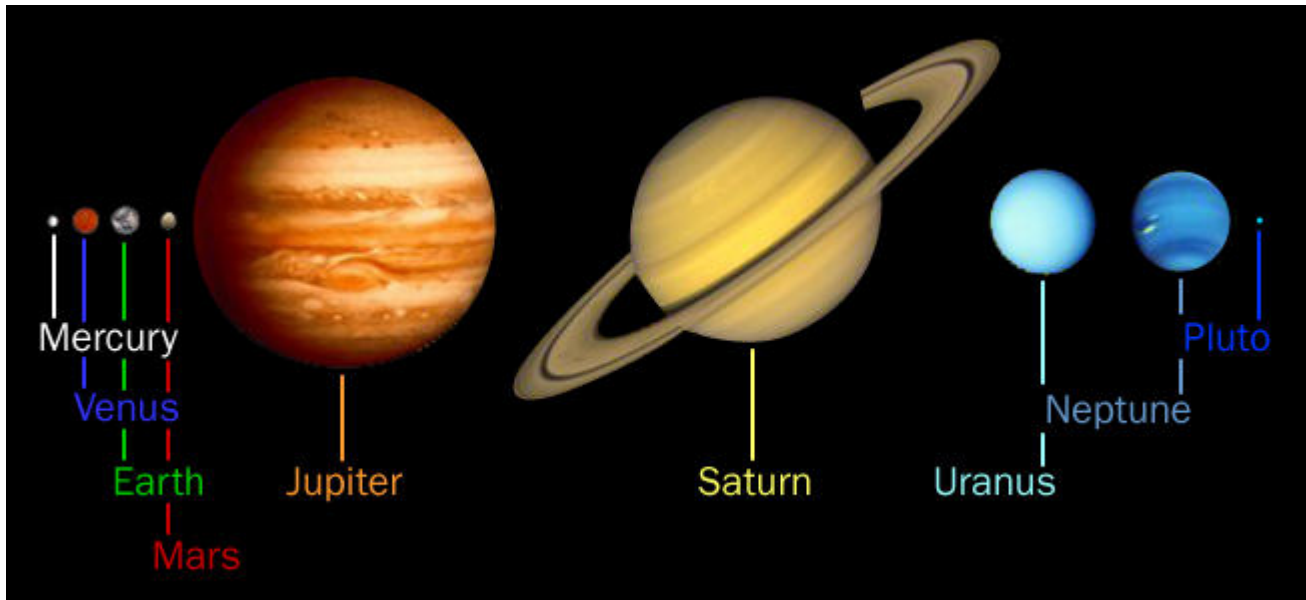
Astronomers estimate the age of the universe by:

- Measuring the rate of expansion of the universe to see when it began as a single mass
- Looking for the oldest stars
- Using methods that compare the rate of decay of known radiometric substances

Earth Science: Astronomy and Cosmology

Our sun, solar system, and planets

All the planets orbit the sun in the same directions and on almost the same plane which suggests a common origin. The system has a counter clockwise spin as observed from the north side of the solar system according to the way the North Pole of the Earth points.



Earth Science: Astronomy and Cosmology

Most of the planets spin counterclockwise, except Venus and Uranus which spin clockwise. Mercury, Venus, Earth and Mars are all considered terrestrial planets while Jupiter, Saturn, Uranus, and Neptune are considered Jovian planets—mostly balls of gas. Pluto has properties more like the moons of the Jovian planets, and in 2006 was reclassified as a dwarf planet.

Because the weight of an object depends on the mass of a planet and the gravitational attraction of that planet, an interesting exercise is to imagine what your weight would be on another planet. Using the gravitational factor from the table below you can see how much this can vary. If you weigh 120 lb on Earth, on Mercury you would weigh $120 \text{ lb} \cdot 0.38$, or 46 lb. On Neptune, you would weigh $120 \text{ lb} \cdot 1.2$, or 144 lb.

Now consider that your age depends on the number of Earth years that have passed, but a year on another planet is not the same length of time as it is on Earth. To find your age according to the length of another planet's year, divide your age in Earth years by the period of revolution (in Earth years) of the planet listed in the table below. If you are 47 Earth years old, on Mercury you would be $47 \text{ years} \div 0.241$, or 195 Mercury years old. On Neptune's orbit, you would be $47 \text{ years} \div 164.8$, or 0.285 years old. That is only 3 and a half Neptunian months old! The phrase “you can never be too slim or too young” takes on a

whole new meaning, but it may not be worth moving to Mercury or Neptune!

Planet	Etymology	Gravitational Force (relative to Earth)	Period of Revolution (relative to Earth years)
Mercury	Roman God of Commerce and Thievery – moves fast across the sky	0.38	0.24 (or 88 days)
Venus	Roman Goddess of Love and Beauty – easy to see	0.91	0.62 (or 225 days)
Earth	“Earth” is from the German originally but has many other names in many languages	1.0	1.0
Mars	Roman God of War	0.38	1.9 (or 687 days)
Jupiter	Roman King of the Gods – largest of planets	2.54	11.9
Saturn	Roman Father of Jupiter	0.93	29.5
Uranus	Greek God of the Heavens	0.8	84
Neptune	Roman god of the sea	1.2	164.8
Pluto	Roman God of the Underworld - dark and cold	.06	248.5

13. Earth Structures and Composition

Earth Science: Earth Structures and Compositions

Lesson Objective

In this lesson, we are going to cover the important features of our Earth.

Previously we covered...

We earlier reviewed the basic concepts of astronomy, including tools of the trade, our solar system, and the age of the universe.

Earth Science: Earth Structures and Composition

Introduction and Terms

In the second century BC, Eratosthenes calculated the size of the earth using simple geometry and measurements from the angles of shadows cast in two places. His calculations were amazing accurate. Some known characteristics of Earth:

Volume (using $\frac{4}{3} \pi r^3$) is $1 \cdot 10^{27} \text{ cm}^3$

Mass (calculated using law of gravity) is $5.5 \cdot 10^{27} \text{ g}$

Density is 5.5 g/cm^3 (compare Saturn's 0.687 g.cm^3 and Mars' 3.82 g.cm^3)

Since surface material density is 2.7 g.cm^3 the core must be more dense and is assumed to have a molten layer from earthquake evidence. Seismic vibrations travel through molten materials differently than from solid materials. The core is believed to be iron, nickel, or a combination of both. The core's temperature is over 2000K and under very high pressure.

Circumference of the Earth at equator is about 38,625 km (or about 24,000 miles). Since the earth rotates on its axis once every 24 hours at the equator you are traveling about 1,600 km (or 1000 miles) per hour. Seems like we would fly off at that speed but gravity keeps us here.

Time (for us) is dependent on the Earth and the sun. One earth rotation on its' axis is one day. There are $365 \frac{1}{4}$ days in 1 year or one trip of the Earth around the sun (revolution).

The tilt of the earth on its' axis and the revolution of the earth around the sun produces our seasons. Summer is when the sun's rays are most direct. Summer is June, July, and August in the northern hemisphere, and in the southern hemisphere summer is December, January, and February.

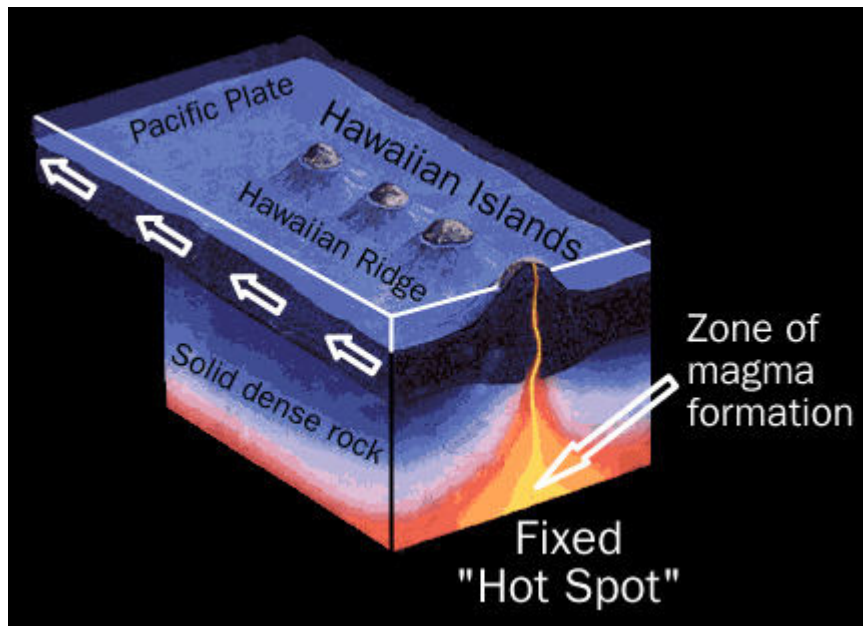
The Earth rotates through 1 degree every 4 minutes or 15 degrees every hour which is what defines the time zones. These lines marking every 15° are called longitude lines. They start in Greenwich, England, (0° longitude - the Prime Meridian) and move westward. This imaginary line that runs through the city's Royal Observatory and marks time for the entire world has been in place since 1884. 180° from the Prime Meridian and half way around the world is the International Date Line where days begin and end.

Earth Science: Earth Structures and Composition

Continental and Oceanic Crust

The surface of the earth is covered by what is labeled the **crust**. This is divided into two types: the continental and oceanic crusts. Because the density of the water is less than the density of the continent, the water floats on top of the continental crust. The oceanic crust is crust covered by ocean by virtue of its elevation. The oceanic crust is a little denser than continental crust as well as being much thinner.

The continental crust is formed as volcanic **magma** cools on the surface. Most of this volcanic activity is found in **subduction zones** where one plate is being pushed under another plate. As this liquid rock erupts, it spreads and repeatedly covers the surface in layers, and more continental crust is built up. Over time, particulate materials are carried by the wind or water and deposited on the surface along with seeds dropped by birds or carried by the wind or water. With time, plants grow and stabilize the surface. The Hawaiian Islands are good examples of land that was formed by volcanoes and populated this way. However, these islands are far away from subduction zones and are thought to be directly over what is called a "hot spot" (more than 3,200 km from the nearest plate boundary). Evidence that supports the explanation for this can be found by investigating the age of the island rocks. Those islands farthest from the active volcano are also the oldest.



Earth Science: Earth Structures and Composition

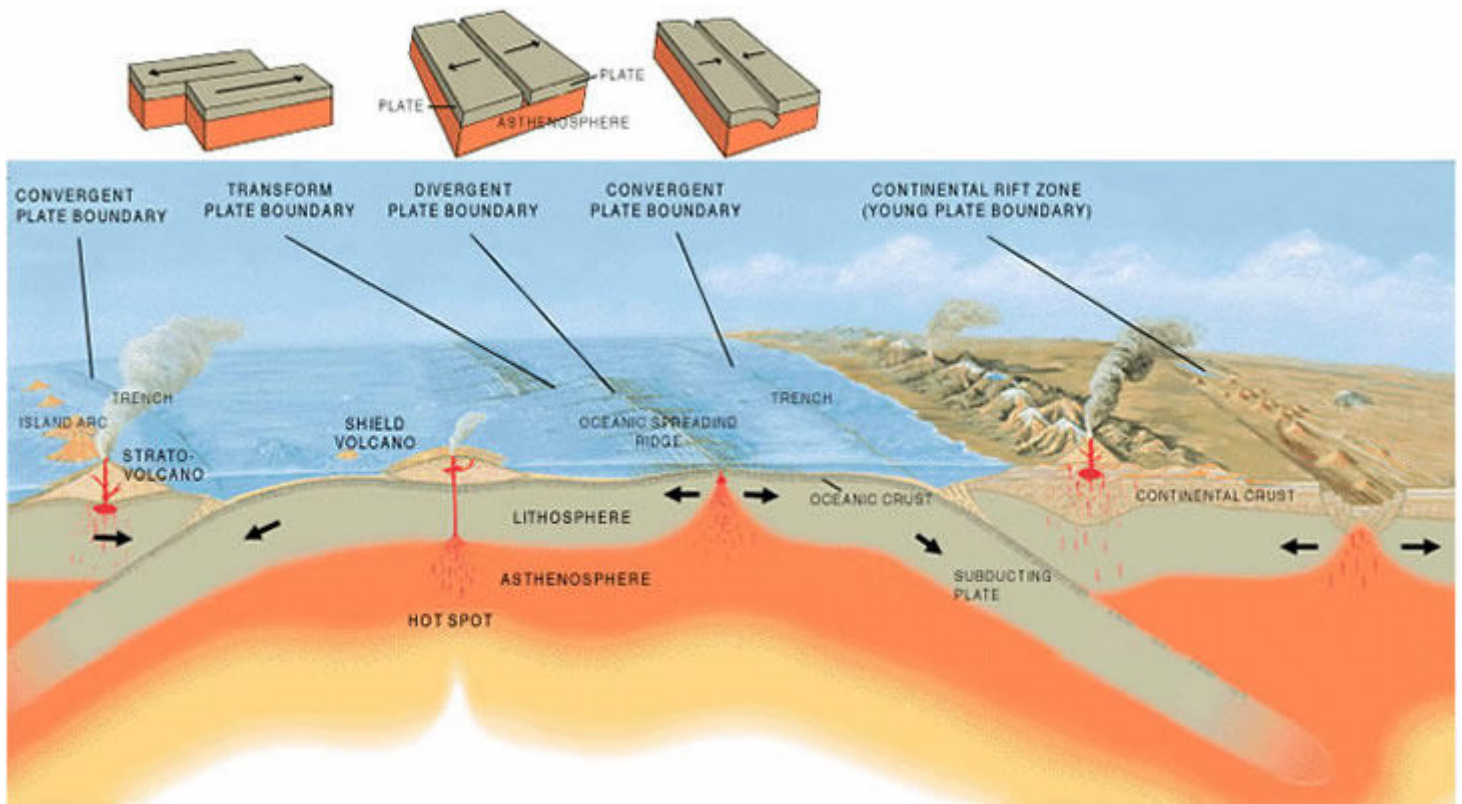
In areas where there is little stabilization from living inhabitants, weathering processes occur, including temperature changes that expand and contract the rocks, and rain which can freeze and crack the rocks or dissolve more soluble materials to expose and weaken the overall structure of the rocks. Eventually, over long periods of exposure, much of the rocks are either dissolved or deposited by erosion into the rivers and streams. These kinetically active areas spread the weathered materials to lower points of elevation and form such areas as fertile river deltas, rich in sediments that build up over time.

These areas can further be changed over time by wave action such as the New Orleans area where sediments are actually moved from the Mississippi river delta and deposited on Texas coastlines over time because of the currents in the Gulf of Mexico.

A result of the man-made levees that prevent the natural distribution and deposition of material through normal flooding is that the city of New Orleans is now actually below sea level and must be maintained that way with a pumping system. An event such as hurricane Katrina has the ability to re-establish the natural equilibrium; however humans call it a catastrophe because of the deleterious results to human endeavor.

The oceanic crust is formed in a similar way, that is, hot magma rises in areas to produce sea floor spreading. The mid Atlantic ridge is an area that evidence confirms the age of the rocks increase with increasing distance from the trench. It is believed that the mid Atlantic Ridge averages a rate of about 2.5 centimeters per year. This crust also disappears at a similar rate in subduction zones at the boundaries of the plates. How old are the oldest rocks on earth? According to most radiometric dating techniques, the oldest rocks are about 4.5 billion years old. These techniques have limitations in their accuracy however.

The spreading zones can clearly be distinguished from the subduction zones with their trenches.



Many of the theories about processes under the earth's surface are based on indirect evidence only as the deepest we have sampled under the continental crust is only about 12 kilometers. In many ways, this is similar to investigating space, using evidence such as seismic waves to infer what we cannot see.

Earth Science: Earth Structures and Composition

Layers of the Earth

The Earth is not a uniform solid object; it is composed of a series of layers of varying densities and characteristics. Our planet is made up of many constituent elements and compounds that are responsible for the components and physical properties of the planet we call home. The main layers are:

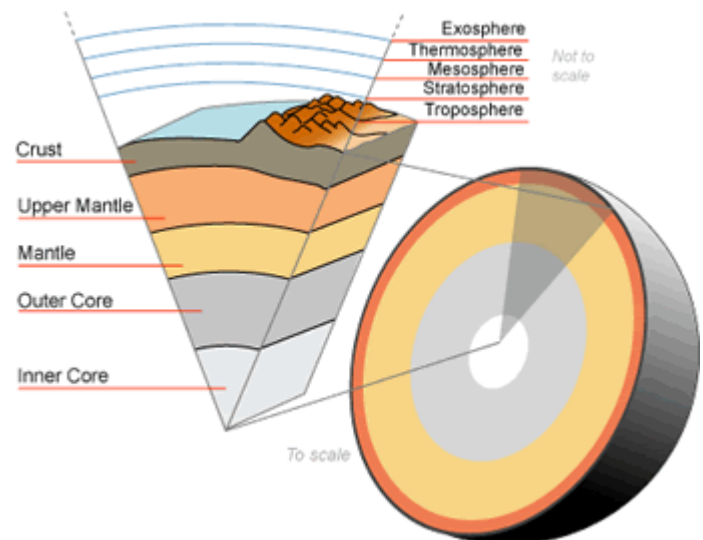
Mantle – uppermost layer – 2890 km deep

Lithosphere - includes the crust to 670 km deep

Asthenosphere - resides just below the lithosphere and is thought to be relatively plastic based on seismic evidence

Outer core – molten – 2890 km to 5150 km

Inner core – solid – 5150km to 6371km



Question:

Describe the constituency of the Earth.

- A The Earth is a uniform solid object.
- B The Earth is a solid object made of layers that do not interact.
- C The Earth consists of interactive layers of different materials with distinct properties.
- D The Earth is an object made from layers of materials with different properties that do not interact.

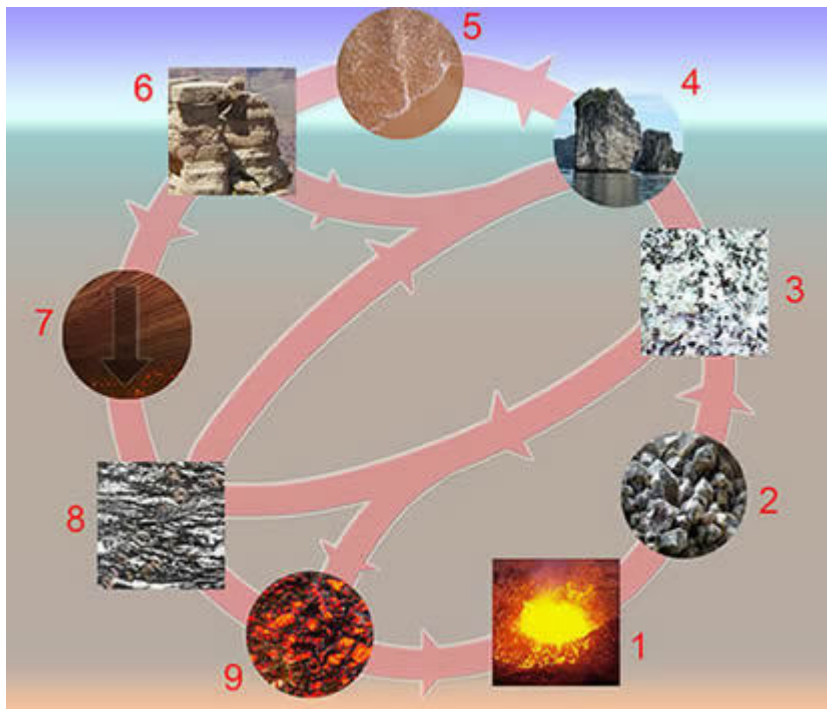
✓Answer

The correct answer is C. We know from seismic wave, microwave, and sonar analyses, that the Earth is not a uniform solid, but an interactive series of layers with different properties and materials.

Earth Science: Earth Structures and Composition

Formation processes of igneous, metamorphic, and sedimentary rocks

The rock cycle can be thought to begin when rocks are liquid, under intense heat and pressure (1). When this liquid reaches the earth's surface the rock cools and crystallizes (2) forming what is called igneous rock (3) either through volcanic activity or sea floor spreading. As they are exposed on the surface they are weathered through erosion (4) and transported by rivers and streams to become sediments such as mud and sand (5). If they are compacted and cemented together they can form sedimentary rocks (6). These rocks can then be subducted and buried (7) to become liquid magma once again or with intense heat and pressure can be metamorphosed to become metamorphic rock (8) found under mountains, for example. Metamorphic rock from mountains can also be eroded and



transported to be deposited as sediments or subducted (9) as well to become magma once again. These processes take many millions of years.

Earth Science: Earth Structures and Composition

Dichotomous Key for the identification of minerals

Dichotomous keys are an excellent tool to help scientists identify virtually anything by means of a series of choices based usually on the presence or absence of particular characteristics. For example, if we wanted to identify a rock that we found on a geology field trip, we would start out using some of the most basic characteristics of the rock in order to narrow the realm of possibilities. One such choice early-on in any rock or mineral key is coloration. Is the rock black or contain black particles? Is the rock brown or contain brown particles? And so on. After each choice, there would be a yes or no dichotomy, hence the name, dichotomous key. There are many such keys freely available and we encourage you to explore various resources at your disposal in order to find a simple and useful guide or dichotomous key for use in your classroom. Another useful exercise is to have students make a dichotomous key.

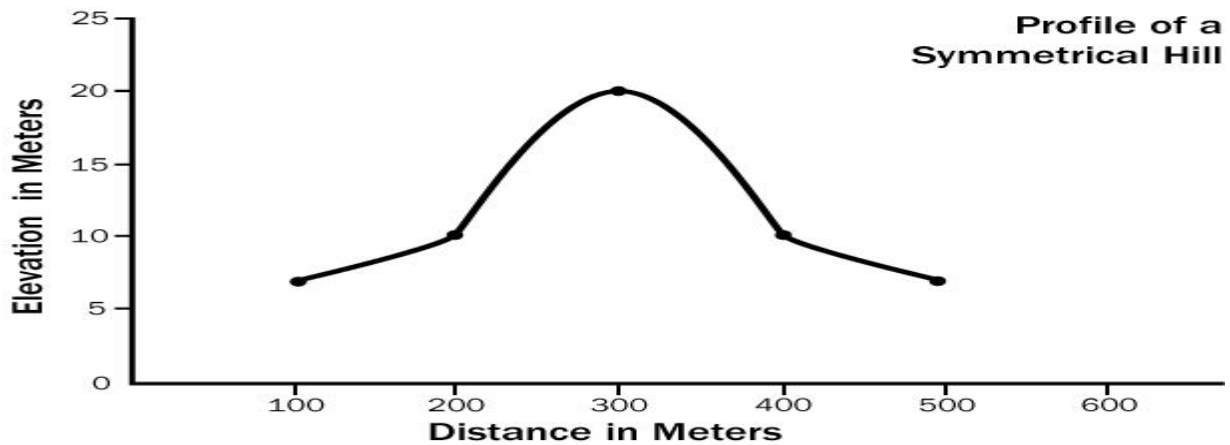
Earth Science: Earth Structures and Composition

Make and interpret contour maps and cross-sections

Contour maps are used to study the relative elevations of areas and can easily be interpreted with a little practice. By making careful measurements with a hand held GPS unit and a tape measure, a grid can be constructed of an area. This grid was constructed every 100 meters. The finer the grid, the more precise the contour map can be produced. Each number on the grid represents a vertical height in meters as well. Here is a simple example:



If you draw a line from A to B and graph the resulting relationship of elevations, you will see a cross section that represents the hill that you just measured.



If you drew a line from C to D and graphed that data, how would the graph differ? You would be correct to say that it would not differ at all. That is why this can be called a symmetrical hill.

14. Magnetic Field, Plate Tectonics, and Structural Geology

Earth Science: Magnetic Field, Plate Tectonics and Structural Geology

Lesson Objective

In the next lesson, we will cover the more complex components of our planet Earth, its magnetism, plate tectonics, and structural geology.

Previously we covered...

In the previous lesson, we reviewed the important basic components of our Earth, its geological processes, and how to map feature of Earth's topography.

Earth Science: Magnetic Field, Plate Tectonics and Structural Geology

Magnetic Fields

If you hold a **compass** in your hand (which is really just a magnet free to turn on its axis) it would point north because of the magnetic lines of force on the Earth. It would point to a place 1600 miles apart from the actual designated North Pole. The geologic record provides evidence that this magnetic north actually wanders over time. As magnetic (iron based) minerals (magnetite) cool in rocks they point to different places at different times. There is no clear explanation for the variation over time. One influence on the earth's magnetic field is the regular flares produced by the sun. Much research is needed to confirm existing theories about these relationships.

Earth Science: Magnetic Field, Plate Tectonics and Structural Geology

Plate Tectonics, Boundaries, Volcanoes, Earthquakes

There are six major plates (and more than a dozen minor plates) of lithosphere that are about 50 miles thick and almost float on top of the asthenosphere which is believed to be a very viscous liquid-

like layer of the Earth. These plates grind and push against each other at some margins while they pull apart at others. These compressional forces are what are believed to cause earthquakes, volcanoes, and mountain ranges.



Plate tectonics and active volcanoes

Earth Science: Magnetic Field, Plate Tectonics and Structural Geology

Elastic Rebound Theory

The elastic rebound theory explains how earthquakes most likely occur. The idea is that earthquakes are the result of an elastic rebound of previously stored potential energy in the form of tectonic built-up strain. Initially, there is a strain at a fault line between two rock faces with different directional forces. This elastic strain energy is stored over a period of time (usually very long periods of time, since plates move relatively slowly) and increases until it finally bursts the threshold of the sheering forces that contain it. The resulting shift creates waves of vibrations we call an earthquake and may repeat until the equilibrium is restored. The stored energy may be released as heat, deformation of the rock, or elastic waves. The elastic rebound theory is now our best explanation of how and why earthquakes happen.

Further Reading in Earth Science

Earth Science: Further Reading

Astronomy and Cosmology

The Illustrated on the Shoulders of Giants: The Great Works of Physics and Astronomy (Stephen Hawking): 2004

Astronomy for Dummies (Stephen P. Maran): 1999

The Backyard Astronomer's Guide (Terence Dickinson, Alan Dyer): 2002

Nightwatch: A Practical Guide to Viewing the Universe (Terence Dickinson): 1998

An Introduction to the Science of Cosmology (Graduate Series in Astronomy) (Derek Raine, Ted Thomas): 2002

Structure and Composition of Earth

The Practical Geologist : The Introductory Guide to the Basics of Geology and to Collecting and Identifying Rocks (Dougal Dixon): 1992

Physical Geology (Charles C Plummer, et. al.): 2004

Earth's Magnetic Field, Plate Tectonics and Structural Geology

Plate Tectonics: An Insider's History of the Modern Theory of the Earth (Naomi Oreskes-Editor): 2003

Plate Tectonics (Kent C. Condie): 1997

The Magnetic Field of the Earth (Ronald T. Merrill, et. al.): 1998

Earth Magnetism: A Guided Tour through Magnetic Fields (Wallace H. Campbell): 2001.

History of Earth

Earth: An Intimate History (Richard Fortey): 2004

A Short History of Planet Earth: Mountains, Mammals, Fire, and Ice (J. D. MacDougall): 1998.

Earth's Atmosphere

National Audubon Society Field Guide to North American Weather (David Ludlum): 1991

The USA Today Weather Book: An Easy-To-Understand Guide to the USA 's Weather (Jack Williams): 1997

Earth's Water

Prentice Hall Science Explorer: Earth's Waters (Barbara Brooks Simons, Thomas R. Wellnitz): 2002

Science Explorer: Earth's Waters (Michael J. Padilla PhD, et. al.): 2002

Ocean Currents (Catherine Halversen, et. al.): 2001

Only One Ocean (Catherine Halversen, et. al.): 2000

Glaciers & Glaciation (Douglas I. Benn): 1998

Earth's Resources and Hazards

Atmospheric Pollution (Mark Z. Jacobson): 2002

Pollution: Problems & Solutions (National Wildlife Federation): 1998

Growing Clean Water: Nature's Solution to Water Pollution (B. C. Wolverton, John D. Wolverton): 2001

The Earth's Resources (Steve Parker): 2001

Chapter: Physics

1. Work, Energy, Power, and Momentum

Physics: Work, Energy, Power, and Momentum

Lesson Objective

The lesson will cover the basics of energy, work, power, and momentum.

Physics: Work, Energy, Power, and Momentum

Energy

Energy is everywhere around us. It is a fundamental quantity that all physical systems contain in one form or another. The concept of energy is not difficult to understand. Energy is a quantity that can be moved or transferred from one place or from one form to another, and like mass, it cannot be created or destroyed. The simplest way to define energy is that energy is the ability to do work. All energy and work can be interconverted between actual work done, potential energy, and kinetic energy. Energy is also defined as the amount of work required to change the state of a physical system (e.g., from liquid to gas) Potential energy is sometimes called "stored energy".

Here are some of the ways that energy is stored:

- Chemical energy - Energy that is stored in chemical bonds. For example, remember the breakfast that you ate this morning? The calories contained in the chemical bonds are now available to your muscles as chemical potential energy.
- Gravitational energy - Energy that is stored in the gravitational field between two masses. This is sometimes also called potential energy.
- Elastic energy - Energy that is stored in objects that stretch or bend, like your skin, trees, rubber bands, strings, and diving boards.
- Kinetic energy is sometimes viewed as energy of motion, or expressed energy.
- A moving object has kinetic energy due to its' motion.
- A falling object possesses both potential and kinetic energy.
- A hot stove possesses both potential and kinetic energy.

Physics: Work, Energy, Power, and Momentum

How do we change energy between its various forms? Sometime this occurs naturally, as when an object falls toward the earth. "working." **Work** is done when energy is transferred from one place to another. More specifically, the amount of work done equals the amount of transferred energy. Here are a few examples of when work is done:

- Chemical energy stored in a battery transfers to radiant energy from a light bulb.
- Gravitational potential energy of elevated water transfers into kinetic energy as the water cascades over a water wheel.
- Chemical energy stored in the muscles of a mountain climber transfers into lifting energy as she climbs up a mountain.
- Random kinetic energy of individual water molecules in steam transfers into kinetic energy in a turbine.

In a parallel fashion, energy can be transferred from one form of storage into another. Using the examples from above, the electromotive force in a battery enables the energy to transfer from chemical energy to radiant and heat energies in the circuit. Similarly, the gravitational force enables energy to transfer from potential energy into kinetic and heat energies through the turning of a water wheel.

Physics: Work, Energy, Power, and Momentum

How would you explain the operation of a car in terms of energy and work? Think about all the ways that energy is converted, used, and stored during the car's operation. Also consider how forces enable the energy to transfer from one mode into another. Click on the following link to check your explanation:

👉Answer

Chemical energy is stored as chemical bonds in the gasoline. When gasoline combusts, the liquid is changed to a gas through combustion, and the gas expands to do work on the pistons. The pistons transfer the energy into kinetic energy that turns the drive shaft and the tires. The frictional force between the tires and the road transfers that kinetic energy to the kinetic energy of the car. Hence, the car moves.

Physics: Work, Energy, Power, and Momentum

How do we calculate work? When objects are moved, work is done when the applied force is in the same direction that the object will be moved. Motion in any other direction than the proposed direction of motion does not count toward the work being done. For example, when an object is lifted vertically, work (***W***) is calculated by taking the product of the force applied (***F***) and height that it is lifted (***h***). In this case the height the object is lifted against gravity becomes the distance, and the work is called "gravitational work". Thus the normal work equation $\text{Work} = \text{force}(f) \times \text{distance}(d)$ becomes:

$$W = F h$$

The force that we're lifting against is, of course, the gravitational force. This force is calculated by taking the product of an object's mass (***m***) times the strength of the gravitational field ($g = 9.8 \text{ N/kg}$ on the surface of the earth). So, our equation becomes:

$$\text{Work} = m g h$$

For example, how much work would it take to lift a 40 kg barbell to a height of 2 meters from the ground?

$$W = m g h = 40 \text{ kg} \cdot (9.8 \text{ N/kg}) \cdot 2 \text{ m} = 784 \text{ J}$$

Note: $m \times g$ is the weight of an object

Practice Question: How much work would it take to carry the same barbell 5 meters ***across the room?***

- A 784 J
- B 3784 J
- C 0 J
- D 5 J

👉 **Answer**

The correct answer is C. No work is done because the applied force (gravity in this case) is not in the direction of the motion. The calculation looks like this: $W = mgh = 40 \text{ kg} \cdot (9.8 \text{ N/kg}) \cdot 0 \text{ m} = 0 \text{ J}$

Physics: Work, Energy, Power, and Momentum

Working Simply

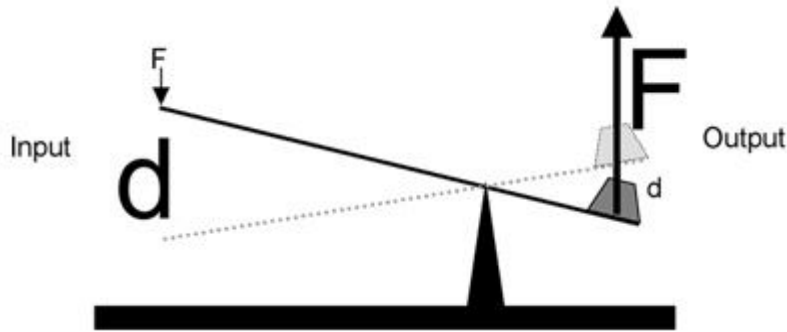
Sometimes we don't have the physical strength or mechanical power to apply enough force to get a job done. **Simple machines** are devices that make work easy. They can help us by changing the direction of the applied force, reduce the magnitude of the input force, or help to add speed to the rate at which work is done. This sounds almost magical, like we're getting something from nothing. But, alas, the law of energy conservation still governs the universe. Reduced forces applied through simple machines are a consequence of increasing distances. For example, the equation

$$\text{Work in} = \text{Work out}$$

$$(F d)_{\text{in}} = (F d)_{\text{out}}$$

Where F = force, and d = distance, the formula shows how an ideal machine transfers no energy to heat by frictional forces, since "work in" equals "work out."

A classic example, the lever, can significantly reduce the input forces and yield large output forces. The handle is easily moved over a large distance and an object is pried through a small distance as shown in the following figure:



Physics: Work, Energy, Power, and Momentum

The work equation can be written as follows in this case:

$$(F d)_{in} = (F d)_{out}$$

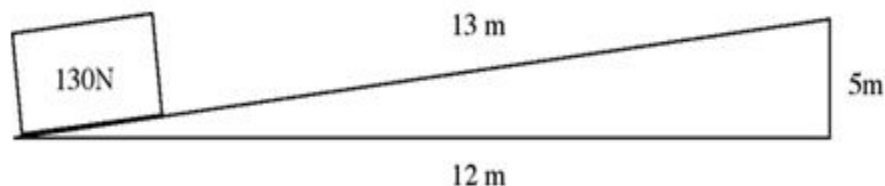
The mechanical advantage (MA) of a simple machine is the ratio between the output force (F_{out}) to the input force (F_{in}):

$$MA = \frac{F_{out}}{F_{in}}$$

For example, we can calculate the mechanical advantage for a worker using a hammer to pry out a nail. A 20 N force is applied to the handle that results in an 80 N force that pulls up on the nail. The mechanical advantage (**MA**) is calculated as follows:

$$MA = \frac{F_{out}}{F_{in}} = \frac{80N}{20N} = 4$$

The inclined plane is another example of a simple machine. Instead of lifting directly up against the gravitational force, the inclined plane enables the user to push with a smaller force a greater distance diagonally up the ramp. For example, a 130N box is pushed up the incline shown in the picture below.



We can calculate the force needed to push it up the ramp as follows:

$$(F d)_{in} = (F d)_{out}$$

$$F \cdot 13m = 130N \cdot 5m$$

$$F = 50 N$$

Calculate the mechanical advantage for this inclined plane.

▢ Answer

Pulleys, wedges, ramps, and screws are some other examples of simple machines that offer a mechanical advantage. It is a good exercise to think about how these simple machines save us work in our everyday lives.

Physics: Work, Energy, Power, and Momentum

Working Powerfully

What is the relationship between energy, work, and power? **Power (P)** is the rate at which work is done. For example, 100-Watt light bulb uses twice as much energy in a second as a 50-Watt light bulb. The following equation can be used to calculate power:

$$P = \frac{E_{\text{transferred}}}{\text{time}} = \frac{\text{Work}}{\text{time}}$$

Where ***E transferred*** is the energy that is transferred in the process of doing work and ***P*** is the total power of the system.

To calculate the power output of a 150N child that climbs 5 meters up a rope in 10 seconds, the following calculation is made:

$$P = \frac{\text{Work}}{\text{time}} = \frac{Fd}{t} = \frac{150\text{N} \cdot 5\text{m}}{10\text{s}} = \frac{750\text{J}}{10\text{s}} = 75\text{W}$$

Question: Who is more powerful: a man who lifts a 200-N barbell 2 meters vertically in 2 seconds, or a boy who lifts a 100-N barbell 1 meter in 0.5 seconds?

▢ Answer

They both have the SAME power:

$$P_{\text{man}} = \frac{\text{Work}}{\text{time}} = \frac{Fd}{t} = \frac{200\text{N} \cdot 2\text{m}}{2\text{s}} = \frac{400\text{J}}{2\text{s}} = 200\text{W}$$

$$P_{\text{boy}} = \frac{\text{Work}}{\text{time}} = \frac{Fd}{t} = \frac{100\text{N} \cdot 1\text{m}}{0.5\text{s}} = \frac{100\text{J}}{0.5\text{s}} = 200\text{W}$$

Physics: Work, Energy, Power, and Momentum

Conserving Momentum

Like energy and mass, the momentum of a system is also conserved. **Momentum (p)** is a product of an object's mass (***m***) and its velocity (***v***):

$$p = m v$$

In other words, momentum is a product of a mass in motion. Momentum also has direction associated with it and is considered a vector. For example, we can calculate the momentum of a 2000 kg car heading north at a speed of 20 m/s.

$$\mathbf{p} = m \mathbf{v} = 2000\text{kg} \cdot 20 \text{ m/s} = 40,000 \text{ kg m/s north}$$

But what about momentum being conserved? This concept is a consequence of Newton's second law and can be written as:

$$F_{\text{net}} = ma = m \frac{\Delta v}{\Delta t} = \frac{\Delta mv}{\Delta t} = \frac{\Delta p}{\Delta t}$$

The equation now becomes:

$$F_{\text{net}} = m\Delta v / \Delta t = \Delta p$$

$$\text{or } F_{\text{net}}(\Delta t) = m(\Delta v) = \Delta p$$

F_{net} is the net force of the system, Δv is the change in velocity, Δt is the change in time, and Δp is the change in momentum. The term $F_{\text{net}}(\Delta t)$ is called impulse, and is exactly the same quantity as $m(\Delta v)$. It gives us another way to view momentum.

If there is no net force applied to a system, then this implies that Δp is zero. In other words, with no unbalanced force on a system there is no momentum change.

$$\begin{aligned} (\Delta p = 0)_{\text{system}} \\ (p_f - p_i = 0)_{\text{system}} \\ (p_i = p_f)_{\text{system}} \end{aligned}$$

where p_i is the initial momentum of the system and p_f is the final momentum of the system.

For example, consider a billiard ball moving at 2 m/s that squarely strikes an identical billiard ball that's at rest. The moving ball stops and the momentum is completely transferred to the other ball, which picks up a speed of 2 m/s. Momentum is NOT conserved for the first billiard ball alone because it experiences a net force. Momentum IS conserved for the SYSTEM of both balls because the collision forces are internal to the system.

Physics: Work, Energy, Power, and Momentum

What if two objects of different masses collide? For example, what if a 2000-kg boxcar moving at 30 m/s hits and links with a 1000-kg boxcar that's initially at rest? How fast does the combination move after the collision? To answer this, we must note that the amount of moving mass increases after the collision. This means that the speed of the system must decrease so that the momentum is conserved.

$$\begin{aligned}
 (p_i &= p_f)_{system} \\
 (m V_i &= M V_f)_{system} \\
 (2000\text{kg} \cdot 30\text{m/s} &= 3000\text{kg} \cdot v_f)_{system} \\
 v_f &= 20\text{m/s}
 \end{aligned}$$

Another example of momentum conservation is in the operation of rockets. As a rocket ejects combusted gases rearward at high velocities, the more massive rocket is propelled forwards at a lesser velocity. In other words, the backward momentum of the exhaust gases equals the forward momentum of the rocket.

Try this one on your own. A 20-kg child holding a 2-kg brick is standing still on the slick surface of an ice skating rink. She throws the brick forward at a speed of 5 m/s. Completely describe her resulting motion and calculate her speed.

Answer

$$\begin{aligned}
 (p_i &= p_f)_{system} \\
 (m V_i &= M V_f)_{system} \\
 22\text{kg} \cdot 0\text{m/s} &= 2\text{kg} \cdot 5\text{m/s} + 20 \cdot v_f \\
 v_f &= -0.5\text{m/s}
 \end{aligned}$$

2. Mechanics of Fluids

Physics: Mechanics of Fluids

Under Pressure

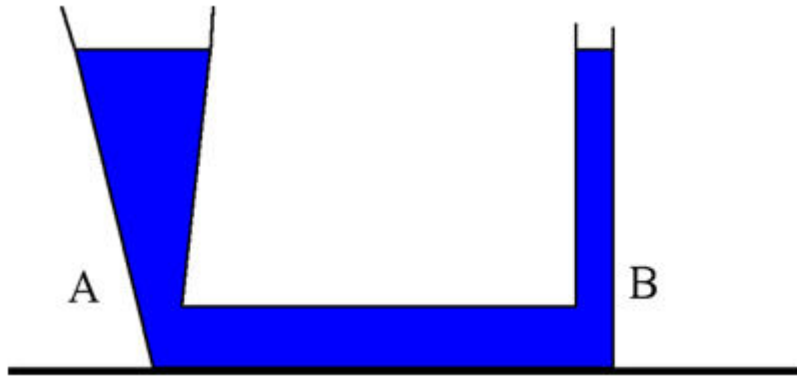
When we increase our altitude, our ears sometimes “pop” indicating that we experienced a change in air pressure. When we swim deep under water, we feel the pressure increasing. Pressure, then, is dependent on our vertical location in a liquid or a gas. The **pressure (P)** exerted by a fluid on an object is defined as the ratio of the perpendicular force (F) of the fluid on the object to the surface area (A) over which the force acts:

$$P_2 - P_1 = \rho g h$$

Fluids such as water are considered to be **incompressible**, meaning that their density does not change significantly with pressure. This simplifies the calculation for pressure underwater since density (ρ) is not a function of depth (h) from the top of the water. The pressure under water is calculated using the following formula:

$$P_2 = P_1 + \rho g h$$

where P_1 is the pressure at the top of the water, P_2 is the pressure at depth h , ρ is the density of the fluid, and g is the gravitational field strength (9.8 N/kg on the earth).



For example, the pressure on top of the water shown above is $1.01 \cdot 10^5 \text{ Pa}$ and the density of water is $1.000 \cdot 10^3 \text{ kg/m}^3$. Both points A & B are 2.0 meters below the water level. How do the pressures at points A & B compare? Try using the equation above to calculate each pressure.

✓Answer

Since both A and B are the same distance below the water, their pressures will be the same and are calculated as follows:

$$P_2 = P_1 + \rho g y$$

$$P_2 = 1.01 \cdot 10^5 \text{ Pa} + (1.000 \cdot 10^3 \frac{\text{kg}}{\text{m}^3})(9.8 \frac{\text{N}}{\text{kg}})(2\text{m})$$

$$P_2 = 1.01 \cdot 10^5 \text{ Pa} + 1.96 \cdot 10^4 \text{ N/m}^2$$

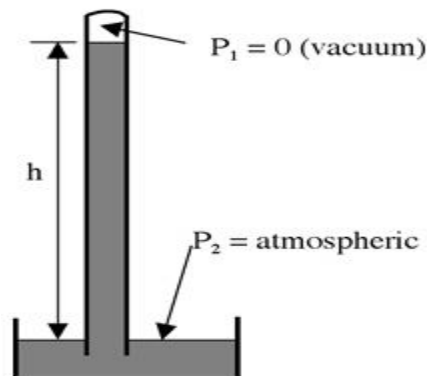
$$P_2 = 1.21 \cdot 10^5 \text{ Pa}$$

Physics: Mechanics of Fluids

How much pressure is under all this air?

Now that we understand how we can measure pressures at different depths in incompressible fluids, is there a way we can measure air pressure?

A mercury barometer is a simple device that measures our atmospheric pressure. It consists of a sealed tube that is filled with mercury and inverted so that the open end is upside-down in a pool of mercury.



The fluid level in at the top (closed) end of the tube changes depending on the atmospheric pressure, and the pressure is nearly zero in the empty (vacuum) space at the top of the tube.

Since mercury is considered to be incompressible, we can apply the pressure formula from the previous section:

$$P_2 = P_1 + \rho gh$$

$$P_{atm} = 0 + \rho gh$$

$$P_{atm} = \rho gh$$

$$\text{where } \rho = 13.6 \text{ kg / m}^3 \text{ for mercury}$$

$$\text{and } g = 9.8 \text{ N / kg at the surface of the earth}$$

If the height of the barometer tube is 780 millimeters, try calculating the atmospheric pressure using the equation above. Click here to check your [answer](#).

Physics: Mechanics of Fluids

Floating and sinking bodies (Archimedes principle)

Previously we learned that pressure results from molecular forces acting on a specific surface area.

Try pushing a beach ball under water and it will be forced up to the surface. Float on your back in the water and a force will support you (called buoyant force). The **buoyant force** is the net upward force caused by different fluid pressures at varying depths. Archimedes (ca. 287-212 B.C.) was a Greek scientist who recognized this, and developed the equation for determining the buoyant force on a submerged or partially submerged object.

Archimedes principle is stated as follows: the magnitude of the buoyant force (F_B) equals the weight of the fluid (W_{fluid}) displaced by the object. In equation form, it looks like this:

$$F_B = W_{fluid}$$

For example, using Archimedes principle, we can determine if a square wood raft (3m on each side and 0.4 m thick) floats on the water. Assume the wood has a density of 500 kg/m³. The volume, mass, and weight of the raft can first be calculated:

$$Volume_{raft} = 3m \cdot 3m \cdot 0.4m = 3.6m^3$$

$$mass_{raft} = \rho \cdot Volume = (500 \frac{kg}{m^3})(3.6m^3) = 1800kg$$

$$W_{raft} = mg = 1800kg(9.8 \frac{N}{kg}) = 1.8 \cdot 10^4 N$$

The maximum possible buoyant force for the raft can be determined by finding the greatest weight of water the raft can displace (using the density of water to be 1.000 10³ kg/m³):

$$F_{B_{\text{max}}} = \rho_{\text{water}} V_{\text{raft}} g = (1.000 \cdot 10^3 \frac{\text{kg}}{\text{m}^3})(3.6 \text{m}^3)(9.8 \frac{\text{N}}{\text{kg}})$$

$$F_{B_{\text{max}}} = 3.5 \cdot 10^4 \text{N}$$

Since this maximum buoyant force is greater than the weight of the raft, the raft can be supported.

Now try this on your own: How deep is the raft beneath the water when its weight is fully supported?

Answer

$$W_{\text{raft}} = \rho V g = \rho (l w h) g$$

$$h = \frac{W_{\text{raft}}}{\rho l w g} = \frac{W_{\text{raft}}}{\rho l w g} = \frac{1.8 \cdot 10^4 \text{N}}{1000 \frac{\text{kg}}{\text{m}^3} (3 \text{m})(3 \text{m})(9.8 \frac{\text{N}}{\text{kg}})}$$

$$h = 0.2 \text{m}$$

Physics: Mechanics of Fluids

The Venturi Effect (Bernoulli's principle)

In our discussion of fluids so far, we have focused on fluids that are in static equilibrium (*i.e.*, at rest). What happens when fluids are in motion? You might expect that pressures go up when a fluid is in motion, but just the opposite happens. When the speed of a fluid increases, its pressure decreases.

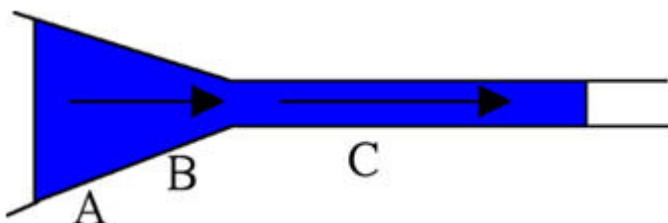
When water flows through a pipe, the amount of water flowing per second is constant, even if the diameter of the pipe changes. For example, when you put your thumb over the end of a garden hose, the water has to move faster through the closed end so that the flow rate (gallons per second) remains the same. This means that water speeds up in narrow parts and slows down in wider parts so that the volume flow rate remains constant.

Daniel Bernoulli (1700-1782) discovered that speed, pressure, and elevation are related for incompressible fluids like water. **Bernoulli's principle** can be stated as follows, if the elevation of the fluid does not change: **when the speed of a fluid increases, its pressure drops**. This aspect of Bernoulli's principle is sometimes called the **Venturi effect**.

Physics: Mechanics of Fluids

Now let's apply Bernoulli's principle to the water flowing through the tube pictured below.

Question:



1. Which section has the greatest volume flow rate?

- A A
- B B
- C C
- D They all have the same flow rate

✔**Answer**

The answer is D. Water cannot be created or destroyed and is also incompressible. Therefore, the volume flow rate (gallons per minute) must be constant throughout the pipe.

2. At which point does the water have the greatest speed?

- A
- B
- C
- All three have the same speed.

✔**Answer**

The answer is C. The smaller the cross section, the greater the speed so that the volume flow rate remains constant.

3. At which point does the wall experience the MOST pressure?

- A
- B
- C
- Each point has the same pressure.

✔**Answer**

The answer is A. The greatest pressure is where the speed is the least according to Bernoulli's principle.

3. Thermodynamics

Physics: Thermodynamics

Calorimeters and specific heat

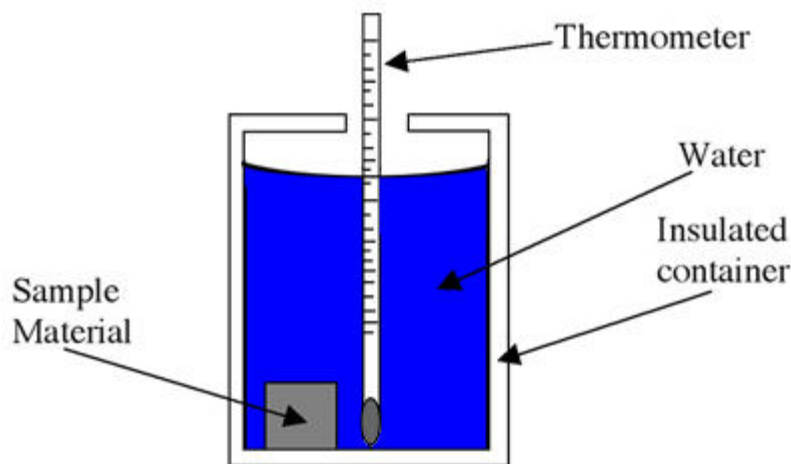
Energy must be added to matter in order to increase its temperature. The amount of energy (Q) needed to heat any material depends on three quantities:

- The temperature change (ΔT) that the material experiences.
- The mass (m) of the material.
- The specific heat capacity (c) of the material, with units of $J/(kg \text{ } ^\circ C)$

The equation looks like this:

$$Q = cm\Delta T$$

The specific heat capacity of a material can be determined using an instrument called a **calorimeter**. To use a calorimeter, begin by heating a sample of the material to a known temperature (like the boiling point of water). Then, the sample is placed in an insulated container that is filled with a known mass of water at a known temperature. Eventually, both the water and the sample reach a common temperature (equilibrium). Since the system is isolated in an insulated container, heat energy from the sample transfers to the water and the container. According to the law of conservation of energy, the heat energy lost by the sample equals the heat energy gained by the water and the container. Using this law along with the equation for heat above, the specific heat capacity of the material may be calculated.



Physics: Thermodynamics

Ideal gas model

In the chemistry review, you studied the following three main points for the kinetic theory of gases:

- The particles in gases are in constant, random motion.
- The motions of the particles are unaffected by one another unless they experience a collision.
- Electromagnetic forces between gases can be ignored under most conditions.

The molecules in real gases, however, have complex shapes that are capable of having electromagnetic interactions. At high pressures and at low temperatures these interactions may be significant. At most conditions, however, **the ideal gas model** may be adequate to describe how gases interact. Molecules in ideal gases are sufficiently far apart so they have very few interactions. In fact, we can assume that the interactions they do have are elastic, meaning that they occur without

any loss in kinetic energy. Although no gas is truly “ideal,” the ideal gas model is appropriate in a large number of cases

Physics: Thermodynamics

Law of partial pressures

Gas pressure is the result of the collision of gas particles with an object. What would happen to the pressure if the number of particles in a certain volume were increased? Kinetic theory of ideal gases predicts there will be more collisions between the particles and thus more pressure. Besides depending on the number of particles, pressure also depends on the average kinetic energy of the particles, or temperature.

What if different gases are combined at a constant volume and temperature? At constant temperature, the average kinetic energy of the mixture is constant and the type of gas particle is not important. Each gas will contribute to the new pressure as it is combined with the mixture. The contribution of each gas in the mixture makes to the total pressure is called the [partial pressure](#). John Dalton (1766-1844) proposed that in a mixture of gases, the total pressure is simply the sum of all the partial pressures in the gases. This is called the [law of partial pressures](#).

For example, consider two gas containers. One is filled with oxygen gas at a pressure of 300 kPa, another is filled with nitrogen gas at a pressure of 400 kPa, and both containers are at the same temperature of 25 ° C. If both gases are combined in the same container, what is the pressure of the combined gases?

✓[Answer](#)

According to the law of pressures we add the pressure of the oxygen (P 1) to the pressure of the nitrogen (P 2) as follows:

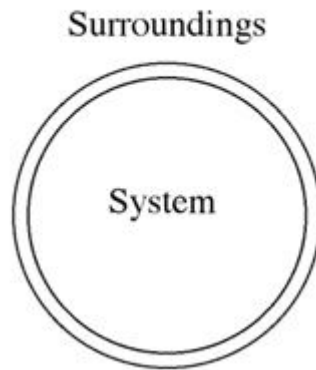
$$P_{\text{total}} = P_1 + P_2 = 400\text{kPa} + 300\text{kPa} = 700\text{kPa}$$

Physics: Thermodynamics

Heat is a “special form” of energy, right? Well, not really. Energy is energy. As you’ve already learned, energy cannot be created or destroyed, but it may be transferred, transformed, and/or stored. The **first law of thermodynamics** is another name for the law of conservation of energy for a system. If heat flows into a system from its surroundings, the system gains internal energy as the random kinetic energy of its particles increases. Likewise, a system will also gain energy if an outside agent does work on the system through the application of forces.

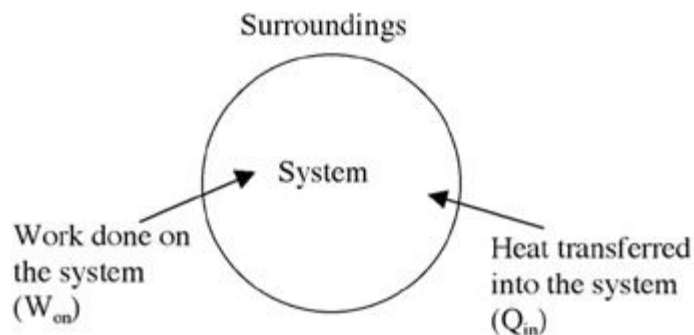
The figure below shows an isolated (insulated) system in which the energy stays constant.

Isolated system



The next figure shows a system that has energy flowing in from the surroundings.

System gaining energy



The first law of thermodynamics predicts the change in internal energy (ΔE_{int}) of a system as follows:

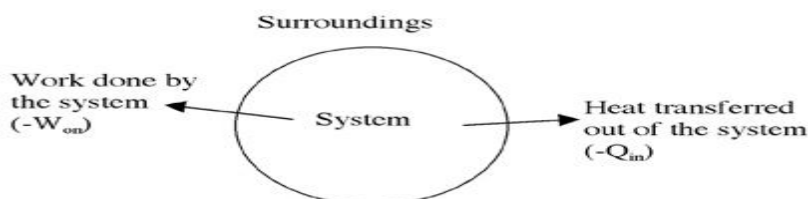
$$\Delta E_{int} = Q_{in} + W_{on}$$

Where Q_{in} is the heat that transfers into the system and W_{on} is the work done on the system.

Physics: Thermodynamics

If the system is doing work on its surroundings, the internal energy of the system decreases. Then W_{on} is considered to be negative (see figure below). If heat flows out of the system, the internal energy of the system also decreases and Q_{in} is considered to be negative.

System losing energy



For example, let's say that 5 joules of work are done by stirring a beaker of warm water. During this time, 15 joules of heat leave the poorly insulated container. By how much did the internal energy of the container/water system change?

✓Answer

Assuming that the beaker is the system, the process of stirring added heat energy to the system making $W_{\text{on}} = +5\text{J}$. Since heat flowed out of the container, the system loses energy making $Q_{\text{in}} = -15\text{J}$. Therefore,

$$\Delta E_{\text{int}} = Q_{\text{in}} + W_{\text{on}}$$

$$\Delta E_{\text{int}} = -15\text{J} + 5\text{J}$$

$$\Delta E_{\text{int}} = -10\text{J}$$

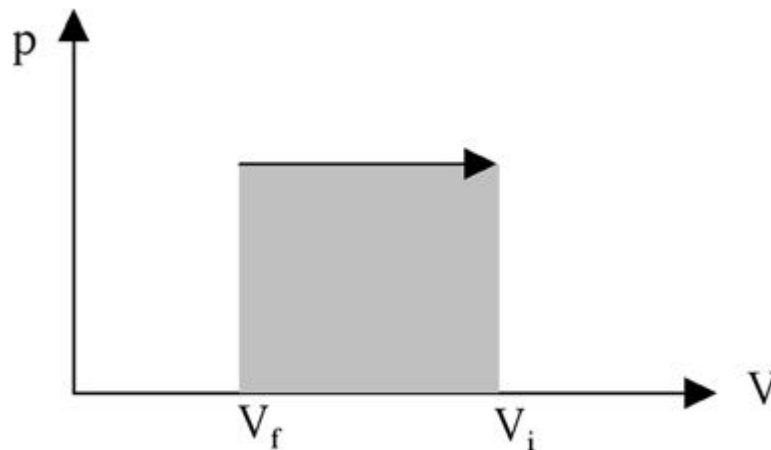
The system lost 10 joules of internal energy.

Physics: Thermodynamics

p-V diagrams

Ideal gases may do work through changes in pressure, volume, and/or temperature. Thermodynamic processes of ideal gases are represented on a pressure-volume (p-V) diagram. By knowing both the pressure and volume at any point on the graph, the state of the gas is completely specified. Three common thermal processes for enclosed gases are isobaric, isochoric, and isothermal.

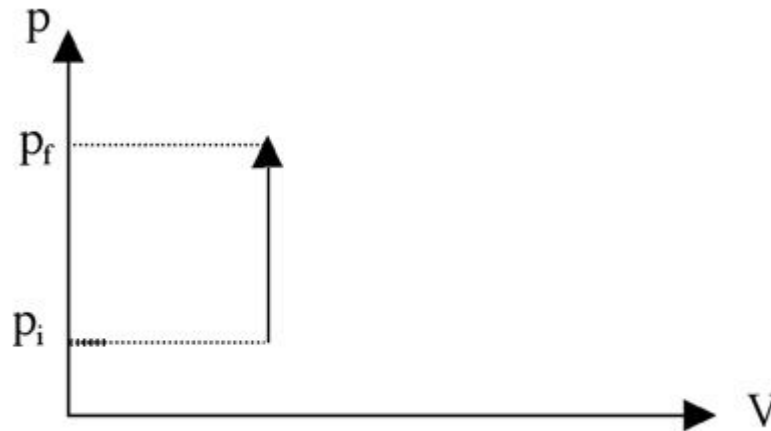
An isobaric process is one that occurs at constant pressure. For example, a heated gas in a container expands to lift a piston that applies a constant pressure. In the process of lifting the piston, work is done by the gas in increasing its volume. This is represented as follows on a p-V diagram:



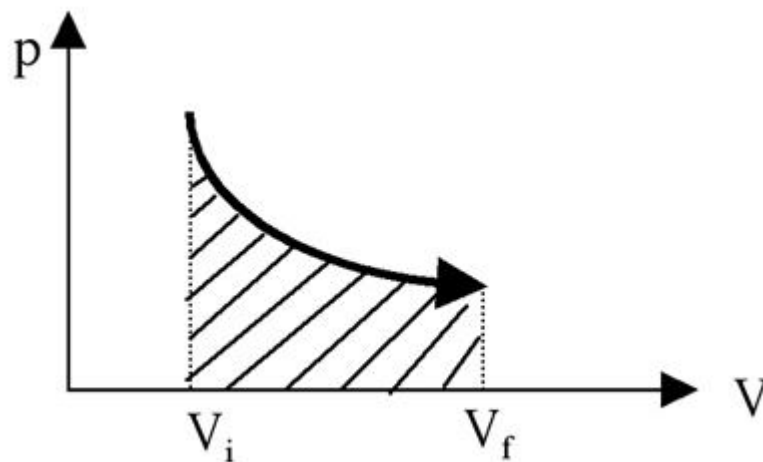
The area of the shaded region represents the energy transferred from the gas to the gravitational energy stored in the lifted cylinder.

An isochoric process is one that occurs at constant volume. For example, a heated gas in a closed container has no room to expand; therefore its pressure must rise. Even though the gas exerts more

and more force on the walls, the walls do not move and the gas does no work on the container. This process is represented on the following p-V diagram:

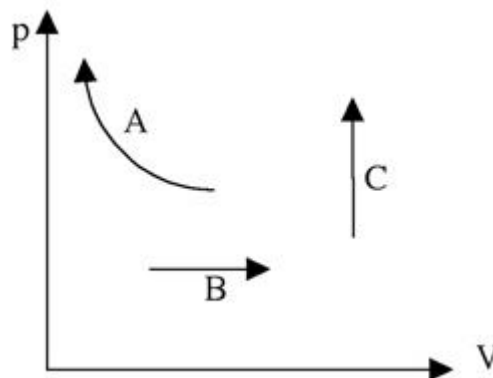


An **isothermal process** is one that occurs at constant temperature. The pressure and volume of the gas must both change in order for the temperature to remain constant. For example, the following p-V diagram represents an ideal gas expanding isothermally:



Notice how the pressure decreases and the volume increases. The area of the shaded region represents the energy transferred from the gas to its surroundings during the expansion.

Physics: Thermodynamics



Consider the p-V graph above and answer the following questions.

1. Which line demonstrates an ideal gas heated isochorically?
2. Which line demonstrates isothermal compression of an ideal gas?
3. Which line demonstrates isobaric expansion of an ideal gas?

👉 Answers

1. The answer is path C. Isochoric heating occurs at constant volume while the pressure increases.
2. The answer is path A. In isothermal compression occurs at a constant temperature. As the pressure of the gas increases, the volume of its container decreases.
3. The answer is path B. Isobaric expansion occurs when the volume of the container increases while the pressure remains constant.

Physics: Thermodynamics

Refrigerators and air conditioners

Refrigerators and air conditioners are devices that rely on the laws of thermodynamics in order to operate. Both devices move heat energy from one location to another through the change of phase using a refrigeration fluid (like Freon) Actually, they are heat engines that operate in reverse. That is, instead of using the P-V concept to do work on their surroundings, these devices remove heat energy (the ability to do work) from an enclosed space and expel that energy as a waste product thereby producing a cooling effect on the enclosed space. Stand outside near a working air conditioner and you can feel the expelled heat.

The **second law of thermodynamics** states that heat naturally flows from warm regions to cold regions. This is bad news for refrigerators. In order to keep the interior of a refrigerator cold, a pump must do work to force the refrigerant through small openings inside the cooling unit. As the refrigerant evaporates, unwanted interior heat is transferred into it. Thus, the refrigerant enters the exterior condenser coils of the refrigerator as a gas. When the gas condenses back into the liquid phase in these coils, it releases heat energy into the kitchen (the surroundings) before it is pumped back into the cooling unit to repeat the cycle. Air conditioners operate in the same way as refrigerators, except they pump heat energy from inside the house to the outdoors.

Let's check your understanding with the following question. Is it possible to cool your house by leaving the door of the refrigerator open?

👉 Answer

While you initially feel cooler when the door of the refrigerator is open, the refrigerator will start to do more work to move the heat from inside the refrigerator to the outside. Unfortunately, that heat will enter right back into the kitchen from the coils. In addition, according to the second law of thermodynamics, energy from the work is also deposited in the kitchen.



Classroom Demonstration Video

In order to view this video, you must have RealPlayer installed on your computer. If you do not, you may download it for free from [this site](#).

This video demonstrates the first and second laws of thermodynamics.

To watch with a dial up connection click [here](#).

To watch with a high speed connection click [here](#).

4. Mechanical Waves

Physics: Mechanical Waves

Lesson Objective

In this lesson, we'll study how wave energy transfers through or across a material.

Previously covered:

Energy has the capability of producing change, and that energy can be transferred from one location or form to another without losing any energy.

Physics: Mechanical Waves

Wave Energy

Drop a pebble in a lake and waves spread out in all directions. Clap your hands and sound waves move throughout the air around you. Shake the end of a taut rope and a wave pulse moves down the rope. In each case, a disturbance produces waves, and this disturbance moves through or across a material (water, air, and the rope in our examples). The material through which the wave travels is called the [medium](#).

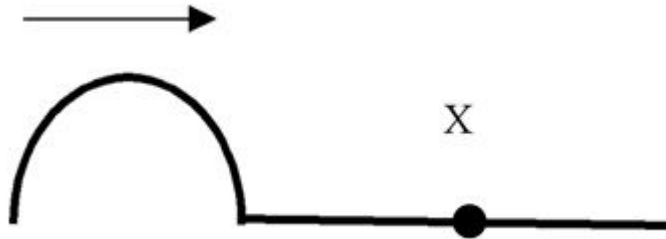
What exactly is a wave? A [wave](#) is disturbance that carries energy and moves through a medium without producing a net change in the medium. But in what way does this wave move through the medium? When waves hit a bobber floating in the water, for example, the bobber simply “bobs” up and down (as well as forward and backward). So the bobber (which is part of the medium) vibrates as the wave energy goes through it. Likewise, in the case of the wave moving down the rope, the rope also vibrates as the wave moves through it. In other words, the medium does not follow along with the wave. As a rule, wave energy propagates through a medium without any gross displacement of the medium itself.

Vibrations of physical objects disturb air and produce sound waves. A guitar string, for example, vibrates the surfaces in the guitar. These surfaces push back and forth on the air and sound waves spread out into the room. The particles of air between the source and the receiver vibrate back and forth as the sound energy travels through them. If the air vibrates back and forth 256 times per second, the receiver hears the note “C.” The more intensely the air vibrates, the louder the note is perceived. Sound can also travel through other media like water and steel.

Physics: Mechanical Waves

Answer the following question and click on the link that follows to check your answer.

Question: As the wave pulse travels to the right in the rope pictured, what happens to the section of rope marked "X?"



- A It moves to the right along with the wave and stays slightly displaced after the wave passes through it.
- B It vibrates up and down as the wave energy travels through it, then returns to its former position.
- C It stays stationary.
- D It moves slightly to the left to displace the wave's energy.

✓Answer

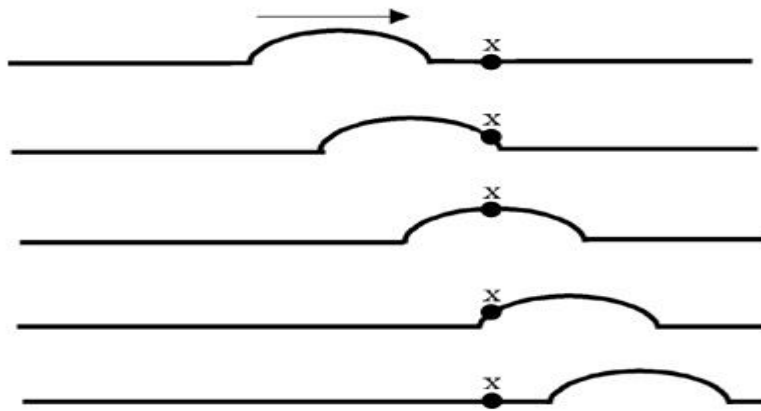
The correct answer is B. The medium simply vibrates as the wave energy travels through it. With waves, there is never any gross displacement of the medium.

Physics: Mechanical Waves

Transverse and Longitudinal Waves

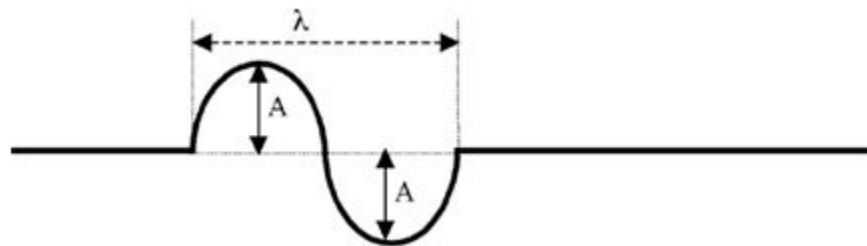
In the last lesson, we reviewed the fact that a medium vibrates as wave energy travels through it. Depending on the type of wave, the medium may vibrate in different ways relative to the motion of the wave.

If the medium vibrates up and down at 90-degree angles to the motion of the wave, the wave is classified as a **transverse wave**. For example, the point "X" on the rope pictured below first travels up and then down as the wave crest travels to the right.



Besides traveling along ropes, waves also possess transverse characteristics in other media like water. In the previous lesson, we discussed how a bobber in the water moves up and down vertically as a wave moves through it (although it also has some vibration forward and backward). As we shall see in the lesson on polarization, light is also classified as a transverse wave.

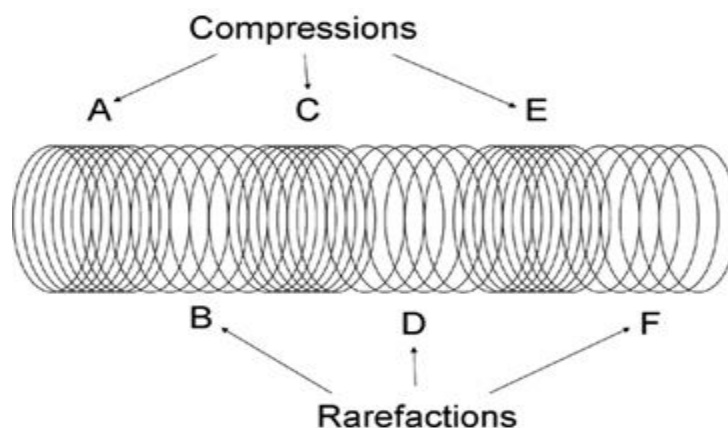
One complete transverse wave is pictured below:



Physics: Mechanical Waves

The length of one complete wave (a full crest and a trough) is called the **wavelength** (λ), as shown on the figure. The **amplitude** (A) of the wave is the distance from the normal at rest position of the medium or midpoint of the wave's vibration to either the top of the crest or the bottom of the trough.

If the medium vibrates back and forth along the same direction that the wave moves, the wave is classified as a **longitudinal wave**. For example, consider shaking the end of a large-coil spring (a.k.a. Slinky) along the axis of the spring as follows:



As the compressions move through the spring, the coil labeled C will initially move slightly to the right, then to the left, and finally back to where it started. Because the coil moves along a line parallel to the motion of the pulse, this wave is a longitudinal wave. Sound waves are also longitudinal because air compressions and rarefactions vibrate air molecules in a similar manner. The wavelength of a longitudinal wave is the distance from compression to compression. The amplitude (or intensity) of the wave is measured by determining the density of the medium. For example, the amplitude at point C in the spring picture above would be the number of coils per centimeter.

Physics: Mechanical Waves

To check your understanding, answer the following question. Check your answer with the link that follows.

Question: Two children construct a primitive “phone” by attaching a tight wire in between the ends of two tin cans. How would you classify the wave that they use to communicate with from can to can?

- A Transverse
- B Longitudinal
- C Both transverse and longitudinal
- D Neither transverse nor longitudinal

👉Answer

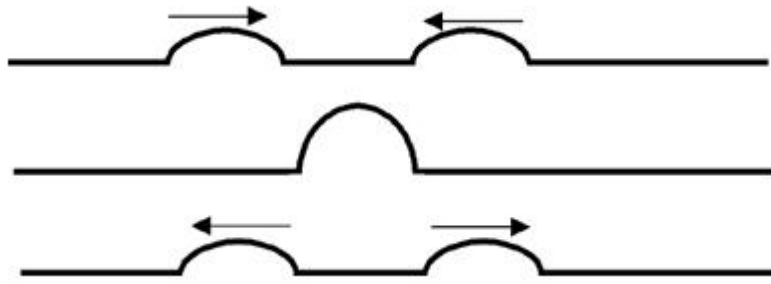
The correct answer is B. The longitudinal sound vibrations that travel from child #1 push the ends of the can back and forth along the length of the wire (like the diaphragm on a microphone). These vibrations travel along the wire and continue to make it vibrate back and forth parallel with the motion of the wave. This vibration causes the receiving can to act as a speaker that also produces longitudinal waves.

Physics: Mechanical Waves

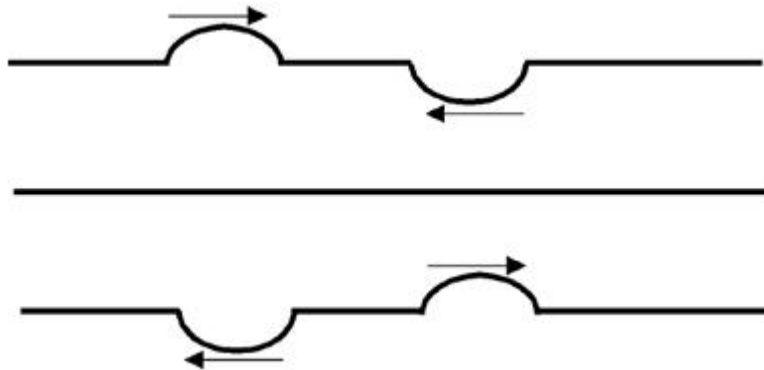
Wave Superposition and Interference

What happens when a wave hits another wave? Do waves collide like particles? The answer is **NO**. Since waves are energy they are able to pass right through each other and occupy the same place in the medium as they move along the medium. This process is called interference.

For example, imagine what happens when a wave crest hits another identical wave crest. When they are on top of each other, the size (or amplitude) of the wave doubles. This is called **constructive interference** and is demonstrated with the following diagram:



What happens when a wave crest hits an equal sized wave trough? The amplitudes actually cancel temporarily as they collide or pass through each other. This is called **destructive interference** and is demonstrated with the following diagram:



This addition and subtraction of wave amplitudes is governed by the **superposition principle**: the net amplitude of two waves at the same location in space is the sum of their individual amplitudes, where a crest has positive amplitude and a trough has negative amplitude. For example, the amplitude of the combined wave when a $+0.2\text{m}$ crest meets a $+0.1\text{m}$ crest is a wave with amplitude of $+0.3\text{m}$.

Physics: Mechanical Waves

Try this on your own and click on the following link to check your answer.

Question: A wave crest 0.4 meter from a wave machine in a pool interferes with a 0.3 -meter wave trough reflecting from a wall. What is the amplitude and shape of the combined wave?

- A 0.4 meter crest
- B 0.3 meter trough
- C 0.7 meter crest
- D 0.1 meter crest

✔Answer

The correct answer is D. The crest was bigger, so it dominated during the collision. According to the superposition principle, the amplitude is calculated as follows: $0.4\text{m} - 0.3\text{m} = +0.1\text{m} = 0.1\text{m}$ crest

Physics: Mechanical Waves

Wave speed and the effects of frequency, wavelength, period, and amplitude

Previously you learned that the wavelength is the length of one complete wave pattern. We also learned that the amplitude is the measure of the distance of a wave crest above or below a resting point. In this lesson, we will try to determine what we can change about a wave in order to alter the wave's speed.

Imagine stretching a long spring across the floor and sending a wave pattern down the spring. What can we do to make that pattern move more quickly down the spring? If you try making a larger wave (i.e. by changing the amplitude), you'll find that it has **no effect** on the wave speed. This implies that just because a wave has more energy it does not mean that it moves any faster through the medium. For example, loud sounds coming from a trumpet in an orchestra travel at the same speed as softer sounds coming from a flute.

What else can we change that might affect a wave's speed? What if we make the wave more frequent? Frequency is defined as the number of waves per second and is measured in units called Hertz (Hz). Oddly enough, increasing the frequency of the wave has **no effect** on the speed, just like our results for amplitude. What changes, then, if you increase the frequency of the wave? The frequency of a wave (f), and the wavelength (λ), are indirectly related. Expressed mathematically we can say $f = 1/\lambda$. If the frequency is increased then the wavelength will decrease. Note that the velocity of the wave will remain unchanged. The velocity of the wave is actually the product of the frequency and the wavelength. Velocity (v) = $f \lambda$.

There must be something we can do to change the speed of the wave on the spring. What if we make the spring tighter? The wave speed will increase significantly as the tension of the spring increases. As a rule, for mechanical waves **the speed of a wave is affected by changes in the medium**. To change the speed of a sound wave in air, for example, we could change the temperature of the air. Louder sounds and higher pitches, however, will not change the speed of sound

Physics: Mechanical Waves

The time it takes to generate one wave is called the **period** (t). Since the period is the number of seconds per wave and frequency is the number of waves per second, they are inverses of each other as follows:

$$f = 1/t$$

or

$$t = 1/f$$

Speed is the ratio of distance to time, so the speed of a wave can be calculated by taking the length of one wave (λ) divided by the time for one wave to go by (t):

$$v = \lambda / t$$

$$v = \lambda (1/t)$$

$$v = \lambda f$$

The last equation above is sometimes called the wave equation. But there seems to be an inconsistency here. Didn't we say earlier that wave speed does NOT depend on frequency or wavelength? Remember, though, that as the frequency goes up, the wavelength goes down proportionately so that the wave speed stays constant. This is true as long as the medium stays fixed.

Let's try an example of applying the wave equation. Imagine a surfer who rides with a wave at a speed of 5.0 m/s. If the wave troughs are each 20.0 m apart, what are the frequency and the period of the wave?

Given: $v = 5.0 \text{ m / s}$ and $\lambda = 20.0 \text{ m}$ (trough to trough)

Equation: $f = v / \lambda = (5.0\text{m/s}) / (20.0\text{m}) = 0.25 \text{ Hz}$

$t = 1 / f = 1 / (0.25 \text{ Hz}) = 4.0 \text{ seconds}$

Physics: Mechanical Waves

Try this on your own and click on the following link to check your answer.

Question: A wave generator at a pool makes 30 waves per minute and the wave crests are 5 meters apart. Calculate the speed of the waves in meters per second. What could you do to increase this wave speed?

Answer

Given: $f = 30 \text{ waves / minute} = 0.5 \text{ waves / sec}$

and $\lambda = 5.0 \text{ m}$

Equation: $v = \lambda f$

$(5.0\text{m})(0.5 \text{ waves / sec}) = 2.5 \text{ m / s}$

The only way to change the speed of the wave is to change the medium, perhaps by changing the depth of the water. Increasing the amplitude of the disturbance will have NO effect on the speed. Likewise, increasing the frequency only shortens the waves and has NO effect on the speed of the wave.

Physics: Mechanical Waves

Wave energy in two and three dimensions

Previously we covered how waves move in one dimension. We studied the fact that the wave medium and its characteristics are the only variables that affect wave speed. In this lesson, we will study what happens to wave energy as it spreads out in two- or three-dimensional space.

When you clap your hands, what happens to the intensity of the sound as it spreads out? The wave intensity will decrease as it spreads out spherically from the source. The intensity (I) can be calculated as follows:

$$I = P / A$$

where P = the power of the sound and A = area of the surface that the wave energy spreads out across.

Since sound and light waves spread out spherically from a source, the area through which the energy flows is the surface of a sphere. So for three-dimensional waves, the intensity can be calculated as follows:

$$I = P / A = P / (4\pi r^2)$$

where r = the radial distance from the source and P = the power of the wave.

In conclusion, the intensity of three-dimensional waves is inversely proportional to the square of the distance from the source.

Question: The wave intensity at a distance of 1 meter from a loudspeaker is 8 Watts/m². What is the wave intensity at a distance of 2 meters from the speaker?

- A 16 W/m²
- B 8 W/m²
- C 4 W/m²
- D 2 W/m²

✓Answer

The answer is D. The intensity of sound is inversely proportional to the square of the distance from the source. Since the distance from the source is doubled, this means that the intensity will drop to one-quarter of what it was: $I = (8 \text{ W/m}^2) / 4 = 2 \text{ W/m}^2$.

As water waves spread out in circular two-dimensional patterns, their intensity (amplitude) also attenuates, but the relationship is different than the one given above used to calculate the change in intensity.

5. Electricity

Physics: Electrostatics

Electrostatics

What is the reason for the warnings printed on gas pumps cautioning us not to get in and out of the car when we're pumping gas? The reason is that cars pick up electrostatic charges as they run, and the car's tires insulate that charge from the ground. **Electrostatics** is the study of electrical charges on objects at rest.

There are two fundamental charges: positive and negative. We know that similarly charged objects repel and oppositely charged objects attract. Besides this, objects that are neutral (i.e. objects with an

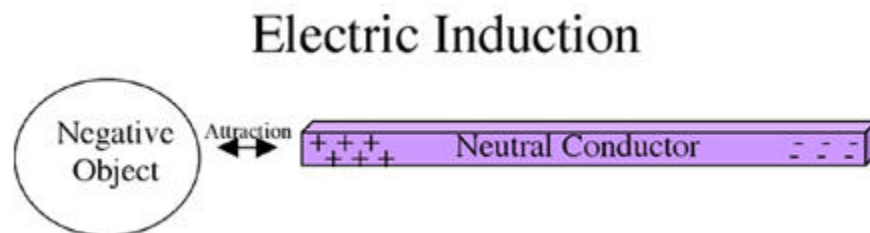
equal amount of positive and negative charge) are attracted to both positive and negative objects. Why do we know this? Let's first review the basic model of the atom.

The very center of the atom is a tiny concentrated region that contains positive particles (protons) and neutral particles (neutrons), called the nucleus. The number of protons in the nucleus uniquely determines what element it is. This number will not change unless a "drastic" nuclear event occurs (i.e. fission or fusion). In the large region of space around the tiny nucleus there is likelihood that you will find negative particles (electrons). In neutral atoms, the number of electrons equals the number of protons. In order for an object to gain a negative electric charge, it gains extra electrons. To pick up a positive charge, the object loses electrons. Thus, electrons are the "mobile fluid" responsible for charging objects. An object will **always** have the same amount of protons before and after gaining an electrostatic charge.

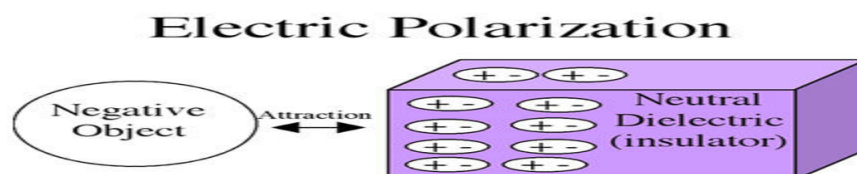
Physics: Electrostatics

Some elements are naturally good conductors of electricity. **Conductors** are materials in which electrons flow easily from atom to atom. Metals are excellent examples of conductors. **Dielectrics**, or insulators, are materials in which the electrons are tightly bound to a particular nucleus. Rubber, plastic, and air are examples of good insulators. Under conditions with very high voltages, even insulators may have electrons travel throughout the material.

Why are neutral conductors and neutral insulators attracted to charged objects? The explanation is a little different for each. When a negatively charged object is brought near a conductor, the electrons in the conductor are repelled by the electrons in the charged object. The free electrons in the rod are forced to move to the opposite side of the rod, leaving the positive nuclei to attract the negative object. This process is called electric induction and is represented in the following diagram:



In contrast, when a charged object is brought near a dielectric (insulator), the electrons will not move to the one side of the entire object. Rather, the electrons tend to move within the atom such that the atoms are polarized. For example, if a negative balloon is brought near a wall, electrons in the atom of the wall are repelled to the opposite side of the nucleus. This leaves the positive nucleus in close proximity to the negative object and they attract one another. This process of polarization is represented in the following diagram:



Physics: Electrostatics

Try this on your own and click on the following link to check your answer.

Question: In an electrostatics experiment, two pieces of tape attract each other. You can **firmly** conclude that:

- A at least one of the pieces of tape must be charged.
- B the two pieces of tape must be negatively charged
- C the two pieces of tape must be oppositely charged.
- D you did the experiment incorrectly.

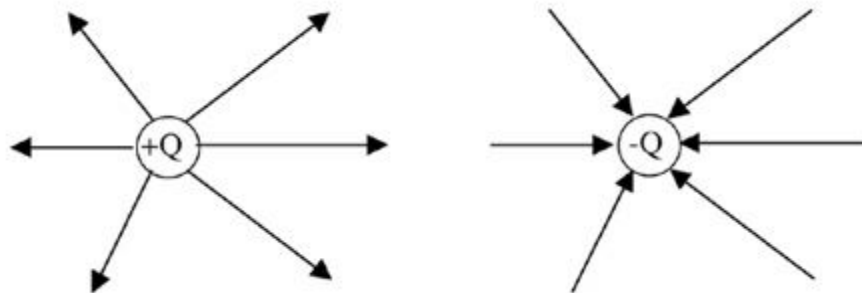
✓Answer

The correct answer is A. It is tempting to answer C because we know that oppositely charged objects attract, but that is not the *only* case in which we observe an attraction. Neutral objects also attract charged objects, so all we can confidently conclude in this question is that at least one of the pieces of tape is charged. The other piece of tape could be neutral or oppositely charged.

Physics: Electrostatics

Electric Fields

In the vicinity of charged objects, there exists an **electric field** in which other charged objects will experience forces. The charged objects have “lines of force” or “flux lines” emanating from them. The direction of the force exerted on a positive test charge placed near a charged object is shown by placing arrowheads pointing into the object to represent a negatively charged body, or arrowheads pointing out of the object if it is a positively charged body. For example, the first diagram below shows that a positive test charge is repelled from a positive central charge (+Q). The second diagram shows that the same positive test charge is attracted to a negative central charge (-Q).



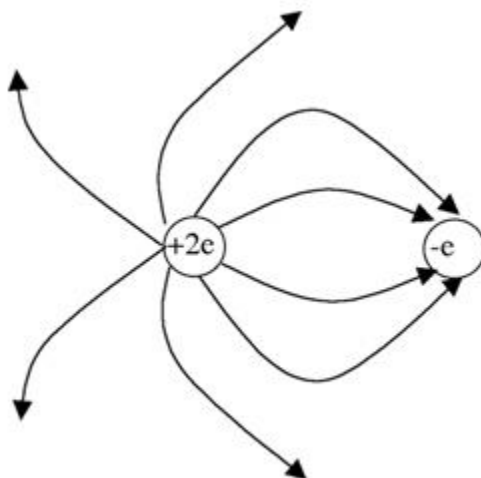
When drawing electric field line patterns, there are some basic facts to keep in mind:

1. Electric field lines always begin at and point away from positive charges. They point toward and end at negative charges.
2. The number of field lines entering or leaving a charge is representative of the magnitude of each charge.
3. Field lines never cross.
4. The electric field is stronger in regions where the field lines are closer together and weaker in regions where the lines are far apart.

5. Electric field lines are perpendicular to the surface of the charged, conducting object.
6. Electric field lines do not exist within a charged, conducting object.

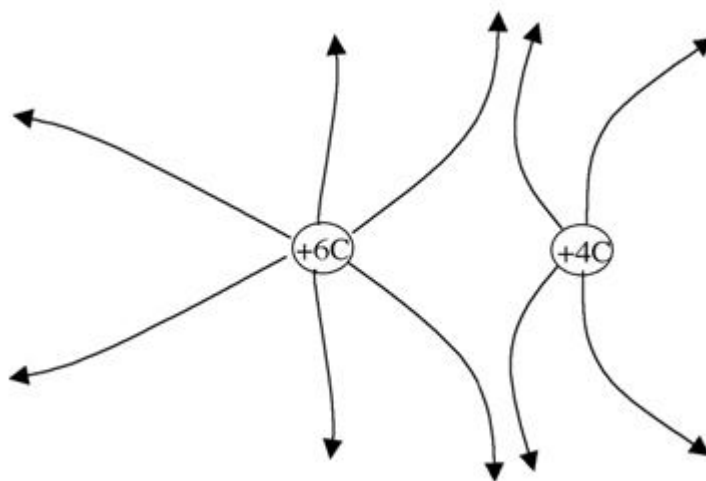
Physics: Electrostatics

For example, what would the electric field pattern look like if two protons ($+2e$) were in the vicinity an electron ($-e$)? The following diagram will show the pattern:



Some of the field lines that leave the positive charge connect to the negative charge and some extend beyond the scale of the drawing.

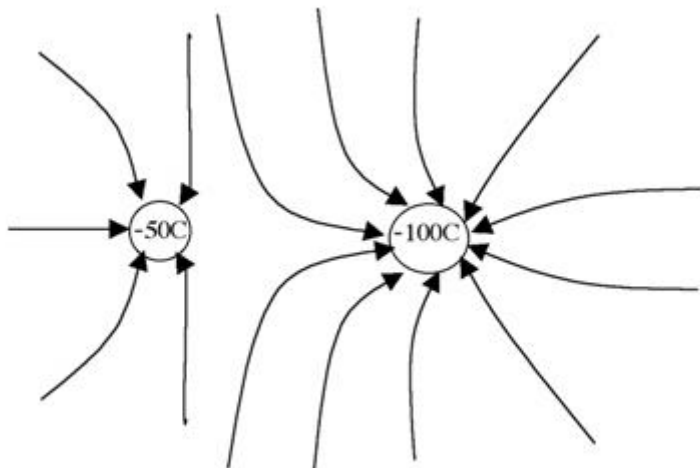
What do field lines look like in the vicinity of two repelling charges? For example, the following diagram shows the electric field pattern in the vicinity of a $+6$ Coulomb charge and a $+4$ -Coulomb charge:



Notice how the field lines never cross. Also, notice the empty region of space between the charges. This indicates that the electric field is weak in the region between the charges (in fact, there is a point nearer to the $+4C$ charge where the electric field is zero).

Now try sketching the electric field line pattern in the vicinity of a $-50C$ and a $-100C$ charge.

👉 [See the answer](#)



Physics: Electricity

Electromotive Force

Previously we covered that work is done when forces displace objects. When this occurs energy is transferred from one storage mode into another. In this lesson, we will study how energy is transferred in electrical circuits caused by electromotive force.

Electrical circuits may be powered by a variety of energy sources. Here are a few examples of devices that serve as energy sources for circuits:

- Batteries: Devices that transfer chemical energy to electrical energy.
- Generators: Devices that transfer mechanical energy to electrical energy.
- Solar panels: Devices that transfer radiant energy to electrical energy.

Each of these devices applies an **electromotive force (EMF)** that does the work on the electrons in the circuit to transfer energy.

The wires in a circuit provide a pathway for energy transfer. For example, using a simple circuit between a battery and a light bulb, the electrons within the circuit carry energy from the battery to the bulb. These electrons are never created nor destroyed during the process of transferring the chemical energy in the battery to radiant energy shining from the bulb. In a circuit powering an electric blanket, for example, electrical energy is transferred to heat energy.

The electromotive force (EMF) is the potential energy per unit charge that can be transferred to the electrons in a circuit. The units are "joules per coulomb," which is defined to be a volt. The EMF is measured by finding voltage, or electric potential difference, across the two ends of the power supply when there are no electrons flowing. If current is running through the power supply, the voltage measurement is actually less than the EMF. Thus, the EMF is the maximum possible potential difference measured across a power source.

Physics: Electricity

Try this on your own and click on the following link to check your answer:

Question: A 9.0-Volt battery establishes current in a simple circuit. Which of the following measurements are possible if a voltmeter is placed across the battery in the circuit?

- A 8.5 V
- B 9.0 V
- C 9.5
- D All of the above are possible.

👉Answer

The correct answer is A. The maximum possible voltage measurement is the EMF (9.0 Volts) and this is measured with no current in the battery. When current is flowing, the voltage drops because of the internal resistance of the battery. Therefore, 8.5 V is the only possible measurement in the options given

Physics: Electricity

Electric Current

Previously you have seen that an electromotive force is responsible for providing the potential to move electrons in a circuit. You also learned that electrons are charged particles that carry energy in a circuit. In this lesson, we will formally define the concept of electric current.

When there is a difference of pressure across the two sides of a water pipe, water will flow from a region of higher pressure to a region of lower pressure. Thus, water current is established in the pipe, and this current is measured in gallons per second. Likewise, when there is a difference of electric potential (voltage) across a wire, electrical current is established. **Electric current (I)** is a measure of the number of electrons (measured in Coulombs Q) that pass a point in a circuit over a certain amount of time (t). The equation is written like this:

$$I = Q / t$$

The units of electrical current are Coulombs per second which is defined as the Ampere (A).

Electrical current may be classified as “direct” or “alternating.” **Direct current (DC)** occurs when the electrons circulate in one direction throughout the circuit. Batteries naturally produce DC current. The electrons move quickly in a DC circuit, but the energy they carry is transmitted almost instantaneously throughout the circuit. **Alternating current (AC)** occurs when the electrons vibrate back and forth at a particular frequency. Generators naturally produce AC current. As we shall see in a later lesson, AC current is typically used when a significant amount of energy is transferred through long distances.

Physics: Electricity

Try this on your own and click on the following link to check your answer:

Question: 25 Coulombs of electrical charge moves through a cross-section of wire every 5 seconds. What is the current in the wire?

- A 0.2 A
- B 5 A
- C 125 A
- D More information is needed to determine the current.

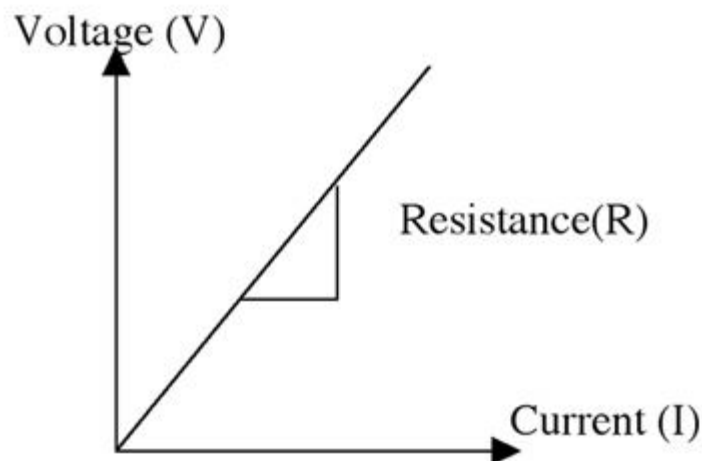
✔Answer

The correct answer is B and is calculated as follows: $I = Q / t = (25 \text{ C}) / (5 \text{ s}) = 5 \text{ C} / \text{s} = 5 \text{ A}$

Physics: Electricity

Resistance and Ohm's Law

When electrons move in an electric circuit the parts of the circuit resist the movement of the electrons. This property in an electric circuit is called resistance. Some electrical devices allow electrical current to flow easily through them. We say that these devices have a low resistance to the flow of electrons. Devices with a high resistance, on the other hand, resist the flow of current. These devices require a power source with a larger voltage to establish the same current as a low resistance device. Consider a simple circuit consisting of a battery and some device (like a light bulb). As the voltage of the battery increases, the current running through the circuit will increase. The **resistance** of a device is the ratio of the voltage across it to the current running through it as demonstrated on the following graph:



A graph with a greater slope indicates that a device has a larger resistance. Devices with greater resistance demand a greater voltage to draw the same current as devices with lower resistance. Ohm's Law is the equation of the linear graph above:

$$y = mx + b$$

$$V = R I + 0$$

$$V = I R$$

where V = voltage, I = current, and R = resistance.

The measurement unit of resistance is the ohm (Ω) and is defined as the ratio of volts to amps.

Physics: Electricity

Try this on your own and click on the following link to check your answer:

Question: What is the resistance in the 30 Amp heating coil of a coffee maker that operates on a 120 V circuit?

- A 0.25 ohms
- B 4.0 ohms
- C 90 ohms
- D 3600 ohms

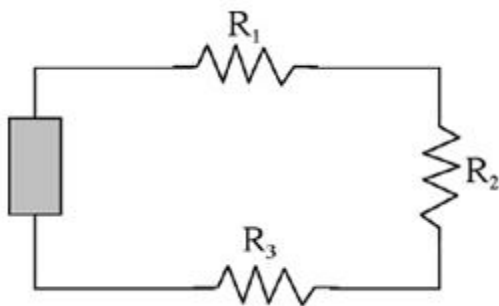
✔Answer

The correct answer is B. The numbers are plugged into Ohm's law as follows: $R = V/I = (120 \text{ V}) / (30 \text{ Amp}) = 4.0 \text{ ohms}$.

Physics: Electricity

DC Circuits

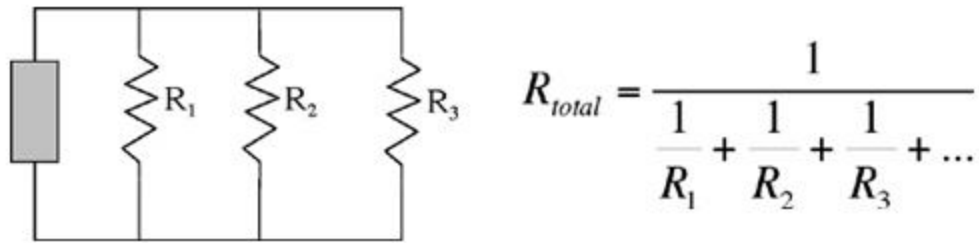
One way to increase the electrical resistance is to put a string of devices in series along the same electrical path. The total resistance of the path is the sum of all the individual resistances in the path as follows:



$$R_{\text{total}} = R_1 + R_2 + R_3 + \dots$$

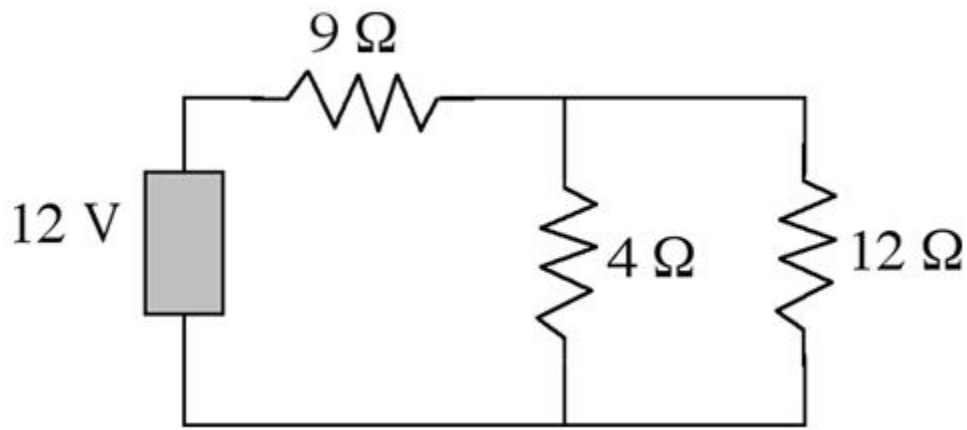
With the extra resistance in the circuit, the current running from a power source will drop.

Circuits can also be wired in parallel where there are multiple paths for the electrons to take. With the extra pathways, the resistance of the circuit drops as follows:



The total resistance in parallel is always less than the least resistant path. Because of their low resistance, these circuits tend to draw large currents from power sources.

Most electrical devices are a combination of series and parallel devices. For example, consider the following combination circuit:

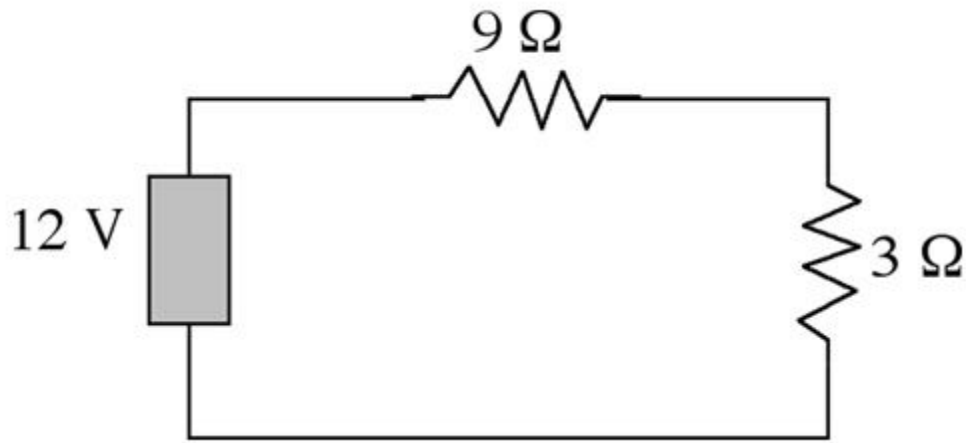


Physics: Electricity

The 4 Ω and the 12 Ω devices are wired in parallel, so they can be replaced with an equivalent resistance of:

$$R_{total} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots}$$

Now, the circuit can be simplified as follows:

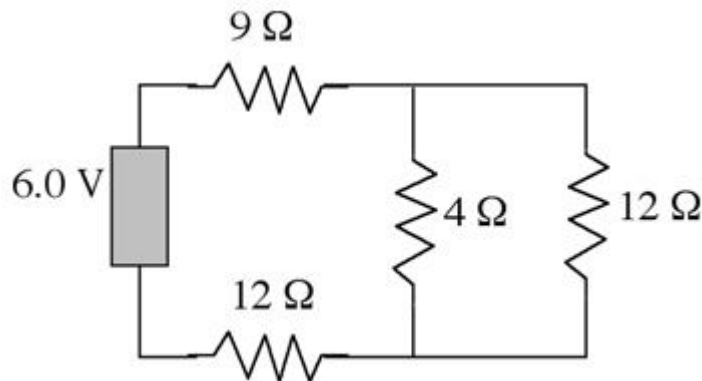


Since the $9\ \Omega$ and the $3\ \Omega$ resistors are in series, this circuit has a total resistance of $9\ \Omega + 3\ \Omega = 12\ \Omega$.

Thus, applying Ohm's law, the total current drawn by the circuit is:

$$I = V / R_{\text{total}} = (12\text{V}) / 12\ \Omega = 1\ \text{A}$$

Physics: Electricity



Question: The circuit shown above has a total resistance of $24\ \Omega$. What is the total current drawn by the battery?

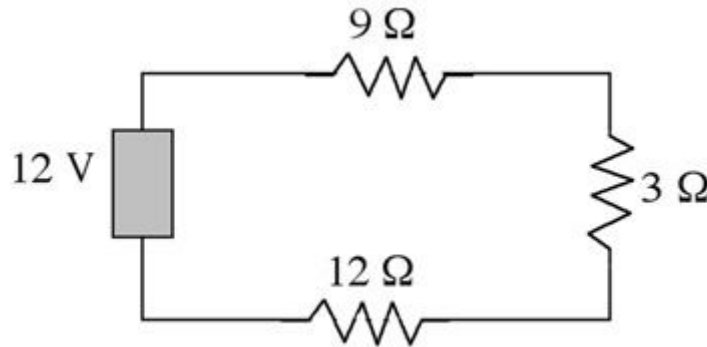
- A 0.25 A
- B 4.0 A
- C 5.0 A
- D 144 A

Answer

The correct answer is A. Applying Ohm's Law to the circuit, we obtain the current by dividing the voltage of the power supply by the total resistance:

$$I = V / R_{\text{total}} = (6.0\text{V}) / (24\ \Omega) = 0.25\ \text{A}$$

To calculate the total resistance, first determine the resistance of the 4 W and 12 W resistors in parallel. This is 3 W as shown earlier in this lesson. Now the circuit looks like the following series circuit:



The total resistance is the sum of all three resistors:

$$R_{\text{total}} = 9 + 3 + 12 = 24 \text{ W}$$

Physics: Electricity

AC & DC Circuits

Previously we covered that electrical energy is delivered via direct current (DC) or alternating current (AC). In this lesson, we will study the applications that are appropriate for DC and AC.

When current flows through a wire, the wire will heat up because of the wire's resistance. For applications that require low current flow through short distances, the amount of heating in the wires is negligible. Batteries produce DC and are used to deliver energy through short distances in circuits.

When distributing large amounts of energy to electrical power grids, high currents are needed for energy transmitted at common household voltages (120V). The amount of line heating in the wires is prohibitive with these large currents, costing millions of dollars per mile of wire every hour just to power a medium-sized city. When AC is used, however, step-up transformers increase the transmitting voltage and drop the current to levels where the energy loss due to line heating is acceptable. At the household level, step-down transformers drop the voltages back down to 120V and raise the current to levels demanded by the consumer. Transformers only operate with AC current.

6. Magnetism and Electromagnetism

Physics: Magnetism and Electromagnetism

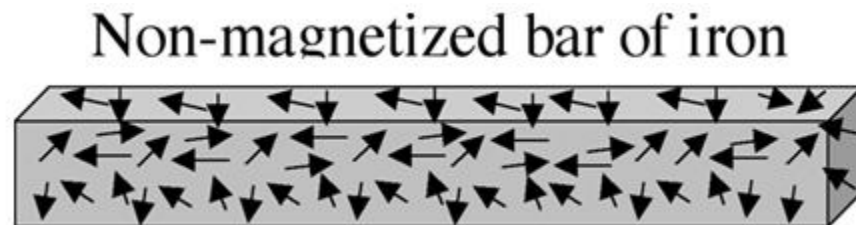
Magnets

Some basic facts about magnets:

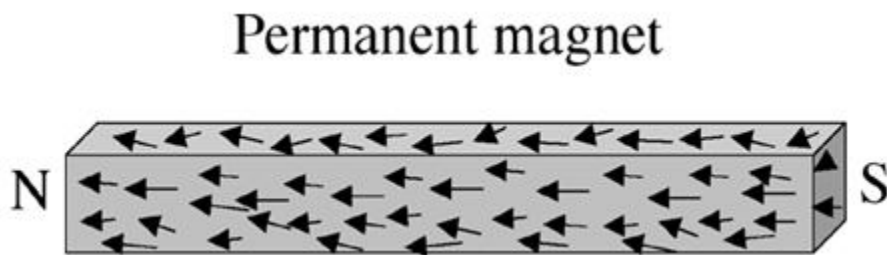
- Every magnet has two poles: a “north” pole and a “south” pole. These poles cannot exist independently (i.e. there are no magnetic monopoles).
- When a magnet is broken in half, the two halves become smaller magnets, each with a north and a south pole.

- When opposite poles of a magnet are close to each other, there is a force of attraction between them. This is also how opposite electric charges attract each other.
- When like poles of a magnet are close to each other, there is a repulsive force pushing the magnets away from each other. This is similar to how electric charges repel each other when they have the same charge.
- When magnets are brought near certain materials that are not magnets, a force of attraction may be observed.

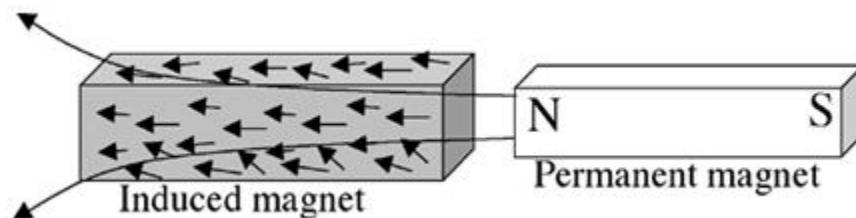
Some materials like iron, cobalt, and nickel are classified as **ferromagnetic**. These materials have tiny regions in them called “magnetic domains” that can be visualized as miniature magnets. The atoms in each magnetic domain have their electron spins aligned along a common axis. In a bar of iron that is not a permanent magnet, the arrows below represent the fact that the domains point in random directions (note that this is only a representation; there are so many domains in the bar and they are so small that it is impossible to draw them all).



Magnets, on the other hand, have domains that generally point in the same direction as shown below:



Why are paper clips and other non-magnetized ferromagnetic materials attracted to magnets? The magnetic domains within these materials temporarily align themselves in the direction of an external magnetic field, through a process known as **induced magnetism**. Induced magnetism is demonstrated in the following diagram:



When the permanent magnet is removed, the domains in the material of the induced magnet usually snap back to their original positions and lose their induced magnetism.

Under certain conditions, the domains of an induced magnet may continue to point in the direction of the external magnetic field even after that field is removed. This phenomenon is known as [magnetic remanence](#), a property used to create permanent magnets. There are 4 common ways that magnetic remanence is obtained:

- Exposing the ferromagnetic material to a very large external magnetic field.
- Heating and then cooling the ferromagnetic material in the presence of an external magnetic field.
- Striking the material in the direction of the external magnetic field.
- Exposing the material to an external magnetic field for a long period of time.

How do magnetic forces of attraction and repulsion arise? Magnetic forces occur when electric charges move with a velocity that is not parallel to external magnetic fields. In contrast to magnetism, charges experience electric forces in electric fields whether they are moving or not. Consider two bar magnets applying magnetic forces to one another. The first bar magnet establishes an external magnetic field. When the second bar magnet with electrons spinning about a common axis is placed in this field, it may experience an attractive or repulsive force.

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Physics: Magnetism and Electromagnetism

Try this on your own and click on the following link to check your answer.

Question: A common but somewhat outdated technology involves storing information on magnetic tape (e.g. cassette tape recordings of music). Information is stored permanently on the tape using what physical phenomenon?

- A Electric induction
- B Electric polarization
- C Magnetic remanence
- D Magnetic domination

✔Answer

The correct answer is C. Magnetic tape, which usually has the ferromagnetic molecule chromium-dioxide throughout it, is heated and then swept under the recording head. This recording head imprints magnetic information in the molecular domains. When the tape is cooled, magnetic remanence insures that the domains retain their new alignment.

Physics: Magnetism and Electromagnetism

Magnetic field lines

Previously we learned that electric field lines are lines of force that exist in the vicinity of charged objects. The directions of these lines of electric force are determined by the direction of force on a positive test charge. In this lesson, we will study lines of magnetic force.

A classic grade-school experiment is to place a bar magnet under a piece of paper and to sprinkle iron filings over the paper. The iron filings align themselves like compass needles to show the magnetic field around the magnet. To determine the direction of a magnetic field, we imagine placing a compass in that field. The north needle of the compass points in the direction of the magnetic field and is used to map out the **magnetic field lines**. For example, the magnetic field for a bar magnet is shown below:

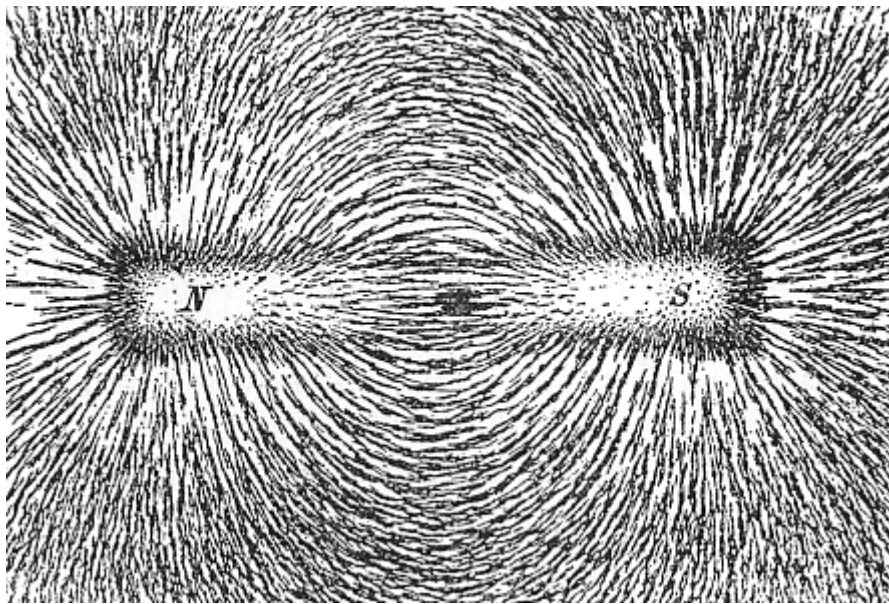


Figure 1: Magnetic Field of Bar Magnet shown by iron filings on paper

On the figure above, the magnetic field lines point away from the north end of the magnet. This is because the north needle of a compass is repelled from the north end of the magnet. Likewise, the north needle is attracted to the south end of the magnet.

Notice how the magnetic field lines continue into the bar magnet. The field lines within the magnet demonstrate how the magnetic domains within the iron are aligned along the field. Magnetic field lines always form closed loops because it is impossible to have a single magnetic pole (monopole). In other words, if magnetic field lines leave a north magnetic pole, they have to loop back to the south pole of the same magnet.

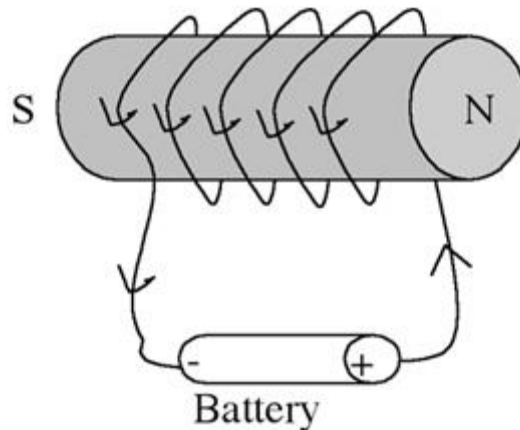
Physics: Magnetism and Electromagnetism

Currents and magnetic fields

Previously we learned that magnetic forces are exerted on moving charges. In this lesson, we will see that moving electrical charges produce magnetic fields.

In 1820, Hans Christian Oersted made an observation that marked the beginning of the field of **electromagnetism**. When current flowed through a wire, he noticed that a nearby compass needle moved. This indicated to him that current-carrying wires produced magnetic fields. This exercise highlighted the strong connection between electricity and magnetism.

Oersted's discovery was used to create electromagnets. When current is sent through a coil of wire, the coil behaves like a magnet, as the following diagram shows:



When an iron core is placed within the windings of an electromagnet, the magnetic domains within the core align themselves with the field. This serves to strengthen the magnetic field that is produced.

Physics: Magnetism and Electromagnetism<

Try this on your own and click on the following link to check your answer.

Question: Oersted's famous experiment with a current-carrying wire and a compass marked the beginning of the study of

- A electricity.
- B electromagnetism.
- C magnetism.
- D electrostatics.

👉Answer

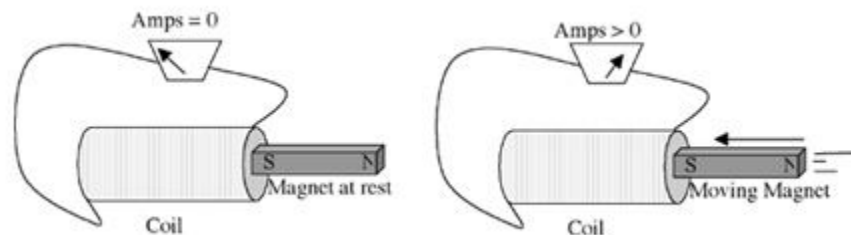
The correct answer is B. Oersted's observation showed the connection between electricity and magnetism.

Physics: Magnetism and Electromagnetism

Faraday's Law

Oersted's experiment demonstrates that moving electrical charges produce magnetic fields, but is the reverse true? That is, do magnetic fields produce electrical currents? The answer is yes, but only under certain conditions.

Consider a coil of wire attached to a current meter. When a magnet sits inside the coiled wire, no current will be detected. However, if the magnet is **moving** back and forth in the coil, a current will be detected. Work must be done to move the magnet against the magnetic force, and this transfers energy to the circuit.



In order to induce current in a closed loop, the **magnetic flux** must be changing within the wire. Magnetic flux is a measure of the amount of magnetic field lines that flow into a loop. There are three ways to change the magnetic flux in a loop:

- Increase or decrease the strength of the magnetic field within the loop.
- Increase or decrease the area of the loop
- Rotate the loop so that more or fewer field lines permeate the loop.

An induced electromotive force (EMF) across the ends of the loop occurs when any of these three changes occur. **Faraday's law** states that the induced EMF equals the time rate of change of magnetic flux within a loop. The quicker the flux changes, the greater the induced EMF.

Electric generators use the ideas embedded in Faraday's law to operate. An external source of mechanical energy does work to rotate a coil in the presence of a magnetic field. This rotation results in a flux change through the coil and electricity is generated.

Physics: Magnetism and Electromagnetism

Try this on your own and click on the following link to check your answer.

Question: Which of the following will NOT produce an induced EMF across the ends of a coil?

- A Increasing the strength of the magnetic field within the coil
- B Maintaining a steady and strong magnetic field within the coil
- C Reducing the area of the coil while it's in a magnetic field

D Pulling a magnet away from the coil, along its axis

👉Answer

The correct answer is B. According to Faraday's law, the magnetic flux must change within a coil to induce an EMF.

Physics: Magnetism and Electromagnetism

Electromagnetic waves and the electromagnetic spectrum

Previously we learned that moving electrical charges produce magnetic fields and that changing magnetic field generates electricity. In this lesson, we will study how electricity and magnetism produce electromagnetic radiation. We will also study the spectrum of electromagnetic waves.

How is light produced? When electrons drop energy levels in an atom, energy is released as light. Because electrons are charged, they produce an electric field in their vicinity. When the electrons move, they also produce magnetic fields. The changing electric and magnetic fields around moving electrons is radiation that we call light. As we shall see, not all of this radiation is visible to the human eye.

How are radio waves produced? Imagine a transmitting antenna for a radio station. If electrons are accelerated up and down the wires in the antenna, changing electric and magnetic fields will be produced in a similar manner to the electrons changing energy levels in atoms. This radiation moves out into the air at very high speeds. In fact, this radiation doesn't even need air to move. Radio waves can be transferred through the vacuum of deep space.

Visible light and radio waves are both electromagnetic waves. In fact, there are many other types of electromagnetic radiation depending on the frequency of the vibration that produced it. Here is a list of the electromagnetic spectrum in order, from low frequency (long wavelength) to high frequency (short wavelength), as well as some common properties of each:

- Radio waves—This lowest frequency radiation is used mainly for communication (details above).
- Microwaves—This radiation (sometimes classified as radio waves) is also used for communication. A specific frequency of microwave radiation resonates water molecules. This frequency is used in microwave ovens to heat moist food.
- Infrared (IR) waves—Certain frequencies of this type of radiation vibrate molecules in our skin and are detected as heat energy. Heat lamps in cafeterias emit IR radiation. Other applications include sending signals from remote controls and detecting heat patterns using night vision goggles.
- Visible light—This is the radiation detected by the human eye. The lowest visible frequency is the color red and the highest is violet. The full order is red, orange, yellow, green, blue, and violet (the mnemonic for this is ROY G. BIV).
- Ultraviolet (UV) radiation—This radiation is responsible for both suntans and sunburns and is linked to skin cancer. Certain frequencies of UV radiation are used to destroy bacteria.
- X-rays—This radiation is able to permeate human flesh to expose film on the other side of the body. X-rays are completely blocked by lead. X-rays are also linked to cancer.

- Gamma rays—A very high frequency electromagnetic wave that is produced spontaneously by the nuclei of radioactive substances. Exposure to gamma radiation is extremely dangerous.

Physics: Magnetism and Electromagnetism

You may have noticed on the spectrum above that as the frequency of the radiation increases, the wave becomes more dangerous. This is because the higher frequency radiation is more energetic and has the ability to alter DNA.

What do all the types of electromagnetic radiation have in common? They are all waves that can move through a vacuum. Unlike sound waves and water waves, electromagnetic waves do not need a physical medium to travel. In a vacuum, they all travel at a speed of 300 million meters per second ($3.00 \cdot 10^8 \text{ m/s}$). The only way to slow down this radiation is to change the medium. For example, when light strikes a diamond, its speed slows down to $1.24 \cdot 10^8 \text{ m/s}$.

Try this on your own and click on the following link to check your answer.

Question: Which of the following is fundamentally different from the others?

- A Radio Waves
- B Sound Waves
- C Gamma Rays
- D Light Waves

✓Answer

The correct answer is B. Sound waves require a medium to travel. All the other types of waves are electromagnetic radiation that travels about one million times faster than sound.

7. Optics

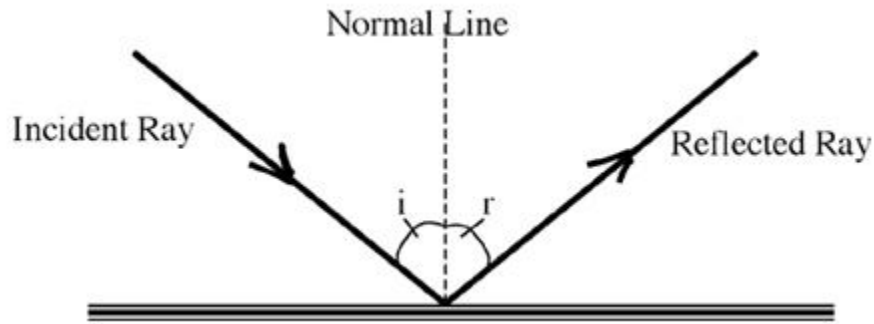
Physics: Optics

Reflection, refraction, and absorption

When light hits a boundary between different media, three phenomena occur:

- **Reflection** --Some of the energy bounces back into the original medium.
- **Refraction** --Some of the energy transmits into the new medium.
- **Absorption** -- Some of the energy transfers to heat energy at the boundary.

Instead of focusing on the crests and troughs, we show the path of light waves with rays. The ray that strikes a boundary is called the incident ray. The ray that bounces back into the original medium is called the reflected ray. Both rays make equal angles with respect to a line perpendicular to the surface (the “normal line”), as shown in the following figure:

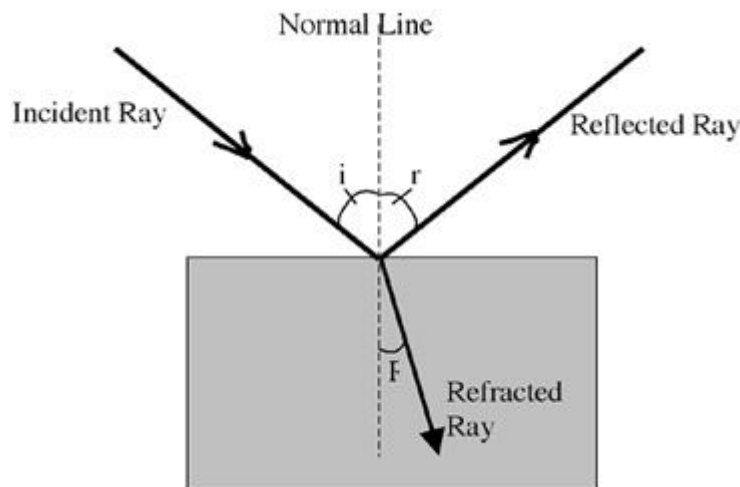


The **law of reflection** is stated as follows:

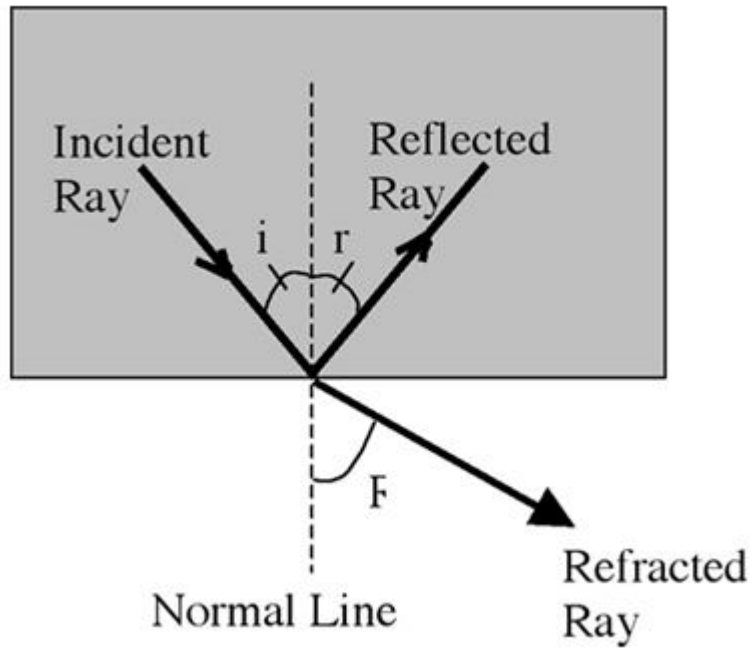
- The angle of incidence (i) is equal to the angle of reflection (r)
- The incident ray, normal line, and reflected ray exist in the same plane.

The law of reflection applies to all surfaces: shiny, curved, or rough. When light rays hit rough surfaces, though, the normal line direction varies for each part of the surface and the light diffuses in all directions.

What happens when light hits an optically transparent medium? Some of the light energy will always reflect back into the original medium. But much of the light and energy usually enters the new medium. Depending on the optical density of that medium the light will "bend" or refracts a slight amount from its original path, or it may refract quite a bit from its original path. If the new medium slows down the light we say that the medium has a higher optical density. When this occurs, the light bends to a smaller refraction angle (R) relative to the normal line as shown in the following diagram:



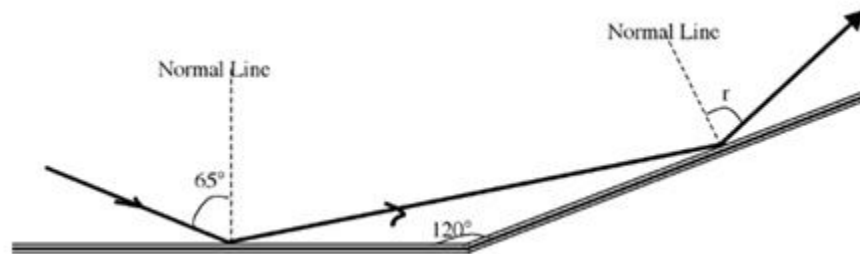
If the light ray exits a denser medium, the ray will bend back out to a large refraction angle as shown in the following diagram:



Physics: Optics

Answer the following question and click on the following link to check your answer.

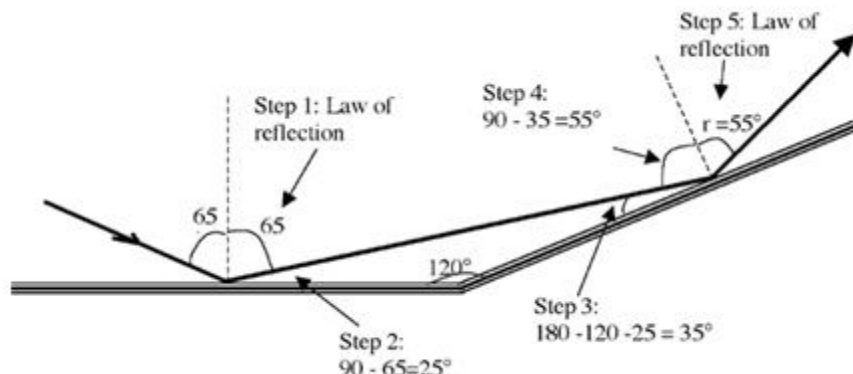
Question: What is the final angle of reflection (r) in the following figure (not to scale)?



- A 65°
- B 55°
- C 45°
- D 35°

✔Answer

The correct answer is B; $r = 55^\circ$. The steps are as follows:



Physics: Optics

Total internal reflection

When light rays attempt to exit a medium with high optical density, refraction may not occur. Rather, the energy may be completely reflected back into the denser medium. This phenomenon is called **total internal reflection (TIR)**. What determines when TIR occurs? It depends on the “critical angle” of the materials involved. Every pair of transparent materials has a unique critical angle depending on their optical densities. The following table lists some common critical angles:

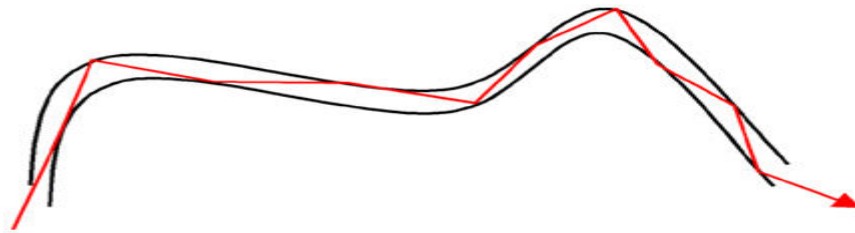
Light starting in....	Light trying to enter...	Critical angle
Water	Air	49°
Glass	Air	41°
Glass	Water	61°
Diamond	Air	24°

Notice that the critical angle is only relevant when light starts in an optically dense material and attempts to move into a less dense material. The critical angle is used with following logic to determine if TIR occurs at a boundary:

- When the incident angle is less than the critical angle, partial reflection and partial refraction occur.
- When the incident angle equals the critical angle, a tiny amount of light exits at a 90-degree refraction angle while the majority of the energy reflects back into the denser medium.
- When the incident angle is greater than the critical angle, total internal reflection occurs.

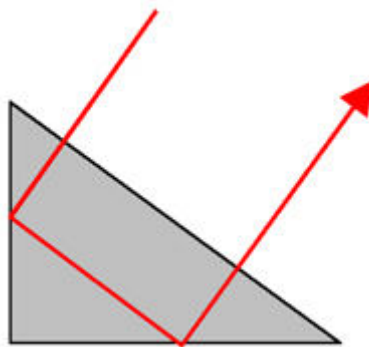
For example, when light attempts to exit a diamond into air at an angle of 20 degrees, it will partially reflect and partially refract because its incident angle is less than the critical angle of 24 degrees. When light tries to exit at 30 degrees however, it will totally reflect because its angle is greater than the critical angle.

Total internal reflection is used in optical fibers to send information efficiently from one location to another. The following diagram shows the total internal reflections that occur through a light pipe:



Optical fibers are the main technology behind endoscopes. Light is sent down tiny fibers that illuminate the inside of the human body. The image is then piped back to a video monitor for the surgeon to evaluate.

The phenomenon of total internal reflection is also used to reflect light in prisms as follows:



These prisms are sometimes used in binoculars to reflect and shift light images.

Physics: Optics

Answer the following question and click on the following link to check your answer.

Question: When a light ray attempts to move from glass into air at an incident angle of 45 degrees, which of the following phenomenon occurs? (Note: the critical angle for glass/air is 41 degrees.)

- A Total refraction
- B Total internal reflection
- C Partial refraction and partial reflection
- D Total absorption

Answer

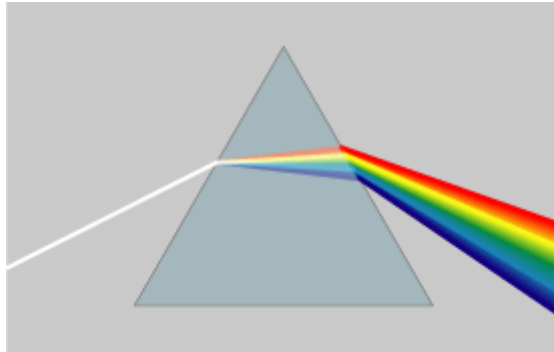
The correct answer is B because the incident angle is greater than the critical angle.

Physics: Optics

Dispersion

Previously we learned that different colors of light have different frequencies, where red light has the lowest frequency and violet light has the highest frequency. In this lesson, we will study how light of various frequencies refract differently in glass.

When white light hits a glass prism just right, the light exiting the prism will bend into a full rainbow of colors through the process of **dispersion**. This occurs because high-frequency visible light tends to interact with the glass molecules more than the low frequencies. The result looks like this:



In the diagram it is evident that the lower-frequency red light bends less than the higher-frequency violet light.

Dispersion is responsible for rainbows. If sunlight hits water droplets in the air just right, the droplets behave like little prisms and disperse and reflect a rainbow of light toward the observer.

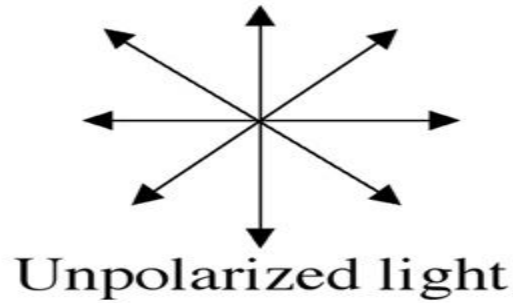
Light can also be dispersed using prism spectrometers (a.k.a. spectroscopes). These devices analyze visible light so the observer can identify the colors (frequencies) that are present in a particular light source.

Physics: Optics

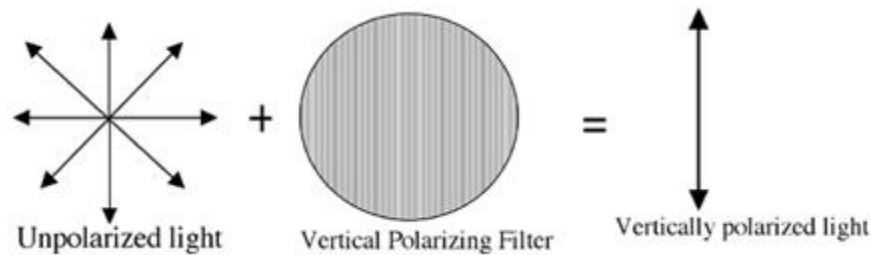
Polarization of light

Previously we learned that transverse waves vibrate the medium at right angles to the motion of the wave energy. Longitudinal waves, on the other hand, vibrate the medium parallel to the direction of wave motion through compressing the medium. Since light radiation consists of electric and magnetic vibrations that are perpendicular to the direction of wave motion, light is classified as a transverse wave. In this lesson, we will study the phenomenon of light polarization that provides evidence that light is a transverse wave.

The vibrations that produce sunlight are in random directions. Likewise, the electron vibrations in candle flames and the filaments of light bulbs are also in all directions. These sources produce **unpolarized light** because the transverse vibrations that produce the light are in many directions. Imagine looking at a beam of light coming straight toward you. The following diagram represents unpolarized transverse light waves vibrating horizontally, vertically, and at angles:



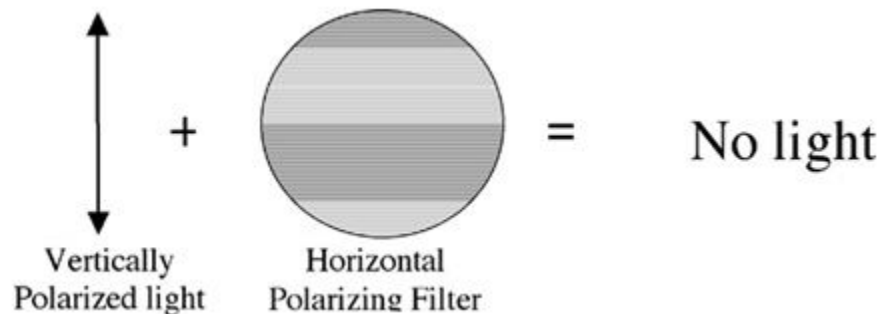
When unpolarized light is sent through a polarizing filter, all the components of vibration that are not aligned with the filter are absorbed. The light that emerges from the polarizing filter is called **polarized light**.



The intensity of light that exits a filter in this case is half of the original intensity.

Physics: Optics

When vertically polarized light attempts to get through a horizontal filter, the intensity drops to zero:



When unpolarized light hits horizontal surfaces at large angles to the normal line, the reflected light is horizontally polarized. Vertically polarized sunglasses are effective at eliminating this glare off horizontal surfaces. They also reduce the intensity of all the other light by one-half.

Answer the following question and click on the following link to check your answer.

Question: A beam of light moves through a horizontal and then a vertical polarizing filter. The intensity of the light emerging from the combination is

A zero.

- B one-quarter of the original intensity.
- C half the original intensity.
- D the same as the original intensity.

👉Answer

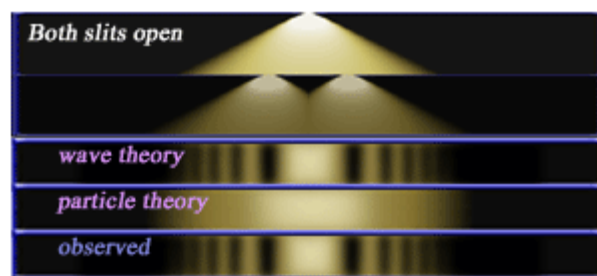
The correct answer is A. Only horizontally polarized light is able to get through the first filter. Since the second filter is vertical, the horizontal light is completely absorbed.

Physics: Optics

Interference of light

Previously we have seen that waves are energy. When a wave meets a wave, the waves pass right through each other. When they occupy the same space, they interfere with one another. If identical parts of the waves interfere (**e.g.** a crest meets a crest), the disturbance grows due to constructive interference. If opposite parts of the wave interfere, the disturbance is reduced through destructive interference. In this lesson, we will study different ways that light waves interfere and how this provides evidence that light behaves like a wave.

Historically, there was much debate about whether light behaves like a wave or like a particle. In fact, the scientific community generally believed that light behaved as a particle up until 1801. In that year, Thomas Young performed an experiment by sending monochromatic light (one frequency) through two tiny openings. When the light hits a screen, it showed multiple bright areas of constructive interference as well as dark areas of destructive interference. **Two-slit interference** is shown in the following diagram:



As you can see in the diagram, the light has equal distances to move to the center of the screen, so the waves arrive in phase (trough on trough). This results in constructive interference and a bright spot is observed. On either side of the central bright spot, the waves arrive out of phase (crest on trough), resulting in a dark area due to destructive interference. The pattern continues to alternate between light and dark bands as you go out on the screen.

When light hits soap bubbles or a film of gasoline on water, a beautiful rainbow of colors often results. Why does this occur? To explain this, we must realize that the light is actually reflecting from two surfaces. In the gasoline example, the light reflects from the surface of the gasoline as well as the water. The reflected rays may interfere constructively or destructively depending on their frequency

(color). As the thickness of the film varies, certain colors interfere constructively and these are the ones that we see. This phenomenon is called **thin film iridescence**.

Physics: Optics

Answer the following question and click on the following link to check your answer.

Question: Young's famous two-slit experiment demonstrates which of the following properties of light?

- A Polarization
- B Reflection
- C Its wave-like nature
- D Its particle-like nature

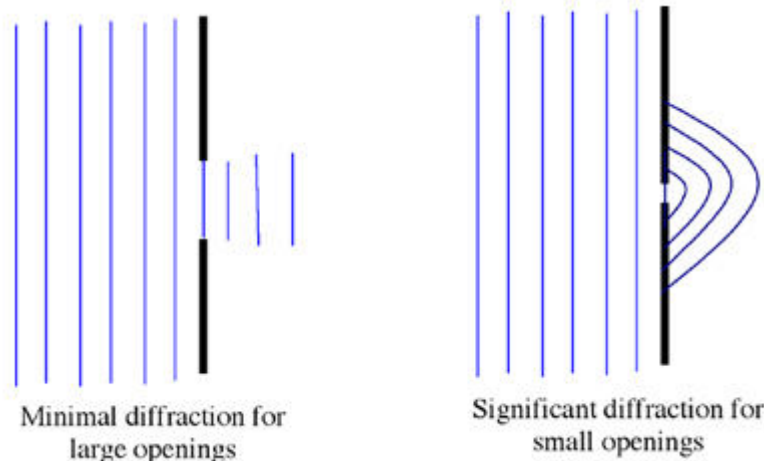
✔Answer

The correct answer is C. The two-slit experiment shows interference patterns from light. Interference is a phenomenon associated with waves.

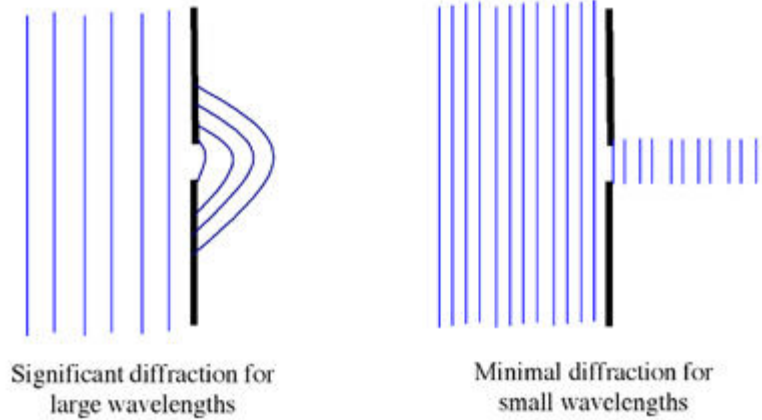
Physics: Optics

Diffraction of light

When waves hit an opening, they tend to fan out in many directions. **Diffraction** is the bending of waves around obstacles. The amount of diffraction depends on the size of the opening as in the following figure:



The amount of diffraction also depends on the wavelength of the disturbance:



To summarize, the amount of bending due to diffraction is directly related to the wavelength and inversely related to the width of the opening (or obstacle)

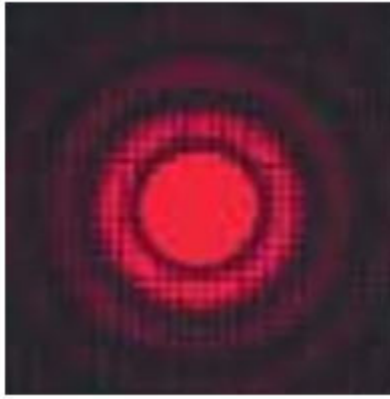
Physics: Optics

Since light is a wave, it also diffracts. If light goes through a big opening like a window, the light does not diffract significantly. This is because the wavelength of light is too small compared to the width of the opening. If light travels through a tiny slit, it spreads out significantly. So one might expect to only see a bright center pattern fading to the edges. But besides this pattern, the following figure shows interference patterns similar to those seen in Young's two-slit experiment.



Screen pattern after light diffracts through a single slit (bright center)

When light diffracts through a small circular aperture, a similar observation may be made. The screen pattern has a bright center fading to the edges along with concentric circles of interference, as shown in the following picture:



Laser light diffraction pattern through circular aperture

Light diffraction distorts images of very tiny objects like those on microscope slides. Tiny objects have dimensions that are similar to the wavelength of light. This results in significant bending around the objects and their images are not clearly seen. In order to see tiny objects clearly, they must be illuminated with wavelengths that are significantly shorter than light. Electron beams, like those used in electron microscopes, have tinier wavelengths than light and enable scientist to observe very small objects. For each source of illumination, diffraction sets a limit on the resolution of images.

Physics: Optics

Answer the following question and click on the following link to check your answer.

Question: In which of the following cases is the amount of light diffraction the most significant?

- A Long wavelength of light and tiny opening
- B Long wavelength of light and large opening
- C Short wavelength of light and tiny opening
- D Short wavelength of light and large opening

Answer

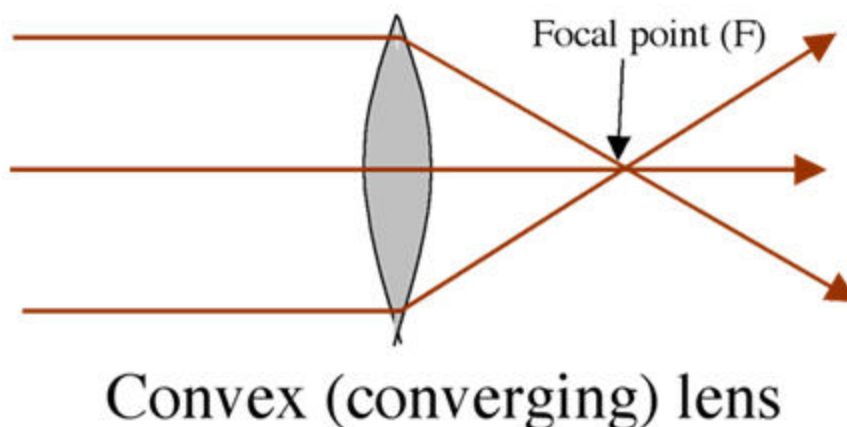
The correct answer is A. The amount of wave diffraction depends on the ratio of wavelength to the size of the opening.

Physics: Optics

Lens ray diagrams

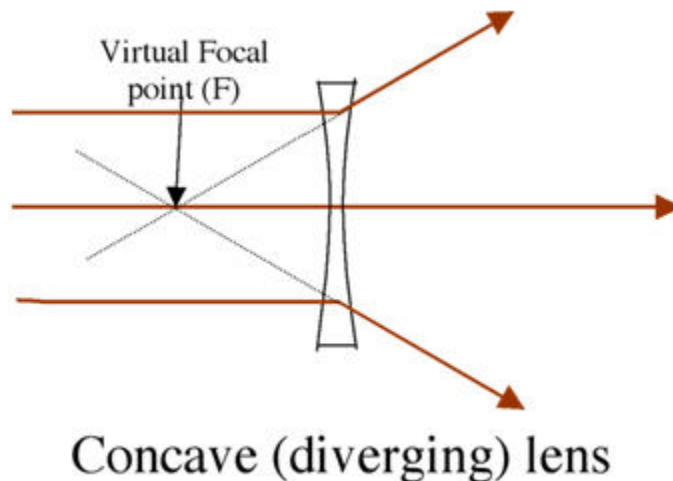
Previously you have learned that when light hits a medium with a different optical density, the beam refracts and bends to different angles. In this lesson, we will study the images produced when light refracts through lenses.

Lenses are used in a variety of applications, including glasses, microscopes, telescopes, and the human eye. There are two types of lenses: convex or concave. A **convex lens** (or converging lens) is thicker in the middle and takes parallel light rays and focuses them to a common point, called the focal point (F)



It is for this reason that they are sometimes call converging lenses.

A **concave lens** (or diverging lens) is thinner in the middle and takes parallel rays of light and spreads them apart. The diverging rays appear to originate from the focal point (F), sometimes called a virtual focal point because the rays don't actually go through this point.



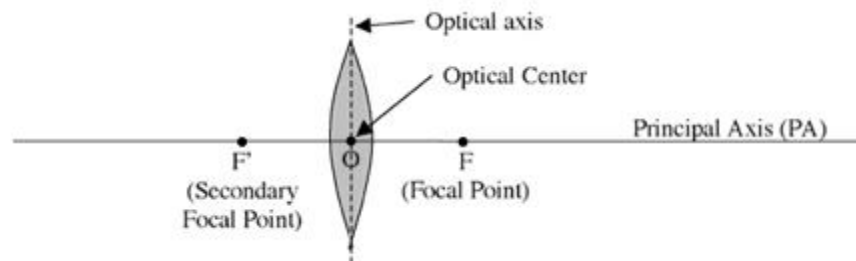
When light reflects off an object, it typically diffuses out in all directions. As this reflected light hits a lens, the rays are bent to form images of the object. Images are classified in the following manner:

- Type—Real images formed by converging light rays or virtual images that are an illusion formed by diverging light rays.
- Orientation—Upright (erect) or inverted with respect to the object.
- Size—Larger, smaller, or same size as compared to the object.

An image's characteristics depend on the type of lens used as well as the location of the object with respect to the lens.

Physics: Optics

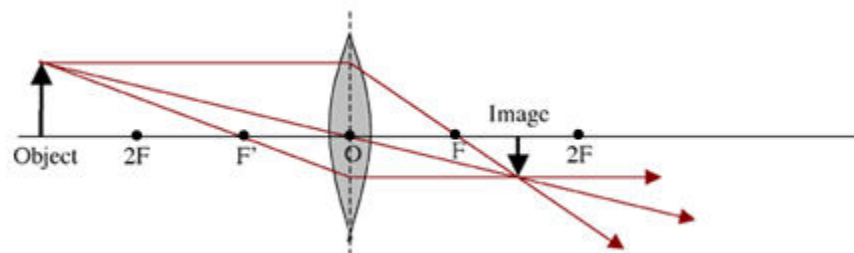
- To determine the location of images, lens ray diagrams are used. The following terms are used in the ray diagram rules:
- Optical axis—A line along the center axis of the lens where the rays are shown to bend at.
- Principal Axis (PA): A line that goes through the middle of the lens, striking the optical axis at a 90-degree angle
- Focal point (F)—The point where rays parallel to the PA converge to (or appear to diverge from). This point is one focal length from the lens.
- Optical Center (O)—The very center of the lens.
- Secondary focal point (F')—A point on the PA that is one focal length from the lens but on the other side of the lens from F.



The following three rules are used for constructing ray diagrams for convex (converging) lenses:

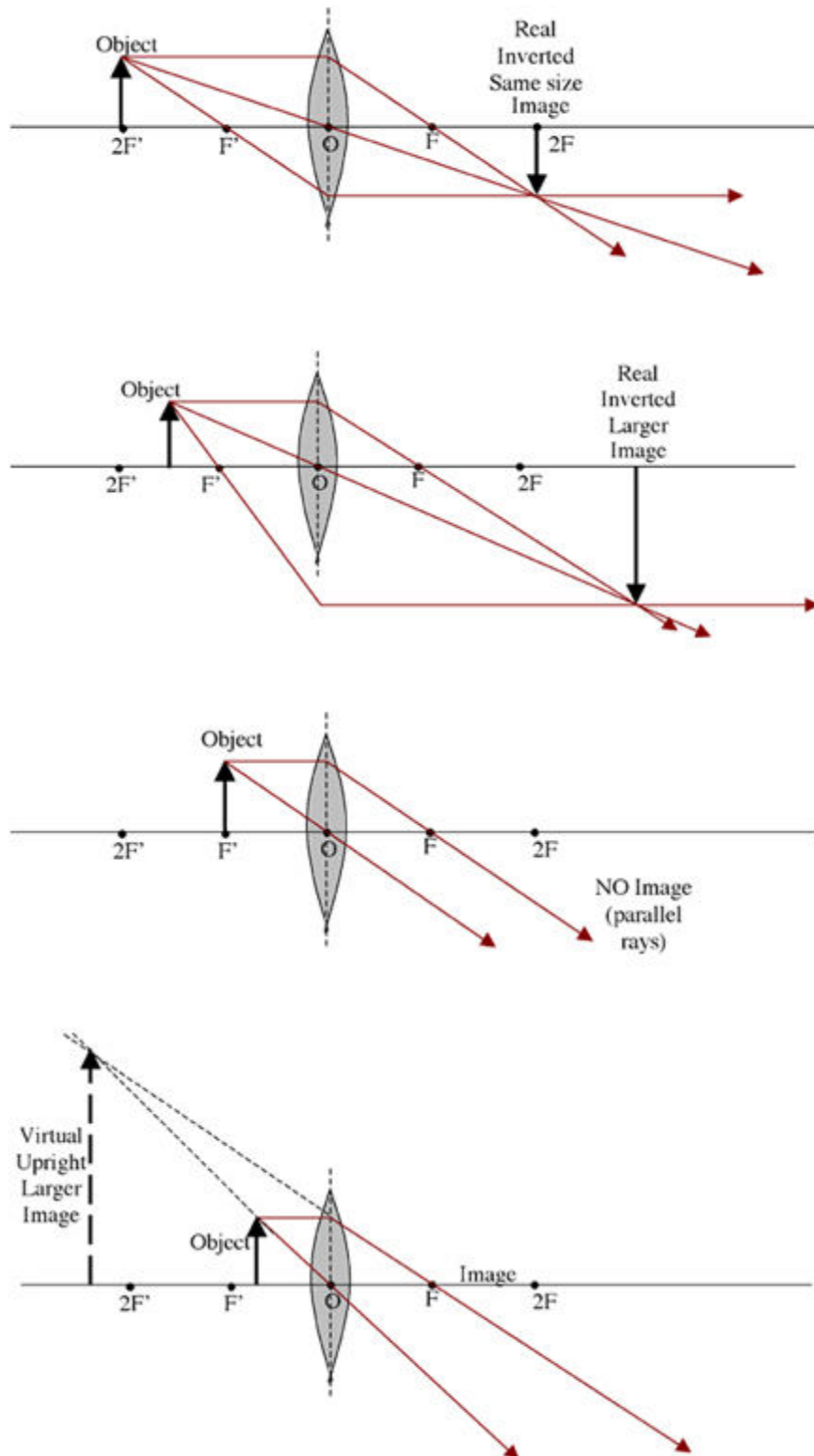
- Any ray parallel to the principal axis refracts through the focal point.
- Any ray going through the secondary focal point refracts parallel to the principal axis.
- Any ray going through the optical center goes straight through the lens (if it's a thin lens).

Let's begin by looking at objects that are located beyond two focal lengths from the lens and apply the three rules above.



The characteristics of this image are real, inverted, and smaller. Real, because actual light rays converge to a point; inverted, because the rays intersect below the principal axis; and smaller, because the image arrow is smaller than the object.

Here are some other diagrams with the object at different locations:

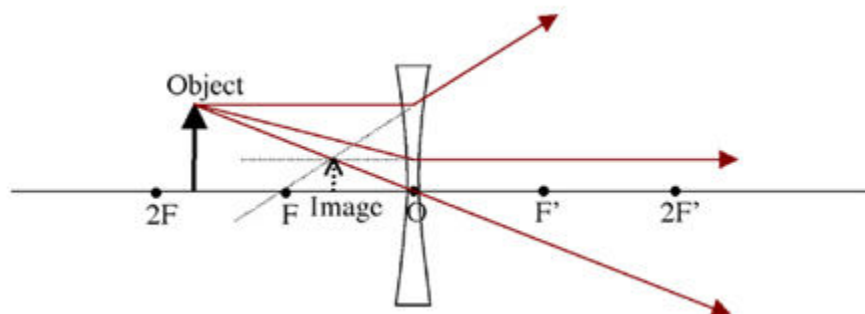


The last ray diagram above shows how in the formation of a virtual image the real light rays do not intersect. To see the image, it must be viewed by looking back through the lens, giving the illusion of a magnified image. This is how a simple magnifying lens works, but only if the object is within one focal length of the lens. An example of convex lenses would be the ones used as reading glasses to correct farsightedness.

Physics: Optics

The ray rules are almost identical for concave (diverging) lenses:

- Any ray parallel to the principal axis diverges as it comes from the virtual focal point.
- Any ray going toward the secondary focal point refracts parallel to the principal axis.
- Any ray going through the optical center goes straight through the lens (if it's a thin lens).



Concave lenses always produce virtual, smaller, and upright images. Concave lenses are used as distance glasses to correct myopia (nearsightedness).

The table below summarizes the images formed by lenses:

Lens Type	Object Distance from Lens	Image Type	Image Orientation	Image Size	Possible Applications
Convex	Beyond two focal lengths	Real	Inverted	Smaller	Camera, Human eye
Convex	At two focal lengths	Real	Inverted	Same Size	Copy machine (100%)
Convex	Between 1 & 2 focal lengths	Real	Inverted	Larger	Movie Projector
Convex	At one focal length	None	None	None	Spot lights
Convex	Between lens and focal point	Virtual	Upright	Larger	Reading Glasses
Concave	Anywhere	Real	Upright	Smaller	Distance Glasses

Physics: Optics

Answer the following questions and click on the following link to check your answer.

Question

A copy machine is used to make an image that is 50% of the original. What type of lens may be used to

project the right size image to copy?

- A Convex
- B Concave
- C Diffraction
- D Myopic

✔**Answer**

The correct answer is A. Real light rays must be focused to a point in order to burn an image onto the cop. Only convex lenses are capable of producing real images.

Question

A copy machine is used to make an image that is 50% the size of the original. How far from the lens should the original be placed?

- A Less than 1 focal length
- B 1 focal length
- C 2 focal lengths
- D More than 2 focal lengths

✔**Answer**

The correct answer is D. In order to get a smaller image, the original must be beyond two focal lengths from the lens.

Physics: Optics

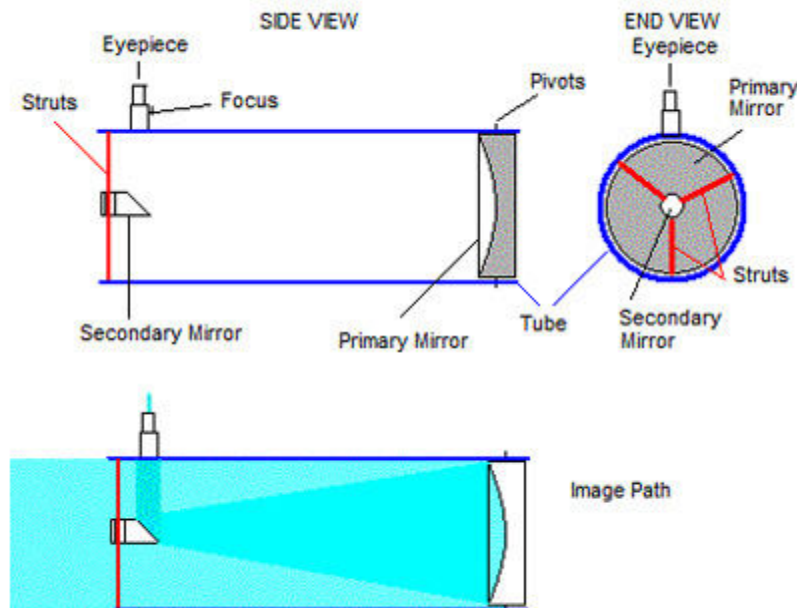
Applications of lenses

Lenses (as well as mirrors) are used in combination to produce significant magnifications. The compound microscope, for example, takes the rays coming from a microscope slide and refracts

them through a convex lens (the objective lens) to produce a real, inverted, larger image. This image is viewed through a second convex lens (the eyepiece lens) that magnifies it even more. **Compound microscopes** have 2 or more lenses, depending on the resolution needed.

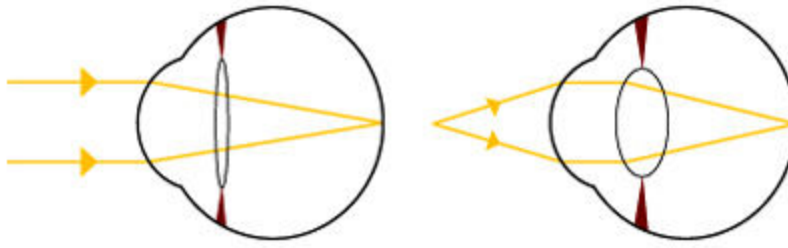
Astronomical refracting telescopes usually use two convex lenses in combination. The light from distant planets is refracted to a real, smaller, inverted image through the first lens (the objective lens). The second lens (the eyepiece lens) magnifies this image. The image coming through the two-lens system is inverted relative to the original objects.

Mirrors are also used in combination with lenses to produce images. Sir Isaac Newton designed the first reflecting telescope in 1668. The **Newtonian reflecting telescope** uses a concave mirror to focus the light from distant stars to a diagonal plane mirror as shown in the diagram below. The plane mirror reflects the rays through a hole in the side of the telescope into an eyepiece lens. Because large diameter mirrors can be supported better than lenses, these telescopes gather more light than astronomical telescopes.



Newtonian telescope diagram

The human eye can also be visualized as a two-lens system. The front part of the eye, called the cornea, is where most of the refraction occurs. Significant bending occurs here because light slows down significantly as it enters the cornea. After the light bends through the cornea, it hits the lens. The lens makes fine adjustments in order to focus the light on the retina. The retina sends the image information to the brain for processing.



Human eye lens

Further Reading in Physics

Physics: Further Reading

General Mathematics and Kinematics

Quantum Kinematics and Dynamics (Julian Schwinger): 2000

The Complete Idiot's Guide to Physics (Johnnie T. Dennis): 2003.

Dynamics

Engineering Mechanics, Dynamics (Engineering Mechanics) (J. L. Meriam, L. Glenn Kraige): 2001

Concepts of Force: A Study in the Foundations of Dynamics (Max Jammer): 1999

The Complete Idiot's Guide to Physics (Johnnie T. Dennis): 2003

Work, Energy, Power, and Momentum

How Things Work: The Physics of Everyday Life (Louis A. Bloomfield): 2000

The Illustrated on the Shoulders of Giants: The Great Works of Physics and Astronomy (Stephen Hawking): 2004

Mechanics of Fluids

Mechanics of Fluids (Irving Shames, Irving Shames): 2002

Mechanics of Fluids (Merle C. Potter, David C. Wiggert): 2001

Thermodynamics

Fundamentals of Heat and Mass Transfer, 5th Edition (Frank P. Incropera, David P. DeWitt): 2001

Schaum Engineering Thermodynamics (Schaum's Outlines) (Merle Potter): 1994

Thermodynamics (E. Fermi): 1937

Waves

Waves in Fluids (James Lighthill): 2002

Cymatics: A Study of Wave Phenomena & Vibration (Hans Jenny): 2001

Linear and Nonlinear Waves (G. B. Whitham): 1999

Electricity

Electricity: Principles and Applications (Richard J. Fowler): 1998

Basic Electricity (Nooger Van Valkenburgh): 1995

Delmar's Standard Textbook of Electricity (Stephen L. Herman): 1998

Magnetism and Electromagnetism

Treatise on Electricity and Magnetism, Vol. 2 (James Clerk Maxwell): 1954

Physics for Scientists and Engineers: Electricity and Magnetism, Light (Paul A. Tipler): 1998

Classical Electricity and Magnetism: Second Edition (Dover Books on Physics) (Wolfgang K. H. Panofsky, Melba Phillips): 2005.

Optics

Introduction to Modern Optics (Grant R. Fowles): 1989

Principles of Optics: Electromagnetic Theory of Propagation, Interference and Diffraction of Light (7th Edition) (Max Born, Emil Wolf): 1999

Optics (4th Edition) (Eugene Hecht): 2001.

Chapter: Biochemistry & Cell Biology

1. Biochemical Basis of Life

Biochemistry & Cell Biology: Biochemical Basis of Life

Lesson Objective

We will now cover the biology content in more depth; starting with the building blocks of life, organic molecule. We will review the types of organic molecules, what they are composed of, and how they

Previously we covered...

We have just covered the most important aspects of Physics in depth. The last lessons covered electromagnetism and optics, the properties of waves, light, and the electromagnetic spectrum.

function in living organisms. The biochemical basis of life is fundamental to all other aspects of biology and the life sciences.

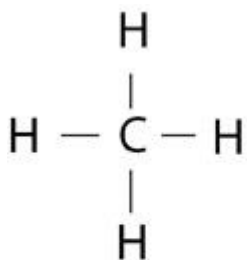
Biochemistry & Cell Biology: Biochemical Basis of Life

Organic Molecules

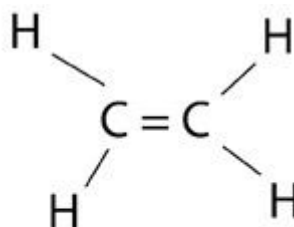
As we understand the universe, all matter is fundamentally composed of atoms. Depending upon the numbers of protons, neutrons, and electrons, an atom can be any one of at least 259 known elements (with perhaps half a dozen more yet to be discovered). Of these 259 elements, only about a dozen are important for life — and the molecules formed by these elements are called **organic** molecules. Organic chemistry is one of the most important and complex disciplines within chemistry and overlaps considerably with biochemistry and biology. Living things are composed primarily of organic molecules.

Organic molecules are those that have a carbon skeleton with hydrogen and/or other **functional group** attached. Because carbon has four valence electrons, it tends to form **covalent bonds** with up to four other atoms. Coincidentally, the energy used by living things is usually stored in the covalent bonds of organic compounds.

Hydrocarbons or alkyls are the simplest organic compounds, containing only carbon and hydrogen. **Alkanes** are saturated hydrocarbons, meaning there are no carbon double bonds present. Methane, shown below, is an example of an alkane. **Alkenes**, on the other hand, are characterized by having a double bond; they are unsaturated hydrocarbons. The degree of saturation of a hydrocarbon influences its reactivity and shape. Below is also shown an example of a simple alkene, ethene.



methane



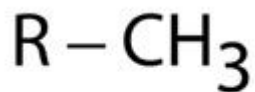
ethene

Examples of Alkanes

The functional groups attached to carbon compounds determine the reactivity and classification of more complex organic molecules. Classes of organic compounds are often represented by the functional group bonded to a generic organic group that can vary among the amino acids. These generic organic groups are sometimes represented as an R. Likewise, there are other symbols for specific types of functional groups.

Biochemistry & Cell Biology: Biochemical Basis of Life

Let's review a few of the major types of functional groups.



methyl group

Example of the methyl group

Methyl Group

- Single carbon hydrophobic alkyl group
- Component of fatty acid chains
- Insoluble in water
- Common component in many organic molecules (including biodiesel)



ether group

Example of the ether group

Ether Group

- Oxygen bonded to two alkyl groups
- Are of very low chemical reactivity.
- They should not be confused with similar compounds:
 - The aromatic rings with an oxygen
 - Compounds that have oxygen bonded to a sulfur or nitrogen, like esters, acetals, anhydrides, and anhydrides.

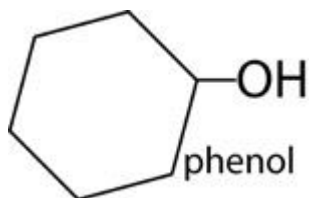


hydroxyl group

Example of the hydroxyl group

Hydroxyl Group

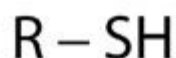
- Simple: OH group common to many organic molecules
- Present in alcohols, sugars, and amino acids
- Highly reactive with other compounds and usually short-lived
- Important in atmospheric chemistry to oxidize otherwise noxious gases



Example of the phenol group

Phenols

- Hydroxyl groups bond to an aromatic hydrocarbon (ring)
- Some phenols are germicidal
- Some are endocrine disruptors (they mimic animal sex hormones)
- Similar to alcohols, but the hydroxyl group is bonded to a saturated carbon

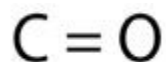


sulfhydryl group

Example of the sulfhydryl group

Sulfhydryl Group

- Sulfur analog of hydroxyl group
- Functionally similar to alcohols
- Form disulfide bonds in some amino acids, important in protein structure
- Can be important in biological catalysts
- Molecules with these are called thiols
- They have relatively low boiling points and solubility

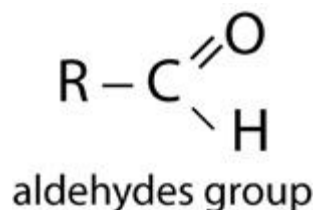


Carbonyl group

Example of the carbonyl group

Carbonyl Group

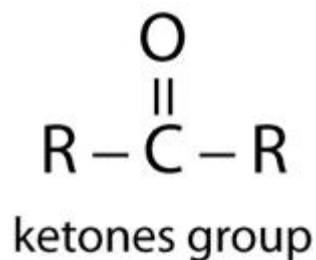
- Present in sugars, amino acids, and nucleotides
- Water soluble
- Because of the molecule's polarity, it is highly reactive
- Present in many other types of functional groups like aldehydes, ketones, carboxyls, esters, amides, and anhydrides.



Example of the aldehyde group

Aldehydes

- Carbonyl group at end of a carbon backbone
- React to form more complex molecules
- Include odors of cinnamon, vanilla, and rancid butter

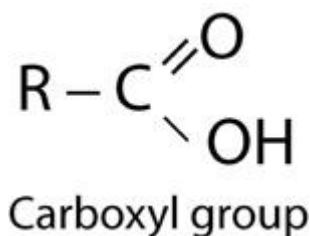


Example of the ketone group

Ketones

- Carbonyl group attached in the middle of a carbon backbone
- Good solvents or polymers

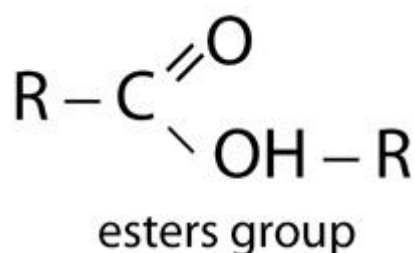
- The carbonyl group is polar, making ketones very polar compounds
- Are more volatile than alcohols and carboxyl acids



Example of the carboxyl group

Carboxyl Group

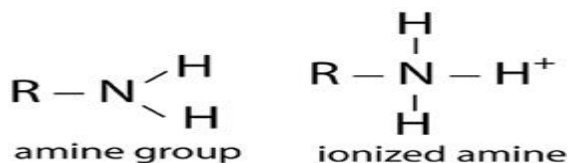
- Associated with organic acids
- Present in amino acids and fatty acids
- Very polar and water soluble
- Act as acids by ionizing by giving up H^+ ions in solution
- Vinegar is a common example



Example of the ester group

Esters

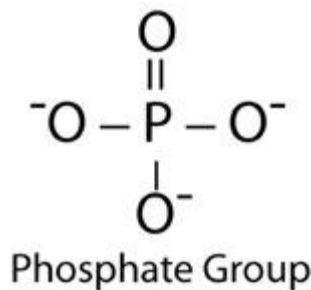
- Formed by the reaction between an alcohol and an acid
- An alkyl group replaces the H on an organic acid and water becomes condensed
- Because of their distinctive odors, they are often used in flavorings and fragrances
- Fruit odors and aspirin are common examples



Example of the amine group

Amine Group

- Nitrogen-based derivative of ammonia
- Present in amino acids and nucleotides
- Can act as relatively strong bases
- Water soluble
- Act as a weak base in solution by attracting protons to produce an ionized form



Example of the phosphate group

Phosphate Group

- Found in DNA, RNA, ATP, and many proteins and phospholipids
- Water soluble and acidic
- High-energy bonds
- Often a limiting resource in most biological systems

Biochemistry & Cell Biology: Biochemical Basis of Life

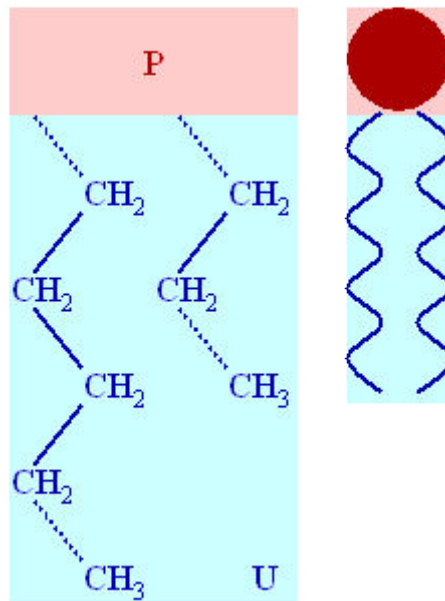
Making and Breaking

Complex organic macromolecules called **polymers** are formed from simple organic **monomers**. Living things are composed primarily of only four kinds of organic polymers: carbohydrates, lipids, proteins, and nucleic acids. Each type of these macromolecules is made of a distinctive combination of organic monomers. Organic monomers undergo **dehydration synthesis** (also called condensation reaction) to produce complex polymers. In a condensation reaction, one monomer loses an H^+ ion and the other loses an OH^- ; to create water (H_2O) and a new bond linking the formerly two molecules into one. In the opposite reaction, called **hydrolysis**, polymers are broken down into monomer subunits by the addition of water.



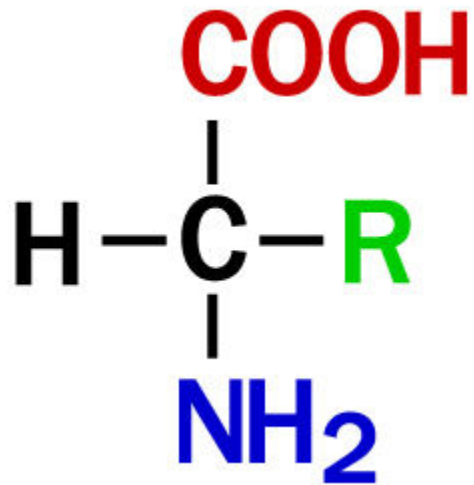
Common dietary sources of carbohydrates

Carbohydrates are standard energy storing molecules and are commonly called sugars and starches. The monomers of carbohydrates are called **monosaccharides** or sugars. They produce polymers called **polysaccharides** or starches by forming **glycosidic bonds**. There are several classes of carbohydrates that we will discuss in detail later.



Example of lipid structures

Lipids typically contain long **fatty acid** chains, are non-polar, and water insoluble. Fats, like triglycerides and oils, are lipids composed of glycerol bonded to fatty acid chains. Other lipids, such as steroids, contain distinctive ring structures and can have powerful biological properties.

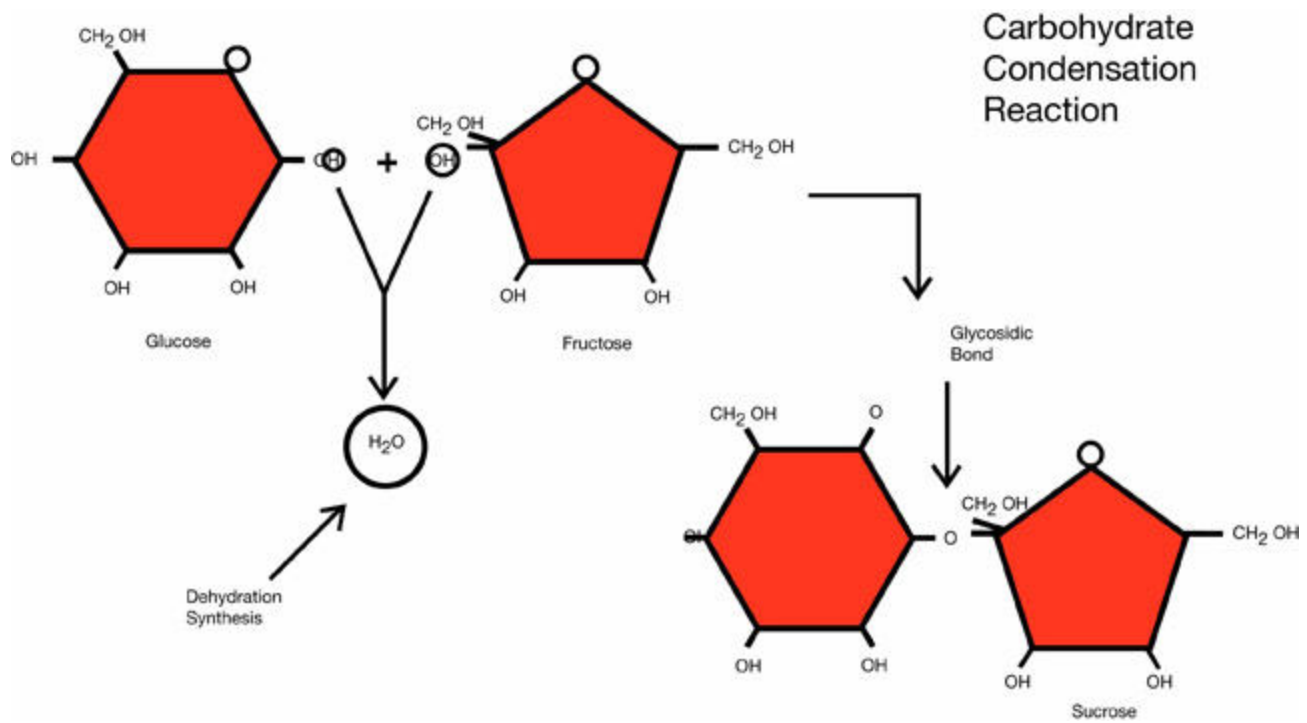


General amino acid chemical structure. Note the carboxyl, amine, and R groups.

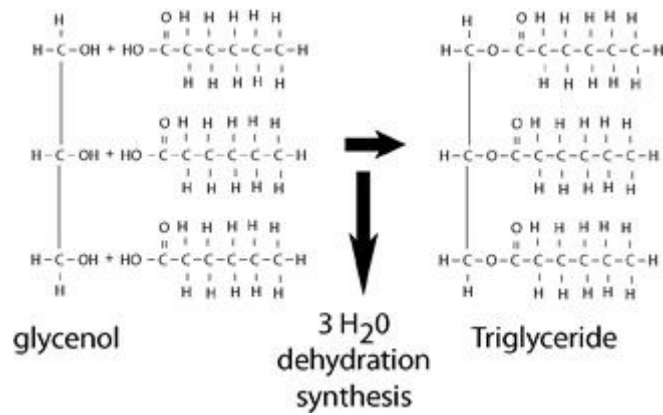
Proteins have several levels of structure and importance, but all are composed of **amino acid** monomers joined by **peptide bonds** in dehydration synthesis. Proteins are very important in controlling metabolic reactions as enzymes and have many other important functions at the cellular level.

The monomers of the nucleic acids DNA and RNA are called nucleotides. Nucleotides form **phosphodiester bonds** in dehydration synthesis to form the DNA backbone. Another important nucleotide in all living things is called **adenosine triphosphate** (ATP). It is considered to be the most important of the energy storing biomolecules and may play a future role in nanotechnological energy sources. It is composed of a pentose sugar called ribose, an amine called adenine, and three phosphate groups. The line of phosphates contains very high energy bonds that are easily broken. Energy is transferred during the dehydration synthesis by making and/or breaking high-energy bonds in ATP.

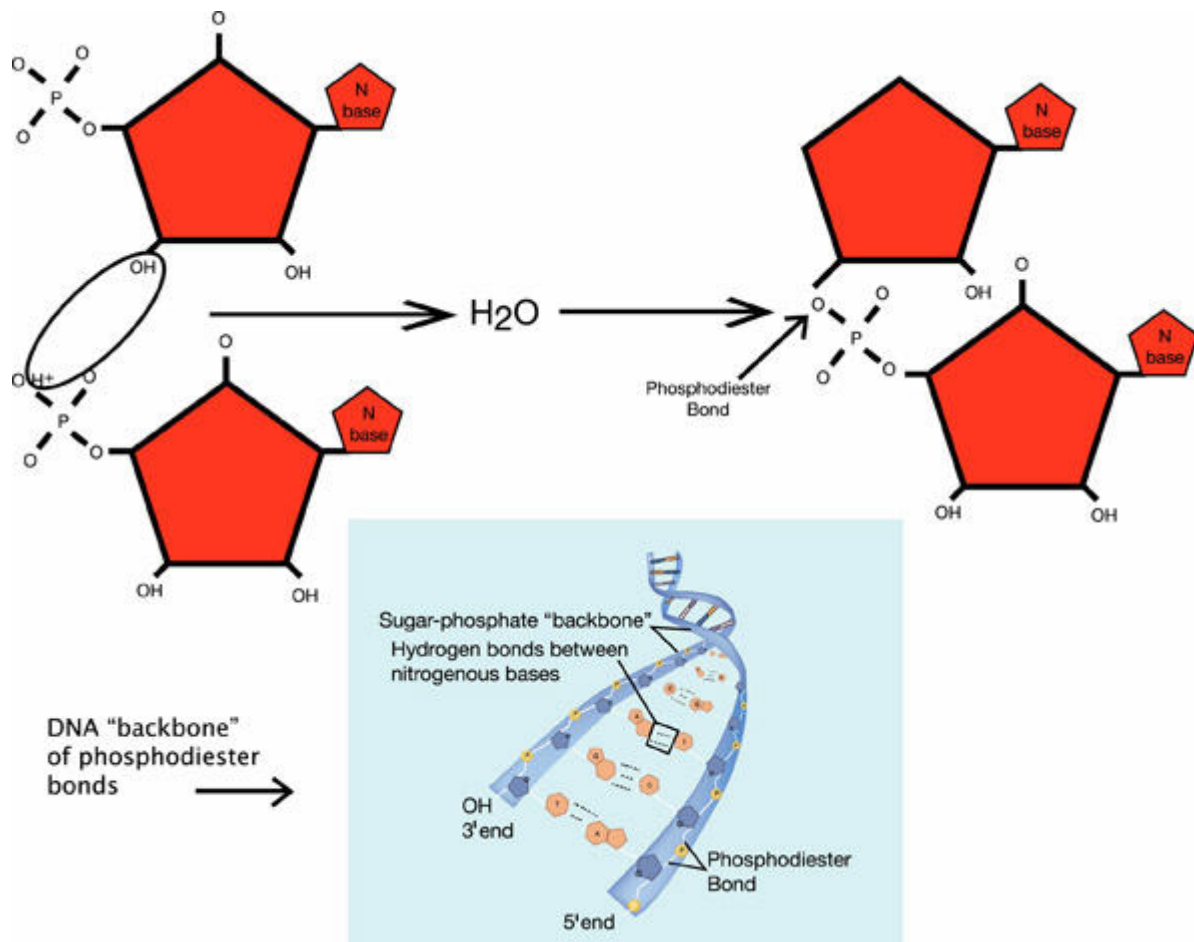
Dehydration synthesis reactions occur when two molecules become covalently bonded to each other while water is being lost. Examples of dehydration synthesis (also called condensation reactions) for three of the four main classes of organic macromolecules are shown below.



Dehydration synthesis in a carbohydrate



Dehydration synthesis in a lipid



Dehydration synthesis in a nucleic acid

Hydrolysis reactions are the opposite process of that shown above; they take a single molecule and cleave it into two separate new molecules by adding a molecule of water. In hydrolysis, water is split by hydrolytic enzymes, breaking it into an H⁺ atom and an OH⁻ group. These react to form simple monomers with the two separate parts of the former larger molecule when the molecular bonds of the polymer are broken.

Question

What is formed by the dehydration synthesis of sucrose?

- A Glucose and fructose
- B Monosaccharides
- C Water
- D Cellulose

👉Answer

The correct answer is C. Dehydration synthesis builds complex molecules from simple ones (hence the name synthesis), and water is produced as a by-product

Biochemistry & Cell Biology: Biochemical Basis of Life

Lesson Objective

In this lesson, we will review the kinds and properties of carbohydrates.

Previously we covered...

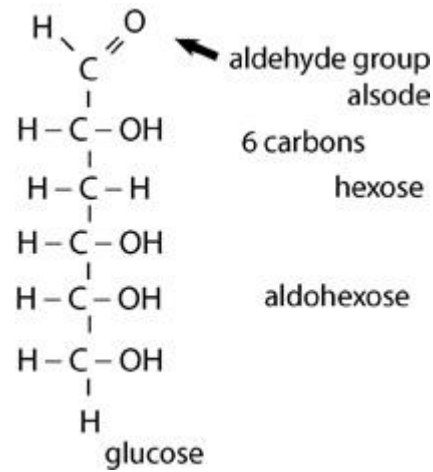
- Organic molecules are made primarily from carbon, hydrogen, and oxygen. About ten other elements are the main players in other organic molecules.
- Functional groups bonded to the carbon backbone of organic molecules determine the chemical reactivity of the molecule.
- The four main classes of organic polymers in living things are carbohydrates, lipids, proteins, and nucleic acids.
- Complex organic molecules called polymers are formed from condensation reactions involving simple monomers.
- Energy is stored in the bonds of organic macromolecules.

Biochemistry & Cell Biology: Biochemical Basis of Life

Carbohydrates

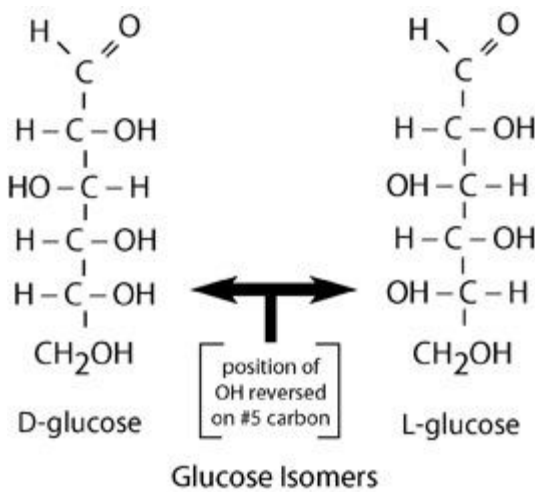
Carbohydrates are important sources of quick energy. Energy used by cells is released from carbohydrate bonds such as glucose. Carbohydrates also function in energy storage as starch and glycogen, and as important structural elements, particularly for plants, fungi, and the cell walls of arthropods.

The simplest carbohydrates, monosaccharides, are classified by the number of carbons present in the chain. For example, a **triose** contains three carbons; a **pentose** contains five, and a **hexose**, such as glucose, contains six carbons. Sugars may also be classified based on functional groups present. An **aldose** contains an aldehyde group; a **ketose** contains a ketone group. Glucose is an aldohexose; it is a six carbon sugar with an aldehyde attached. The naming scheme has both specific and general names; so many macromolecules can have more than one name. For example, glucose is also one of the many types of hexose.



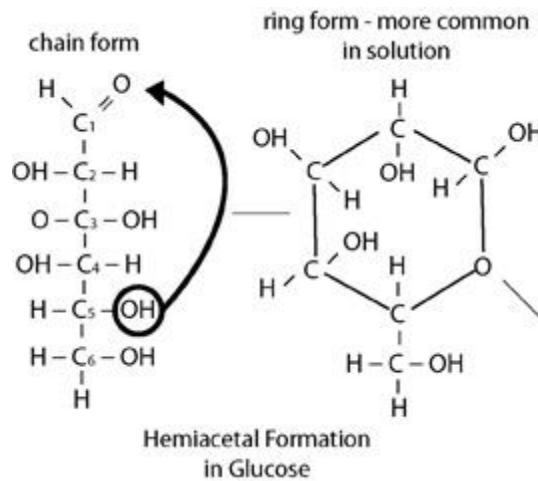
Glucose

Monosaccharides often exist as **isomers**. Isomers are molecules with the same chemical formula and often the same kinds of bonds between atoms, but in which the atoms are arranged differently. Glucose, for example, can have as many as sixteen different configurations of atoms. This can seem unimportant, but is actually crucial for most biomolecules. Various isomers of glucose are named according to location of functional groups. Unique isomers of simple carbohydrates are involved in many important metabolic pathways.



Example of the isomers of glucose

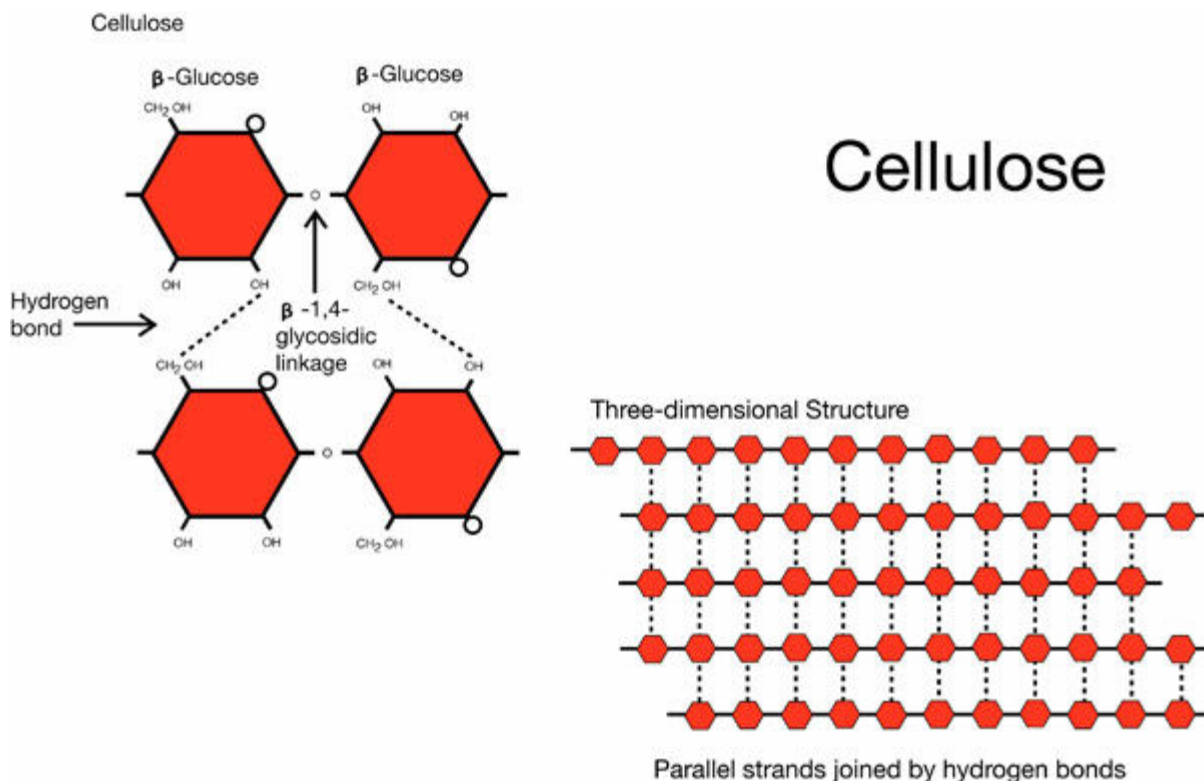
Monosaccharides may also exist as straight chains, bent structures, or as ring forms. When there are five or more carbons in a chain, very stable ring structures called **hemiacetals** may form. This occurs when the carbon on one end of a chain reacts with the hydroxyl on the opposite end. Several combinations are possible in pentose and hexose sugars. In living things, most five and six carbon monosaccharides most often occur in ring forms. This is primarily due to the high stability of these molecules relative to their sister isomers.



Example of ring structure of hemiacetals

An **oligosaccharide** is a more complex carbohydrate composed of two to ten monosaccharide subunits. A **disaccharide** is an oligosaccharide composed of two monosaccharides, such as the sucrose molecule shown in the dehydration reaction for carbohydrates. Polysaccharides are very complex, composed of more than 10 monosaccharides. Cellulose, starch, glycogen, and chitin are all biologically important polysaccharides.

Cellulose is the most abundant polymer on Earth. Cellulose is the primary structural component of plant cell walls. So, if you are wearing cotton, sitting on a wooden chair, or taking notes, you are wearing, sitting, or writing on cellulose. Moreover, almost all of our dietary fiber comes in the form of cellulose. Cellulose monomers are linked together through 1-4 glycosidic bonds in a straight chain. In cellulose microfibrils, hydroxide groups in the monomers hydrogen-bond with each other, holding the chains firmly together creating a lattice structure. This gives cellulose fibers high tensile strength. In plant cell walls, cellulose forms a matrix with hemicellulose and lignin to give plants support.

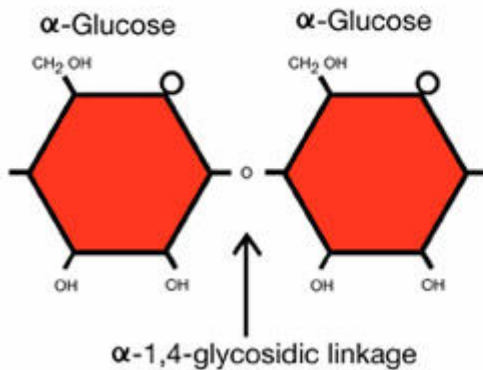


Cellulose

Cellulose

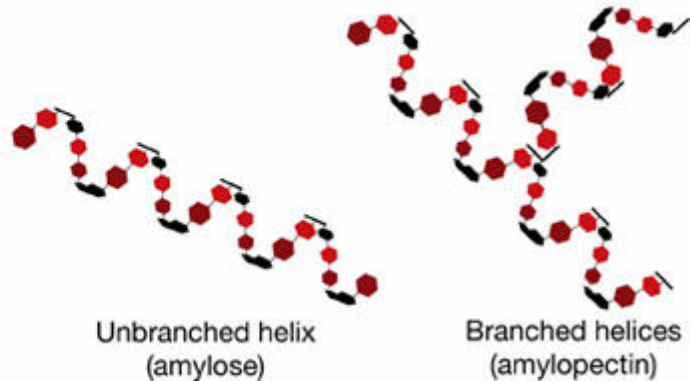
Starch and **glycogen** are energy storage carbohydrates. Starch is the primary form of energy storage in plants, while glycogen is the form of carbohydrate energy storage in animals. Starch and glycogen are polymers of alpha glucose. Amylose, a form of starch, has alpha 1-4 glycosidic bonds; while the starch amylopectin and glycogen have alpha 1-4 glycosidic bonds and alpha 1-6 glycosidic bonds. Starch polymers occur as either unbranched or branched helices, while glycogen occurs as complex branched helices.

Starch



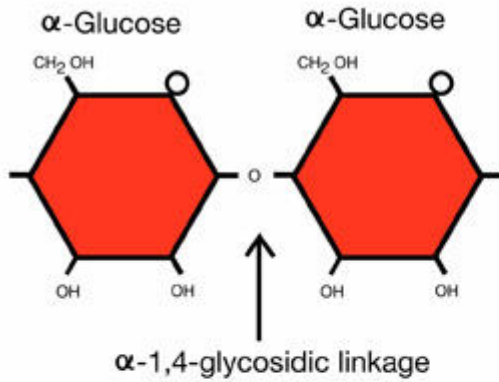
Starch

Three-dimensional Structure



Example of a starch

Glycogen



Glycogen

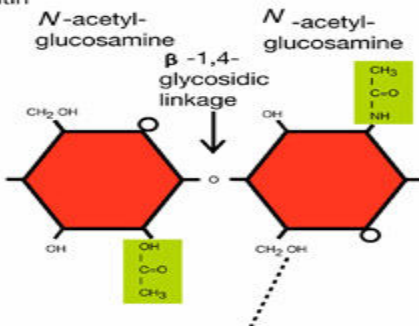
Three-dimensional Structure



Example of glycogen

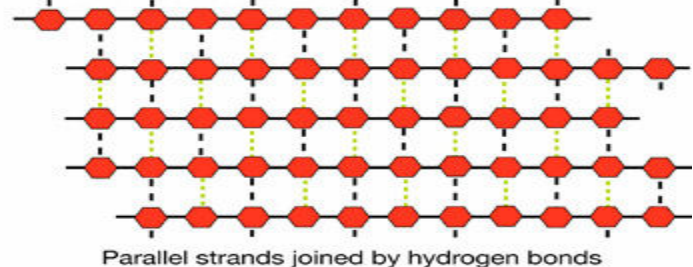
Chitin is a complex carbohydrate common to fungi and arthropods. It is a primary component of fungal cell walls and of the hard exoskeleton of insects and crustaceans. Chitin is structurally similar to cellulose. It is made out of monomers of acetylglucosamine linked together in the same way as glucose units in cellulose. Chitin differs from cellulose in that one hydroxyl group on each monomer is replaced by an acetamino group. This allows for increased hydrogen bonding between adjacent polymers and increased strength.

Chitin



Chitin

Three-dimensional Structure



Chemical structure of chitin

2. Lipids

Biochemistry & Cell Biology: Lipids

Lesson Objective

In this lesson, we will review the types and properties of lipids.

Previously we covered...

- Living things store energy in the carbon bonds of organic molecules.
- Monosaccharides are named and classified by their number of carbons and types of functional groups.
- Monosaccharides bond to form more complex carbohydrates called oligosaccharides or polysaccharides. Important carbohydrates in living things include cellulose, starch, glycogen, and chitin.

Super High Energy: Fats, oils, waxes, and other chub

Lipids all contain long chains or rings of hydrocarbons that give them their relatively **hydrophobic** and **non-polar** characteristics. Examples of lipids include fats and oils, waxes, phospholipids, and ringed steroids, such as cholesterol and steroid hormones. Lipids are crucial components of cell membranes, serve as a form of long-term energy storage, act in transport, and function as chemical messengers themselves.

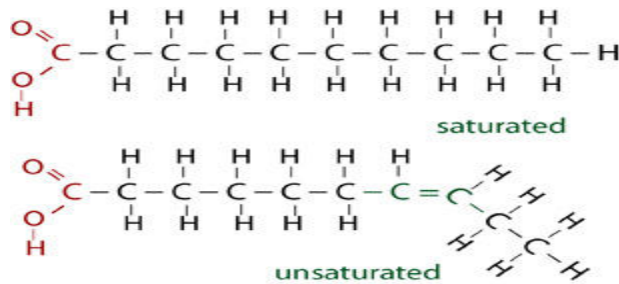
Fats and oils are triglycerides, esters of glycerol, and fatty acids. They are formed by dehydration synthesis reactions. Triglycerides are the primary form of long-term energy storage in plants and animals. Fatty acids are long chains of 12 to 24 hydrocarbons with a carboxyl group at the end. Bonding within fatty acid chains gives fats and oils their important energy-warehouse characteristics.

Fats and oils can be classified as saturated, monounsaturated, or polyunsaturated, depending on the number of double bonds between carbon atoms in the fatty acid chains.

Animal fats have all have single-carbon bonds and so are bonded to the maximum number of hydrogen atoms possible. The single bonds form a straight fatty acid chain. They are called **saturated** fats and are solid at room temperature. In general, these are the fats that most Americans have too much of in their diets.

Oils that have double bonding of carbon atoms are **unsaturated** fats. The double bonds create bends in the fatty acid tails, which makes unsaturated fats become liquid at room temperature. Most plant fats are unsaturated.

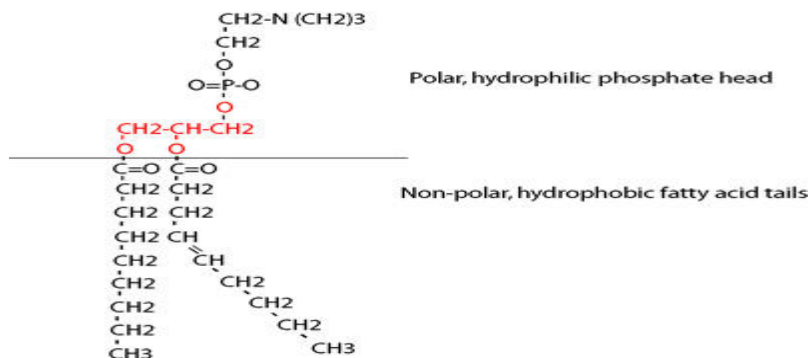
Polyunsaturated fats have multiple double bonded carbons.



Example of saturated and unsaturated fats. Note the difference in the number of hydrogens and the double-bonded carbons

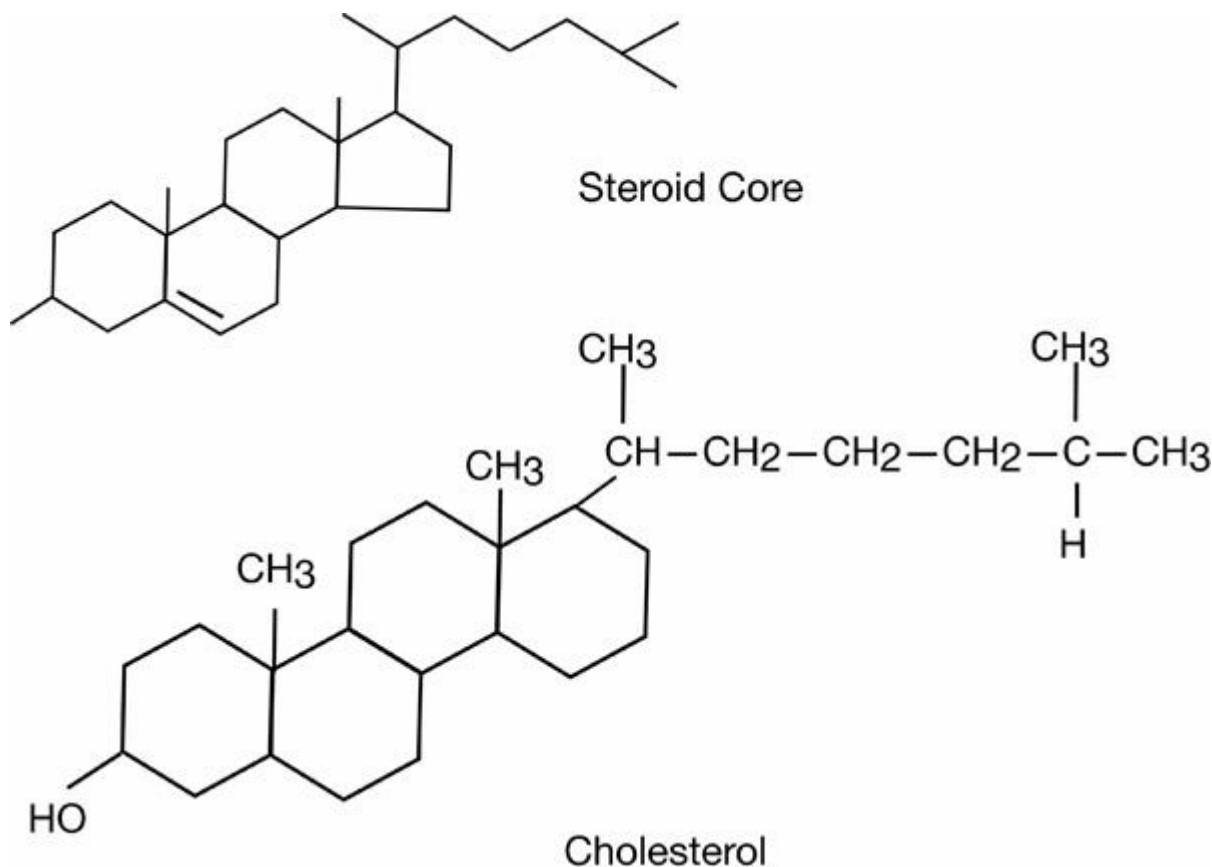
Waxes are also esters of long chain fatty acids bonded to long chain alcohols. Waxes function to provide a water-proof coating on many living things. Plant cuticles are waxy, as are many of the oils secreted by the skin. The exoskeleton of insects, for example, also contains wax.

Phospholipids are composed of glycerol, two fatty acids, and a phosphate head. The fatty acid tails of the molecule are hydrophobic, while the phosphate end of the molecule is **polar** and **hydrophilic**. This arrangement is ideal for function in double layered cell membranes. In solution and in cells, the polar heads of phospholipids arrange themselves opposite each other, creating an oily membrane interior. The unique structure of phospholipid bilayers makes them selectively permeable. One of the most interesting properties of phospholipids is that they naturally form layers and may have been one of the most important structural components of the first life on Earth.



Phospholipid structure

Steroids are lipids that contain a core skeleton consisting of four fused hydrocarbon rings. Hundreds of different steroids play very important roles in biological systems for plants and animals, especially as hormones. Examples of steroids include cholesterol, hormones, and many vitamins. Steroids are differentiated by the unique groups bonded at the outer regions of the four-ring core.



Steroid structure: Cholesterol

Cholesterol is an important component of cell membranes. It gives membranes their fluidity. In humans, the liver processes cholesterol in order to produce bile. Precipitated cholesterol can produce gall stones and excess cholesterol in the blood can lead to cardiovascular disease.

Hormones are chemical signals that act only on cells with specific receptors. Steroid hormones include the sex hormones estrogen, progesterone, and testosterone. Cortisone is also a steroid hormone, which is important in carbohydrate metabolism. It has anti-inflammatory properties that make it important in treatment of some diseases. A group of similar steroids acts as “Vitamin D”.

Lipoproteins are composed of proteins and several types of lipids bonded together. Some lipoproteins serve as catalysts, and many are associated with membrane-bound proteins. Some lipoproteins transport other lipids, such as cholesterol and steroids, throughout the body. Lipoproteins are classified by their density. High-density lipoprotein (HDL) transports cholesterol to the liver. Low-density lipoprotein (LDL) transports cholesterol to body tissues. Very low-density lipoprotein (VLDL) transports triglycerides for storage as fat.

Question

Identify types of lipids.

- A Ketones, fats, carbohydrates

- B Waxes, fatty acids, steroids
- C Vitamins, sugars, fats
- D Tri-layered membranes, esters, ketones

👉Answer

B is the correct answer. The term lipid encompasses a diverse assemblage of molecules and is a generic term for partially water-insoluble substances of biological origin, including waxes, fatty acids, fatty-acid phospholipids, and steroids (to name just a few). Some lipids are linear, while others are in ring structures. Ring-like molecules are usually aromatic, but many lipids are not necessarily that way.

3. Proteins

Biochemistry & Cell Biology: Proteins

Lesson Objective

In this lesson, you will review proteins.

- *Proteins are complex organic molecules composed of amino acid monomers joined in peptide bonds.*
- *Proteins have multiple levels of structure.*
- *Proteins called enzymes are important in controlling metabolism.*

Previously we covered...

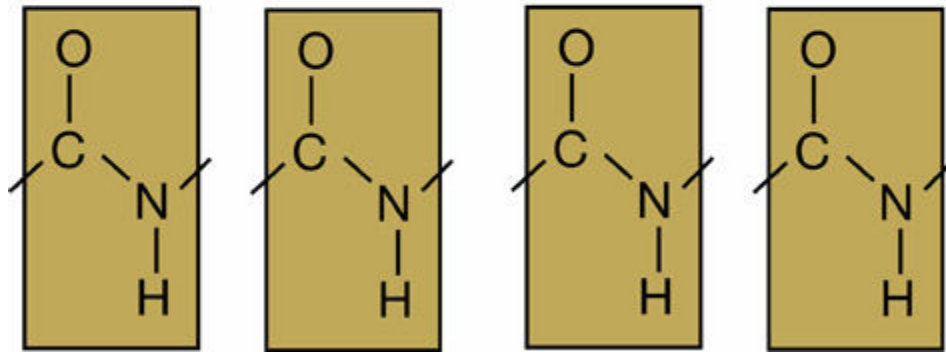
- Lipids are non-polar and insoluble in water.
- Phospholipids and the steroid cholesterol are important components of cell membranes.
- Triglycerides are esters that provide a form of long-term energy storage.
- Lipoproteins act in transport, and some steroids function as vitamins or chemical messengers.

Biochemistry & Cell Biology: Proteins

Function and Shape

Proteins are the stuff of life. As enzymes, they control metabolism and literally make life functions possible. The genetic information found in DNA contains codes for production of proteins. Proteins are important structural components, particularly in animals. They are involved in transport, immunity, and storage, and dynamically function as hormones. It is the shape of a protein that gives the protein its unique function. Its shape is determined by the chemical composition of the protein. We deconstruct protein shapes into secondary, tertiary, and quaternary structure, depending on complexity.

Primary protein structure- a polypeptide chain

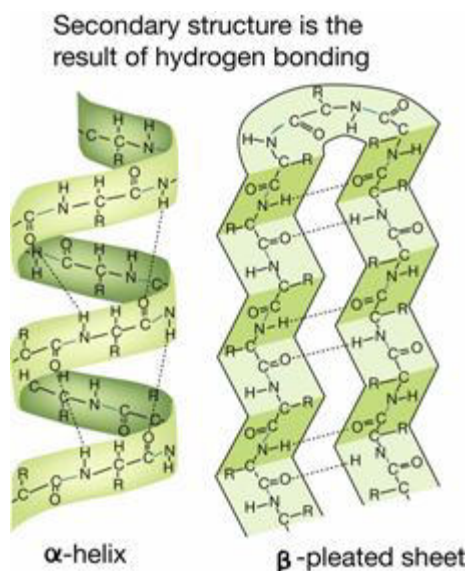


Examples of a polypeptide chain

Proteins are composed of **amino acid** monomers, which always have a nitrogen-based amine group and a carboxyl group bonded to a carbon or hydrocarbon side chain. The unique side chain of each amino acid is usually designated “R.” There are 20 unique amino acids. The **R** group of an amino acid affects its reactivity. Some amino acids have polar side chains, while others have non-polar side chains; some act as acids, others as bases. The sequence of amino acids in a primary protein determines its ultimate shape.

Amino acids undergo dehydration synthesis to form polypeptide bonds. Polypeptide chains represent the primary level of protein structure.

The secondary structure of a protein results from hydrogen bonding between amino acids in the peptide chain. This leads to twisting or folding of the chain into the alpha helix and the beta pleated-sheets based mostly upon weak hydrogen bonds between peptides.



Example of secondary structure of a protein

Tertiary structure results from the hydrophobic effect — a folding of the polypeptide chain due to positioning of polar and non-polar amino acids. Non-polar amino acids are typically inside the three-dimensional structure and polar side chains are on the outer surface. Hydrogen bonds and disulfide bonds stabilize tertiary structure.

Quaternary structure involves a complex grouping of two or more polypeptide chains into a stable, multi-subunit structure. They are stabilized by hydrogen bonding, **van der Waals interactions** and ionic bonding, and occasionally by disulfide bonds. **Rubisco**, the most abundant protein on Earth, has 16 subunits. Not all proteins have quaternary structure, and some function as simple primary polypeptide chains.

Proteins are important structural elements, especially in animals. The proteins actin and myosin are the main components of the cytoskeleton. These proteins function in cell movement and support. Actin and myosin are the main component of muscle cells and their interaction results in muscle contraction. Much of the non-cellular matrix of our bodies is composed of protein.

Proteins are also important structural components of cell membranes. Proteins embedded in cell membranes allow the control of movement of materials in and out of cells. Many membrane-bound proteins act as enzymes.

Proteins function in transport as well. Hemoglobin, the protein found in red blood cells, transports oxygen around the body. Sickle cell anemia is a disease that is caused by a misshapen hemoglobin protein, making it less efficient at transporting oxygen. Lipoproteins are important in transport of lipids. Within cells, molecules are transported along **proteinaceous** cytoskeletal elements.

Many hormones are also proteins. Insulin and human growth hormone (HGH) are proteins that are now produced by genetically engineered bacteria for use in treating human disease. Protein hormones function by interacting with specific chemical receptors on cells. Hormone receptor reactions are called signal transduction pathways and depend on the physical fit between the molecules.

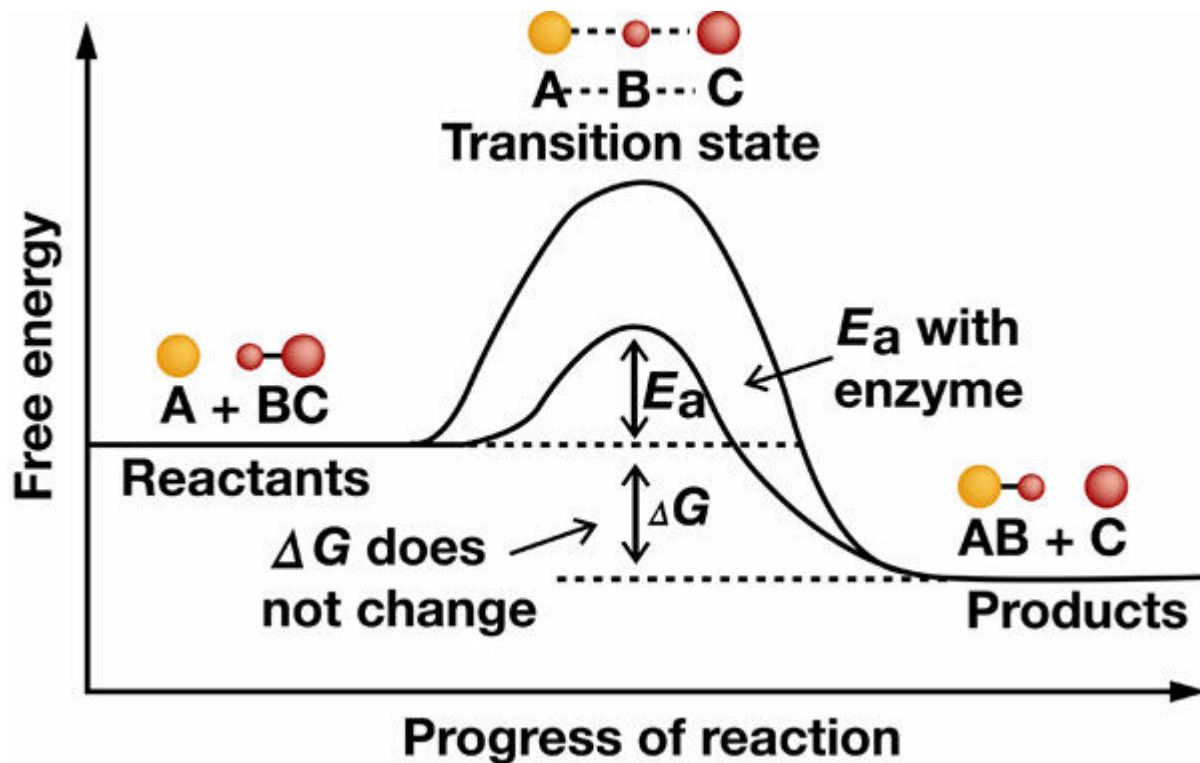
The immune system produces proteins called antibodies that neutralize pathogens, such as viruses. Antibodies function by fitting correctly with the invader it is designed to neutralize. Once a pathogen has been encountered, the immune system “remembers” how to produce the correctly shaped antibody.

Biochemistry & Cell Biology: Proteins

Enzymes

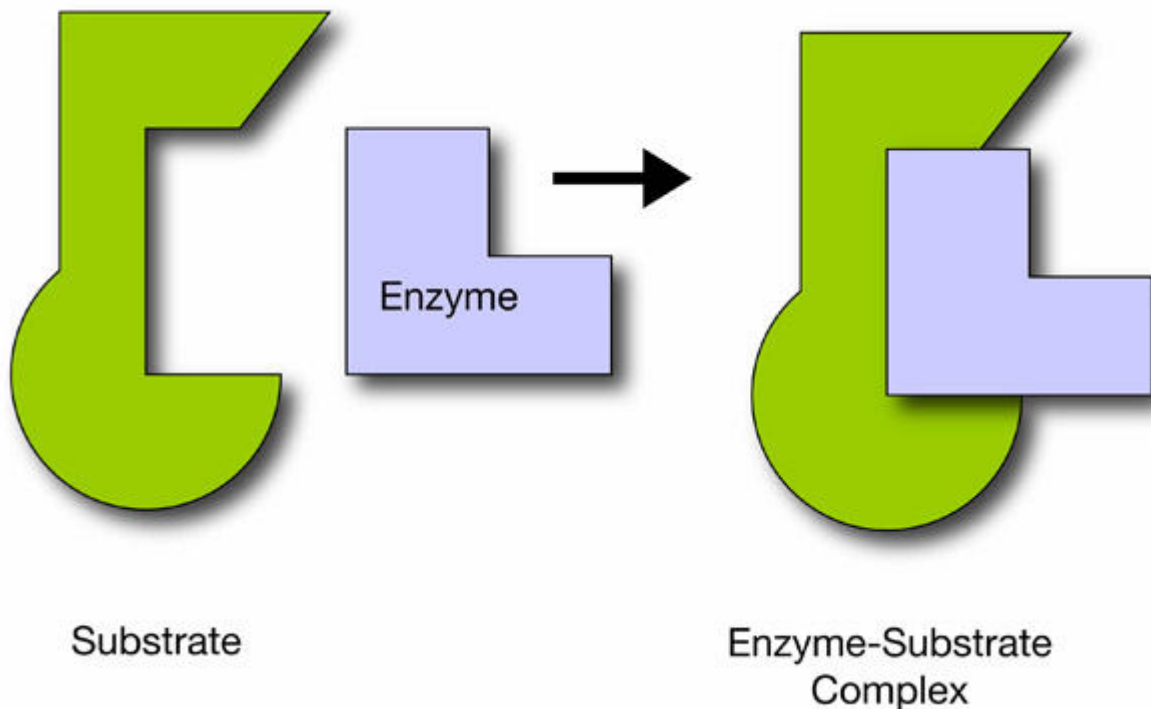
Enzymes are proteins that control all of the chemical reactions in cells. They do so by acting as organic **catalysts**, lowering the **activation energy** needed for chemical reactions. Their action allows metabolic reactions to occur millions of times faster than they would proceed uncatalyzed. Enzymes are important parts of many **metabolic** pathways and are vital to both **anabolic** and **catabolic** reactions.

Enzymes catalyze reactions by binding with specific **substrates**. When enzyme-substrate complexes are formed, molecules of reactant substrates are positioned in a way that destabilizes bonds, allowing chemical reactions to proceed. Such destabilization is called the transition state of a chemical reaction. A substrate is converted to a product and released by the enzyme. Enzymes are not used up or changed by the reactions they catalyze.



Example of how enzymes help reactions progress

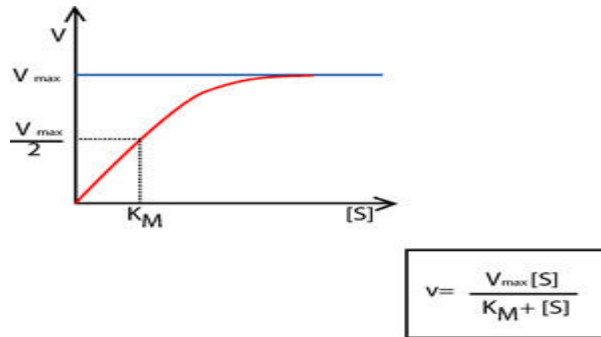
Enzyme function depends on the physical fit with the substrate. Substrates bind at an enzyme active site in a key-in-lock or hand-in-glove configuration. Many genetic diseases in humans are caused by misshapen enzymes. It is possible for cells to control enzyme activity by altering the shape of the enzyme or by blocking the binding site.



Enzymes' lock-and-key substrate complex

Many enzymes need other molecules called cofactors in order to function. These non-protein molecules are called cofactors and there are three kinds: coenzymes, activators, and prosthetic groups. Coenzymes are organic molecules that usually serve to transport atoms or functional groups between enzymes. Many vitamins act as coenzymes, as do ATP and other nucleotides. One of the most important coenzymes is nicotinamide adenine dinucleotide (NAD⁺), which often acts as an electron acceptor in a process called enzyme-catalyzed-oxidation-reduction. Activators are inorganic ions that are required for full enzyme activity. One of the most common examples is the calcium ion needed for blood clotting by the enzyme thrombokinase. Similarly, magnesium and potassium are also common activators for enzymes. Prosthetic groups are basically tightly bound cofactors and are usually responsible for transporting electrons for the enzyme.

Understanding enzyme function is vital in modern medicine and biotechnology. Much of our knowledge comes from the study of enzyme kinetics. The rate of enzyme catalyzation can be calculated by changes in the concentrations of reactants and product(s). Each specific enzyme complex has a rate constant (k_m) derived from the substrate concentration, at which an enzyme-catalyzed reaction proceeds at half its maximum velocity. The **Michaelis-Menten equation** is used to describe the velocity of an enzyme-catalyzed reaction at unlimited substrate concentration. Enzyme function can be analyzed via comparison to kinetics of function under the Michaelis-Menten equation.



The Michaelis-Menten equation and graph showing the relationship

The rate of enzyme catalysis depends on temperature, pH, ionic concentration, the nature of the reactants, and the relative concentrations of enzymes and substrate(s). Many important enzymes are inhibited at very high temperatures due to denaturation or change in protein shape. Each enzyme has an optimal temperature range for highest activity.

Shifts in pH and ion concentration can also change the non-covalent bonding patterns and shapes of proteins. Recall that protein shape beyond the primary polypeptide is the result of reactions between amino acid side chains. Hydrogen and polar bonds are readily broken when pH changes. When the non-polar bonds break, secondary and tertiary enzyme structure can change, and the substrate may no longer fit the active site of the enzyme.

The relative amounts of enzyme and substrate also affect the rate of activity. When all of the active enzyme sites become bound to substrate, the system is saturated. That means the chemical reaction being catalyzed is proceeding at the maximum rate and adding more substrate will not change that rate. The Michaelis-Menten equation was derived based on conditions of substrate saturation.

Often the products of enzyme-catalyzed reactions will serve as **feedback inhibitors** for further enzyme activity. Sometimes enzyme activity is regulated by competitive binding at the enzyme active site. Often a feedback inhibitor will be the product of some metabolic pathway initiated by the enzyme being inhibited.

Allosteric enzyme regulation occurs when binding of a signal molecule at an allosteric site changes the shape of an enzyme. Binding by allosteric inhibitors prevents enzyme-substrate interaction. Allosteric activators bind to allosteric sites to change protein shape and they produce the key-in-lock enzyme substrate fit. In allosteric activation, the enzyme will not function until its shape is changed by the signal molecule. Allosteric enzyme regulation is also a part of many complex metabolic pathways.

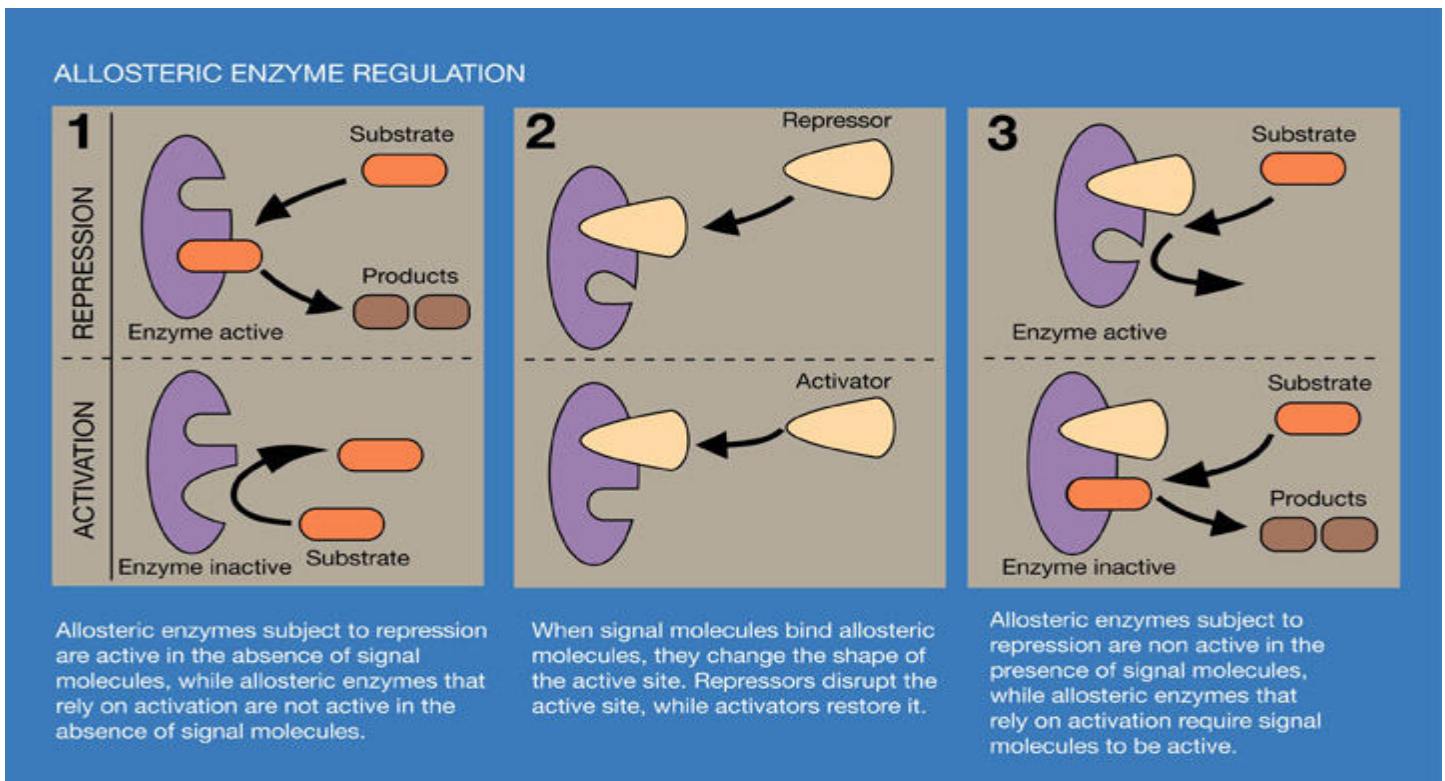


Diagram of an allosteric enzymatic reaction

Question

Why is pH important to protein function?

- A H⁺ ions can affect bonding patterns of amino acids
- B H⁺ ions act as allosteric inhibitors and activators
- C H⁺ ions competitively bind to the enzyme active site
- D H⁺ ions act as coenzymes to activate enzymes

Answer

The correct answer is A. Protein function depends on shape. Changes in pH mean changes in H⁺ concentration, which impacts protein function by disrupting H bonds.

4. Nucleotides and Nucleic Acids

Biochemistry & Cell Biology: Nucleotides and Nucleic Acids

Lesson Objective

In this lesson, we will review nucleotides and nucleic acids.

Previously we covered...

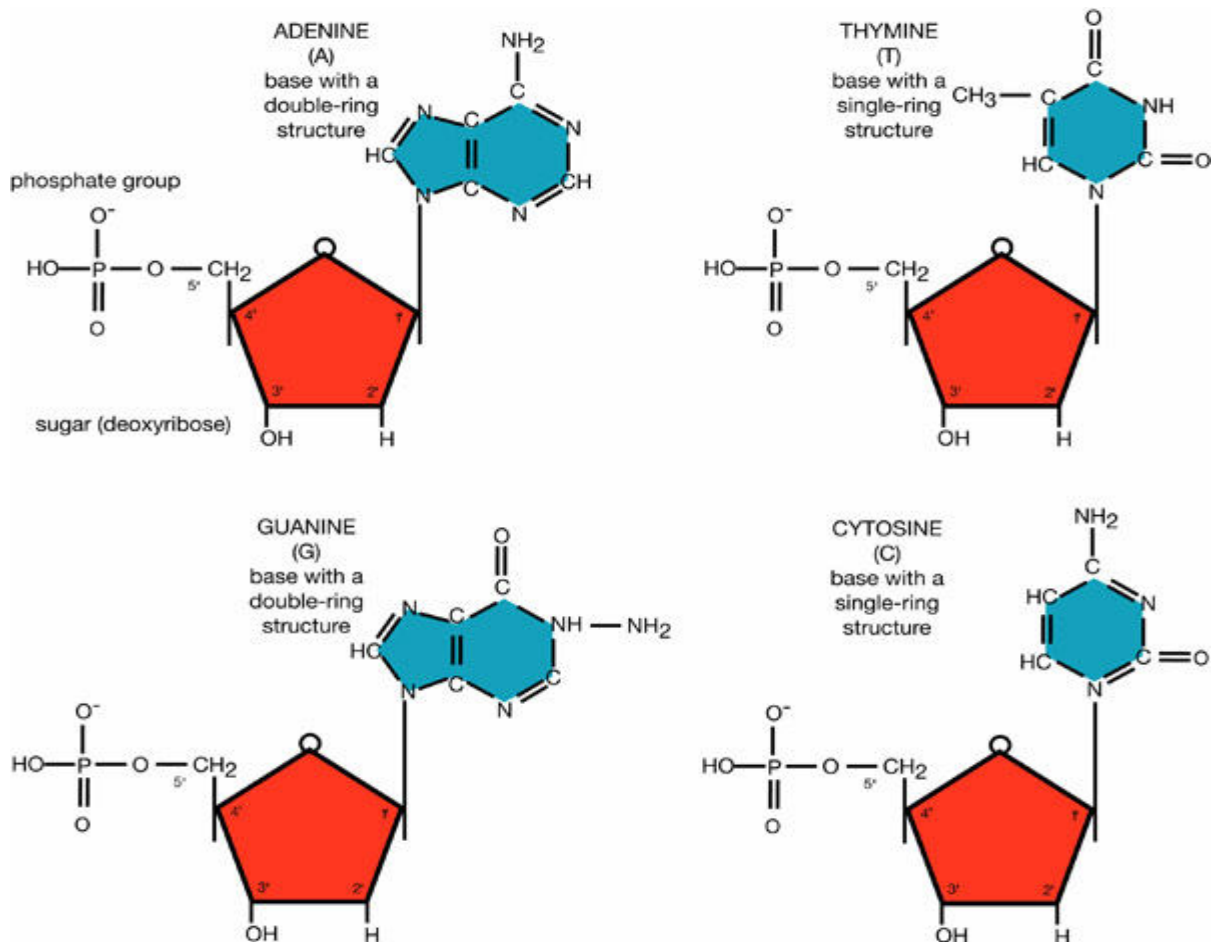
- The genetic blueprint for life, DNA, codes for production of proteins.
- Proteins are complex organic molecules formed by peptide bonding of 20 unique amino acids.
- Protein function is determined by shape. Protein shape is determined by the amino acid sequence.
- Enzymes are special proteins that regulate metabolism by acting as organic catalysts

Biochemistry & Cell Biology: Nucleotides and Nucleic Acids

Instruction Manual of Life

The nucleic acids, deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), carry the instructions for the development, structure, and function of all living things. Those instructions are stored in DNA and passed from generation to generation. The instructions are carried out and used to build proteins by RNA. It is thought that life began when a strand of RNA became incorporated in a cell membrane with proteins.

Nucleotide monomers contain a five-carbon sugar called a pentose, one or more phosphate groups, and a nitrogenous base. The pentose sugar of RNA is ribose; its counterpart in DNA is deoxyribose. When nucleotide monomers form phosphodiester bonds the phosphate of one monomer bonds to the sugar of another, forming the backbone of the nucleic acid molecules.



Structure of the five nucleotide monomers

Each monomer contains one of five nitrogenous bases. They are classified as either pyrimidines or purines. The three pyrimidines — cytosine, thymine, and uracil — are single-ring structures. The purines — guanine and adenine — are double-ring structures. Adenine, guanine, and cytosine all occur in both DNA and RNA molecules. Thymine is unique to DNA and uracil is unique to RNA.

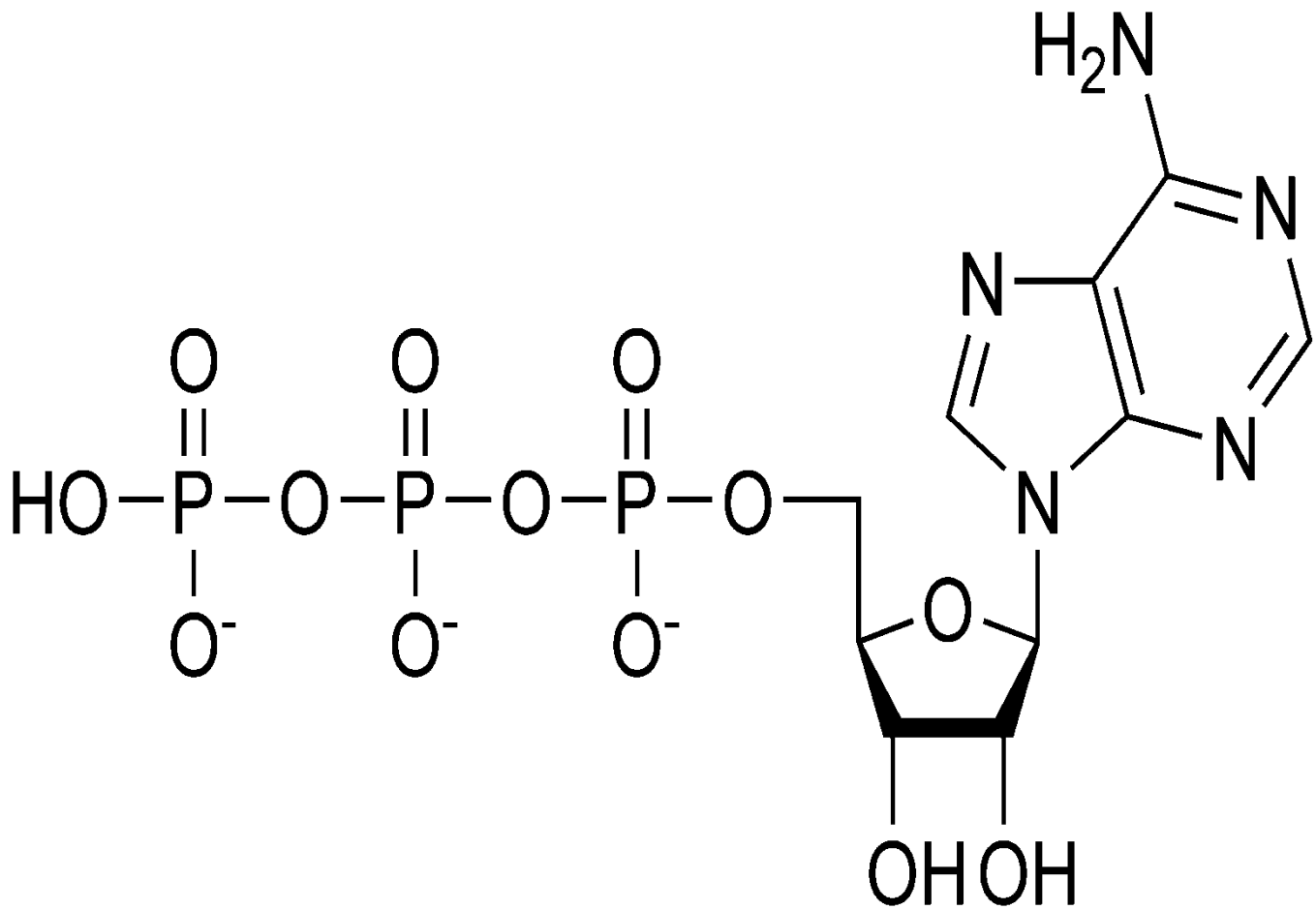
RNA is a single-stranded molecule, while DNA is double-stranded. The double-stranded structure of DNA comes from hydrogen bonding between pyrimidines and purines. The hydrogen bonded nitrogen bases form the rungs of the DNA double helix ladder. In DNA adenine always forms two hydrogen bonds with thymine, and cytosine always forms three hydrogen bonds with guanine. In RNA, uracil pairs with adenine. No other hydrogen bonding configuration between bases is possible.

The double helix of DNA is composed of a coding strand and a template strand. The template strand is used by the cell in the nucleus to build complementary strands of RNA. Single-stranded RNA carries the code in complementary bases to the site of protein production in the cell cytoplasm.

Other nucleotides are important in cell metabolism and in enzyme regulation. Several nucleotides (NAD and NADP) are important coenzymes in photosynthesis and respiration. Many are important in substrate level phosphorylation reactions.

Adenosine triphosphate (ATP) is the form of energy used by cells to do work. ATP is the form of energy produced by plants during the light reactions of photosynthesis. It is the form of energy released during cellular respiration. Each ATP molecule is composed of a ribose, adenine, and a chain of three phosphate molecules. Because the phosphates have a negative electrical charge, they

tend to repel each other. It takes energy to maintain those bonds; when they are broken, energy is released.



Structure of the ATP molecule

When the endmost bond is broken energy is released and adenosine diphosphate (ADP) and a free phosphate are produced. Cells use energy to form the bonds in ATP and release it when those bonds are broken. By continuously cycling ADP and ATP, cells efficiently transform energy.

Question

How does DNA differ from RNA?

- A DNA is single-stranded while RNA is double-stranded.
- B DNA contains the base thymine while RNA contains uracil.
- C DNA contains uracil and RNA contains thymine.

- D DNA is formed by hydrogen bonds and RNA is formed by phosphodiester bonds.

Answer

B is the correct answer, because DNA is double-stranded, it contains deoxyribose, and has plenty of phosphodiester bonds. RNA is single-stranded and contains ribose.

Biochemistry & Cell Biology: Nucleotides and Nucleic Acids

Review of Vocabulary and Concepts

DNA - Just Four Letters!

Deoxyribonucleic acid, or DNA, is a simple chain of sugar phosphates and nitrogenous bases that contains the blueprint for all forms of life. The key is in the base pairs. There must be an infinite number of base pairs in order to code for the tremendous diversity of life on earth, right? Actually, there are only four nucleic acids. Sound impossible? Take a look at this chain of DNA to learn more about these four powerful bases and the way they direct the biological development of every form of life on earth.



Let's take a closer look...

Click to learn more about DNA's structure, the pairings of nucleotide bases, or the sequencing of base pairs.



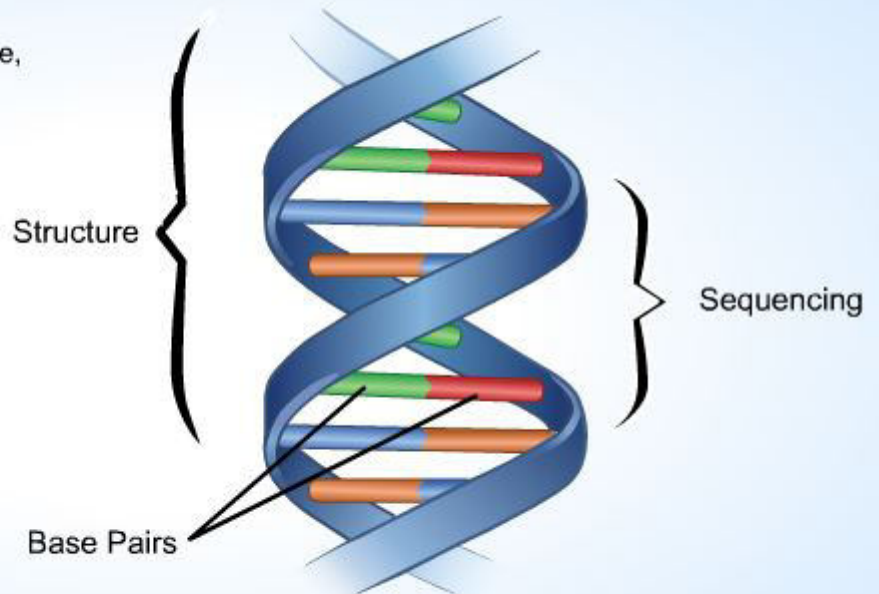
Conclusion

DNA contains 100% of each organism's genetic blueprint. Although DNA has a deceptively simple structure, remember that most organisms have many thousands of base pairs of DNA sequence. When all permutations and combinations are realized, it makes sense that just four nucleotides can be responsible for the amazing diversity and existence of life on earth.



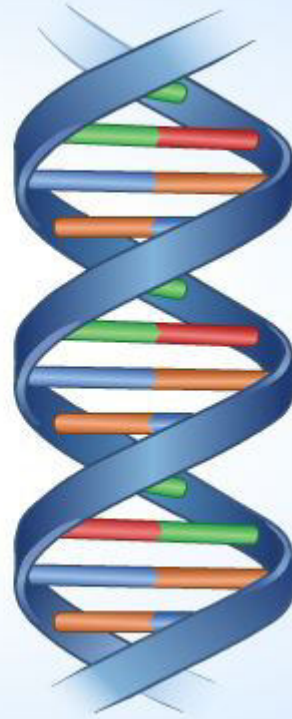
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- Nucleotide monomers form complex organic molecules, such as nucleic acids, coenzymes, and ATP.
- DNA is a double-stranded helix of nucleotide monomers. The backbone of the helix is formed by phosphodiester bonds and the rungs are formed by hydrogen bonds between complementary bases.
- RNA is a single-stranded molecule that is built of complementary bases to a DNA molecule.
- Carbohydrates, proteins, sugars, nucleic acids, fatty acids, and enzymes each play a key role in cell function.

5. Discovering Cells

Biochemistry & Cell Biology: Discovering Cells

Lesson Objective

In this lesson, we will review the fundamental unit of life, the cell. We will cover the different types of cells, how they work, and cover some of the basic parts of each type of cell.

Previously we covered...

We reviewed the important biomolecules and went over their roles in living organisms.

Biochemistry & Cell Biology: Discovering Cells

Studying things you cannot see: the *little animals*

Antonie van Leeuwenhoek made his living selling cloth, but this 17th-century Dutchman could not resist his interest in making lenses. His obsession with making a perfect lens drastically reduced the income he derived from his neglected business, yet he labored on. In 1675, he produced a single lens that when mounted in a metal frame could magnify an object up to 270 times. With his apparatus, an early microscope, Leeuwenhoek was able to see numerous **protozoans** in a drop of water. He called these microscopic creatures **animalcules**, or little animals. His fame grew as he proceeded to identify various bacteria and also, most notably, spermatozoa, which he identified in humans and other animals.

Question

Antonie von Leeuwenhoek was the first scientist to identify

- A cell walls.
- B bacteria.
- C viruses.
- D plant cells.

✔Answer

B is the correct answer. Choices A and D are incorrect because they were identified by Robert Hooke in 1665. The first virus (tobacco mosaic) was not identified until 1898 by Martinus Beijerinck.

Biochemistry & Cell Biology: Discovering Cells

Cell Theory

Earlier, in 1665, Robert Hooke, an English physicist and mathematician, peered into his homemade microscope — one of the world's first — to examine the bark of a cork tree. Hooke saw the tiny box shapes that make up cork tissue, which reminded him of monks' cells. So, Hooke called the minute but ordered structures "cells".

Though Hooke termed the word cell, it was not until 1838 that Matthias J. Schleiden, a German botanist, recognized the significance of cells and elucidated the beginnings of cell theory. In 1839 he and Theodore Schwann, a German scientist, stated that cells are "the elementary particles of organisms," both plant and animal, and that some organisms are unicellular while others are multicellular. Nine years later, another German botanist, Hugo von Mohl, coined the word: **protoplasm** to designate a cell's living material. Cell theory was further advanced by the discovery of the nucleus by Robert Brown in 1833 and the confirmation of its presence in both plant and animal cells.

For a decade, scientists attempted to track down the origin of cells. The then-widely believed but fanciful "free cell hypothesis" stipulated that cells arose mysteriously from a formless, vaporous substance. Though cell division had been observed among unicellular organisms, it was not until 1855 that anyone presented a cogent idea of cell origin. In that year, Rudolf Virchow, a German biologist, stated cell theory unequivocally: "cells come from cells." In other words, cells reproduce.

Question

Cell theory states that

- A an embryo forms from both egg and sperm .
- B all cells contain a membrane-enclosed nucleus.
- C autotrophs feed by photosynthesis.
- D cells reproduce to create more cells.

👉Answer

The correct answer is D. The union of a sperm and egg to form an embryo is the domain of reproductive biology. Choice B is incorrect because not all cells have a nucleus enclosed in a membrane. The processes and functions of cell metabolism are not part of cell theory; therefore choice C is not correct.

Biochemistry & Cell Biology: Discovering Cells

Seeing Cells

So, what is a cell? Biologists today define it as the basic unit that makes up all living things. A cell is the smallest unit of life, and a single cell, such as a bacterium, may be a complete, independently functioning organism. In multicellular organisms, cells may be adapted to perform specific functions within tissue and may not be capable of existing independent from that tissue.

There are two basic types of unicellular organisms: heterotrophs and autotrophs.

- Heterotrophs are cells that feed on other living things, or other cells. These include the amoebas, which engulf and then digest prey in a process called **phagocytosis**.



Giardia: a heterotrophic organism that can cause gastrointestinal distress in humans

- Autotrophs are cells that make their own food via photosynthesis. Algae are typical autotrophs.



Chlamydomonas is an autotroph, making its own food through photosynthesis

Improvements in instrumentation, such as the electron microscope, have allowed scientists to observe and analyze the structure and components of cells and the functions each performs. Observation and analysis shows that all cells share common characteristics of form and function.

Cell size averages between 10 and 30 micrometers in diameter (although there are far larger single-celled organisms). Size is limited primarily by the relationship of surface to volume. Cells survive by exchanging materials with their environment through their outer membrane. If cell volume increases too much surface area decreases, and material exchange through the membrane would be so impaired the cell would not survive.

Question

Phagocytosis is the process in which

- A A heterotrophs engulf and digest living organisms.
- B amoebas move via streaming to find prey.
- C cells arise from non-differentiated material.
- D protoplasm is generated within a living cell.

Answer

The correct answer is A. Heterotrophs are organisms that eat other organisms, and phagocytosis is the process of engulfing prey items. Phagocytosis does not refer to forms of locomotion. The theory that cells arose from undifferentiated material was debunked by cell theory. Choice D is incorrect because the generation of protoplasm is not part of phagocytosis.

6. Prokaryotes and Eukaryotes

Biochemistry & Cell Biology: Prokaryotes

Early Earthlings

The first organisms to live on Earth were probably primitive prokaryotes—the earliest form of simple, single-celled organisms. **Archaea** are the oldest known living things and are grouped in their own domain. Although there is still debate about what organisms actually evolved first, many scientists agree that today's prokaryotes are their closest relatives. Among these ancient organisms were **methanogens**, which synthesize methane from carbon dioxide and hydrogen gases (abundant substances in Earth's early days), **thermoacidophiles**, specialized to survive in extremely hot and acidic environments, and **halobacteria**, which thrive in highly saline conditions. Many of the archaea still living today are extremophiles, living in and adapted to extreme environmental conditions such as deep-sea vents, hot springs, and geysers.



Prokaryotic organisms are some of the simplest forms of life on Earth

Biochemistry & Cell Biology: Prokaryotes

No Nukes

The Archaea probably gave rise to other single-celled prokaryotes called the Bacteria (or possibly vice-versa). No matter which organisms came first, we do know that the two most primitive of the three domains of life, are prokaryotic. Their most singular characteristic is their lack of a membrane-bound nucleus and membrane-bound organelles. In prokaryotes the single, continuous strand of DNA (naked DNA) floats freely in the cytoplasm. Both the Archaea and the Bacteria are prokaryotes.

The fundamental characteristics shared by nearly all prokaryotes include:

- a **phospholipid** and cholesterol cell membrane
- a complex, polymer (peptidoglycan) cell wall that gives the cell shape, but that may also be rigid or flexible
- **flagella** (singular **flagellum**) or **cilia** attached to the cell wall are often present; cilia and flagella beat rapidly to aid locomotion
- reproduction is **asexual** and commonly by binary fission.

Biochemistry & Cell Biology: Prokaryotes

Early Earthlings

Most prokaryote locomotion is accomplished by the rapid beating of the cilia that often completely surround the cell. Some prokaryotes can also have one or more flagella.

Reproduction is usually by binary fission, or cell division. The complex series of steps in mitosis are not needed among prokaryotes because of their simplified, single-stranded DNA. However, mismatching and other chemical errors frequently lead to **mutations** during the binary split. For many prokaryotes, particularly infectious bacteria, a new generation may arise every 15 minutes. Combine the short generation time with the occurrence of mutations and you can see why bacteria evolve quickly and are able to develop resistance to antibiotics.

Some prokaryotes reproduce via **budding**, in which a genetically identical offspring develops out of the parent's body and eventually buds off from the parent. Some prokaryotes are able to generate **spores** that remain dormant, but viable, for long periods. The spores of the bacterium ***Clostridium botulinum***, which causes botulism, can survive hours of boiling and still kill you.

Generally, prokaryotes have one of four characteristic shapes:

- **rod-shaped bacteria**, also called ***bacilli***, are the gram-positive, aerobic bacteria (e.g., ***E. coli***, ***Listeria***). Diseases often caused by Bacilli include tuberculosis, whooping cough, and diphtheria.
- **spherical bacteria**, also called ***cocci*** (e.g., ***Diplococcus pneumoniae***). Diseases that are caused by cocci bacteria are staphylococcus infections, food poisoning, urinary tract infections, throat infections, and most pneumonia.
- **spiral-shaped bacteria**, also called ***spirilla*** (e.g., ***Spirillum***). These are rod-like, spiral-shaped bacteria that cause many diseases of infants and fetal infections prior to birth.

- **incomplete spirals** or comma-shaped bacteria called **vibrios** (e.g., *Vibrio*). These are a diverse assemblage of organisms that create bioluminescence in the ocean and cause cholera.

Two bacteria that have a unique shape are the **spirochetes** (e.g., *Terponema pallidum*, which causes syphilis), which can be incredibly long, and **rickettsiae** (e.g., *Rickettsia prowazeki*, which causes typhus), which are the smallest cells known.

Biochemistry & Cell Biology: Prokaryotes

Early Eaters

Most prokaryotes are **heterotrophs** that mainly consume dead organic matter. It is to bacteria that we owe the existence of organically rich topsoil, because bacteria decompose organic matter in soil. Some heterotrophic bacteria live **symbiotically** in hosts, either as **commensals**, **parasites** (some pathogenic), or in **mutualism** that benefits both organisms. There are even heterotrophic bacteria that are parasites of other bacteria. Some prokaryotes are **chemotrophs** that can use inorganic materials as a source of energy. Archaea are largely chemotrophs, particularly the methanogens that still thrive in anaerobic environments. One group of chemotrophs, vital to the nitrogen cycle, transforms inorganic nitrogen and makes it available to plants.

Some bacteria are photosynthetic. In one group of sulfur bacteria, energy derived from the electrons in sulfur atoms take the place of the electrons derived from water in plants. Nonsulfur photosynthetic bacteria are the ancient cyanobacteria, which were extremely important in the formation of the earliest ecosystems. Cyanobacteria are sometimes called blue-green algae, but they are not related to the true algae (which are eukaryotes). Cyanobacteria contain chlorophyll **a** and break down water during photosynthesis (as do plants). In the process they release oxygen. The countless cyanophytes that lived in the Earth's early oceans contributed the oxygen to our atmosphere that we, and most organisms, require to survive. It is probable that cyanophytes gave rise to the first eukaryotic algae.

Biochemistry & Cell Biology: Prokaryotes

Test Yourself

Question 1

Which of the following is a characteristic of Archaea?

- A They have at least one flagellum.
- B They can thrive in extreme environments like high salinity.
- C They contain no DNA.
- D They all synthesize hydrocarbons.

Answer

The correct answer is B. The presence or absence of flagella is not a characteristic of Archaea. One type of archaeobacteria, the halobacteria, thrive in saline conditions, but only methanogens synthesize hydrocarbons (methane).

Question 2

The most common form of reproduction among prokaryotes is

- A fragmentation.
- B binary fission.
- C budding.
- D sporulation.

Answer

The correct answer is B. Most prokaryotes reproduce asexually via cell division, or binary fission. Fragmentation is the regeneration of a lost part of the organism, as in starfish. Some prokaryotes do reproduce via budding, but it is not common. Similarly, some prokaryotes produce spores, but this is rare among prokaryotes.

Question 3

Most prokaryotes are heterotrophs that ingest

- A autotrophs.
- B other heterotrophic bacteria.
- C inorganic matter.
- D decaying organic matter.

Answer

The correct answer is D. Most prokaryotes live in soil where they ingest and decompose decaying organic matter and release it back into the soil. Some heterotrophic prokaryotes may consume

unicellular autotrophs, but this is not widespread, so A is incorrect. Similarly, some heterotrophic prokaryotes may ingest others of their kind, but this is not common, so B is incorrect. Chemotrophs do metabolize inorganic substances, but they are a small sector of the prokaryotic community, so C is not correct.

Question 4

Which of the following bacteria are photosynthetic?

- A Algae
- B Vibrios
- C Mycoplasmas
- D Cyanobacteria

✓Answer

The correct answer is D. Cyanobacteria are photosynthetic marine bacteria that put oxygen into our atmosphere. Algae are eukaryotic, not bacteria. Vibrios are a category of prokaryotes based on their incomplete spiral shape but are not photosynthetic. Mycoplasmas are heterotrophic, not autotrophic, prokaryotes.

Biochemistry & Cell Biology: Eukaryotes

Setting Boundaries

Eukaryotes are characterized by their membrane-bound nucleus and organelles, and the chromosomes that carry their DNA. The first eukaryotes evolved about 1.5 billion years ago (for the previous 3 billion years, the world belonged to prokaryotes). The evolutionary step from prokaryotes to eukaryotes was one of the most revolutionary events in the biological history of the Earth.

One widely supported theory, the **endosymbiotic theory**, suggests that mitochondria were once free-living bacteria that had developed the ability to use oxygen and make ATP. This conferred such an evolutionary advantage that these bacteria thrived and eventually evolved into aerobic bacteria. It is believed that over time these ATP-producing organisms became incorporated into larger cells, perhaps through ingestion. A prokaryote that incorporates into itself an ATP-generating cell gains a definite energetic, and evolutionary, advantage. Similarly, a large nonphotosynthetic prokaryote that ingests a photosynthetic prokaryote (a proto-chloroplast) also has a survival advantage. The fact that mitochondria have their own very prokaryote-like, single-strand DNA and that their RNA and ribosomes closely resemble those of prokaryotes supports this theory further.

Single-celled eukaryotes are mostly classified as Protists, which includes algae, slime molds, and protozoa.

7. Cells - Pieces & Parts

Biochemistry & Cell Biology: Cells - Pieces and Parts

Lesson Objective

Before we explore the rest of the domain Eukaryota, we will review the important aspects of the entities that make up the machinery of cells. During this review, we will cover all major organelles inside the cell, and describe what they do and how cells operate.

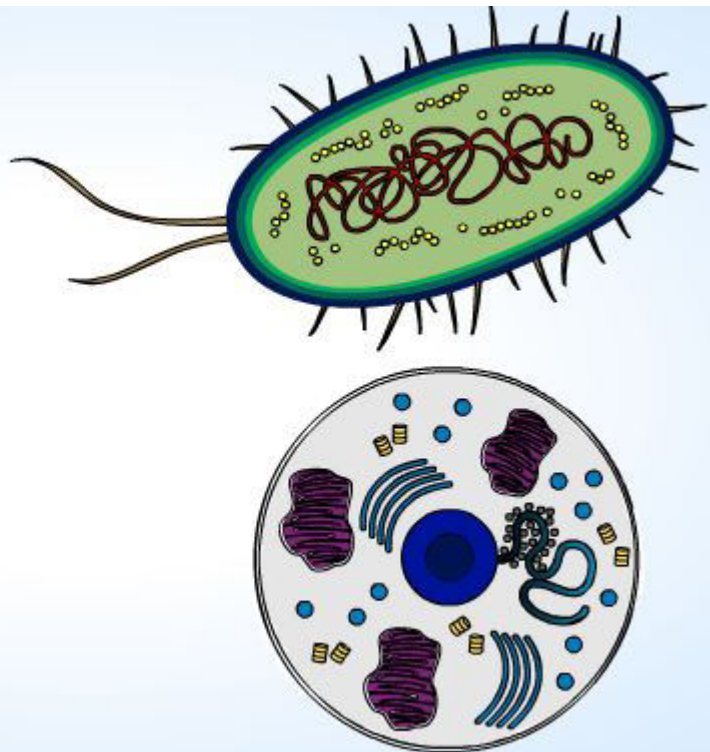
Previously we covered...

We have just reviewed the basics of prokaryotes and introduced some of the eukaryotes. We outlined two of the three domains of life, the Archaea and the Bacteria and introduced some of their major taxa.

Biochemistry & Cell Biology: Cells - Pieces and Parts

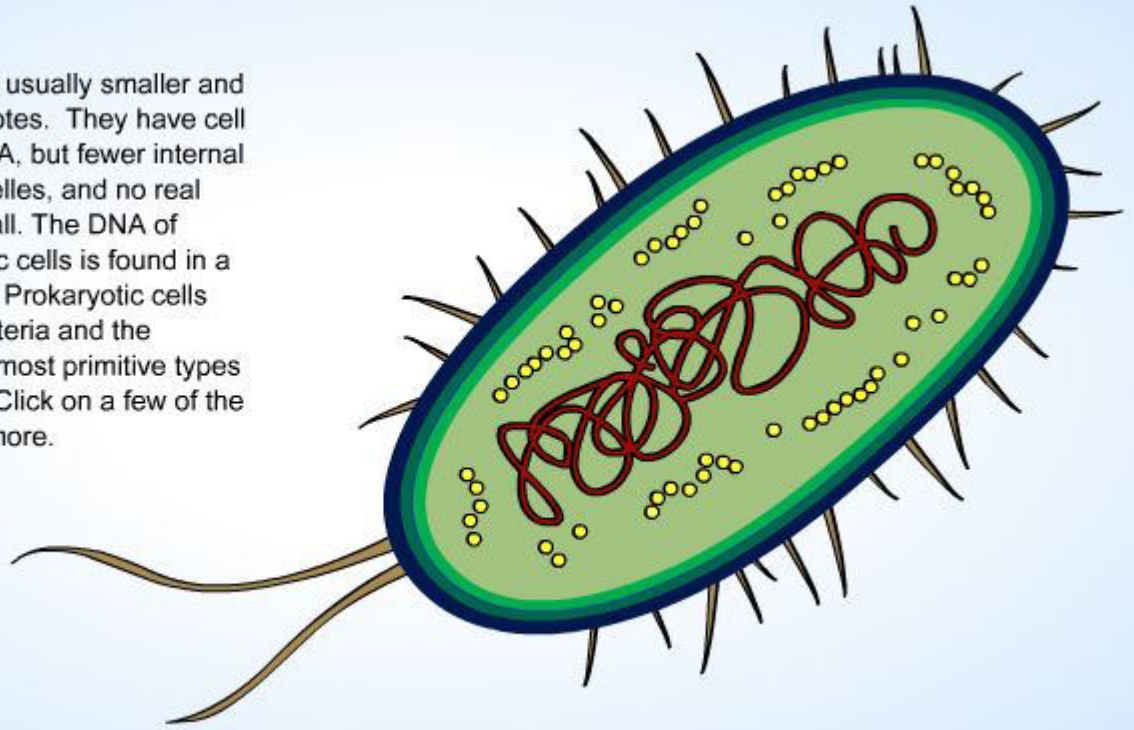
The Cell

Cells are the smallest self-contained and self-sustaining units of life on Earth. They take in the necessary nutrients from their environment, synthesize energy from these nutrients (and sometimes solar radiation), and use that energy to survive and reproduce. Every cell has its own genetic code (DNA) with specific instructions for doing everything the cell needs to do, from making proteins to synthesizing energy and defending itself from infection. Compare and contrast the two main types of cells: prokaryote and eukaryote.

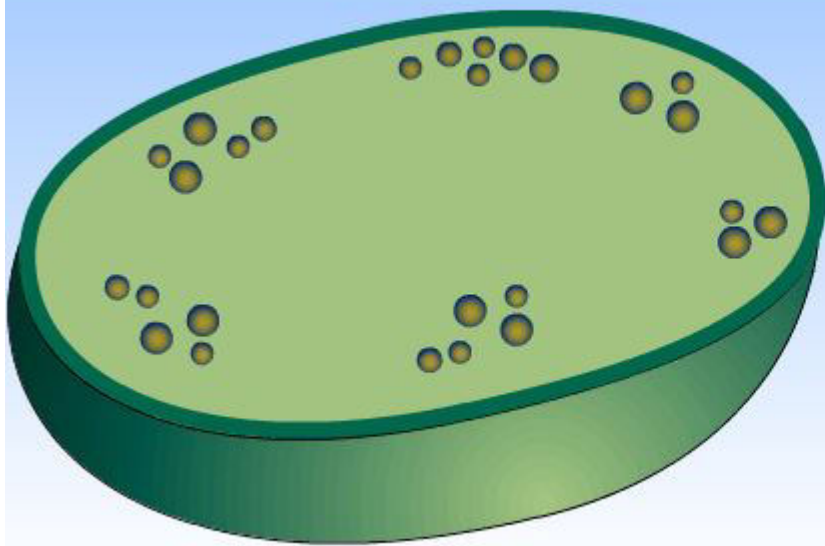


Prokaryotic Cell

Prokaryotic cells are usually smaller and simpler than eukaryotes. They have cell membranes and DNA, but fewer internal structures, or organelles, and no real internal skeleton at all. The DNA of almost all prokaryotic cells is found in a single chromosome. Prokaryotic cells are found in the Bacteria and the Archaea, two of the most primitive types of living organisms. Click on a few of the organelles to learn more.

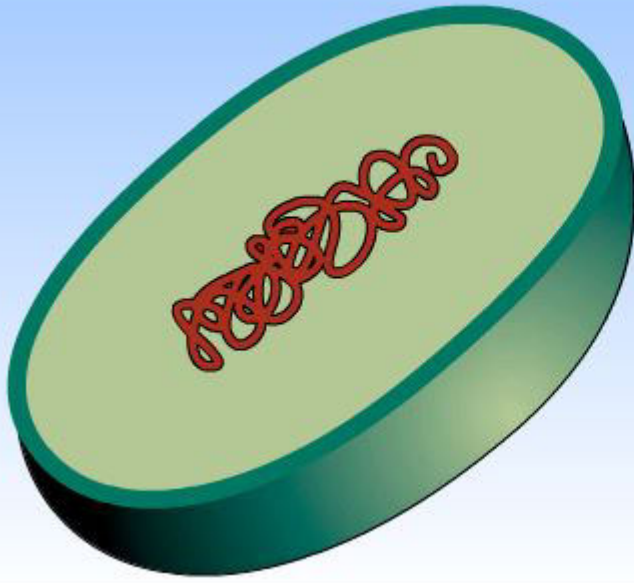


Ribosome



A ribosome is a tiny organelle made up of RNA and protein. The ribosome is where cell proteins are assembled under the direction of mRNA (messenger RNA). The ribosomes of a prokaryotic cell float freely within the cell.

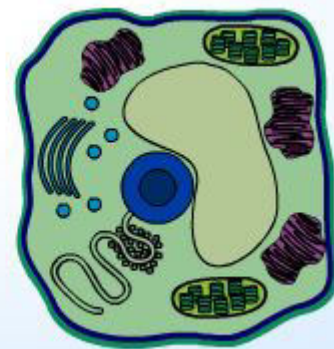
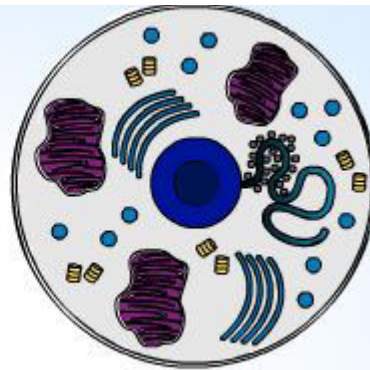
Nucleoid



Prokaryotic cells do not contain an organized nucleus. The genetic material floats freely within the cell, but tends to stay bunched together in a region called a nucleoid.

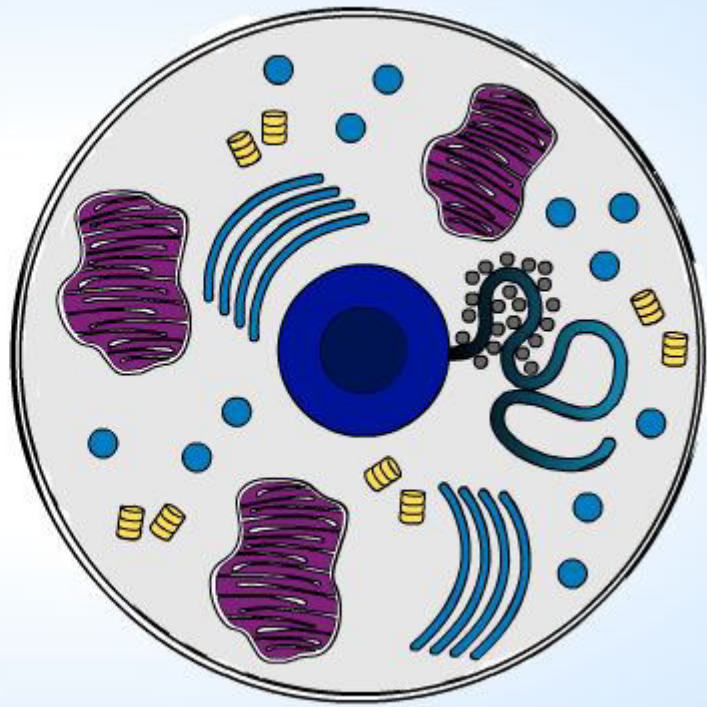
Eukaryotic Cell

Eukaryotic cells (from the Greek, eu and karyon, meaning true nut, or having a nucleus) have a clearly-defined nucleus and many important membrane-bound internal organelles. Eukaryotes are generally bigger and more complex than their prokaryotic sisters. Eukaryotes comprise most of the macroscopic life on Earth: plants, animals, fungi, protozoans, and algae, but represent a single branch in the tree of life.



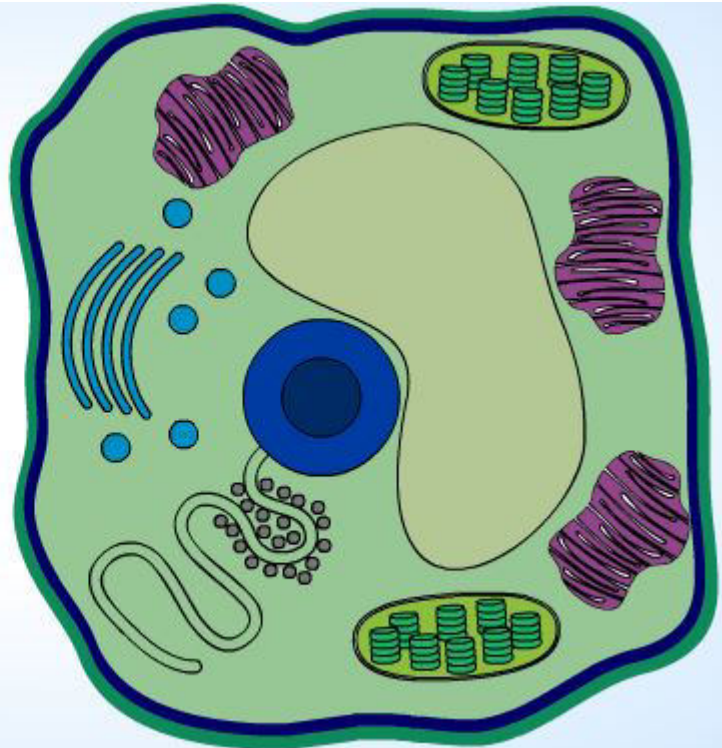
Eukaryotic Animal Cell

Animal cells are distinct from plant cells because animal cells lack cell walls, chloroplasts and vacuoles. Due to the lack of a rigid cell wall, animal cells are circular when not deformed by other cells (contrasted with plant cells which have rigid walls and are usually packed like cement blocks in a wall).



Eukaryotic Plant Cell

The cells of plants are quite different from other eukaryotic cells. Plant cells contain certain structures that set them apart. These structures include a large central vacuole which acts as a storage vessel and helps maintain the osmotic pressure within a cell, a cell wall made up of cellulose and protein, and chloroplasts which contain chlorophyll, the pigment that gives plants their green color and allows them to perform photosynthesis. Like other eukaryotic cells, plant cells typically also have a nucleus, containing most of the cell's DNA, and mitochondria, the 'power plants' of the cell.



Membranes and Organelles

Despite their microscopic size, cells contain numerous internal structures called **organelles**. The structure and function of organelles is often highly complex, and nearly all organelles are involved in intricate biochemical reactions that maintain the living cell. The major organelles in cells are outlined below.

1. The cell membrane, or **plasma membrane**, is the thin (0.005 micrometer wide) membrane that encloses all components within the cell and controls the passage of materials into and out of the cell. Cell membranes are composed of phospholipids (both hydrophilic and hydrophobic) and sterols (mainly cholesterol). The hydrophobic “tails” attached to these molecules are clustered on the inner part of the membrane. The exterior of the membrane may contain chains of carbohydrates as well as transport proteins, or **permeases**, which regulate the transport of materials across the cell membrane. Some proteins also occur on the inner membrane.

2. **Internal membranes**, which are present only in eukaryotic cells, are membranes that surround organelles. They have the same basic structure as the plasma membrane, often with modifications, and also regulate transport into and out of the organelle. Because the various functions that organelles perform in the cell may require different conditions (pH for example), internal membranes maintain these distinct conditions by isolating organelles from each other.

3. The cell **nucleus** contains its genetic material, or **DNA** (deoxyribonucleic acid). The nucleus is, therefore, the control center of the cell and is separated from the rest of the cell by the **nuclear envelope** (whose presence distinguishes **eukaryotes** from **prokaryotes**, the latter which lack a nuclear envelope). The minute **pores** in the nuclear envelope permit substances to pass from the nucleus to the cytoplasm. As cellular conditions warrant, subsets of DNA in the nucleus are created that program for the building of specific proteins required by the cell. RNA acts as the intermediary between the DNA in the nucleus and the protein-building apparatus outside the nucleus in the cell, called **cytoplasm**. The cell nucleus contains a suborganelle called the nucleolus, which is the site of ribosome production.

4. **Mitochondria** are the metabolic engines of the cell, occurring in both plant and animal cells. Mitochondria are surrounded by a permeable bilipid membrane similar to the plasma membrane. The mitochondrion's inner membrane is shaped to contain a huge number of folds, called **cristae**. The inner part of the organelle, called the matrix, is a space filled with enzymes and other metabolic substances.

Biochemistry & Cell Biology: Cells – Pieces and Parts

Organelles

Mitochondria oxidize the products of metabolism from the cytoplasm and convert this energy into **ATP** (adenosine triphosphate), which fuels cell function. The essence of ATP production, which takes place in the matrix, lies in the transfer of electrons to and from various compounds, with ATP as the final product. A mitochondrion converts fats, amino acids, and sugars into acetyl coenzyme A. The acetyl part of this compound is then oxidized to yield carbon dioxide and hydrogen atoms, which are transferred to the hydrogen acceptors, coenzymes NAD (nicotinamide adenine dinucleotide) and FAD (flavin adenine dinucleotide). Adding hydrogen produces NADH and FADH 2. Oxidation of these compounds occurs gradually, controlled by proteins in the cristae, and eventually yields ATP.

1. **Lysosomes** have a single phospholipid bilayer membrane called **vesicles**. Vesicles are large, liquid-filled sacs containing enzymes, including hydrolases, which break down and process some cell products, such as proteins and lipids. Their low pH (~ 5) assists in the degradation of cell materials. Once broken down, or lysed, some of these products are transported across the lysosome membrane and used to make organic compounds required by the cell. The remaining waste usually remains inside the lysosome and is termed a residual body.

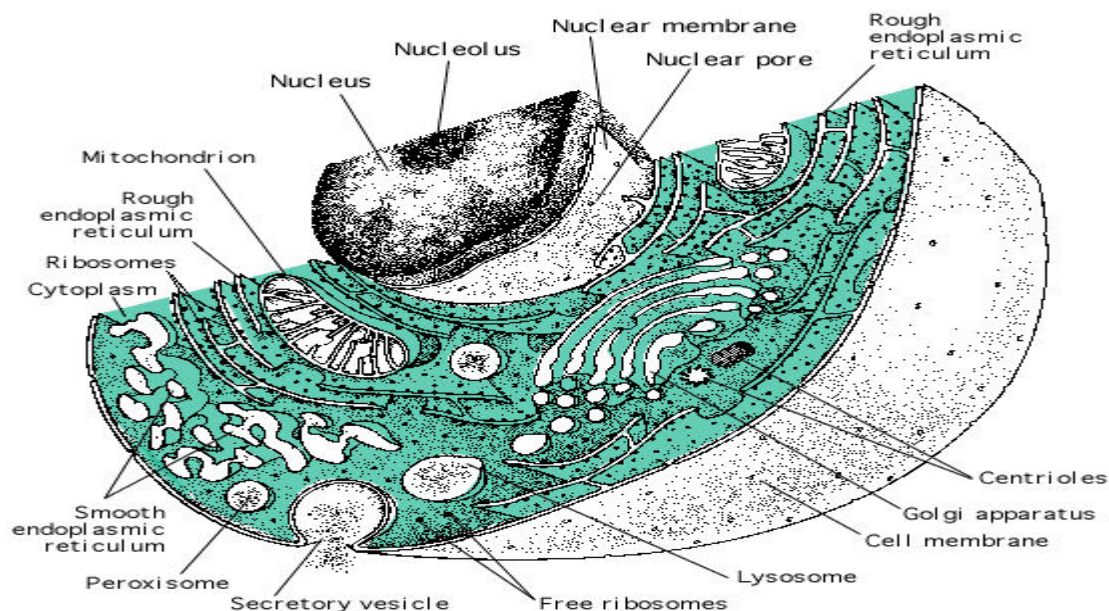
2. **Peroxisomes** are also vesicles that contain lysing enzymes. Peroxisomes specialize in degrading purines — nitrogenous compounds in cells. The degradation of purines produces hydrogen peroxide, a substance toxic to cells. So peroxisomes use other enzymes, like catalase, to break down hydrogen peroxide into harmless water and oxygen.

3. The **Golgi apparatus**, or Golgi bodies, is made up of a stack of five to eight flat, dish-shaped membrane-bound sacs. The stack of sacs is surrounded by tubules and vesicles. Golgi bodies are like factories and redistribution centers. They receive the proteins and carbohydrates that occur on the surfaces of cell membranes, even their own, and then reassemble them. The Golgi apparatus gets vesicles from the endoplasmic reticulum, then alters the vesicle membranes, and finally processes and distributes their contents to other cell components, including the plasma membrane.

Biochemistry & Cell Biology: Cells – Pieces and Parts

The **endoplasmic reticulum (ER)**, which occurs only in eukaryotic cells, is a membranous network of connected flattened sacs, tubes, and channels that may make up as much as half the total membrane in the cell. There are two types of ER, rough and smooth, which are continuous with each other; although each has a distinct function.

Smooth endoplasmic reticulum (SER) is a mesh of membranous tubules that synthesizes phospholipids and cholesterol. The SER accomplishes this with enzymes bound to its membrane. Some of these products remain in the ER; others are transported to other organelles. SER is called “smooth” because it lacks **ribosomes**, cell particles made of RNA and proteins that synthesize other proteins from amino acids. The membrane of **rough endoplasmic reticulum (RER)** is made up of flattened sacs and vesicles and is covered with bump-like ribosomes. Therefore RER is key in making and releasing important cell proteins and glycoproteins. The RER synthesizes and distributes the enzymes necessary to lysosomes and proteins required by the Golgi apparatus, the ER, and the plasma membrane. A freshly synthesized protein moves from the RER through the SER and then to the Golgi apparatus. The protein is processed and slightly altered at each step, sometimes by splitting its amino acids, sometimes by adding carbohydrates.



Cross-section of a typical eukaryotic cell showing the many different organelles

Biochemistry & Cell Biology: Cells - Pieces and Parts

Test Yourself

Question 1

ATP is the substance that fuels a cell. In what organelle is ATP produced?

- A Lysosomes
- B Cristae
- C Golgi apparatus
- D Mitochondria

Answer

D is the correct answer. Lysosomes contain enzymes that break down and process cell products. Cristae are not an organelle; they are the folds found in mitochondria. Golgi apparatus receive and reassemble proteins and carbohydrates.

Question 2

How does rough ER differ from smooth ER?

- A SER contains lysing enzymes.
- B RER has a very low pH of approximately 5.0.
- C RER contains ribosomes that synthesize proteins.
- D SER contains ribosomes that synthesize cholesterol.

Answer

If you selected C, you are correct! Choice A refers to peroxisomes. Choice B refers to lysosomes, not ER. Choice D is incorrect because SER does not contain ribosomes, and ribosomes do not synthesize cholesterol.

Biochemistry & Cell Biology: Cells - Pieces and Parts

Staying in Shape

The **cytoplasm** is the living contents inside a cell, excluding the nucleus and the large vesicles. The cytoplasm contains a clear, colorless liquid termed the **hydroplasm** in which the organelles occur. Cytoplasm is about 90 percent water, but that water is a rich solution of ions, especially potassium, sodium, and chloride. Of course, the cytoplasm is bound and contained within the plasma membrane.

A cell's vesicles help support the cell and keep it in shape. A cell's **cytoskeleton** consists of interconnected protein filaments in the cytoplasm. The cytoskeleton not only maintains the cell's three-dimensional shape, it also anchors its organelles and helps the cell move.

There are three basic types of structures that make up the cytoskeleton:

1. **Microtubules**, often only 20 nanometers in diameter, are long, hollow strands of the protein tubulin. Microtubules extend from the center of the cell to its plasma membrane. They are a “scaffold” for the building of other cell structures; they also play a key role in cell division. Many microtubules are constantly being built or taken apart, as required by the cell. In unicellular organisms, they are a permanent part of the flagella and cilia and thus are key to locomotion (as in the tail of a sperm cell).

Microtubules are the main organizers of the cytoskeleton and may control the position and function of both actin filaments and intermediate fibers, as well as the movement of certain organelles inside the cell.

2. **Actin filaments** are far smaller than microtubules and are made from the cell protein actin. In non-muscle cells, actin filaments link the plasma membrane to the cytoplasm and are involved in some types of cellular movement. In muscle cells, actin filaments have a broader role. Arranged in an orderly fashion, they interact with filaments made from another protein called myosin, which with actin is crucial for muscle contraction.

3. The size of **intermediate fibers** falls between that of the microtubules and actin filaments. Intermediate fibers are rope-like and made of fibrous proteins that are not easily disassembled. They are found primarily in cells undergoing mechanical stress.

Question

Which of the following is a cytoskeleton structure?

- A Microtubule
- B Mitochondrion
- C Lysosome
- D Endoplasmic reticulum

Answer

The correct answer is A. The other three choices are organelles.

8. A Little In, A Little Out

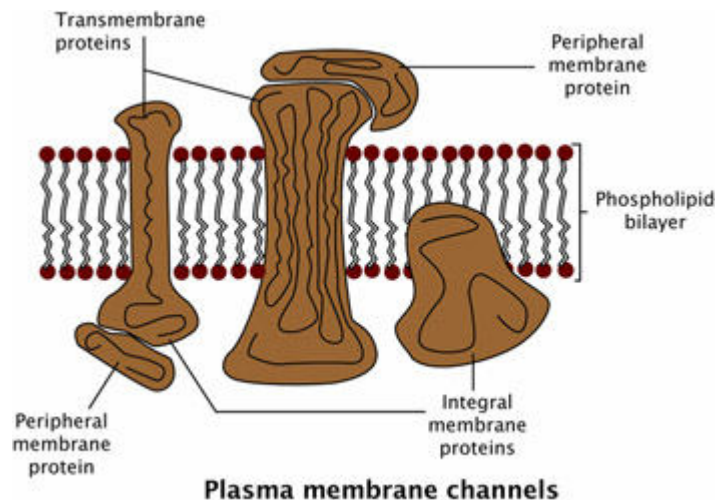
Biochemistry & Cell Biology: A little in and a little out

Rites of passage

The plasma membrane encloses and protects the contents of the cell. As with all living things, however, cells do interact with their environment. This means that material must be able to pass into the cell and out of the cell through the plasma membrane. The thin, seemingly simple, plasma membrane is actually a complex structure that serves as an effective barrier that keeps unwanted material out of the cell, while permitting the entry of useful substances. This makes the plasma membrane **selectively permeable** — only allowing in needed substances and keeping out unwanted material.

The plasma membrane selectively allows transport of substances into and out of the cell. **Intrinsic proteins** on the membrane enable passage of large, water-soluble molecules and ions across the plasma membrane and into the cell. Some of these proteins produce channels, like tiny pores, through which molecules can pass. Some channels are akin to gatekeepers that open only when a particular chemical signals its “intent” to enter the cell. **Gap junctions** are protein channels that permit communication between cells.

Other intrinsic proteins simulate ferries that carry a particular molecule across the plasma membrane. Some intrinsic proteins act on the molecule chemically to make it appear more “friendly” to the membrane. Still other proteins pump in the necessary molecules.



The Plasma membrane of phospholipids is one of the most versatile and important aspects of the cell

Biochemistry & Cell Biology: A little in and a little out

Diffusion

Most molecules pass through the plasma membrane via **diffusion**. This is where a molecule or substance moves, without any input of energy, from a region where it occurs in high concentration to a region where it occurs in low concentration. Molecules move via diffusion until the entire region

reaches an equilibrium in terms of the concentration of the particular molecule. (The spread of an aroma through a room is an example of diffusion.) The concentrations for most substances inside and outside the cell differ and materials diffuse through channels via **passive transport** until equilibrium is reached. In some cases, intrinsic proteins assist in moving molecules along the concentration gradient; this process is called **facilitated diffusion**.

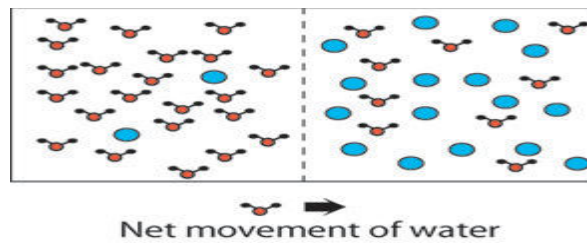


Diagram of diffusion

Biochemistry & Cell Biology: A little in and a little out

Active Transport

There are times, however, when a molecule must be moved into or out of a cell against the concentration gradient; that is, it must be moved from a region of low concentration or equilibrium to a region of high concentration. An input of energy is needed to accomplish this. Membrane proteins provide this energy boost to move molecules via the process of **active transport**.

The sodium-potassium pump is a typical active transport system in cells. In most cells, sodium is maintained in low concentrations inside the cell, though its concentration is higher outside the cell. The reverse is true of potassium. ATP fuels the active transport of these ions across the plasma membrane to maintain the requisite cell concentrations. Both sodium and potassium are carried by a transport protein, which occurs in two forms — one for each ion. The pump acts as follows: a sodium ion binds to make the first form of a protein while ATP attaches a phosphate group. This causes the protein to change into the second form and, while shape-shifting, to deposit the sodium ion outside the plasma membrane. The protein now grabs a potassium ion and releases its phosphate group, which transfigures the protein back to the first form. The protein then releases the potassium ion inside the cell.

Diffusion, facilitated diffusion, and active transport are used to move substances across the membranes of organelles, as well as across the plasma membrane.

Question

What triggers the transfiguration of the intrinsic protein involved in the sodium-potassium pump?

- A the attachment of a sodium ion
- B the attachment of a potassium ion
- C the presence or absence of phosphate

D the ion concentration on either side of the plasma membrane

Answer

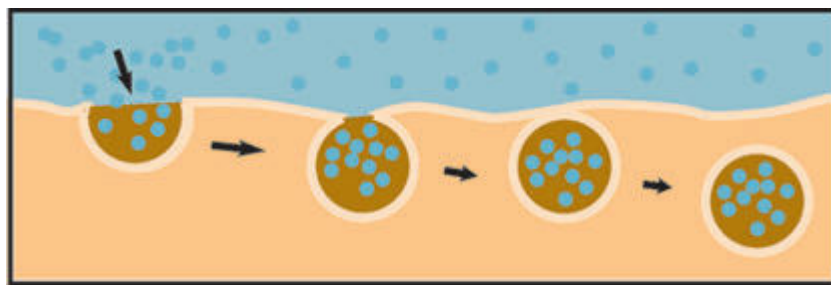
The correct answer is C. The addition or removal of a phosphate group triggers the intrinsic protein to change shape, and causes it to pick up or deposit either sodium or potassium in or out of the cell. A sodium ion binds to an intrinsic protein that is already primed to receive it; it does not trigger changes in the intrinsic protein. The same holds true for the binding of potassium to the intrinsic protein. Intrinsic proteins are involved in active transport, which is transport against ion concentration on either side of the cell membrane. Thus, the ion concentration does not trigger changes in the intrinsic protein that enable it to carry ions against the ion gradient.

Biochemistry & Cell Biology: A little in and a little out

Particular Problems

Proteins and amino acids are large particles, and they are too large to cross the plasma membrane via diffusion or by active transport. Yet cells need these substances, so cells use vacuoles, or vesicles, to get these necessary particles inside.

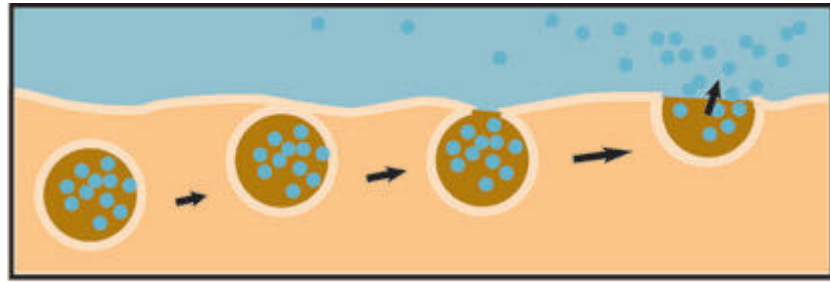
Endocytosis is a transport process that carries large particles into the cell. In **endocytosis**, a protein particle, for example, attaches itself to a special area on the outside of the plasma membrane. Attachment triggers the membrane to bulge inward to form a kind of pouch, or vesicle. The pouch enlarges until the particle is completely enclosed in it. Then the vacuole and its contents are released into the cytoplasm.



Endocytosis

Endocytosis is the engulfing of materials outside the cell and bringing them inside the cell

The same process can be used in reverse when a cell wants to rid itself of a particle. **Exocytosis** occurs when a vesicle is produced by the Golgi bodies that completely encloses a particle inside the cell. The particle-laden vesicle moves to the plasma membrane, fuses with it, then expels its contents outside the cell.



Exocytosis

Exocytosis is the discharging of materials formerly inside the cell to the outside of the cell

Question

During facilitated transport, intrinsic proteins

- A carry ions from regions of lower to higher concentrations.
- B open channels in the plasma membrane when bound to a phosphate.
- C assist in moving molecules across the membrane in the direction of the concentration gradient.
- D assist in the diffusion of other protein particles into and out of the cell via the plasma membrane.

✓Answer

C is the correct answer. In facilitated transport, or facilitated diffusion, intrinsic proteins help move molecules in the direction of the concentration gradient. Carrying ions in a direction against the concentration gradient, which is from a region of high concentration to low concentration, is active transport, not facilitated transport. Gap junctions permit chemical communication among cells. Proteins are too large to move through the plasma membrane via diffusion, and must be moved via active transport.

Biochemistry & Cell Biology: A little in and a little out

Particular Problems

Question 1

In exocytosis, transport vesicles are created in

- A Golgi bodies.
- B smooth endoplasmic reticulum.
- C intrinsic proteins of the plasma membrane.
- D a molecule of ATP.

 Answer

The correct answer is A. Exocytosis creates vesicles in the Golgi bodies, which encase the particle in a membrane that attaches to the plasma membrane, from where the particle is expelled. The SER is involved in the synthesis of cholesterol, not in exocytosis. Intrinsic proteins assist in the transport of needed molecules into the cell. Though in active transport, intrinsic proteins help rid the cell of sodium ions, this is not exocytosis. ATP is the energy source of the cell, created in the mitochondria. Although ATP fuels all cell functions, it is not directly involved in exocytosis.

Question 2

Endocytosis is triggered by

- A chemical activation of ATP.
- B particle attachment at receptor sites on the plasma membrane.
- C production of vesicles by the rough endoplasmic reticulum.
- D particles within the cell that must be expelled.

 Answer

B is the correct answer. When a needed particle attaches to a receptor on the cell surface, endocytosis is triggered to allow the particle into the cell. ATP remains inside a cell and is not activated chemically by particles needed inside the cell. Endoplasmic reticula synthesize necessary materials for the cell but are not involved in transporting substances into the cell. Endocytosis involves the entry of needed particles, such as proteins, into the cell. Choice D is incorrect because it describes exocytosis.

9. Cellular Energetics

Biochemistry & Cell Biology: Cellular Energetics

Energetic Cells

You have read that cells get their energy from ATP (adenosine triphosphate). But what is ATP and where does it come from? ATP is the molecule of choice for energy transfer in all cells. ATP stores the energy that is used in cellular processes in the high-energy chemical bonds between its three phosphates. The breakdown of ATP breaks the phosphate bonds, releasing energy and making it available to the cell. The formula for this reaction is:

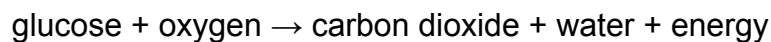


Where P_i is inorganic phosphate. Often, the breakdown of ATP does not release inorganic phosphate, but instead transfers it, with the aid of an enzyme, to another molecule. This process is called **phosphorylation**. Thus, the phosphorylation of ADP creates ATP. Getting ATP from glucose is a multi-step process. The first step is glycolysis, which breaks down glucose; the second step is respiration, which itself consists of two steps: the Krebs cycle and electron transport chain. Both oxidation (the loss of an electron) and reduction (the addition of an electron) may be used to create energy from glucose.

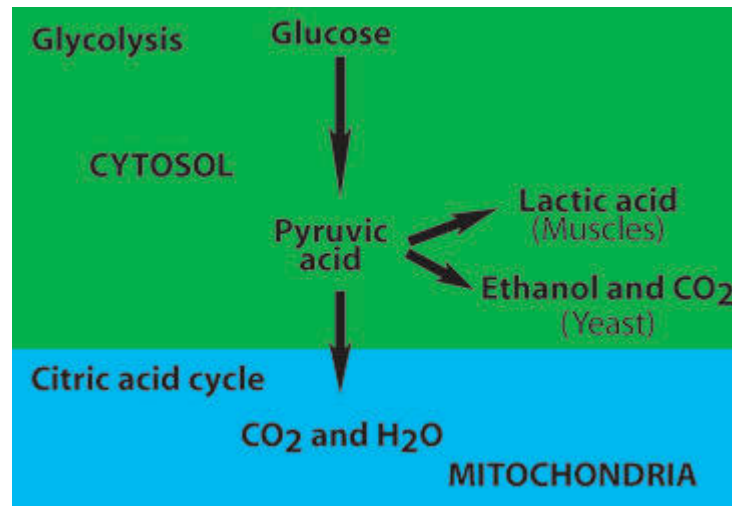
Biochemistry & Cell Biology: Cellular Energetics

Airless Energy: Glycolysis

Glycolysis, which occurs in the cell cytoplasm, is an anaerobic process that entails the splitting, or lysing, of glucose. There is a specific sequence of nine chemical reactions in glycolysis, each catalyzed by a particular enzyme. The overall purpose of glycolysis is to break down the carbon bonds in glucose and to use the released energy to produce fuel, or energy, for the cell (in the form of ATP):



In glycolysis, a phosphate group is transferred from an ATP molecule to a glucose molecule. The glucose molecule then splits apart, and energy is produced as NAD (nicotinamide adenine dinucleotide, a hydrogen carrier). NAD is reduced to NADH (hydrogen having been obtained from PGAL, phosphoglyceraldehyde). Finally, molecules of ADP are phosphorylated to become ATP.



Glycolysis is the lysing of glucose

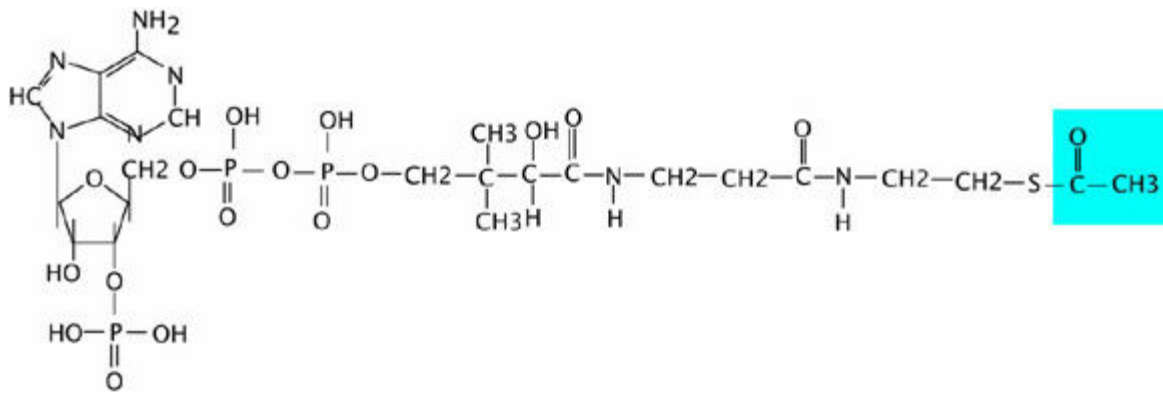
Glycolysis yields 2 ATP plus 2 molecules of pyruvic acid, so its electrons must be carried across the inner mitochondrial membrane. Once this occurs, more ATP molecules are produced. In total, glycolysis yields 8 ATP. The 9-step process (each product is the next reaction's reactant) looks like this:

- $\text{glucose} + \text{ATP} + \text{enzyme} \rightarrow \text{glucose-6-phosphate} + \text{ADP}$
- $\text{glucose-6-phosphate} + \text{enzyme} \rightarrow \text{fructose-6-phosphate}$
- $\text{fructose-6-phosphate} + \text{ATP} + \text{enzyme} \rightarrow \text{fructose-1,6-diphosphate} + \text{ADP}$
- $\text{fructose-1,6-diphosphate} + \text{enzyme} \rightarrow 2 \text{ PGAL}$
(PGAL = phosphoglyceraldehyde, which readies the fuel for oxidation)
- $2 \text{ PGAL} + 2 \text{ NAD} + 2 \text{ P} + \text{enzyme} \rightarrow 2 \text{ 3-phosphoglyceroyl phosphate} + 2 \text{ NADH}$
(hydrogen from PGAL)
- $2 \text{ 3-phosphoglyceroyl phosphate} + 2 \text{ ADP} + \text{enzyme} \rightarrow 1 \text{ 3-phosphoglycerate} + 2 \text{ ATP}$
- $2 \text{ 3-phosphoglycerate} + \text{enzyme} \rightarrow 2 \text{ 2-phosphoglycerate}$
- $2 \text{ 2-phosphoglycerate} + \text{enzyme} \rightarrow 2 \text{ phosphoenolpyruvate} + 2 \text{ H}_2\text{O}$
- $2 \text{ phosphoenolpyruvate} + 2 \text{ ADP} + \text{enzyme} \rightarrow 2 \text{ pyruvate} + 2 \text{ ATP}$
- Biochemistry & Cell Biology: Cellular Energetics

Respiration

Cellular **respiration** is the oxidation of food (glucose) by cells. Cellular respiration entails the further breakdown of glucose to fuel cell function. In cellular respiration, a sequence of reactions oxidizes pyruvic acid, which is produced in the later steps of glycolysis to yield energy, carbon dioxide, and water. Cellular respiration occurs in the mitochondria and involves two steps: the Krebs cycle and electron transport chain.

The prelude to the Krebs cycle is often called the transition reaction. The first step in cellular respiration involves the oxidation of pyruvic acid. The carbon is removed from the three-carbon pyruvic acid and forms 2 CO_2 . Two two-carbon acetyl groups are left (2 CH_3CO). The pyruvic acid's hydrogen atoms are transferred to hydrogen-carrying molecules of NAD to form 4 NADH. Each acetyl group bonds with coenzyme A (a compound made up of nucleotides and forms of vitamin B) to form the substance acetyl coenzyme A, the key compound that links glycolysis with the Krebs cycle. Converting pyruvic acid to coenzyme A yields 6 ATP.



The structure of acetyl coenzyme A is important in its function

Biochemistry & Cell Biology: Cellular Energetics

Krebs Cycle

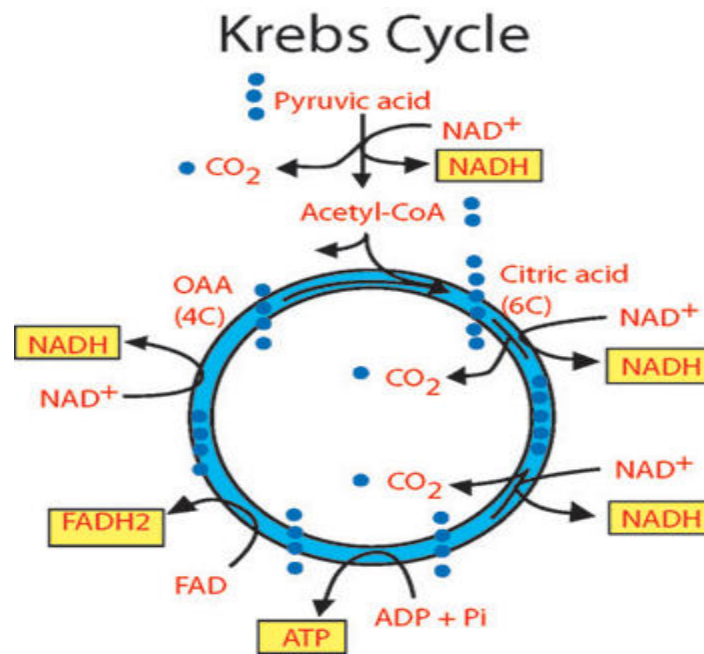
In the **Krebs cycle** carbons from the acetyl group (in acetyl coenzyme A) are oxidized to create carbon dioxide, and hydrogen atoms are transferred in an electron transport process. Coenzyme A is involved both in the oxidation of pyruvic acid and in the Krebs cycle.

When the two-carbon acetyl group enters the Krebs cycle, it is combined with a four-carbon compound (oxaloacetic acid) to form the six-carbon compound citric acid. During this process, two of the six carbons are oxidized to carbon dioxide. Some of the energy released during oxidation and breaking of the carbon-carbon and carbon-hydrogen bonds is used to change ADP to ATP, and some of the energy is used to transform NAD to NADH. Remaining energy is used to reduce another electron carrier, FAD (flavin dinucleotide) into FADH₂. Oxygen is not used during the Krebs cycle. All the electrons and protons released are picked up by the NAD⁺ and FAD. The total number of ATP molecules produced in the Krebs cycle is 24 per molecule of glucose.

Krebs cycle formula

oxaloacetic acid + **acetyl** coenzyme A + **ADP + P i + 3 NAD + FAD** →

oxaloacetic acid + **2 CO₂** + coenzyme A + **ATP + 3 NADH + FADH + 3 H+ H₂O**

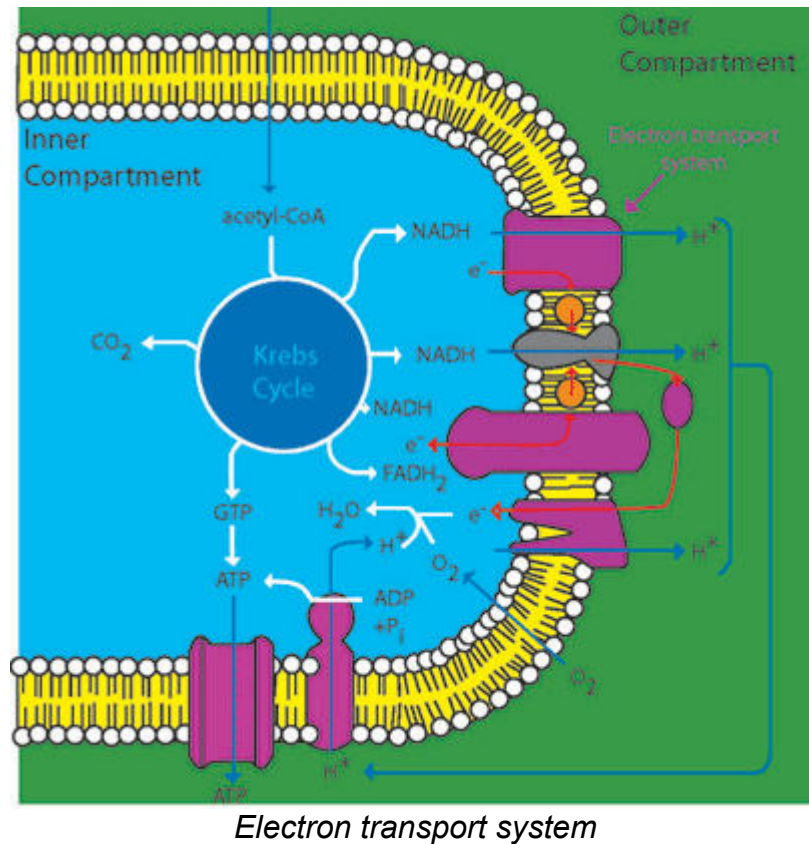


The Krebs Cycle is vital to life

Biochemistry & Cell Biology: Cellular Energetics

Electron Transport Chain

In the **electron transport chain**, electron carriers (NADH and FADH) transfer electrons to lower energy levels, with the energy given up by the electrons being used to create ATP from ADP. The electron transport chain begins with the glucose molecule's carbon atoms thoroughly oxidized. Some of the energy produced in this process was used to create ATP from ADP. But a good deal of energy remains in the electrons that were removed from the carbon-carbon and carbon-hydrogen bonds, which were transferred to the electron carriers NAD and FAD, now NADH and FADH₂. These high-energy electrons are then transferred in a downward process to ever-lower energy levels, bottoming out with oxygen. At each step, an electron carrier moves the electrons along to the next lower energy level. The energy the electrons give up on their downward path is used to re-create ATP from ADP. The process that produces ATP from the energy released as the electrons are moved to each lower level is called **oxidative phosphorylation**.



The main carriers in the electron transport chain are known as **cytochromes**, which are made up of protein and a porphyrin ring. At each step, a different cytochrome, designed specifically to carry an electron at a particular energy level, carries the electron to the next lower level, ending with low-energy oxygen. At the end of the downward slide, the electrons link up with oxygen and then combine with hydrogen ions to yield water.

At each lower step in the chain, the energy released by a pair of electrons is sufficient to transform, or phosphorylate, one ADP to one ATP molecule. Once created, an ATP molecule is moved across the mitochondrial membrane. Simultaneously, an ADP molecule moves into the mitochondrion to begin its phosphorylation into ATP. You can see that the transformation of ADP into ATP, and vice versa, is a perpetual cycle in which a cell creates and uses the fuel that keeps it going.

In summary, glycolysis and cellular respiration yield 38 molecules of ATP to energize the cell.

Biochemistry & Cell Biology: Cellular Energetics

Question 1

ATP is created in the electron transfer chain process because

- A high-energy oxygen is added at each step.
- B ADP is phosphorylated by free electrons.

- C NAD and FAD are created from ADP.
- D energy released by electrons is used in phosphorylation.

✔**Answer**

D is the correct answer. Energy is released as electrons are transferred to lower energy levels. This energy is used in the electron transfer chain to add phosphate to ADP to form ATP. Oxygen is not part of the electron transfer chain until the final step in the process, so no energy is released from oxygen. ADP is phosphorylated in the electron transfer chain, but electrons cannot phosphorylate it, only a phosphate group can. Electron transfer provides the energy for phosphorylation, but electrons neither create nor change molecules. Choice C is incorrect because NAD and FAD are electron carriers; they are not created from ADP, which is the precursor to ATP.

Question 2

The last step in the glycolysis process yields

- A 2 pyruvate + 2 ATP
- B 2 pyruvate + 2 ADP
- C glucose-6-phosphate + ADP
- D glucose + 2 ATP

✔**Answer**

The correct answer is A. The overall purpose of glycolysis is to break down glucose to produce energy for the cell in the form of ATP. The last step in the glycolysis process yields 2 ATP and 2 molecules of pyruvic acid.

Question 3

The substance that provides the necessary acetyl group in the Krebs cycle is

- A adenosine diphosphate.
- B coenzyme A.
- C flavin dinucleotide.
- D oxaloacetic acid.

👉Answer

The correct answer is B. Acetyl coenzyme A provides the two-carbon acetyl group that enters the Krebs cycle and combines with oxaloacetic acid to form citric acid. Adenosine diphosphate is ADP, the precursor to ATP. Flavin dinucleotide is an electron carrier and does not donate an acetyl group to the Krebs cycle. Oxaloacetic acid joins with the acetyl group that is contributed by coenzyme A, but is not the original donor of this molecule to the Krebs cycle.

10. Specialized Cells

Biochemistry & Cell Biology: Specialized Cells

Plant cells — shared characteristics and unique properties

Plant cells share many characteristics with animal cells. Plant cells use cellular respiration for energy, as reviewed earlier. They also have a plasma membrane, cytoplasm, a nucleus and nucleolus surrounded by a nuclear membrane, mitochondria, rough and smooth endoplasmic reticula, Golgi bodies, peroxisomes, microtubules, and other structures. However, plant cells have some unique structures and carry out some unique, and vital, processes.

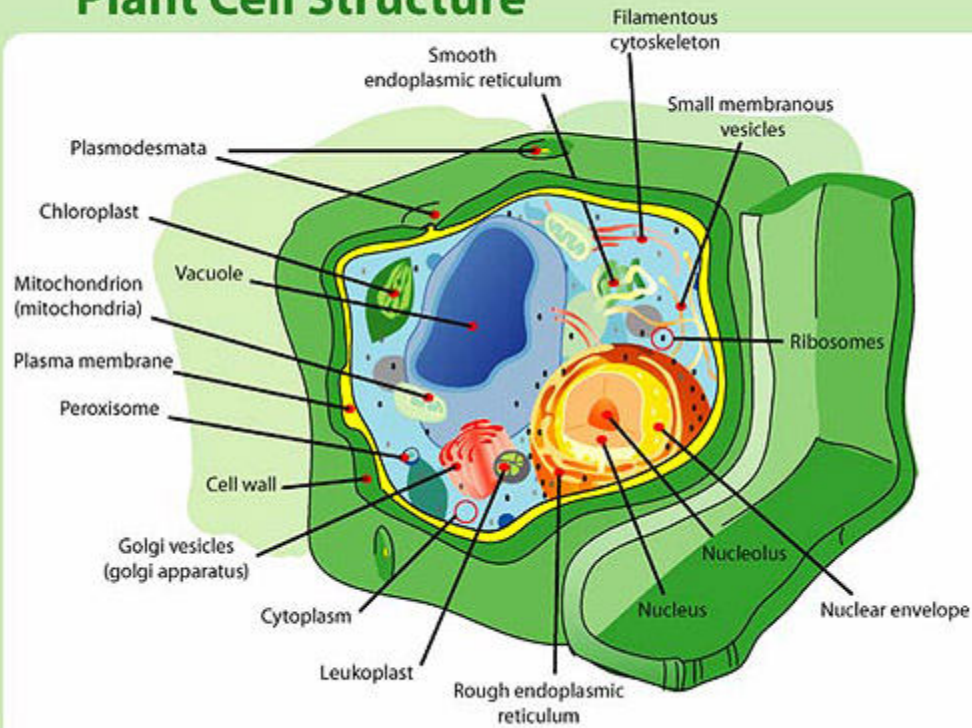
The most distinguishing characteristic of plant cells is their rigid **cell wall** that surrounds the inner plasma membrane. A plant cell wall is made from **cellulose**, which is made from glucose. Thin chains of these glucose molecules are joined as **microfibrils**, which give cellulose its crystal-like properties. The microfibrils are wound together into threads, which themselves are wound into cables. Cellulose is the most abundant substance in plants, but lignin is a close second.

Lignin, a glucose-based polymer, adds further rigidity and strength to the cell wall. Lignin is the major material in wood.

Plants need strong, rigid cell walls for two important reasons. First, the cell walls help support the plant; for example, keeping its stem upright. Second, water drawn up into the plant via the roots is under pressure, and strong cell walls are required to maintain cell shape, and prevent cell explosion, during water intake.

Vacuoles are, in some ways, similar to vesicles in animal cells. However, plant cell vacuoles are usually far larger than vesicles (taking up 90 percent of the space in some plant cells). Vacuoles are membrane-bound sacs filled with liquid called cell sap, which is mostly water. In some plants, the cells' vacuoles contain the pigments that give the plant its color, such as the red pigment in cherries.

Plant Cell Structure

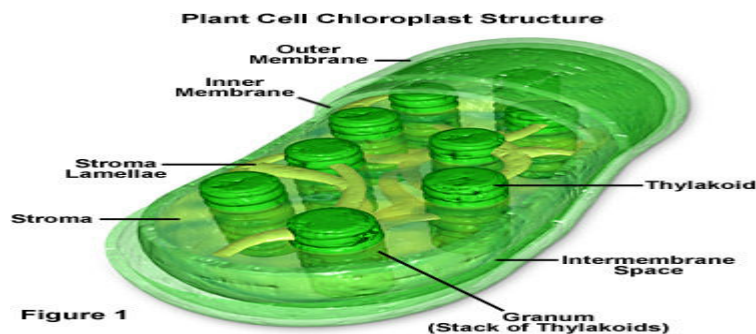


Example of a typical plant cell

Biochemistry & Cell Biology: Specialized Cells

Plant organelles

Chloroplasts are plant cell structures that contain **chlorophyll** and **carotenoid** pigments, and are the sites where photosynthesis occurs. Chloroplasts are disk-shaped **plastids**, components of plant cells bounded by a two-layer membrane. The base substance inside a chloroplast is called the **stroma**. Within the stroma is an intricate and complex system of flat, sac-like membranes called **thylakoids**. A large stack of thylakoids is called a **granum** (plural, grana). Chlorophyll and carotenoid pigments are found in the membranes of the thylakoids. In most plants, these pigments derive from green chlorophyll.



Chloroplasts are the energy dynamos of plant cells

Question 1

What are the two main substances that give rigidity to the cell wall?

- A Microtubules and lignin
- B Lignin and cellulose
- C Cellulose and thylakoids
- D Grana and cellulose

Answer

The correct answer is B. Cellulose forms microfibril chains that, along with lignin, add rigidity to plant cell walls. Microtubules are cytoskeletal structures in animal cells. Thylakoids are pigment-carrying parts of chloroplasts. Grana are stacks of thylakoids.

Question 2

The grana that occur in chloroplasts are primarily made up of

- A numerous plastids.
- B liquid stroma.
- C stacked thylakoids.
- D carotenoid pigments.

Answer

The correct answer is C. Grana are the stacks of pigment-rich thylakoids that occur in the chloroplasts. A chloroplast is itself a plastid, a type of organelle, but its constituents are not plastids. The stroma is the liquid that fills the area around the grana in the chloroplasts. Carotenoid pigments may be incorporated into the thylakoids that make up the grana, but the grana are not made up of these pigments.

Biochemistry & Cell Biology: Specialized Cells

Living on Light

Plants are autotrophs because they make their own food via the process of **photosynthesis**. Photosynthesis is a complex chemical process in which the energy in sunlight is used to convert carbon dioxide and water into a form of glucose a plant can use as food, with oxygen as a byproduct. Photosynthesis takes place in the chloroplasts, particularly in the thylakoids.

Of course, plants take in water through their roots, and the water is drawn upward to every cell in the plant. In most plants, the underside of the leaf contains small, pore-like openings called stomates that take in air.

This is the chemical formula for photosynthesis:



CH_2O is the building block of carbohydrates and when synthesized, can be used as food by the plant.

Different plant pigments absorb different wavelengths, or colors, of light. Chlorophyll, which gives most plants their green color, absorbs wavelengths of light in the violet-blue-red range of the spectrum. Other plant pigments, including carotenoids and phycobilins, absorb other spectra of light.

A **photosystem** includes chlorophyll and other pigments that are embedded in thylakoids. One chlorophyll **a** molecule per photosystem absorbs one **photon** of light. The energy then boosts one of the chlorophyll **a** electrons to a higher level. It moves to an acceptor molecule, and an electron flow is initiated. The chlorophyll **a** molecule is thus oxidized and has a positive charge. In Photosystem I, the activated chlorophyll **a** molecule is designated P 700 (P for pigment; 700 for the optimum wavelength absorbed). In Photosystem II, chlorophyll **a** is P 680. Both photosystems acquire energy from sunlight, each using a slightly different wavelength of light and terminal electron acceptor in the pathway.

Biochemistry & Cell Biology: Specialized Cells

The Light Reaction

P 680 traps a photon, and its excited electron is transferred to an acceptor molecule. The P 680 is then able to replenish its electrons from a water molecule that it splits in a process known as **photolysis**. The electrons cascade along an electron transport chain, forming ATP in the process. The term for this process is **photophosphorylation**.

In Photosystem I, electrons from P 700 are passed downhill until they reach the coenzyme NADP, which is reduced to form NADPH. NADPH provides energy for the synthesis of fuel for the cell.

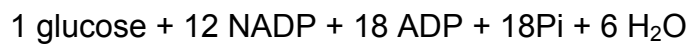
Thus, in the light reaction, electrons flow continuously from water to Photosystem II, and from there back to Photosystem I and to NADP.

The Dark Reaction

Despite its name, the dark reaction often takes place in the presence of light, though light is not required. In this second stage of photosynthesis, carbon from carbon dioxide is chemically reduced. The process occurs in the stroma, and this carbon fixation process is referred to as the **Calvin cycle** after the scientist Melvin Calvin, who first described it.

The Calvin cycle begins and ends with a five-carbon sugar that has two phosphate groups attached to it (ribulose 1,5-bisphosphate, or RuBP). Carbon dioxide is attached to the RuBP, which then splits to form two molecules of PGA (3-phosphoglycerate). The cycle must repeat six times for the final product glyceraldehyde 3-phosphate to result.

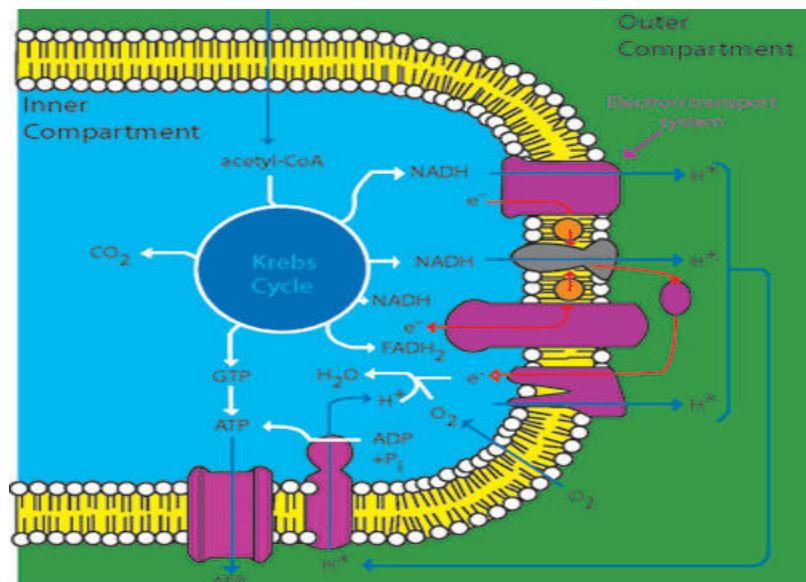
Calvin cycle:



Biochemistry & Cell Biology: Specialized Cells

Electron Transport Chain

In the **electron transport chain**, electron carriers (NADH and FADH) transfer electrons to lower energy levels, with the energy given up by the electrons being used to create ATP from ADP. The electron transport chain begins with the glucose molecule's carbon atoms thoroughly oxidized. Some of the energy produced in this process was used to create ATP from ADP. But a good deal of energy remains in the electrons that were removed from the carbon-carbon and carbon-hydrogen bonds, which were transferred to the electron carriers NAD and FAD, now NADH and FADH₂. These high-energy electrons are then transferred in a downward process to ever-lower energy levels, bottoming out with oxygen. At each step, an electron carrier moves the electrons along to the next lower energy level. The energy the electrons give up on their downward path is used to re-create ATP from ADP. The process that produces ATP from the energy released as the electrons are moved to each lower level is called **oxidative phosphorylation**.



Electron transport system

The main carriers in the electron transport chain are known as **cytochromes**, which are made up of protein and a porphyrin ring. At each step, a different cytochrome, designed specifically to carry an electron at a particular energy level, carries the electron to the next lower level, ending with low-energy oxygen. At the end of the downward slide, the electrons link up with oxygen and then combine with hydrogen ions to yield water.

At each lower step in the chain, the energy released by a pair of electrons is sufficient to transform, or phosphorylate, one ADP to one ATP molecule. Once created, an ATP molecule is moved across the mitochondrial membrane. Simultaneously, an ADP molecule moves into the mitochondrion to begin its phosphorylation into ATP. You can see that the transformation of ADP into ATP, and vice versa, is a perpetual cycle in which a cell creates and uses the fuel that keeps it going.

In summary, glycolysis and cellular respiration yield 38 molecules of ATP to energize the cell.

Biochemistry & Cell Biology: Specialized Cells

Question 1

In the designation P_{680} , the subscript number represents

- A the number of atoms in the pigment molecule.
- B the wavelength of light best absorbed by the pigment.
- C the number of glucose molecules produced in the Calvin cycle.
- D the number of carbon dioxide molecules fixed during photosynthesis.

Answer

The correct answer is B. The subscript number of the pigment indicates the wavelength of light it best absorbs. The subscript number does not indicate the number of atoms in the molecule of pigment. The number of glucose molecules produced in the Calvin cycle varies and is not dependent on the type of pigment. The number of carbon dioxide molecules fixed during photosynthesis depends on certain conditions and is not indicated by the subscript wavelength number designating the pigment.

Question 2

ATP is created in the electron transfer chain process because

- A uses little or no ATP.

- B produces PEP instead of glucose
- C produces glucose using fewer CO₂ molecules.
- D uses CO₂ that would otherwise be lost during photorespiration.

☑ **Answer**

The correct answer is D. In the C₄ cycle, carbon molecules are reduced and the carbon dioxide that results is used in the Calvin cycle instead of being released; so this is a more efficient use of carbon in photosynthesis. All cell functions require the energy of ATP, which has nothing to do with the double processing of the more efficient C₄ cycle. B is not correct because PEP is an intermediate material made during C₄ photosynthesis and does not explain why this type of photosynthesis uses carbon more efficiently. The C₄ cycle does not use fewer carbon dioxide molecules; it just uses the ones it has completely instead of losing them.

Question 3

The substance that provides the necessary acetyl group in the Krebs cycle is

- A a photon of light is transferred among molecules.
- B chlorophyll activates pigments involved in carbon fixation.
- C an activated electron cleaves a molecule of water.
- D carbon dioxide is reoxidized and released.

☑ **Answer**

The correct answer is C. In photolysis, a pigment traps an excited electron, creating energy to cleave a water molecule into its components hydrogen and oxygen. A photon is not itself transferred among molecules, but the photon-activated electron is. B is not correct because carbon fixation is a process separate from photolysis, which involves the splitting of water molecules. Photolysis does not involve the oxidation and release of carbon dioxide; reoxidation of carbon dioxide occurs in photorespiration.

11. Eukaryotes

Biochemistry & Cell Biology: Eukaryotes

Lesson Objective

Now we will focus on some of the diversity of living eukaryotic organisms in order to understand how life has evolved. We will start small and then move on to bigger and more familiar organisms later.

Previously we covered...

We reviewed the basics of cell form and function, including the differences and similarities among prokaryotes, eukaryotes, plants and animals.

Biochemistry & Cell Biology: Eukaryotes

Enter the Algae

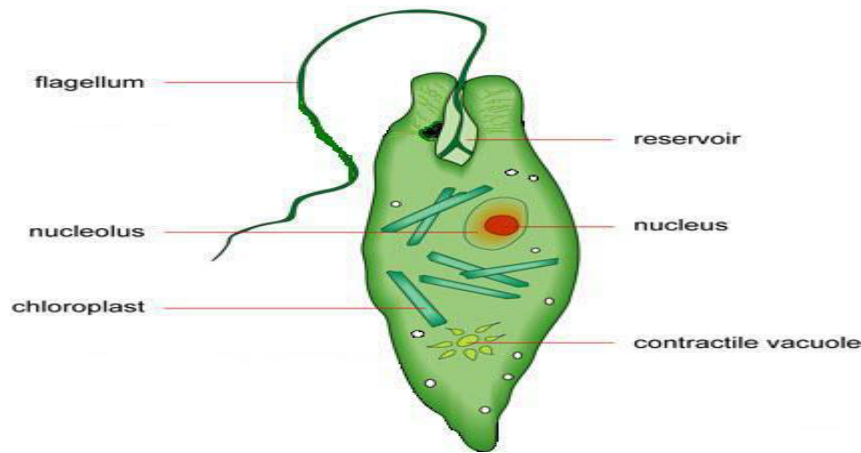
Algae (singular **alga**) are unicellular or simple multicellular organisms that photosynthesize. It is likely that the six divisions of algae known today arose from a common ancestral eukaryotic cell. Three of the six divisions are made up mostly of unicellular organisms; the other three are mainly multicellular and the vast majority of algae are photosynthetic. Algae range in complexity from a single cell to a filament of cells to a solid body of cells that somewhat resembles a plant. The divisions of algae are based on the presence, number, and position of flagella; their pigmentation; and other factors, like how they store food. The components of the algal cell wall, which often feels slimy due to its polysaccharides, also distinguish different algae.

Most single-celled algae occur on the surface of the ocean or freshwater bodies, where they are known as **plankton**. Unicellular algae are free-living autotrophs, though some may live in colonies. Multicellular algae occur primarily in shallow waters along shorelines. Divisions of algae have been named for the algae's dominant pigment, which may hide the greening of the chloroplasts. Each Division is discussed and described below.

Staying Single

Division Euglenophyta consists of about 1,000 species of the ubiquitous **Euglena**. These unicellular freshwater algae contain chloroplasts encased in a three-layer membrane, suggesting that **Euglenas** evolved by ingesting and incorporating green algae, which have a two-layer chloroplast membrane.

Euglenas are generally elongated, two-flagellum cells, with many chloroplasts that give the cell its striking emerald-green color. **Euglenas** have a photoreceptor and are remarkable in that they be either heterotrophs and/or autotrophs. In sunlight, **Euglenas** are green and photosynthetic autotrophs; but put them in a dark closet, and they lose their pigmentation and become heterotrophs.



Generalized structure of *Euglena*

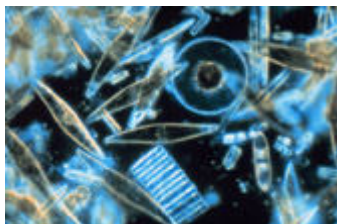
Biochemistry & Cell Biology: Eukaryotes

Staying Single

Division Chrysophyta includes the diatoms (approximately 10,000 species), the **golden-brown algae** (approximately 1,500 species), and the smaller group (approximately 600 species) of **yellow-green algae**. Chrysophyta are characterized by the presence of chlorophylls **a** and **c**; fucoxanthin, a yellow-brown pigment present in all except the yellow-greens; silicon-impregnated cell walls (lacking cellulose); and their storage of food as oil rather than starch.

Diatoms are famous for their beautiful, lacy double shells made of silica. The lacy look of the shells are actually pores that allow passage of materials into and out of the alga. Diatoms, like most plankton, are an important part of the marine food chain. Unlike their Divisional relatives, which reproduce via binary fission, diatoms sometimes reproduce sexually via a fusion of gametes, called **syngamy**.

Division Pyrrophyta, or fire algae, is made up of about 1,000 species of single-celled, marine **dinoflagellates**. Most species are photoautotrophs, but some are heterotrophs; most have two flagella. Dinoflagellates come in a variety of bewilderingly weird forms, kept in shape by rigid cellulose walls. A few are naked, and most of these are parasitic. As their name suggests, most fire algae are red. They are often the culprits in occurrences of toxic red tides. Some dinoflagellates (especially **Gessnerium catenellum**) that form red tides release neurotoxins, which have caused massive fish kills and occasional poisoning of humans who ingest it in filter-feeding mussels and other shellfish.



Diatoms



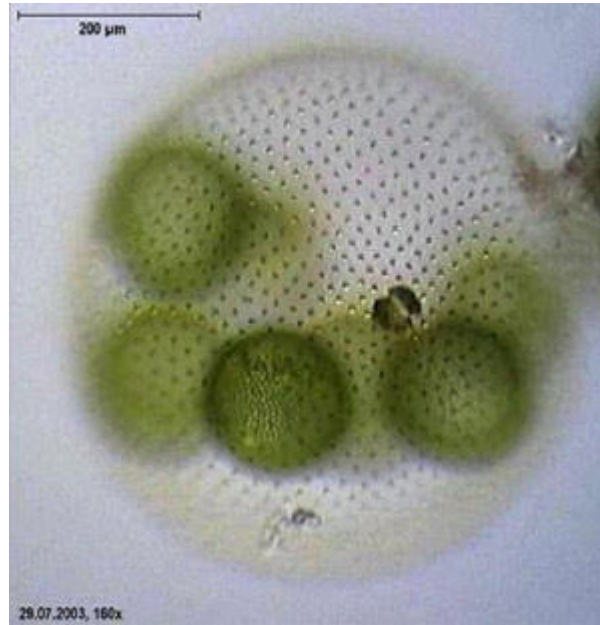
Example of a typical dinoflagellate

Biochemistry & Cell Biology: Eukaryotes

Getting Together

Division Chlorophyta contains the **green algae**, which may be either unicellular or multicellular. Chlorophyta are characterized by their chlorophylls **a** and **b** (as in plants), the presence of beta-carotene photosynthetic pigments, and their storage of food as starch. Most have cellulose in their cell walls. They are believed to be the ancestors of plants. Most green algae are freshwater organisms, although some are marine organisms; some of the 7,000 species in this Division live on tree trunks or in symbiosis with other organisms. The Chlorophyta are unique in that some species in this Division are multicellular. Scientists speculate that multicellularity may have arisen from this Division.

Scientists believe that there are three pathways that lead from unicellularity to multicellularity. The first arose from colonies of single-celled organisms. A colony is a group of independently functioning, single-celled organisms connected to each other via strands of cytoplasm. There are four genera of multicellular Chlorophytes. In order of complexity they are: **Chlamydomonas**, **Gonium**, **Pandorina**, and **Volvox**. **Volvox** is a hollow sphere whose single outer layer is comprised of as many as 60,000 minute flagellated cells.



***Volvox** are the prototypical colonial alga*

The second path toward multicellularity is really an intermediate form of organization, referred to as **coenocytic**. In this case, a single organism consists of many nuclei in a common cytoplasm. Nuclear divisions are not accompanied by separation of the cytoplasm or the formation of cell walls.

Coenocytic algae include the large **Valonia** and the filamentous **Cladophora**.

The third road to multicellularity is represented by algae that undergo nuclear division as well as division of the cytoplasm and the formation of cell walls. Because of this type of cell division, these algae may occur in sheets, filaments, or even three-dimensional form. One green algae species that evinces this type of multicellularity is **Spirogyra**.



*Example of a mat of **Spyrogyra***

Biochemistry & Cell Biology: Eukaryotes

Living Together

There are two Divisions that contain only multicellular algae, phaeophyta and rhodophyta. **Division Phaeophyta** consists of the **brown algae** — the seaweeds that thrive in cold marine waters. **Kelps** are members of this Division and occur, sometimes in huge water-forests, offshore in cooler climes. Many species occur along rocky shorelines, where their **holdfasts**, the kelp equivalent of roots, keep them anchored to the rocks and prevent them from being washed away by battering waves. The body of a multicellular alga is called **athallus**, which consists of the holdfast, the stem-like **stipe**, and the leaf-like **blade**. Though these structures are likened to similar structures in plants, their internal organization is very different, and they resemble plant structures only superficially. The rockweed, **Fucus**, is a typical species in this Division.

The **Division Rhodophyta**, the red algae, consists of about 4,000 species of mostly tropical and subtropical marine seaweeds (very few species are freshwater). Their red color is conferred by the presence of phycobilins, and they also contain chlorophylls **a** and **d**, as well carotenoids. Because of these pigments, Rhodophyta can survive at great depths, up to 175 meters below the surface. Some

red algae have a slimy, mucilaginous outer layer, though others — the coralline algae — deposit calcium carbonate in their cell walls and are important in reef building.



Example of kelp forest

Biochemistry & Cell Biology: Eukaryotes

Test Yourself

Question 1

Eukaryotes are characterized by the presence of

- A a plasma membrane.
- B cilia and flagella.
- C chromosomes.
- D DNA.

✓Answer

The correct answer is C. Prokaryotes have naked strands of DNA, while eukaryotes have their DNA on chromosomes in the nucleus. Both prokaryotes and eukaryotes have plasma membranes. Eukaryotes are not characterized by cilia or flagella, and all cells have DNA.

Question 2

Which of the following is a form of multicellular algae?

- A Diatoms
- B Volvox
- C Chlorophyta
- D Kelp

👉Answer

The correct answer is D. Kelp are members of Division Phaeophyta, which contains only multicellular algae. Diatoms are unicellular algae with rigid silicon shells, so A is incorrect. Volvox are colonies of independent unicellular algae, so B is not correct. Chlorophyta is a Division of algae that includes both unicellular and multicellular algae, so C is not correct.

Biochemistry & Cell Biology: Eukaryotes

Micro-Critters

The word **protozoa** means "first animals" and it refers to the animal-like organisms in various phyla of the **Kingdom Protista**. Protozoa are unicellular heterotrophs, mainly free-living or parasitic. They reproduce asexually via binary fission, though some have sexual cycles and others undergo conjugation, or nucleus exchange between cells. Protozoa are organized into phyla based primarily on their mode of locomotion:

- by flagella
- by pseudopodia (false feet)
- by cilia

Phylum Mastigophora contains the most primitive protozoa, which generally have two whip-like flagella, though larger members of this phylum may have many. Most Mastigophora reproduce asexually via binary fission, though some reproduce sexually or through **syngamy**. Most Mastigophora are parasites, though some are free-living; many have no cell wall and are able to form pseudopodia (brief extensions of the cell body) used for locomotion or to engulf prey. Among the parasitic Mastigophora is the flagellate **Trypanosoma gambiense**, which causes African sleeping sickness, transferred to humans by the nefarious tse-tse fly. Members of the genus **Trichonympha** are symbionts in the gut of termites and help them digest wood.

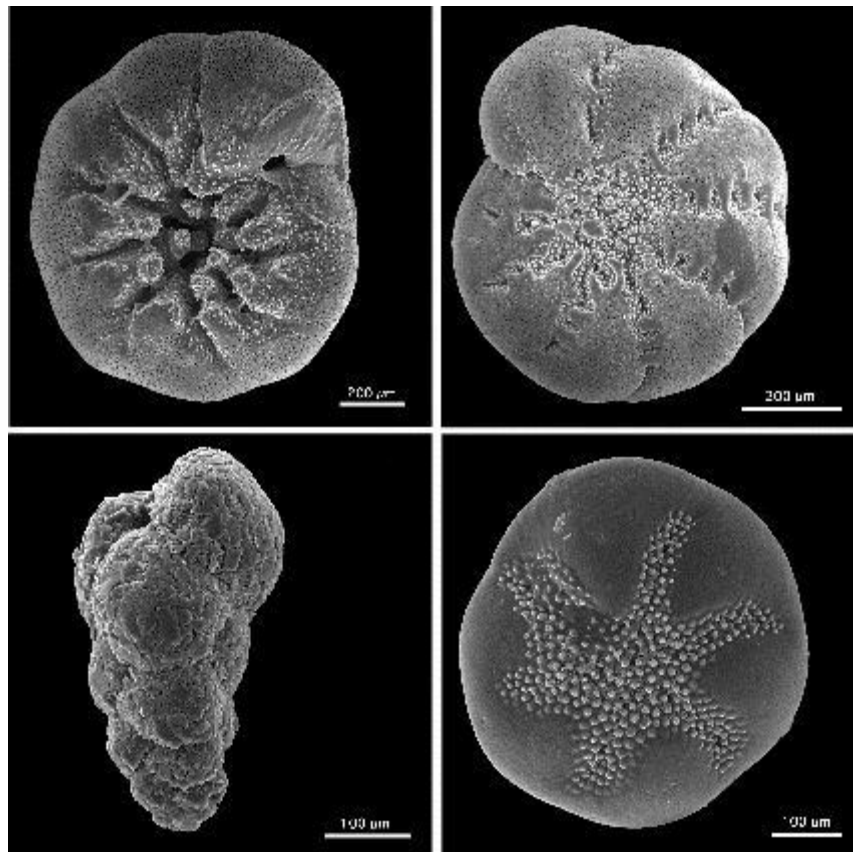
Phylum Sarcodina contains the ever-popular amoebas, for whom the formation and use of pseudopodia is a way of life. Locomotion solely with pseudopodia is called streaming. Amoebas create pincer-shaped pseudopodia to catch and engulf prey, a process called **phagocytosis**. The prey is then drawn into the cell and digested. The cell is sensitive to the chemical stimulus of nearby

prey and streams toward its victim when it detects the prey's chemical signals. Although amoebas are nonphotosynthetic, they do have photoreceptors. When a pseudopodium is exposed to bright light, the amoeba withdraws it and streams away. Interestingly, if an entire amoeba is exposed to constant strong light, it will eventually learn to live with it and carry on its normal behavior.

Biochemistry & Cell Biology: Eukaryotes

Sarcodines reproduce both asexually via mitosis (but without breakdown of the nuclear envelope), or sexually via meiosis and the formation of gametes and zygotes. Sarcodines are usually free-living and found mainly in salt water and fresh water, and some, like the one that causes amoebic dysentery, are parasites. Some Sarcodines stiffen their pseudopodia with protective spines made from microtubules (*e.g.*, ***Actinosphaerium***).

Foraminifera, the most common of all protozoans, produce beautiful and delicate shells of calcium carbonate extracted from ocean water. The shells of dead Foraminifera have accumulated on the seabed or on cliffs over time, creating million-year-old **foraminiferan ooze**. Britain's White Cliffs of Dover are made from Foraminifera skeletons. Another Sarcodine group, the radiolarians, also has skeletons that form a **radiolarian ooze** on the ocean bottom.

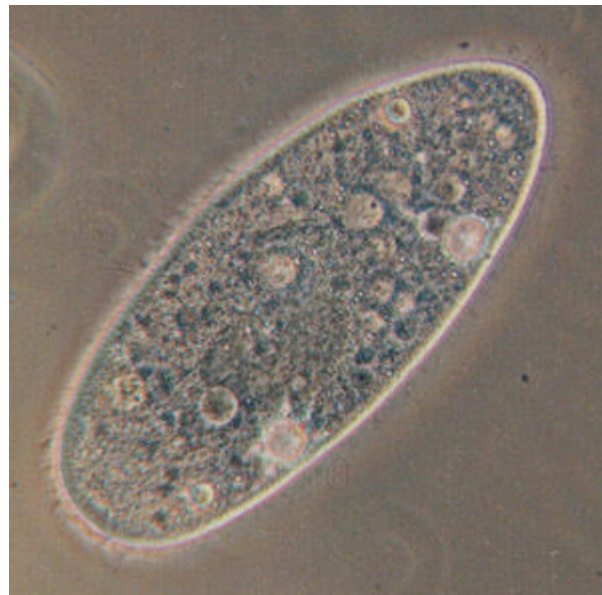


Example of some foraminifera tests

Phylum Ciliophora contains another popular protozoan, the paramecium. As the phylum's name suggests, its members move by the rapid beating of the cilia on the outside of the cell. In some Ciliophora, the cilia bind together to form clumps, called cirri; or brush-shapes called **membranelles**; both of which actually enable the cell to “jump” or “walk” along on these stiffened protrusions. Cilia arise from cilia basal bodies, which coordinate the even, sequential movement of cilia that propel the cell. Ciliophora have both contractile vacuoles, which rid the cell of liquid, and food vacuoles that fill

with enzymes when food particles are swept into it. Ciliophora, oddly, have two types of nuclei, the micronuclei and the macronuclei, which have a very complicated mode of genetic communication. Each cell may have one or more of each type. Reproduction involves **conjugation** in which genetic information is transferred through direct contact between the cells. During Ciliophora conjugation, micronuclei undergo meiosis, and the two cells exchange haploid micronuclei, which then fuse to form diploid micronuclei. One macronucleus dissolves, and a new one develops from one of the diploid micronuclei.

Like amoebas, paramecia are responsive to external stimuli, including subtle changes in the temperature and chemistry of their environment. A paramecium's cilia beat constantly, directing water toward an oral groove that is forever sampling the environment. Negative stimuli, such as the presence of a toxic substance, cause a paramecium to stop dead in its tracks and beat a hasty retreat. If the negative stimulus is not so dire — a change of temperature, for example — the paramecium will simply turn or move away.



Example of a paramecium

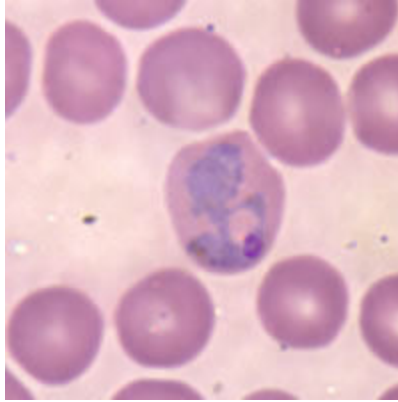
Biochemistry & Cell Biology: Eukaryotes

Micro-Critters

The organisms in the **Phylum Opalinida** are evenly covered in cilia or flagella and have at least two nuclei (though not the differentiated nuclei of the Ciliophora). Opalinids produce gametes that fuse to form a zygote. Most members of this phylum live their lives in the guts of frogs and toads, or sometimes in the digestive tracts of fish and reptiles.

All members of the **Phylum Sporozoa** are parasites, and some, like the malaria-causing **Plasmodium**, are quite nasty. All Sporozoa lack cilia and flagella, and have no means of locomotion. Sporozoa produce spores as part of their complex life cycle. **Plasmodium** begin life in an amoeboid state, as sporozoites, in the bloodstream of a warm-blooded host. Asexual reproduction occurs in the host's liver and the resulting merozoites enter the bloodstream and cause malaria. There they reproduce asexually in red blood cells and causing the cells to explode. Eventually the merozoites enter a sexual stage, when they are called gamonts, which produce gametes. A mosquito will pick up gamonts when it bites an infected person. Then fertilization occurs and zygotes develop in the insect's gut. The oocysts (fertilized eggs) divide asexually to produce sporozoites, which travel to

the mosquito's salivary glands. The next bite transfers the sporozoites to their next victim. Malaria is still one of the top five most lethal diseases in the world.



*Example of the Malaria parasite, **Plasmodium vivax** in a human red blood cell*

Biochemistry & Cell Biology: Eukaryotes

Test Yourself

Question 1

Which phylum contains protozoa that use pseudopodia almost exclusively as their means of locomotion?

- A Mastigophora
- B Sarcodina
- C Opalinida
- D Ciliophora

✓Answer

The correct answer is B. Sarcodines, which include the amoebas, create pseudopodia and use them to move via streaming. Most Mastigophora use mainly flagella, Opalinida use cilia or flagella for locomotion, and Ciliophora use cilia exclusively.

Question 2

The skeletons of which protozoan genus accumulate on the ocean floor to form an ooze?

- A Paramecia
- B Trypanosomes
- C Radiolarians
- D Plasmodium

👉Answer

The correct answer is C. Radiolarians create calcium carbonate shells that accumulate on the ocean floor when the organisms die. Paramecia do not form rigid outer coverings, Trypanosomes are Mastigophora that have no cell walls (and that cause sleeping sickness), and Plasmodium are parasites that cause malaria.

Question 3

Which phylum includes the most pathogenic parasites?

- A Sarcondina
- B Opalinida
- C Ciliophora
- D Sporozoa

👉Answer

The correct answer is D. All members of the Phylum Sporozoa are parasitic and many are pathogens. Sarcodina contains some pathogenic parasites, but most members of this phylum do not. Opalinida live symbiotically in the guts of amphibians or reptiles, and Ciliophora are ciliates that are generally neither parasitic nor pathogenic.

Question 4

Phagocytosis is accomplished by which of the following structures?

- A Pseudopodium

- B Oral groove
- C Food vacuole
- D Membranelle

👉Answer

The correct answer is A. A pseudopodium is a temporary extension of the cell body, as in an amoeba, that engulfs prey, which is then ingested. This is the process of phagocytosis. Paramecia have an oral groove that receives food that is swept in by cilia, and also have food vacuoles that receive food from the oral groove. A membranelle is a tuft of cilia used for locomotion in Ciliophora.

12. Viruses

Biochemistry & Cell Biology: Viruses

Wanted Dead or Alive

Viruses are not part of any organismal taxonomy, because it is not clear if viruses are living things. They are not cells, as they do not perform metabolic functions on their own; and outside a host, a virus cannot survive. It has no independent metabolism, respiration, motility, reproduction, or any other function that defines a living organism.

Viruses are snippets of DNA and/or RNA wrapped in a protein coat. Receptors on the protein coat are specific for the type of cell the virus infects. Only when a virus infects its target cell can it hijack the cell's abilities to replicate and spread. The virus's sole purpose is to enter a cell or inject its DNA into a cell, commandeer its reproductive processes, and make the cell replicate the virus's DNA. Some viruses destroy the cells they infect, others do not. There are viruses adapted to infect just about every type of cell there is, including bacteria. These viruses are called bacteriophages.

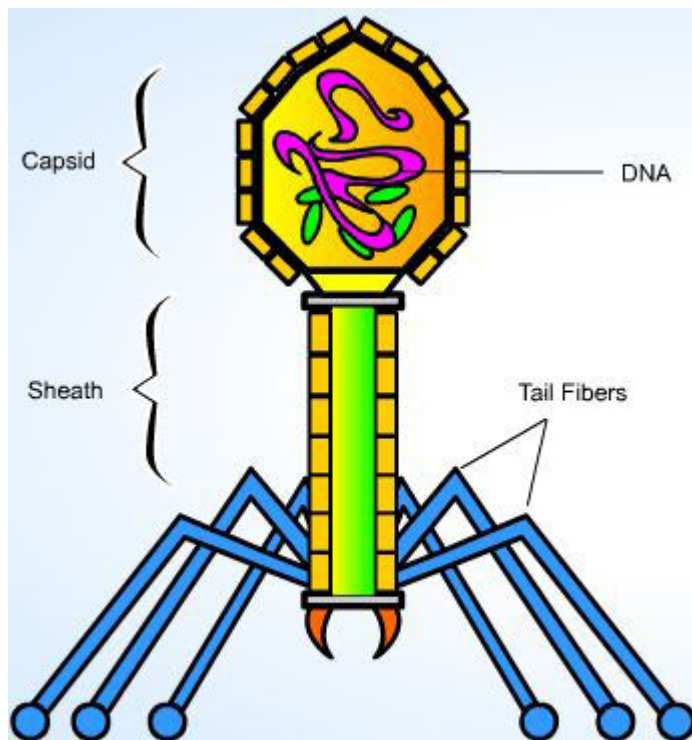
Different viruses have different modes of transmission to a host, whether through the air, contaminated food or water, or direct contact. Once it enters a host, the virus makes its way to the target cell. The receptor on the virus coat (the key) mimics the receptor on the cell surface (the lock), allowing the virus to attach to the cell. Then the virus enters the cell or injects its DNA into the cell. Viral proteins have many foul ways to take over a cell's reproductive machinery. Some viral proteins kick a resting cell into reproductive mode; others force the cell to reproduce only viral DNA. In some cases, as with some enteric adenoviruses (intestinal viruses), a single infected cell may churn out hundreds of thousands of newly formed viruses in one day.



The Marburg virus, an extremely virulent disease

Viruses are also amazingly good at avoiding the attacks of the host's immune system. Many viruses are adept at masking or shutting down cellular production of interferon, which calls the immune system into play. Viruses' evasion tactics are wildly inventive — a product of natural selection. Hepatitis B virus has its host cell create and eject empty decoy viral envelopes, which are attacked by the immune system while countless real viruses escape and continue to reproduce. Retroviruses, such as *HIV*, integrate their DNA into the DNA of infected cells. Every time the cell replicates its DNA, the viral DNA is also copied. After a period of replicating in cells, the *HIV* infects helper T-cells, that activate virus-specific T- and B-cells designed to fight pathogens. Thousands of *HIV* genomes are replicated in helper T-cells, which then die and cannot activate the immune system. So the immune system pumps out more helper T-cells, which are infected, make more *HIV*, and die. In short, the more helper T-cells the immune system makes to jump-start an attack, the more virulent the disease becomes. Quite insidious.

Biochemistry & Cell Biology: Viruses



Viruses

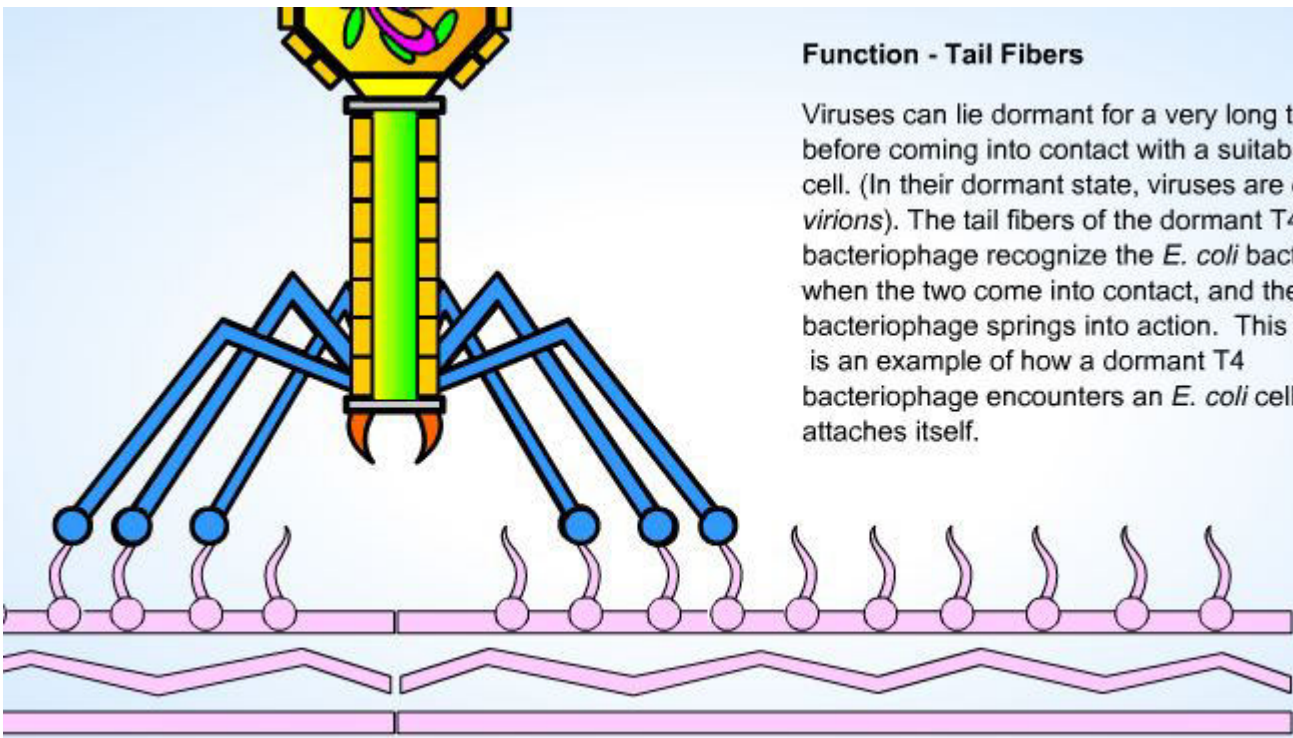
Viruses are non-living entities that attack healthy cells and transform them into virus factories. All viruses are parasites. Animals, plants, fungi, and bacteria are all susceptible to viral attack. A bacteriophage is any virus that specifically targets a bacterial cell, such as the T4 virus, which is designed to attack the *E. coli* bacteria. The T4 bacteriophage is a prototypical virus.

Roll over the different parts of the T4 bacteriophage to learn more about its structure.

Click on the button below to take a closer look at the function of the T4 bacteriophage and how viruses work.

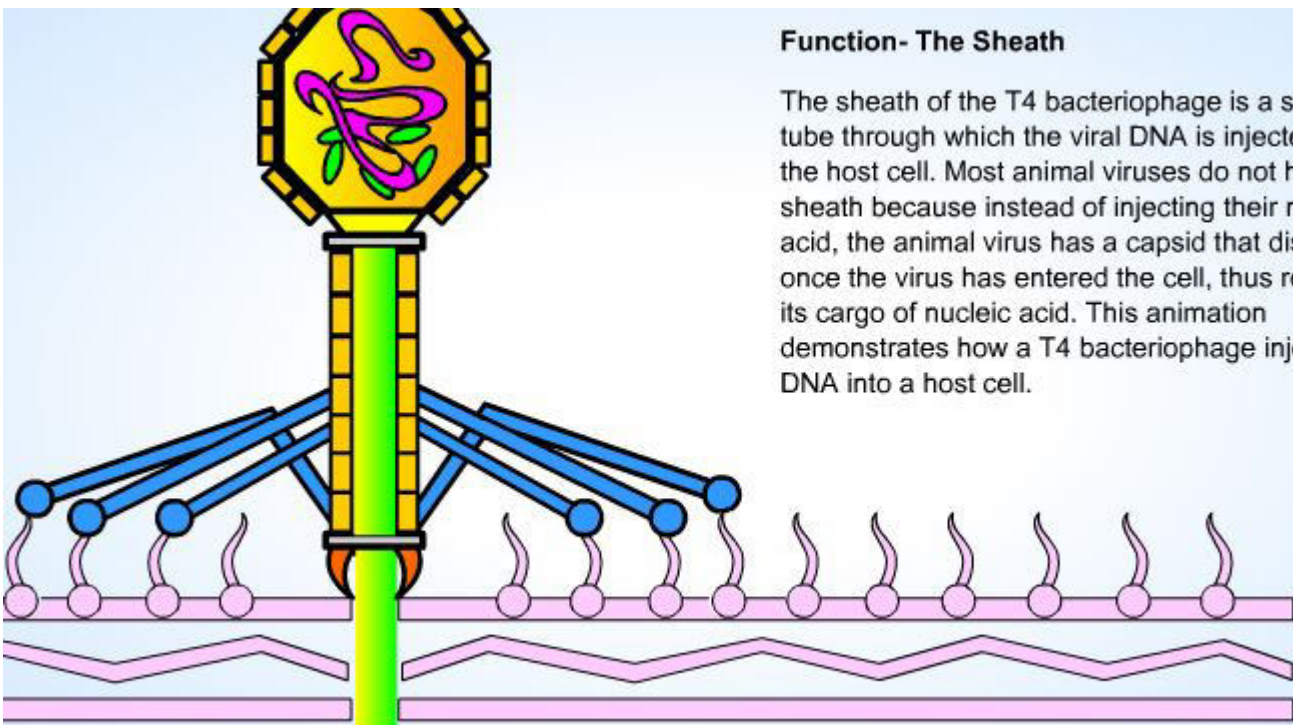
Function - Tail Fibers

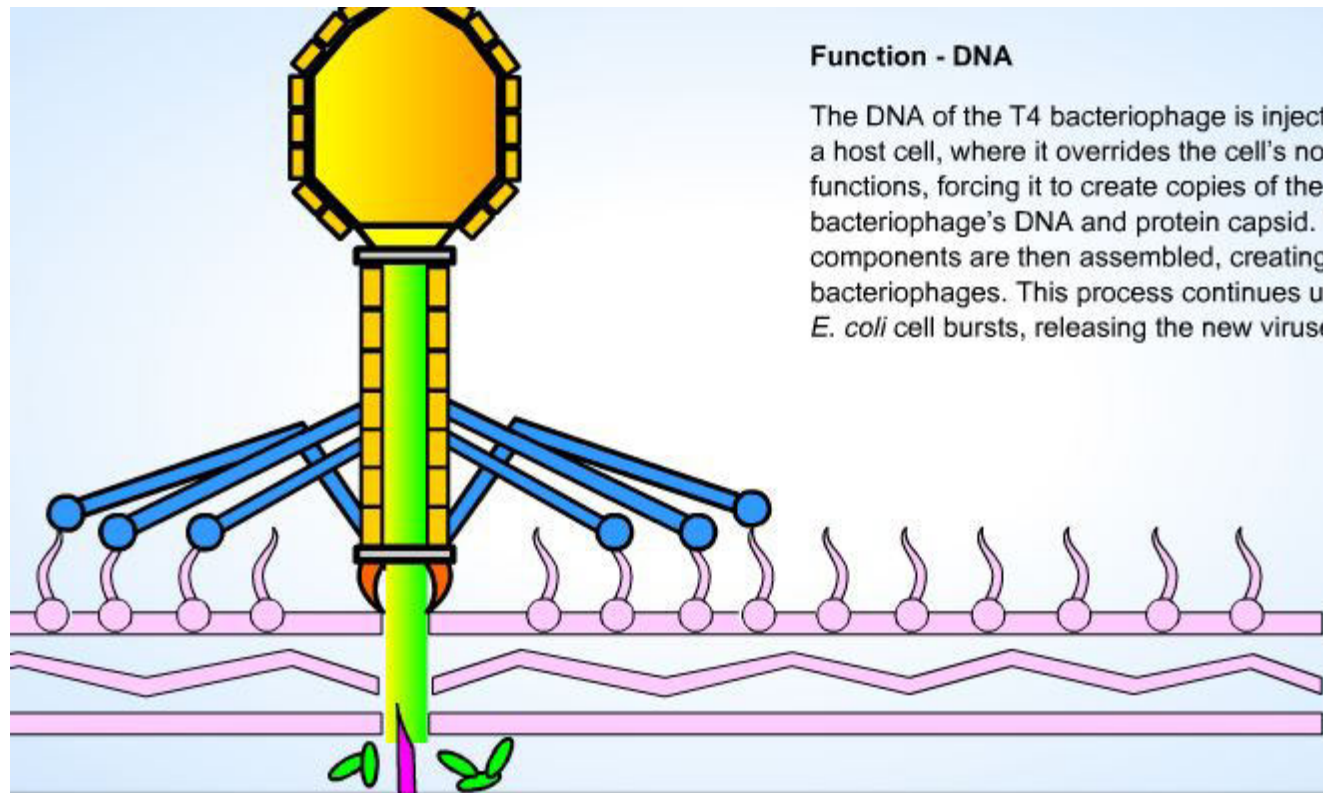
Viruses can lie dormant for a very long time before coming into contact with a suitable host cell. (In their dormant state, viruses are called *virions*). The tail fibers of the dormant T4 bacteriophage recognize the *E. coli* bacteria cell when the two come into contact, and the bacteriophage springs into action. This animation is an example of how a dormant T4 bacteriophage encounters an *E. coli* cell and attaches itself.



Function- The Sheath

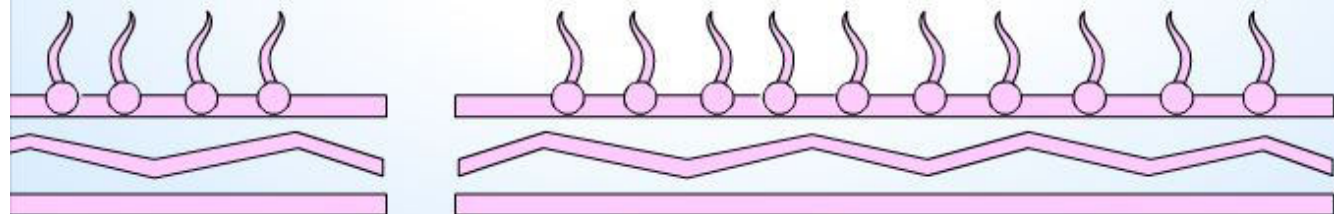
The sheath of the T4 bacteriophage is a slender tube through which the viral DNA is injected into the host cell. Most animal viruses do not have a sheath because instead of injecting their nucleic acid, the animal virus has a capsid that dissolves once the virus has entered the cell, thus releasing its cargo of nucleic acid. This animation demonstrates how a T4 bacteriophage injects its DNA into a host cell.





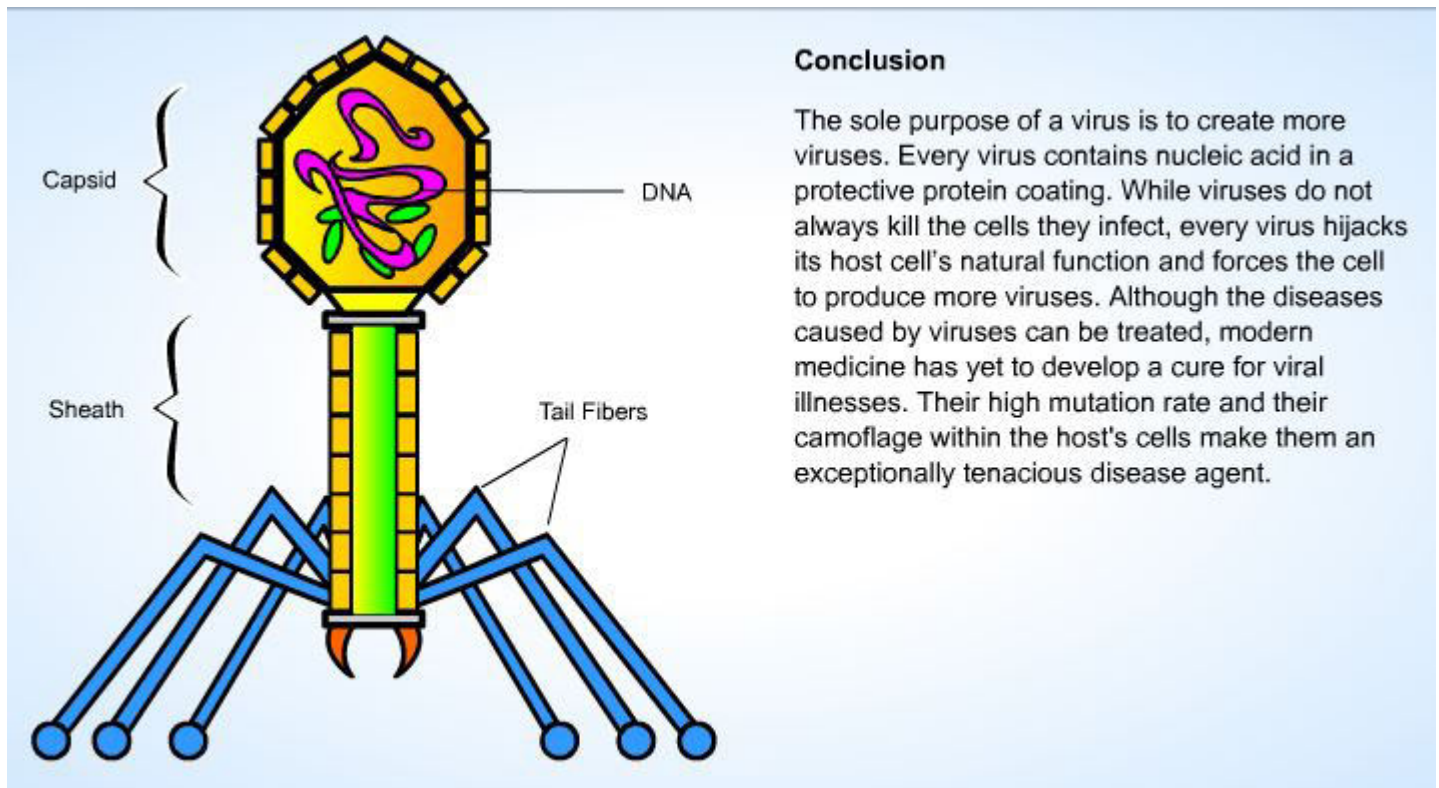
Function - DNA

The DNA of the T4 bacteriophage is injected into a host cell, where it overrides the cell's normal functions, forcing it to create copies of the bacteriophage's DNA and protein capsid. These components are then assembled, creating new bacteriophages. This process continues until the *E. coli* cell bursts, releasing the new viruses.



Function - DNA Replication

Viruses lack the biological tools necessary for reproduction, so they have to "steal" this function from the living cells around them, forcing the cell to assemble more viruses in a process called *replication*. The DNA of the T4 bacteriophage is injected into a host cell, where it overrides the cell's normal functions, forcing it to create copies of the bacteriophage's DNA and protein capsid. These components are then assembled, creating new bacteriophages. This process continues until the *E. coli* cell bursts, releasing the new viruses.



Prions: Alien Proteins

Prions are tiny proteins that have somehow been altered from their normal configuration to become self-replicating infectious entities. The most famous has become Mad Cow Disease (bovine spongiform encephalopathy, or BSE) and is caused by prions in the brain that are able to change normal brain proteins into prions. In BSE (and similarly in Creutzfeldt-Jakob disease, and kuru in humans; and scrapie in sheep), normal brain proteins that can be lysed and removed by enzymes when they die are transformed into prions that are invulnerable to the enzymes. The abnormal proteins accumulate in the brain and create holes. Prion diseases are degenerative and invariably fatal. Scientists have been unable to find any trace of genetic material (either DNA or RNA) in prions or in infected brains. Prions also do not elicit an immune response from the body. Prions are so strange that their existence and behavior are not well understood despite focused research. The good news is that not all prions are potentially bad. There are many naturally occurring prions in yeast and other fungi that are actually beneficial for the organism. Fungi utilize prions in kin recognition and sexual selection.

Question 1

How do viruses perform the function they have in common with living organisms?

- A Viruses move through the air, like seeds, as their means of locomotion.
- B Viruses metabolize fuel for energy after they have entered a living cell.
- C Viruses use a cell's reproductive machinery to replicate their own DNA.

- D Viruses produce interferon to hijack all cellular process for their own use.

👉Answer

The correct answer is C. Viruses only function is to reproduce their genetic material, which can be accomplished only when they get an infected cell's reproductive processes to replicate their DNA for them. Locomotion refers to an organism's expended energy to move on its own. Viruses cannot move on their own and have no energy of their own to expend. Viruses also never metabolize fuel; they only hijack cells' reproductive apparatus. Living host cells produce interferon to signal infection to the immune system.

Biochemistry & Cell Biology: Viruses

Molds: Strange, Bizarre, and Weird

The last, and perhaps the strangest group of the Protista, are the **slimemolds**. Some taxonomists place the slime molds in their own subkingdom of fungi, and sometimes call them **lower fungi**. Taxonomists who classify them with protists point out their close connections to amoebas. Despite their nomenclatural handicap, slime molds are fascinating organisms. There are two distinctly different, and perhaps totally unrelated, types of slime molds.

Acellular slime molds (Division Myxomycota) create a slimy mass called a **plasmodium**, akin to a monstrous amoeba, that slithers slowly over moist areas in forests. The plasmodium may contain pigments, likely used as photoreceptors that give them a beautiful color. **Acellular** slime molds use phagocytosis to feed on bacteria, spores, and other bits of decayed organic matter. The plasmodium is actually a cell-like organism containing many nuclei, which result from numerous mitotic divisions. Acellular slime molds spend their nonreproductive lives as creeping protoplasm that continues to grow (up to 50 g) as long as there is food to eat. When times are tough, the plasmodium breaks up into globs of protoplasm. Each globule develops into a sporangium>> perched atop an elongated stalk. Then meiosis occurs and produces haploid spores. The spores are released into the air until they land in a new, suitable site, where each will divide and, after several intermediate forms, become new plasmodium. To avoid confusion, we need to make sure to realize that this plasmodium (name of a body form) is different from the other organism that causes malaria, **Plasmodium** (the genus of protozoan passed on by mosquitoes).

Cellular slime molds (Division Acrasiomycota) are not plasmodia; instead, as cells, they exist as free-living amoebas in damp environments. When conditions dry out, or when food becomes scarce, these slime molds emit a **pheromone** called cyclic AMP, or cAMP. The call of cAMP is irresistible and causes hordes of amoeboid slime molds to congregate into a pile. It is then that truly bizarre things happen. Together, these once-independent cells form a primitive type of multicellular organism with specialized cells. In its first incarnation, this organism becomes a slug-like entity, actually moving around like a slug. Soon a fruiting body, made up of some of its amoeboid components, is extruded by the slug-like entity. A few of these cells are then transformed into spores. A sexual cycle fuses two haploid spores, which can then develop into more cellular slime molds.



Example of the slime molds

Question

Both Divisions of slime molds share

- A the production of the pheromone cAMP.
- B the presence of many nuclei in the cytoplasm.
- C a life cycle that resembles that of the fungi.
- D a life stage during which they are multicellular.

✓Answer

The correct answer is C. Both types of slime mold reproduce with spores but only cellular slime molds produce cAMP. Only acellular slime molds contain many nuclei and only cellular slime molds congregate to form a multicellular organism.

Biochemistry & Cell Biology: Viruses

Fungi: The Tip of the Iceberg

Members of the **Kingdom Fungi** are mostly **coenocytic** or multicellular organisms that are made up of masses of filaments, or **hyphae** (singular **hypha**), though some, such as yeasts, are unicellular. Collectively, all the hyphae of one fungal organism are called a **mycelium**, which makes up the main body of the fungus. Mycelium grows from the tip of the hyphae, and may reach a length of one kilometer in only 24 hours. The part of fungi that most people are aware of — mushrooms — are simply hyphae that are compacted and “packaged” to form the spore-producing fruiting bodies of the otherwise hidden organism. Curiously, the cell walls of fungi contain chitin, the same material that makes up insect exoskeletons, and not the cellulose that stiffens plant cells. Some fungi are parasites that feed directly from the host. Most fungi are characterized by their unique heterotrophy. Fungi release digestive enzymes onto something edible in surrounding substrate. The enzymes dissolve

some of the nutritional material in the food, and the fungus absorbs these molecules. Fungi, with bacteria, are the primary **decomposers** of organic material.

Fungi are famous for producing **spores** and they may reproduce both sexually and asexually, the latter being the spore-producing stage. Spores are produced asexually in structures called **sporangia**, and they are held in specialized hyphae called **sporangiophores**. Fungal spores have a tough coating that allows them to survive unfavorable conditions until they find a suitable environment in which to grow. Fungi may also reproduce asexually through fragmentation of the mycelium, with each section developing into a new organism.

Sexual reproduction in fungi occurs when some hyphae produce a structure called a **gametangium**. Gametes may be fused in the gametangium and then released, or two gametangia may fuse to form a kind of fertilized egg.

Characteristics of the Kingdom Fungi

Division	No. Species	Examples	Characteristics	Diseases
Chytridomycota	~ 650	Chytridium	mostly aquatic chitin cell walls	lettuce corn
Oomycota	~ 475	potato blight fungus	forms eggs and sperm, cellulose in cell walls	blight and mildew of plants
Zygomycota	~ 600	black bread mold	tough, resistant spores	none
Ascomycota	30,000	yeasts morels truffles	sexual spores in asci	powdery mildew ergot Dutch elm disease chestnut blight
Basidiomycota	25,000	mushrooms toadstools	sexual spores in basidia	rusts smuts
Deuteromycota	25,000	Penicillium	no sexual cycle	ringworm athlete's foot

Table of fungal diversity and reproduction

Biochemistry & Cell Biology: Viruses

The **Kingdom Fungi** is comprised of six major Divisions, five are characterized by the structure and the sexual reproductive pattern of its members. The members of a sixth Division, Deuteromycota, or imperfect fungi, do not reproduce sexually.

Division Chytridiomycota, the chytrids, is likely the most ancient group of fungi. Most are small, produce little mycelium, and anchor themselves to a substrate via **rhizoids**, which absorb nutrients. Rhizoids resemble hyphae but contain no nuclei. The chytrid sporangium contains numerous nuclei, and during reproduction each separates into a flagellated spore. Chytrids are the only fungi with flagellated gametes. Chytrids occur in both salt water and fresh water, as well as in damp soil. They may also live parasitically on algae, plants, or other fungi. Interestingly, these ubiquitous fungi have been implicated in global declines of amphibians and may be at least partially responsible for many widespread die-offs in frogs and salamanders from Australia to Costa Rica.

Division Oomycota contains species that, as its name suggests, produce eggs (as well as sperm) during a sexual reproductive phase. Eggs and sperm are borne on separate gametangia and fuse to form zygotes. Oomycetes also reproduce asexually with spores that have two flagella. Most oomycetes are aquatic, but some species are terrestrial. Oomycetes have unique cell walls for fungi

because they are made up mainly of cellulose, not chitin. Nearly all oomycetes live on decaying organic matter. Some are parasitic and others pathogenic — most notably ***Phytophthora infestans***, the fungus responsible for killing the potatoes that led to the Irish Potato Famine.

Fungi in the ***Division Zygomycota*** are all terrestrial, living mainly in soil, where they consume dead organic material. Some members of this Division are parasites or pathogens that infect mainly plants, insects, or tiny soil fauna. Zygomycete spores have no flagella. Sexual reproduction occurs when two different ***mating*** hyphae fuse, forming gametangia, which themselves fuse to form a multinucleated zygospore.

A common, though unwelcome, member of this Division is black bread mold, ***Rhizopus stolonifer***. This mold has rhizoids that anchor it to bread or fruit and whose hyphae worm their way through and rot it.



Example of common bread mold

Biochemistry & Cell Biology: Viruses

The Tip of the Mushroom

Division Ascomycota, the largest with 30,000 species, includes the yeasts, powdery mildews, black- and green-molds, as well as the highly valued morels and truffles which look more like regular mushrooms. Many ascomycetes are pathogens, particularly of plants, causing such devastating diseases as Chestnut Blight and Dutch Elm Disease. Hyphae are divided by walls, or septa, each containing a separate nucleus. Spores may be formed either sexually or asexually. The tiny sac, called an ***ascus***, produced during sexual reproduction is characteristic of ascomycetes. Gametes and gametangia are produced before the ascus, which, after several meiotic and mitotic divisions of the gametes, holds eight haploid spores. The ascus bursts to release them. Yeasts are small, oval, unicellular ascomycetes noted for their asexual reproduction through budding. Sexual reproduction may also occur when two yeast cells, or ascospores, join to form a zygote.

Division Basidiomycota includes the familiar edible mushrooms. A mushroom is the ***basidiocarp***, a spore-producing structure composed of compacted hyphae, of basidiomycetes. The body of basidiomycetes is the mycelium growing invisibly on a nutritional substrate, such as soil or a tree trunk. A single basidiomycete mycelium may grow to an astonishing 35 meters in diameter, though mushrooms usually form only around its edges. This accounts for the ***fairy rings*** of mushrooms that

appear in a field after a good rainfall. The moisture triggers the production of new protoplasm in the mycelium, and the protoplasm forms hyphae that burst out of the ground as mushrooms. Sexual reproduction involves meiosis and fusion of haploid nuclei, which occurs externally in specialized hyphae called the **basidium**, where the spores form. The basidiomycetes comprise the most common and popular edible field mushroom (***Agaricus campestris***), as well as numerous types of poisonous mushrooms, notably ***Amanita***. ***Psilocybe mexicana***, a hallucinogenic mushroom, is also in this group. These are all ***gill fungi***, so called because gill-like slots under the mushroom cap hold their spores.



Example of common basidiocarp mushroom

Biochemistry & Cell Biology: Viruses

Lichens

Ascomycetes are the fungi almost always associated with green algae or cyanobacteria to form lichens. Lichens thrive in harsh, adverse environments, such as deserts or tundra. Lichens do not need an external source of food, as their photosynthetic component provides it for them, though the fungus part of the lichen may derive certain minerals from the substrate to which it is attached. There are about 25,000 different types of lichens, each characterized by the species of fungus it contains. About 26 genera of photosynthetic algae or cyanobacteria live symbiotically in lichens with their fungus partner.



Example of a Lichen – the symbiotic relationship between a fungus and a cyanobacteria

Biochemistry & Cell Biology: Viruses

The tip of the toe cheese

The Division Deuteromycota contains the imperfect fungi that cannot reproduce sexually. Many fungi in this Division are pathogenic parasites of plants or animals. In humans, ringworm and athlete's foot are infections caused by these fungi. Deuteromycetes are not all bad, however; some are instrumental in making Roquefort and Camembert cheeses, as well as in the production of penicillin.

Mycorrhizae

Mycorrhizae are the symbiotic relationships between a fungus and the roots of vascular plants. The fungi help the plant roots absorb nutrients, particularly phosphorus. In exchange, the plant roots supply the fungi with food, usually sugars or amino acids. About 90 percent of vascular plants have endomycorrhizae, or fungal hyphae in their root cells. Research has found that many vascular plants cannot survive apart from this intimate relationship with fungi. Mycorrhizae are one of the most important **commensalisms** that occur in nature.

Question 1

The main body of a fungus is the

- A hyphae.
- B sporangium.
- C basidium.
- D mycelium.

👉Answer

The correct answer is D. The mycelium is the body of a fungus made up of all the hyphae. Hyphae are the filaments that make up the body of the fungus, or mycelium. The sporangium is the structure in which spores are produced and the basidium is a structure unique to basidiomycetes where the fungus's spores are produced.

Question 2

Members of the Division Deuteromycota are called Imperfect Fungi because they

- A do not produce spores.

- B do not reproduce sexually.
- C exist only symbiotically with algae.
- D are all parasitic.

✔ **Answer**

The correct answer is B. Deuteromycetes do not have the ability to reproduce sexually, unlike other fungi. Deuteromycetes do produce spores, ascomycetes exist symbiotically with algae or cyanobacteria as lichens, and while some deuteromycetes are parasitic, others, such as those used to produce cheese, are not.

Question 3

Gill fungi release spores from which structure?

- A Gametangium of the mycelium
- B Cells at the tips of the hyphae
- C Furrows under the cap of the fruiting body
- D Rhizoids that anchor the mushroom to the substrate

✔ **Answer**

The correct answer is C. Among the gill fungi in the Division Basidiomycota, spores are released from the gill-like furrows under the cap of the mushroom, or fruiting body. The gametangium is not part of the mycelium but is a specialized structure produced by hyphae for the purpose of sexual reproduction. B is not correct because it refers to the site where mushrooms emerge onto the surface from the mycelium below ground. Rhizoids anchor mycelium to the substrate but do not release spores.

Question 4

Lichens are organisms in which ascomycetes fungi live symbiotically with

- A algae.

- B plant roots.
- C fungal spores.
- D ergot cells

👉Answer

The correct answer is A. Lichens are algae or cyanobacteria living symbiotically with ascomycetes fungi. Mycorrhizae are fungi that live on or in the roots of vascular plants, spores are the mode of reproduction in fungi and do not involve any symbiotic relationship with other organisms. Ergot is a disease of rye grain caused by one type of ascomycetes.

Further Reading in Biochemistry & Cell Biology

Biology: Biochemistry & Cell Biology: Further Reading

Biochemical Basis of Life

Lehninger Principles of Biochemistry, Fourth Edition (David L. Nelson, Michael M. Cox): 2004

Biochemistry: Board Review Series (Dawn B. Marks): 1998

High-Yield Cell and Molecular Biology (Ronald W. Dudek): 1999

Schaum's Outline of Biochemistry (Philip W Kuchel): 1997

The Complete Idiot's Guide to Biology (Glen Moulton): 2004

Cell Biology

Outline of Molecular and Cell Biology (William Stansfield): 1996

Cells, Gels and the Engines of Life (Gerald H. Pollack): 2001

Natural Obsessions: Striving to Unlock the Deepest Secrets of the Cancer Cell (Lewis Thomas-Foreword, Natalie Angier): 1999

Board Review Series Cell Biology and Histology (Book with CD-ROM) (Leslie P. Gartner, et. al.): 2002

High-Yield Cell and Molecular Biology (Ronald W. Dudek): 1999

Chapter: Genetics and Physiology

1. Classical Genetics

Genetics & Physiology: Classical Genetics

Lesson Objective

In this lesson, we will review genetics, Mendel's principles and rules of inheritance, phenotypes and genotypes, pedigrees, genetic diseases, and non-lethal abnormalities.

Previously we covered...

In the lessons preceding this one, we reviewed the biochemical basis of life, the organic molecules, and their functions for living organisms. We also covered the basics of respiration, photosynthesis, and movement within and between cells.

Genetics & Physiology: Classical Genetics

Inheritance: Tracing Traits

After Van Leeuwenhoek discovered sperm cells in 1677, biologists were divided into two warring camps. The “ovists” insisted that it was the egg that carried the traits of the offspring, an adult in miniature. The “spermists” insisted with equal vehemence that the complete future offspring was contained in the animalcule, or the sperm.

And so it went, until the mid-nineteenth century yielded the concept of blended inheritance, which suggested that the offspring's traits arise from a complete blending of all the information in both **gametes**, or sex cells. In this view, making babies was akin to mixing different color paints — if Dad is red and Mom is white, the kids will all be pink.

An Austrian monk named Gregor Mendel realized the fallacy in this concept simply by noticing that all offspring were not, in a sense, pink. Traits skipped generations; offspring sometimes seemed to resemble neither parent. These anomalies intrigued Mendel and he used his position as monastery gardener to attempt to figure out what was really going on with inherited traits.

Mendel made the very fortuitous decision to conduct his experiments with common garden peas. He recognized that certain pea varieties seemed to be “pure” for specific characteristics; that is, their offspring always expressed these traits. Furthermore, pea traits were easy to observe. Mendel studied pea plant height (stem length), seed form, seed color, flower color, and other characteristics.

Mendel was not the first to notice or experiment with pea plant traits. He was, however, the first to study them for several generations, and to set up a rigorous scientific process to organize his methods and data. Additionally, he also made accurate counts of the number of plants with given traits he found in each generation and he analyzed his results mathematically. Perhaps Mendel's greatest achievement, however, was the synergy of these. He was the first scientist to apply mathematical analysis to a biological problem concerning inheritance, and that is his claim to fame.



Genetics & Physiology: Classical Genetics

Mendel's Principle of Segregation

Mendel worked with 32 different types of pea plants with different physical characteristics. Mendel cross-bred pea plants with different traits by hand, pollinating the flowers from one strain with the pollen from another, so that he knew exactly which plants were the parents for every cross. He found that in the first generation of offspring (F₁), one trait was expressed in all offspring and one trait completely disappeared. Mendel termed the traits that always appeared in the F₁ generation **dominant traits** because they masked, or dominated, the traits that did not show up at all.

Mendel let the pea plants self-pollinate to produce the F₂ generation. The traits absent from F₁ were present in some plants of the F₂ generation. Mendel understood that for these traits to appear in F₂, they must have been present in F₁, even if they were not expressed, or observable. Mendel called these traits **recessive**.

Mendel determined that the ratio of dominant-to-recessive traits in F₂ was approximately 3:1, and this ratio held constant over generations. Mendel's great insight was that each trait is caused by what he called "factors" (what we now call **genes**). These factors had to occur in pairs, one from each parent, for traits to appear, disappear, and reappear over generations. Mendel's **principle of segregation** states that every organism contains a pair of factors for each trait and that the pairs segregate into single-factor units during the formation of gametes.

Mendel's Experimental Results

Trait	Original Crosses (Parents)	Second (F ₂) Generation		
		Dominant	Recessive	Total
Seed form	Round X Wrinkled	5,474	1,850	7,324
Seed color	Yellow X Green	6,022	2,001	8,023
Flower position	Axial X Terminal	651	207	858
Flower color	Purple X White	705	224	929
Pod form	Inflated X Constricted	882	299	1,181
Pod color	Green X Yellow	428	152	580
Stem length	Tall X Dwarf	787	277	1,064

Genetics & Physiology: Classical Genetics

Today, we call the alternate forms of the same gene (Mendel's "factor") **alleles**. When alleles for a trait are the same, the individual is said to be **homozygous** for that trait. When the individual inherits two different forms of a specific allele (e.g., Aa), it is said to be **heterozygous** for that trait. Thus, pure-bred pea plants were homozygous for a given trait; creating smooth seeds, for example. All the seeds that these plants produced were visibly smooth. A visible, or expressed, trait is an organism's **phenotype**. Had some of the pea plants been heterozygous for this trait, they too would have visibly smooth seeds. Yet despite this phenotype, some of these pea plants would have alleles for wrinkled seeds, even though this recessive trait was not expressed. An organism's **genotype** describes its complete genetic makeup, or all its alleles, even those that are not expressed. Mendel had discovered that the unexpressed part of the genotype would be expressed in the phenotype of some offspring in the F₂ generation.

Question

The alleles an individual carries are part of the individual's

- A phenotype.
- B genotype.
- C gametes.
- D DNA.

✓Answer

The correct choice is B. An individual's genotype describes its entire genetic makeup, including all its alleles. Phenotype refers to those traits that are physically expressed and visible in the individual. Because not all alleles are visibly expressed, choice A is not correct. Gametes are sex cells, so choice C is incorrect. Alleles are made up of DNA; they are not a part of it, so choice D is not correct.

Question

Which of the following indicates an individual that is heterozygous for two traits?

- A AABb
- B AaBB
- C AaBb

D aabB

Answer

The correct choice is C. This individual carries both dominant (A, B) and recessive (a, b) alleles for each trait. Choice A is incorrect because this individual carries pairs of identical dominant alleles for each trait. Choice B is not correct because this genotype indicates that the individual is homozygous (BB) for one trait. Choice D is incorrect because this individual, too, is homozygous recessive (aa) for one trait.

Genetics & Physiology: Classical Genetics

Mendel did another set of experiments to look at two traits in cross-bred pea plants. For example, in his first experiments Mendel noted that some plants had green, wrinkled seeds — both recessive traits. But the F₂ generation also produced plants whose phenotype was totally unlike either parent; for example, offspring with smooth, yellow seeds. Mendel wanted to find out where these odd combinations of traits originated.

A Punnett Square allows you to sort and visualize the distribution of alleles in any cross. Capital letters indicate dominance and lowercase letters denote recessive alleles.

A P₁ (Parent) generation has the trait smooth seed allele (S) or wrinkled seed allele (s). The alleles segregate and recombine during gamete formation. So offspring would have one of the following allele combinations for this trait.

	S	S
S	SS	SS
s	Ss	Ss

In this cross all the offspring express the dominant trait of smooth seeds.

Then, in the second generation (F₂), some heterozygous individuals would be crossed. The Punnett Square for this cross is:

	S	s
S	SS	Ss
s	Ss	ss

You can see that one of the offspring would express wrinkled seeds because it inherited two alleles for the recessive trait (ss).

Question

The Punnett Square below shows the sorting of alleles that determine hair color, with B indicating dominant brown hair and b indicating recessive red hair. What is the probability that an offspring of this cross will have red hair?

	B	b
b	Bb	bb
b	Bb	bb

- A One in four
- B Two in four
- C Three in four
- D Four in four

Answer

The correct choice is B. Two of the four possible crosses will be homozygous for the recessive trait, red hair. Choice A is not correct because half the offspring will have brown hair (Bb). Choice C is not correct because there are not three possible combinations that are the same. Choice D is incorrect because half the offspring are genetically different from the other half.

Genetics & Physiology: Classical Genetics

Mendel's Principle of Independent Assortment

Mendel crossed a pure-bred dominant strain (round, yellow seeds) with a pure recessive strain (wrinkled, green seeds). In the F1 generation, all the seeds were round and yellow because the dominant trait was expressed. In the F2 generation, Mendel's results were quite different, though he had correctly predicted them. Mendel used mathematical probability to determine that if his "factors" (alleles) sorted independently of one another, they should be expressed in the phenotype of offspring in a ratio of 9:3:3:1. The **9** represents the number of F2 offspring expressing the two dominant traits in its phenotype. The **1** represents the proportion of offspring that express the recessive phenotype (having two alleles for the recessive form of the trait). The two **3s** represent individuals that show combinations of recessive and dominant traits in their phenotype. (This ratio holds for crosses in which both parents are homozygous — one for dominant traits and the other for recessive traits.) From these results, Mendel formulated his second law. The **law of independent assortment** states that the parts of each pair of genes are distributed independently when gametes are formed. Today, we can restate this to say that if an individual is heterozygous for traits that occur at two unlinked **loci** on **chromosomes**, each locus will sort independent of the other.

In F1, Mendel crossed pea plants that were homozygous dominant for smooth (SS), yellow (YY) seeds with plants that were homozygous recessive for green (ss), wrinkled (yy) seeds.

The first cross was: SSYY x ssyy → all SsYy. The F1 generation all expressed the dominant genes (all were smooth and yellow).

	SY	SY	SY	SY
sy	SsYy	SsYy	SsYy	SsYy
sy	SsYy	SsYy	SsYy	SsYy
sy	SsYy	SsYy	SsYy	SsYy
sy	SsYy	SsYy	SsYy	SsYy

The F2 generation was allowed to self-pollinate. All the genes — S, s, Y, y — sorted independently to form gametes. All the possible gamete combinations are shown in the Punnett Square below.

	SY	Sy	sY	sy
SY	SSYY	SSYy	SsYY	SsYy
SY	SSYy	SSyy	SsYy	Ssyy
sy	SsYY	SsYy	ssYY	ssYy
sy	SsYy	Ssyy	ssYy	ssyy

An analysis of these results shows that:

- 9/16 of the seeds were smooth and yellow
- 3/16 of the seeds were smooth and green
- 3/16 of the seeds were wrinkled and yellow
- 1/16 of the seeds were wrinkled and green

The ratio is 9:3:3:1, just as Mendel predicted.

2. DNA & RNA Replication

Genetics & Physiology: DNA and RNA Replication

Lesson Objective

In this lesson, we will review the process by which DNA and RNA are replicated in a cell.

Previously we covered...

- Gregor Mendel's laws of segregation and independent assortment set the stage for future genetic research.
- The Punnett square is a tool that determines the ratios of genotypes and phenotypes.
- The pedigree chart is a tool that shows several generations and the individuals that carry a particular gene in the genotype.
- Genes can be dominant or recessive, and some are sex-linked.

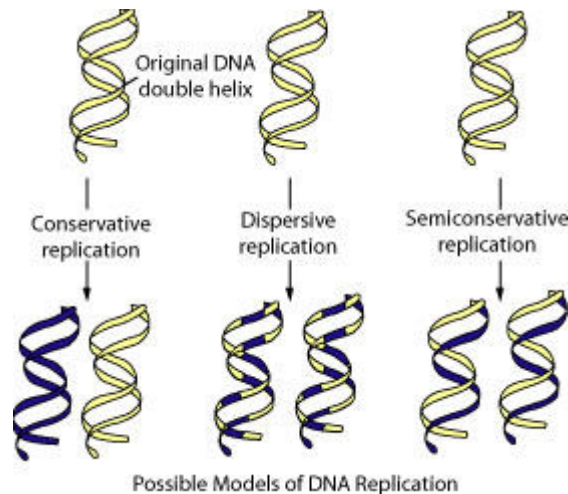
Genetics & Physiology: DNA and RNA Replication

Three Models of DNA Replication

The hydrogen bonds holding the base pairs together in a DNA molecule are relatively weak compared to other chemical bonds. Even hot water is enough to cause the base pairs to separate. Watson and Crick reasoned that, since the hydrogen bonds were weak, the double helix of DNA somehow "unzipped" into two strands. So DNA replication would occur in a few simple steps:

- The original double helix separates into two separate strands of DNA.
- Each original DNA strand attracts new nucleotides that plug into their complementary bases on the original strand.
- The new nucleotides join together to form the sugar-phosphate backbone of a new strand of DNA.
- The result is two DNA molecules identical to the original. Each DNA molecule consists of one "parent" strand and one "new" strand.

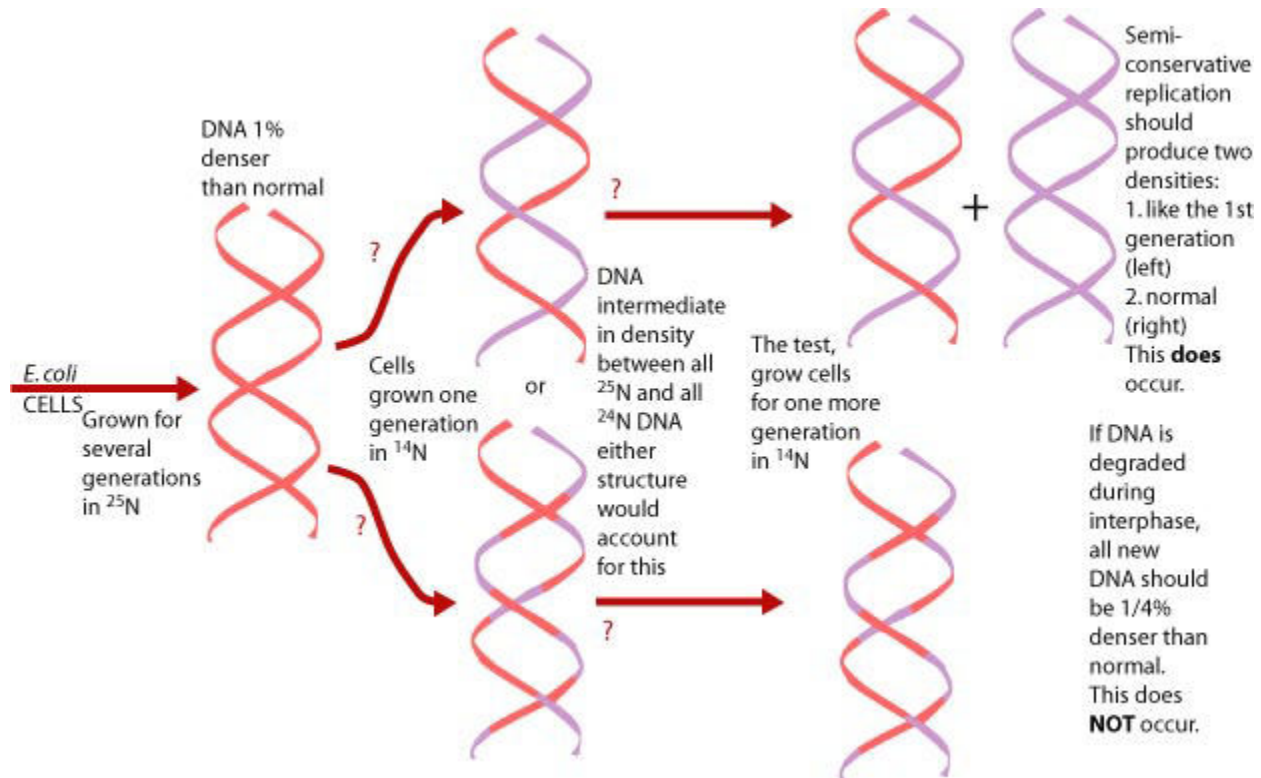
The Watson and Crick model for DNA replication is also known as a semi-conservative model. Two other models of DNA replication were considered. In the conservative model the parent DNA remains intact and an all new copy is created. In the dispersive model each strand of both copies contains a mixture of old and new DNA fragments.



Before biologists could tackle the problem of the details of DNA replication, the correct model had to be identified. Matthew Meselson and Franklin Stahl devised an experiment using different isotopes of nitrogen in bacterial cultures. First, several generations of *E. coli* bacteria were cultured in a medium that contained a heavy isotope of nitrogen, ^{15}N . These bacteria were then transferred to a medium containing only the lighter isotope ^{14}N and cultured for one more generation. It was hypothesized that any new DNA synthesized during this single replication would be less dense than the original DNA because it would have an all ^{15}N DNA strand and an all ^{14}N DNA strand. This difference in density would show up when the extracted DNA was centrifuged. This is exactly what was found and this result eliminated the conservative model from consideration. However, the dispersive model would also produce DNA with an intermediate density. In order to decide which of the remaining two models was correct, the remaining bacteria were allowed to replicate a second time. According to the dispersive model, the resulting DNA would still have a range of intermediate densities.

Genetics & Physiology: DNA and RNA Replication

According to the semi-conservative model, two different densities of DNA need to be present. One would contain DNA with an all ^{15}N DNA strand and an all ^{14}N DNA strand. However, an even less dense DNA would also be present that had two strands containing only newly synthesized all ^{14}N strands. The results showed DNA of only two different densities, exactly as predicted by the semi-conservative model. The diagram below shows the results.



Question

In double stranded DNA, how do the four bases (C, A, T, G) pair up with each other?

- A A:T, C:C, G:G
- B C:T, A:G
- C A:T, C:G
- D C:T, A:A, G:G

Answer

C is the correct answer. Choices A and D are incorrect because bases do not pair with themselves. B is incorrect because of size restrictions, purines always pair with pyrimidines.

Question

Which of the following is the name of the process through which DNA replicates?

- A Semi-conservative.
- B Conservative.
- C Dispersive.
- D Liberal.

✓Answer

A is the correct answer. The experiments of Meselson and Stahl showed that second generation DNA was a combination of original strands with new strands and third generation DNA also contained some completely new chromosomes. Conservative replication would preserve the original chromosome. Dispersive replication would have produced all intermediate chromosomes with a range of densities. While it might seem logical that there is a liberal model to contrast with the conservative model, no such model exists.

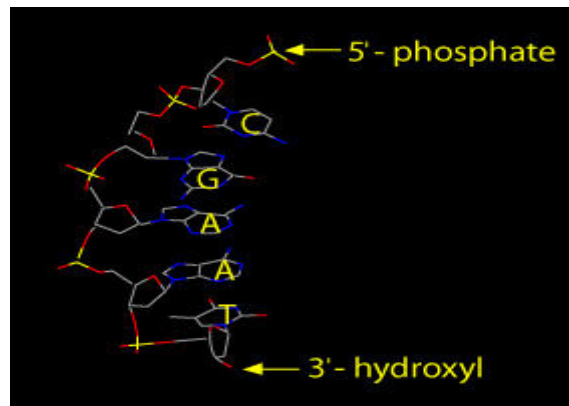
Please take this time to [review DNA](#) in general in our interactive exercise.

Genetics & Physiology: DNA and RNA Replication

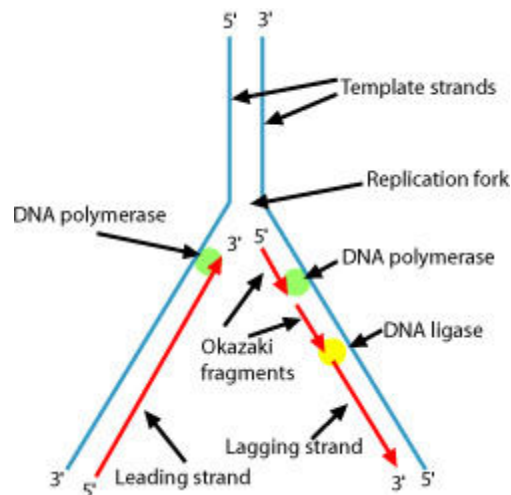
DNA Replication

Watson and Crick's model of semi-conservative replication was supported by experimental evidence, but there were many details yet to be worked out. What caused the strands to separate? How did new bases find their way to the correct spots on the template? What caused the nucleotide bases to connect to form the backbone? What provides the energy for all this to happen?

Each DNA strand has a uniquely identifiable directionality. The two ends of a single DNA strand are different. The five carbon atoms of one deoxyribose sugar of each DNA strand are numbered, from 1' to 5' (' represents prime). A nucleotide's phosphate group is attached to the 5' carbon atom of deoxyribose. The phosphate group of one nucleotide is joined to the 3' carbon atom of the adjacent nucleotide. Thus the DNA strand has a definite polarity. At one end, called the 5' end, a phosphate group attached to the 5' atom of the last nucleotide terminates the strand. At the other end, called the 3' end, a hydroxyl group attaches to the 3' atom of the terminal deoxyribose.



- The initial unwinding and separation of the double helix is triggered by an enzyme known as a helicase.
- Special binding proteins line up along the unwound strands, holding them in position.
- A molecule of a DNA polymerase binds to one strand of the DNA and begins moving along it in the 3' to 5' direction, using it as a template for assembling a leading strand of nucleotides and reforming a double helix. In eukaryotes, this molecule is called DNA polymerase delta.
- Because DNA synthesis can only occur 5' to 3', the lagging strand is synthesized discontinuously. An enzyme called primase synthesizes a short strand of RNA called a primer. This is extended by another DNA polymerase into an Okazaki fragment.
- The RNA primers are replaced with DNA (by yet another DNA polymerase). DNA ligase then connects the Okazaki fragments together into the lagging strand.



The energy that drives this whole process comes from the nucleotides. The nucleotides that serve as substrates for DNA polymerase are nucleotide triphosphates. This molecule is very similar to ATP. The only difference is the sugar component, deoxyribose instead of ribose. As each monomer joins the growing end of a DNA strand or Okazaki fragment, it loses two phosphate groups. Hydrolysis of these phosphates provides the energy.

Question

Which of the following enzymes is not involved in DNA replication?

- A Helicase

- B Ligase
- C Phosphatase
- D DNA polymerase

 Answer

C is the correct answer. Phosphatase is an enzyme that releases phosphates for cell metabolism. It is not involved in DNA replication. The other three enzymes play central and critical roles in DNA replication.

Question

Which of the following enzymes is involved in DNA replication?

- A Suzuki
- B Okazaki
- C Osaka
- D Hirosaki

 Answer

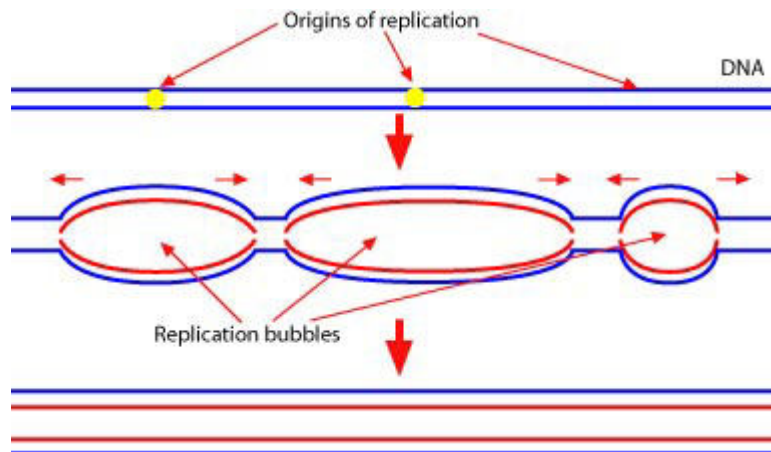
B is the correct answer. Suzuki is the name of a method for teaching music, a brand of motorcycle, and a brand of automobile. Osaka and Hirosaki are the names of Japanese cities and universities.

Genetics & Physiology: DNA and RNA Replication

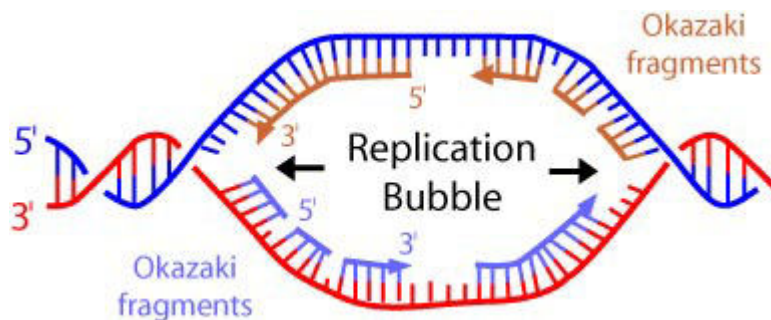
Prokaryotic and Eukaryotic DNA

Prokaryotes, such as bacteria, have a single circular chromosome containing a closed-loop DNA molecule that contains about five million base pairs. Replication of this molecule starts at a single point and proceeds in both directions until complete. In *E. coli*, the rate of replication is about 1,000 base pairs per second, so replication is complete in about one hour. Human cells contain 46 chromosomes, each containing a DNA molecule with about 150 million base pairs. The copying rate in human cells is only about 50 base pairs per second. So if human DNA replicated the same way as prokaryotic DNA replicates, it would take over one month to complete one copy.

Fortunately, there are many places on the eukaryotic chromosome where replication can begin. Replication begins at several "replication bubbles" and proceeds in two opposite directions from each bubble.



Each "bubble" contains two replication forks that move in opposite directions.



Question

Which of the following is an important difference between prokaryotic and eukaryotic replication?

- A Eukaryotic replication occurs in multiple replication bubbles.
- B Prokaryotic base pairing happens at a much slower rate.
- C Prokaryotic replication proceeds simultaneously in two directions.
- D Eukaryotic replication is mediated by several different enzymes.

Answer

A is the correct answer. Since eukaryotic chromosomes contain many more base pairs, replication must occur at several different sites simultaneously. Choice B is incorrect because the rate of prokaryotic base pairing is much faster. Choice C is not a difference; both processes proceed in both

directions. Choice D is not a difference since both prokaryotic and eukaryotic replication are mediated by several different enzymes.

Enzymes that “Proofread” and Repair

The accuracy of DNA replication is not solely caused by the specificity of base pairing. Errors in the completed DNA molecule probably occur in only one out of one billion nucleotides, but initial errors do occur about one in 10,000 base pairs. These mismatches are detected by DNA polymerase during replication. Other proteins also perform mismatch repair. Failure to repair mismatches can lead to accumulated genetic defects.

DNA molecules in a cell are subjected to a variety of chemical and physical assaults, such as damage by ultraviolet, X-rays or chemicals. If not repaired, defects in DNA can accumulate and may lead to certain forms of cancer. Maintenance of DNA in a cell is so important that hundreds of different DNA-repair enzymes have evolved. Most work by some form of excision. The damaged area of the DNA is excised by a DNA-cutting enzyme, such as nuclease, and the gap is then filled in by DNA polymerase and ligase.

Genetics & Physiology: DNA and RNA Replication

Review of Vocabulary and Concepts

- During DNA replication, base pairing enables existing DNA strands to replicate themselves.
- Several different enzymes and other proteins mediate and facilitate the complex processes involved in DNA replication.
- Enzymes “proofread” DNA during its replication and repair damage in existing DNA.
- Watson and Crick discovered the double helix by constructing models that conformed to Franklin's X-ray data.

3. Genetic Storage

Genetics & Physiology: Genetic Storage

Lesson Objective

In this lesson, we will review how the genetic information contained in DNA determines the inherited traits of an organism, and how genetic mutations occur.

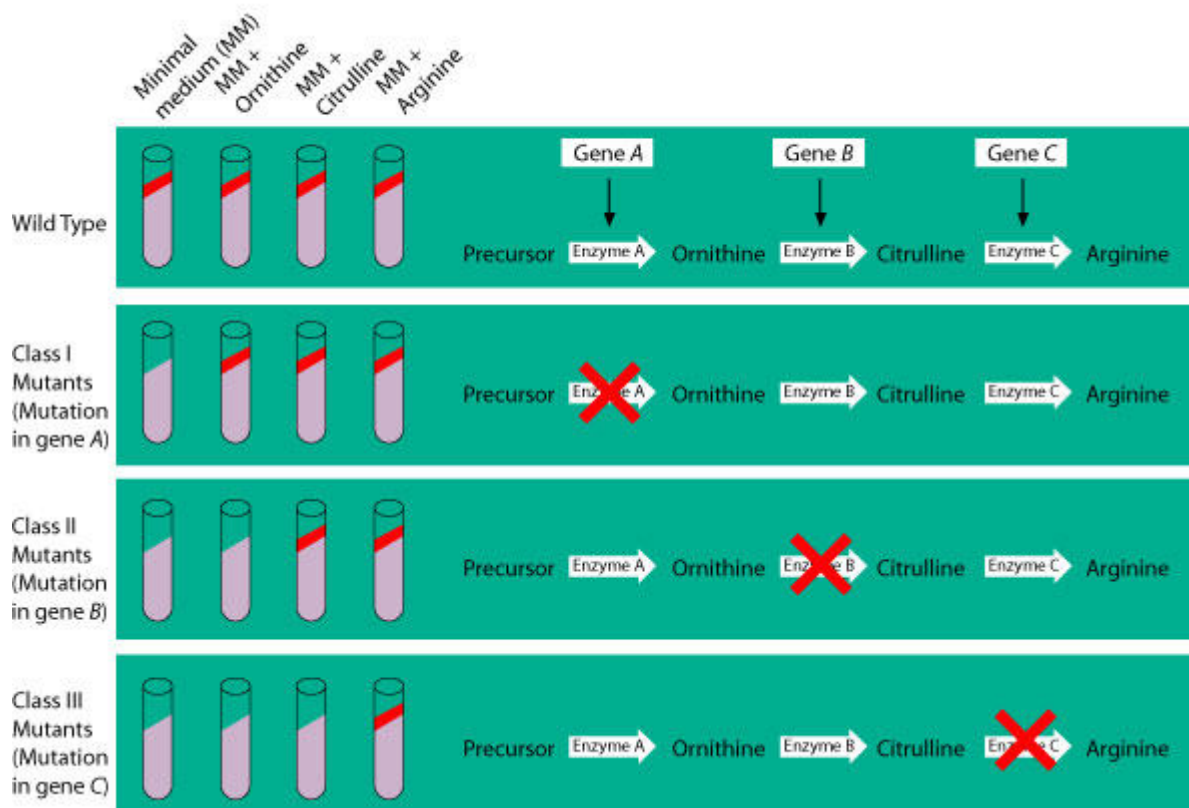
Previously we covered...

- DNA is able to replicate itself through a complex process involving “unzipping” the double strand, followed by assembling matching base pairs to create two new complementary strands.
- The process of DNA replication is mediated and controlled by several different enzymes including ligase, helicase, and several different types of DNA polymerases.
- Enzymes also “proofread” the new strands as they are assembled, ensuring that the error rate remains less than about one in one billion base pairs.

Genetics & Physiology: Genetic Storage

Genes Control Metabolism

The idea that genes dictate phenotypes through catalyzing enzymes in the cell was first proposed in 1909 by the British physician Archibald Garrod. However, it was several decades later that experiments were able to test this idea. George Beadle and Edward Tatum studied mutations in bread mold, *Neurospora crassa*. The wild-type bread mold could exist with a minimal growth medium, such as agar. The mold synthesized everything else it needed. Beadle and Tatum identified three strains of *Neurospora crassa*, called **auxotrophs**, that required additional nutrients (*e.g.*, amino acids, vitamins, and other nutrients) to survive, and required a complete growth medium containing the additional nutrients. To determine a particular strain's genetic defect, Beadle and Tatum took samples of the mutated strains and grew them in several different vials, each containing minimal medium plus a single additional amino acid.



Wild-type *Neurospora crassa* requires only minimal nutrients to survive. The mold uses multiple steps to synthesize several different essential amino acids, which are the building blocks of proteins. One process synthesizes arginine in three steps from a precursor, each step mediated by a specific enzyme. Each mutant class had a missing or defective gene which caused a block (marked by an X) in the synthesis process.>>

Further experiments have slightly modified the one gene/one enzyme hypothesis. Since many proteins, such as keratin, are not enzymes, biologists first suggested a one gene/one protein model. Currently, the most useful model seems to be one gene/one polypeptide. However, most biologists still call it the one gene/one protein model.

Question

Which of the following describes a gene?

- A It is the same thing as a chromosome.
- B It is a segment of DNA with the information for making a protein.
- C It is a triplet of three nucleotide bases.
- D It is a section of RNA that carries information to a ribosome.

✓Answer

B is the correct answer, according to the one gene/one enzyme model. Choice A is incorrect because chromosomes contain thousands of genes. Choice C is a description of a codon. Choice D is a description of messenger RNA (mRNA).

Question

Beadle and Tatum's experiment demonstrated that each kind of mutant bread mold lacked a specific enzyme. This was conclusive evidence that

- A genes code for proteins.
- B mutations are caused by radiation.
- C enzymes can repair damaged DNA.
- D cells need specific enzymes in order to function.

✓Answer

The correct answer is A. Genes contain the information for making specific proteins. Beadle and Tatum did use radiation to induce the mutations, but this was known before the experiment, therefore choice B is incorrect. C is also not correct; although enzymes can repair DNA, Beadle and Tatum's experiment was not proof of this. While it is true that cells need specific enzymes, this was the basis of the experiment, not the result; therefore choice D is incorrect.

Genetics & Physiology: Genetic Storage

Transcription and Translation

Genes do not build proteins directly, they utilize an intermediary RNA, a molecule similar to DNA, but with ribose instead of deoxyribose as its sugar backbone. RNA also contains the nitrogenous base uracil instead of the chemically similar thymine (U instead of T). Furthermore, RNA almost always occurs as single strands instead of the double stranded helix of DNA.

The schematic pathway of polypeptide synthesis is

DNA & RNA & protein

- Transcription: The DNA molecule transcribes the genetic code onto a single strand RNA molecule. Since the RNA molecule leaves the nucleus and moves through the cytoplasm to a ribosome, it is called messenger RNA, or mRNA.
- Translation: In the ribosome, the mRNA molecule translates the DNA information into a sequence of amino acids that are assembled by the machinery of the ribosome into polypeptides.

There are slight differences in this process between prokaryotes and eukaryotes. Since prokaryotes lack a nuclear membrane, the mRNA moves directly from the relatively simple DNA molecule to the ribosome. In eukaryotic cells, precursor RNA is created first and the cell's nuclear machinery then modifies this into mRNA, which then moves through the nuclear membrane and to the cytoplasm.

Question

What is the name of the process by which the information contained in a DNA molecule is copied onto a messenger RNA molecule?

- A Transcription
- B Translation
- C Replication
- D Translocation

✔Answer

A is the correct answer. The DNA sequence is transcribed onto mRNA. Choice B is the name of the process where the mRNA information is used to construct polypeptides. Choice C is incorrect because the strand is not copied exactly, so it is not replicated. Choice D is not a term used in cell processes.

Genetics & Physiology: Genetic Storage

Code, Codons, and Amino Acids

There are 20 different amino acids, which are the building blocks of all proteins, but there are only four different nucleotide bases. So each amino acid must be coded by a sequence of nucleotide bases. Three bases ($4 \times 4 \times 4$) produce 64 different combinations — more than enough to code for the 20 amino bases. So the fundamental "letter" of the genetic "alphabet" is a sequence of three nucleotide bases, read in the 5' to 3' direction. These triplets are called codons.

The 64 codons and the amino acid each codes for.

		Second Nucleotide			
		U	C	A	G
First Nucleotide	U	UUU (Phe/F) Phenylalanine	UCU (Ser/S) Serine	UAU (Tyr/Y) Tyrosine	UGU (Cys/C) Cysteine
		UUC (Phe/F) Phenylalanine	UCC (Ser/S) Serine	UAC (Tyr/Y) Tyrosine	UGC (Cys/C) Cysteine
		UUA (Leu/L) Leucine	UCA (Ser/S) Serine	UAA Ochre (Stop)	UGA Opal (Stop)
		UUG (Leu/L) Leucine, <i>Start</i>	UCG (Ser/S) Serine	UAG Amber (Stop)	UGG (Trp/W) Tryptophan
	C	CUU (Leu/L) Leucine	CCU (Pro/P) Proline	CAU (His/H) Histidine	CGU (Arg/R) Arginine
		CUC (Leu/L) Leucine	CCC (Pro/P) Proline	CAC (His/H) Histidine	CGC (Arg/R) Arginine
		CUA (Leu/L) Leucine	CCA (Pro/P) Proline	CAA (Gln/Q) Glutamine	CGA (Arg/R) Arginine
		CUG (Leu/L) Leucine, <i>Start</i>	CCG (Pro/P) Proline	CAG (Gln/Q) Glutamine	CGG (Arg/R) Arginine
	A	AUU (Ile/I) Isoleucine, <i>Start</i> ²	ACU (Thr/T) Threonine	AAU (Asn/N) Asparagine	AGU (Ser/S) Serine
		AUC (Ile/I) Isoleucine	ACC (Thr/T) Threonine	AAC (Asn/N) Asparagine	AGC (Ser/S) Serine
		AUA (Ile/I) Isoleucine	ACA (Thr/T) Threonine	AAA (Lys/K) Lysine	AGA (Arg/R) Arginine
		AUG (Met/M) Methionine, <i>Start</i> ¹	ACG (Thr/T) Threonine	AAG (Lys/K) Lysine	AGG (Arg/R) Arginine
	G	GUU (Val/V) Valine	GCU (Ala/A) Alanine	GAU (Asp/D) Aspartic acid	GGU (Gly/G) Glycine
		GUC (Val/V) Valine	GCC (Ala/A) Alanine	GAC (Asp/D) Aspartic acid	GGC (Gly/G) Glycine
		GUA (Val/V) Valine	GCA (Ala/A) Alanine	GAA (Glu/E) Glutamic acid	GGA (Gly/G) Glycine
		GUG (Val/V) Valine, <i>Start</i> ²	GCG (Ala/A) Alanine	GAG (Glu/E) Glutamic acid	GGG (Gly/G) Glycine

Because there are only 20 amino acids, many of the possible triplets are equivalent. For example, UCU, UCC, UCA, and UCG all code for serine.

Question

Two nucleotide bases would not be sufficient to code for the amino acids because two bases would sequence only

- A 64 amino acids.
- B 20 amino acids.
- C 16 amino acids.
- D 8 amino acids.

 **Answer**

C is the correct answer. Choices A, B, and D are all incorrect because the number of possible combinations of four letters taken two at a time is $4 \times 4 = 16$.

Genetic Code Evolution

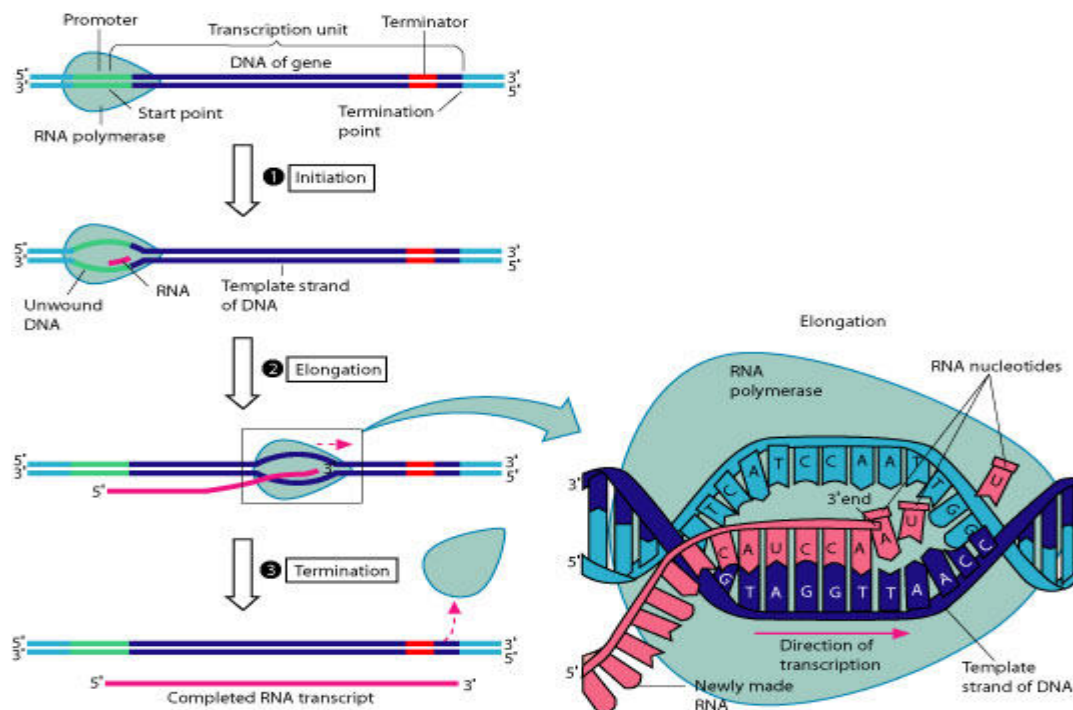
The RNA codon CCG is translated as the amino acid proline in all organisms whose genetic code has been examined. The only differences in this commonality of the genetic code to all organisms occur in some very simple eukaryotes, such as *Paramecium*. The DNA of some specialized cell organelles, such as mitochondria and chloroplasts, also show minor differences. The evolutionary similarity of the genetic codes is strong evidence that all organisms share a common origin somewhere in the distant past.

A consequence of the universality of the genetic code is that pieces of DNA can be clipped out of one organism and inserted into another. Most of the world's insulin supply is produced by bacteria that have been genetically modified in precisely this way.

Genetics & Physiology: Genetic Storage

Transcription

Before the DNA code can be transcribed, the two strands of DNA must be separated. RNA polymerase pries the strands apart. The process begins at a section on the DNA molecule called the promoter and ends at a section called the terminator. The transcription unit between promoter and terminator is a gene. After binding to the promoter, the RNA polymerase begins moving from the 3' end to the 5' prime end of the DNA strand, unwinding and separating as it moves. Nucleotide bases are matched to their pairs by the RNA polymerase. After the RNA polymerase reaches the terminator, the RNA strand is released. While the RNA polymerase moves in the 3' to 5' direction, because of the pairing rules, the RNA strand is assembled from the 5' end to 3' end.



Question

In a cell the nucleotides GAT were temporarily paired with the nucleotides CUA. Where did this pairing most likely occur?

- A In a double stranded molecule of DNA in the cell nucleus.
- B During translation in the ribosome when a protein is being made.
- C During transcription when RNA is being made.
- D In a double stranded molecule of RNA in the cell nucleus.

Answer

C is the best answer because in RNA, uracil replaces thymine. Uracil rarely occurs anywhere else but in RNA, therefore choice A is incorrect. Choice B is incorrect because nucleotide bases are not paired during translation. Choice D is incorrect because RNA is single stranded.

Genetics & Physiology: Genetic Storage

Processing pre-mRNA

In prokaryotes, RNA is immediately released into the cytoplasm where it is available to build proteins in the ribosomes. However, in eukaryotes, RNA is transformed in two different ways before it is released from the nucleus. Each end of the pre-mRNA molecule is modified by the addition of a "cap." At the 5' end, a guanine nucleotide is added. At the 3' end, a poly (A) tail is added, consisting of several tens of adenine nucleotides. Both caps serve to protect the ends of the molecule from degradation by other enzymes that may be floating around. The caps also serve as signals, telling the ribosome where to attach.

Another modification to mRNA is the removal of non-coding segments called introns. Surprisingly, the polypeptide codes are not continuous. The non-coding parts must be removed, leaving behind the parts that will code for proteins, called exons. This RNA splicing is carried out by small nuclear ribonucleosomes or snRNPs. (Some biologists call them "snurps.") The snRNPs recognize splice sites and together with other proteins they form a larger enzyme-like assembly called a spliceosome. The spliceosome cuts out the introns and splices the ends of the RNA back together.

Question

After a precursor mRNA molecule is transcribed from a eukaryotic gene, it is modified. ____ are cut out and ____ are spliced back together to produce a molecule of mRNA.

- A promoters, terminators
- B terminators, promoters
- C exons, introns
- D introns, exons

👉Answer

D is the correct answer. The introns are not expressed in the protein, so they are removed and the exons are spliced back together. Choices A and B are incorrect because terminators and promoters occur on the DNA molecule and mark genes or transcription segments. The terms are reversed in choice C and are therefore incorrect.

Exon and Intron Evolutionary Roles

It may seem like a waste of good nucleotides to have all of the introns mixed up in the genetic code. However, biologists think they may serve very important roles. It is known that the same gene can code for different proteins, depending on which parts are treated as introns. This is more efficient than having a different gene for every protein. Another role may be in the evolution of new and potentially useful proteins. Exon shuffling and gene recombination might create new, novel, useful, and important proteins.

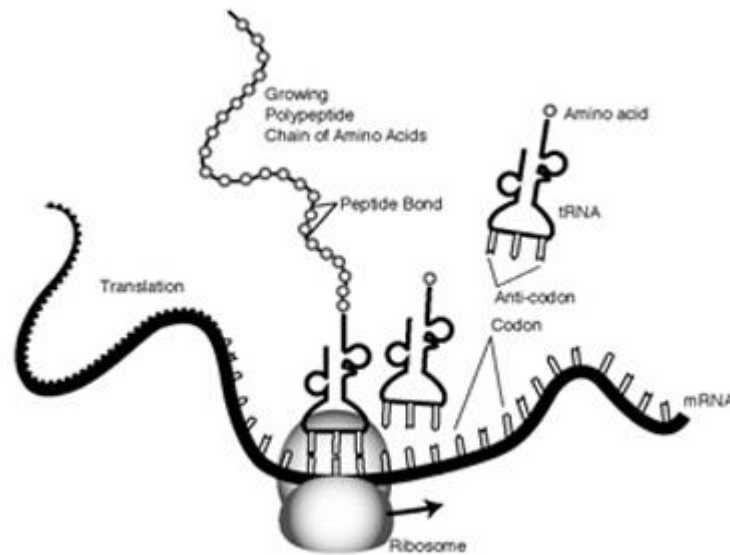
Genetics & Physiology: Genetic Storage

Ribosomal Role

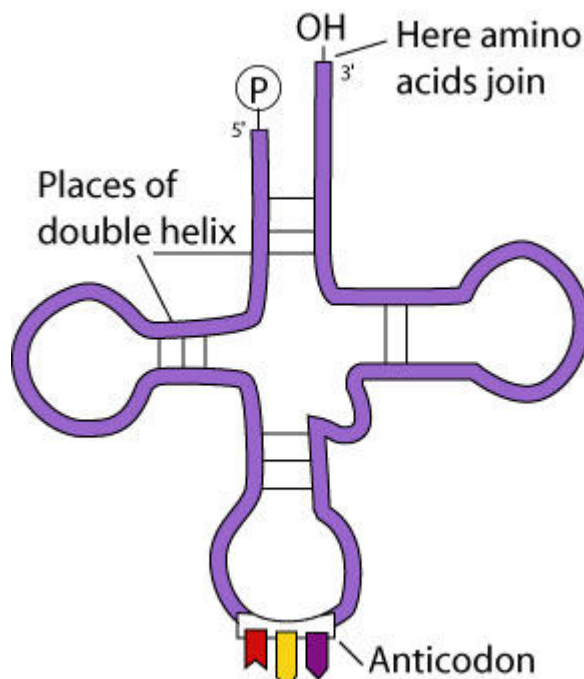
Translation of mRNA to proteins takes place in a cell structure known as a ribosome>>. These structures allow specialized molecules known as transfer RNA (tRNA) to transfer amino acids from the cell's cytoplasm to the ribosome. The ribosome attaches the amino acid brought to it by the tRNA to the growing polypeptide chain, according to the codes on the mRNA strand. The cell keeps its cytoplasm stocked with all 20 amino acids, either by absorbing them from nutrients outside the cell or by synthesizing them from other compounds.

The whole cycle of transcription and translation can happen simultaneously in prokaryotes. Translation of the mRNA to a polypeptide occurs as soon as one end of the strand of RNA is available. The mRNA may start moving through a ribosome while the other end is still being synthesized. Since the mRNA remains intact during the whole process and acts only as a template, a single strand of mRNA will eventually loop through many different ribosomes, all of which are busily producing polypeptides at the same time.

The molecules of tRNA are specialized. Each attaches to a single amino acid. The other end of the tRNA contains an anticodon, a nucleotide sequence complementary to the sequence on the RNA. This attaches to the RNA at the appropriate site according to the base pairing rules and is carried into the ribosome where the amino acid on the other end is attached to the lengthening polypeptide chain. The tRNA then detaches from the RNA as it slides out of the ribosome. Next it is carried away into the cytoplasm where it attaches to another amino acid molecule. So the tRNA is continually recycled and thus acts as a catalyst to the reaction.



A tRNA molecule is only about 74 to 93 nucleotides long. This short strand of RNA folds back on itself and hydrogen bonds form between complementary base pairs. The overall shape of the tRNA is like an "L." However, it is commonly represented as being flattened out into a structure resembling a four-leaf clover.



The machinery for attaching the proper amino acid to the appropriate tRNA molecule is provided by a specific enzyme called an aminoacyl-tRNA synthetase. There are 20 of these enzymes in the cell,

one for each amino acid. The reaction binding the amino acid to tRNA uses energy from ATP to complete the process. After the amino acid is joined to tRNA, the enzyme is free to catalyze another reaction.

Transfer RNA is produced by the same genetic machinery as mRNA. The genes that produce tRNA are found on all chromosomes, except chromosome 22 and the Y chromosome. There are also genes in human cells that code for ribosomal RNA (rRNA) and there are genes found in the cell mitochondria that code for other tRNA.

Question

Two different proteins with different amino acid sequences were translated from two different mRNAs. These mRNAs, however, were transcribed from the same DNA segment in the cell nucleus. Which of the following is the best explanation for this?

- A A mutation altered the gene between the production of the two mRNAs.
- B Different exons were spliced together to form the mRNA segments.
- C Transcription started and stopped at different places on the DNA segment.
- D The mRNA was folded up in two different ways before translation.

Answer

The correct answer is B. It is possible to splice together different exons to produce different mRNA from the same DNA segment. Choice A is incorrect because a mutation is unlikely to have occurred in such a short time. Choice C is incorrect, because transcription always starts at the start codon and stops at the stop codon. Choice D is incorrect because RNA is a single strand that is not folded. Transfer RNA is folded.

Question

Which of the following processes occurs only in the cytoplasm of a eukaryote?

- A Translation
- B Transcription
- C DNA replication

D tRNA replication

👉Answer

A is the correct answer. In eukaryotes, mRNA must move out of the nucleus before translation can begin, while in prokaryotes transcription and translation can happen simultaneously. Choice B is incorrect because transcription occurs in the nucleus of a eukaryote. Choices C and D are incorrect because DNA and tRNA replication occur in the eukaryote nucleus.

Question

An mRNA molecule with a complementary codon is transcribed from the DNA codon ACT. In the process of protein synthesis, a tRNA pairs with the mRNA codon. What is the nucleotide sequence of the tRNA anticodon?

A UGA

B ACU

C ACT

D UCA

👉Answer

B is the correct answer. The anticodon on the tRNA will match the original codon on the DNA except that uracil will replace thymine. The tRNA anticodon will pair up with a codon on the mRNA molecule following base pairing rules. Choice A is incorrect because this is the sequence on the mRNA molecule. Choice C is incorrect because it contains the base thymine. In RNA molecules, thymine is replaced by uracil. Choice D has the correct bases but in reversed sequence.

Genetics & Physiology: Genetic Storage

Genes Revisited

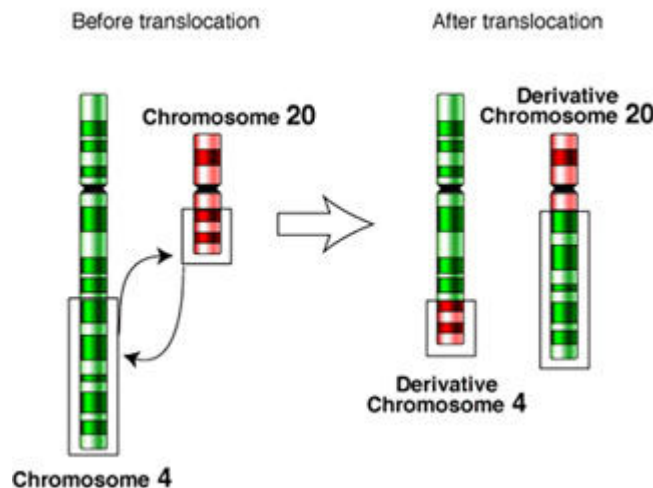
Mendel thought of a gene as a discrete inheritable unit that produces some phenotypic character. Morgan and others identified genes as specific locations on a chromosome. Then a gene was identified as a specific nucleotide sequence along a molecule of DNA. Finally, a gene is functionally defined as a specific nucleotide sequence that codes for a specific polypeptide. This one gene/one enzyme model is still not completely satisfactory, because eukaryotic genes contain non-coding segments (introns). Different biologists also use somewhat different definitions, such as whether the promoter and terminator segments are included as part of the gene. The definition of a gene must also include the genes that code for rRNA, tRNA, and other types of RNA that do not code for polypeptides.

Mutations are changes in the genetic material of a cell or virus. Large scale mutations can occur when a cell's chromosome structure or number is altered in some way. Point mutations are changes in one or a few base pairs in a single gene.

Chromosomal Mutations

Changes in the number or structure of human chromosomes can produce phenotypic characteristics that are unlike the parents and that are usually harmful. Alterations of the number of each type of chromosome are known to produce several different genetic disorders. Aneuploidy can produce cells that are monosomic, meaning they contain only one copy of a particular chromosome. Aneuploid cells can also be trisomic, meaning they contain three chromosomes of a particular type. Down syndrome is caused by cells containing three copies of chromosome 21. Klinefelter syndrome (occurs in males, adults are mentally normal, have male sex organs, but develop breasts and a typical female body conformation during adolescence) is caused by possessing two X chromosomes and one Y chromosome. On the other hand, males with XYY and females with XXX both appear perfectly normal and are indistinguishable from XX or XY counterparts except by **karotype**.

Alterations of chromosome structure can result from deletions, duplications, inversions, or translocations. Deletions occur when sections of the chromosome are left out during cell division. Sometimes the missing fragment will become part of the homologous chromosome, producing duplication. If the fragment reattaches in the opposite direction, it causes a chromosomal inversion. Finally, translocations occur when two non-homologous chromosomes exchange fragments.



Question

How many individual chromosomes (not pairs) does each cell in an individual with Down syndrome have?

- A 23
- B 24
- C 46

Answer

D is the correct answer. Persons with Down syndrome have an extra copy of chromosome 21, for a total of 47 chromosomes. Choices A and C are both incorrect because humans normally have 23 pairs of chromosomes or 46 individual chromosomes. Choice B refers to chimpanzees, which have 24 pairs of chromosomes.

Genetics & Physiology: Genetic Storage**Origins of Variation**

In any population of organisms, a range of phenotypes is usually present. This variation is vital to the survival of a population. The broader the range of expressed phenotypes, the more likely it is that some members of the population will survive sudden environmental catastrophes or even slow climate changes. There are two primary sources for this variation. One is point mutations within a gene. The other is the reshuffling and recombination of chromosomes during sexual reproduction.

Point Mutations

Point mutations are changes in one or a few base pairs in a single gene. These can be substitutions, insertions, or deletions. Insertions and deletions result in frameshifts. Substitutions occur when a different base is inserted into a gene during replication. The mistakes are usually repaired by the cell machinery, but in about once in one billion mistakes the final copy of the DNA has a mutation that gets transcribed.

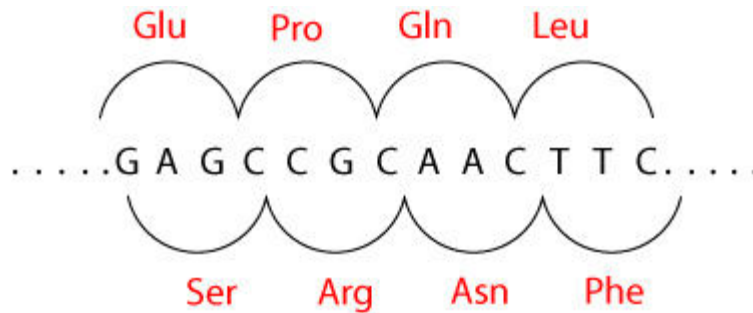
Harmful substitutions can be missense or nonsense substitutions. Missense substitutions result in the production of an incorrect amino acid in a protein, thus changing the protein's function. Nonsense substitutions change a codon into a STOP codon, prematurely terminating a protein. The shorter the protein is, the less likely it will function as it should.

One different base in a sequence may have no effect on the organism at all. The mistake could occur in an intron, so protein production is not affected. In other cases, the wrong base might be in the third position of a codon. There are many synonymous codons, so the wrong base might not result in the wrong amino acid in the polypeptide. These are called **silent mutations**, because they have no effect.

Insertions and deletions are more likely to cause problems because either can result in a frameshift. Unless an insertion is extremely long, extra base pairs in an intron will have no effect. One exception is the Fragile X syndrome. This defect occurs when hundreds of CGG sequences are written into the human X chromosome. This causes the X chromosome to bunch up or fold over on itself or to be restricted in some other way. Males who inherit such a chromosome show a number of harmful phenotypic effects including mental retardation. Females who inherit a fragile X are only mildly affected, if at all.

When a frameshift occurs in a gene sequence that will be expressed as a protein, an insertion of three bases will cause one extra amino acid to be inserted in the protein. This may be relatively

benign. However, the insertion or deletion of one or two base pairs will cause extensive changes in the genetic code. All of the nucleotides "downstream" from the insertion will be incorrectly grouped into codons. Unless the frameshift occurs very near the end of the gene, it is likely to result in a nonfunctional protein.



This figure shows how by shifting the reading frame one nucleotide to the right, the same sequence of nucleotides encodes a completely different sequence of amino acids.

Question

Which statement could explain why a particular point mutation had no effect on the polypeptide expressed by a gene?

- A The mutation was the deletion of a single nucleotide.
- B The mutation was the addition of an additional stop codon.
- C The mutation was the addition of a single nucleotide.
- D The mutation was the substitution of a single nucleotide.

Answer

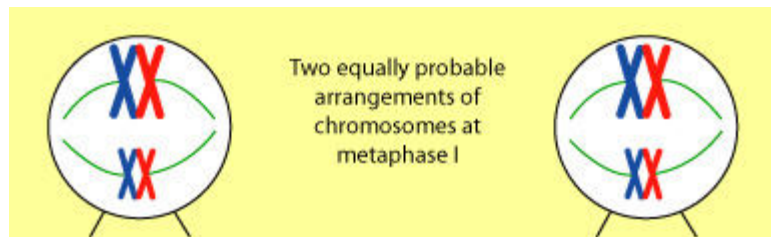
D is the correct answer. If the substitution occurred in the third place in a nucleotide triplet, the expressed amino acid might not be changed. Choices A and C are unlikely because a deletion or insertion would cause a frameshift. Choice B is unlikely because the stop codon would prematurely terminate the polypeptide chain, almost certainly making it nonfunctional.

Recombination

In species that reproduce sexually the chromosomes in each generation are shuffled and mixed in a variety of possible combinations. During meiosis each of the two homologous chromosomes are separated and sorted into gametes independent of the others. Each individual received a set of chromosomes from each parent of that individual. A gamete produced by that individual could conceivably contain only the chromosomes from one parent, but is far more likely to receive a random

mixture of chromosomes from each parent. Since humans have 23 chromosome pairs, there are 223 possible combinations of chromosomes in each gamete —around 8 million possible combinations! Since an offspring receives a set of chromosomes from each parent, each set having 223 possible combinations of chromosomes from the grandparents, it is obvious that there is an enormous number of combinations of chromosomes in each generation, assuring a wide range of phenotypes.

Since chromosomes are randomly mixed but not destroyed during sexual reproduction, the same set of genes, commonly called the gene pool, is preserved for future generations unless something happens to the population. A large gene pool is most desirable. Small gene pools mean that a disease or some other environmental problem could wipe out an entire population. For example, cheetahs the world over are genetically almost identical. Biologists speculate that something wiped out most of the world's cheetahs, leaving only a small population with limited genetic diversity.



Question

Which of the following processes provides genotypic variation in populations, over time?

- A Meiosis
- B Mitosis
- C Asexual reproduction
- D Evolution

✓Answer

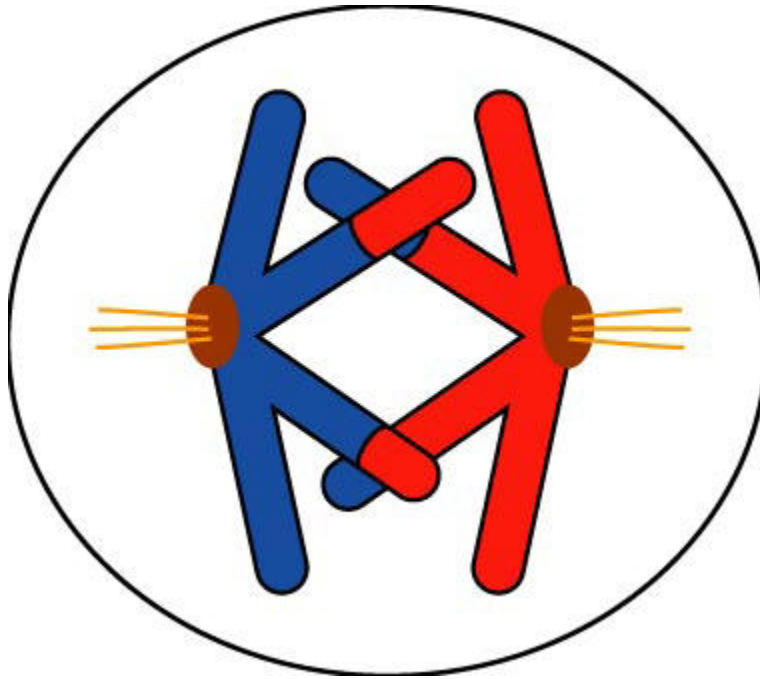
A is the correct answer. Meiosis provides changes in the genotypes of a population over time. Choices B, and C are both incorrect because cell division does not require variation, & D is incorrect because Evolution is driven by variation.

Genetics & Physiology: Genetic Storage

Crossing Over

Sometimes, chromosomes will "cross over" during meiosis. During Prophase I, the homologous chromosomes adhere closely together, something like the halves of a zipper. The pairing is precisely gene-by-gene. During this phase, the homologous chromosomes can exchange segments. In

addition to the many possible combinations of chromosomes from each parent, the crossing over process produces novel but completely viable chromosomes. This is an important source of genetic variation that results from sexual reproduction.



Question

Which of the following statements describes crossing over?

- A Homologous chromosomes exchange corresponding genes.
- B Chromosomes are sorted independently during meiosis.
- C The transfer of genetic material from one chromosome to a nonhomologous chromosome.
- D Insertion of extra bases during transcription of DNA to RNA.

Answer

A is the correct answer. When homologous chromosomes exchange corresponding genes, novel but viable chromosomes are created. Choice B is an important process that produces new combinations of chromosomes but does not change the individual chromosome. Choice C is the process of translocation, which typically produces nonviable or harmful changes in chromosome structure. Choice D is a description of errors that occur during gene replication, not meiosis.

Genetics & Physiology: Genetic Storage

Review of Vocabulary and Concepts

- The classic experiments of George Beadle and Edward Tatum demonstrated that genes specify proteins.
- Transcription and translation are the two main processes by which genes code proteins.
- Triplets of nucleotides called codons code for specific amino acids.
- The genetic code shares so many similarities between organisms that it must have evolved very early in the development of life.
- Transcription is the process of writing the genetic code contained in a strand of DNA onto a single strand of RNA.
- Eukaryotic cells modify RNA after transcription but before translation.
- Translation is the RNA-directed synthesis of a polypeptide.
- Translation occurs in cell structures called ribosomes.
- Transfer RNA (tRNA) is responsible for moving the appropriate amino acid to the polypeptide chain being formed in the ribosome.
- Aminoacyl tRNA synthetase mediates the binding of amino acids to tRNA.
- The definition of a gene must be broad enough to include nucleotide sequences that code for forms of RNA that are not expressed as polypeptides.
- Point mutations can affect protein structure and function.
- Point mutations may be silent (have no effect) because they occur in an intron, or because they occur in the third redundant place of a nucleotide triplet.
- Frameshift mutations disrupt the codon sequence, resulting in a useless or nonfunctional protein.
- Sexual reproduction produces a wide variety of different combinations of chromosomes in each generation.
- Crossing over, the exchange of homologous genes during meiosis, can produce novel combinations of viable chromosomes.

4. Gene Regulation

Genetics & Physiology: Gene Regulation

Lesson Objective

In this lesson, we will review how eukaryotic genes are regulated, which enzymes are expressed by genes, and how this allows cells to function across many conditions and environments.

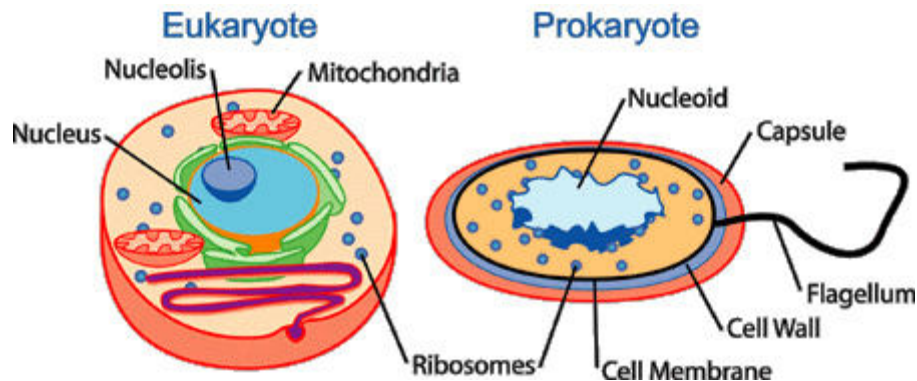
Previously we covered...

- Point mutations can affect protein structure and function.
- Sexual reproduction produces a wide variety of different combinations of chromosomes in each generation.
- Crossing over — the exchange of homologous genes during meiosis — can produce novel combinations of viable chromosomes.
- Natural selection occurring over many generations can increase the proportion of individuals in a population that are better adapted to an environmental condition.

Genetics & Physiology: Gene Regulation

Eukaryotic Gene Regulation

Eukaryotic cells face the same problems as prokaryotic cells. However, eukaryotic cells (except for the protists) are highly differentiated and specialized within the organism. In order to achieve this high level of specialization, different genes must be turned on or off in different cells. A highly specialized cell, such as a neuron, might express only 3 to 5 percent of the genes in its nucleus. A different type of cell will express a different 3 to 5 percent. All cells need to perform certain functions, so there are genes that are always "turned on." However, as cells become more specialized during human development, the number of active genes in any given cell decreases.



Eukaryotes need to regulate their genes for different reasons than prokaryotes. In prokaryotes, gene regulation allowed them to respond to their environment efficiently and economically. While eukaryotes can respond to their environment, the environment of most eukaryotic cells in complex organisms is relatively stable. There are many regulatory systems, for example, in the human body, where the function is to maintain a stable environment for the cells. The main reason eukaryotes need to regulate their genes is cell specialization. Prokaryotes are relatively simple unicellular organisms, while eukaryotes may have hundreds of different cell types, each differentiated to serve a specialized function. Each cell type differentiates by activating a different subset of genes. Because of the multitude of cell types, the regulation of gene expression required to bring about such differentiation is necessarily complex. One way this complexity is demonstrated is in multiple levels of gene expression regulation. The latest estimates are that a human cell, which is a eukaryotic cell, contains 20,000 to 25,000 active genes — at least 10 times that of a prokaryotic cell.

Some genes are expressed in all eukaryote cells at all times. These genes are responsible for the routine metabolic functions (such as respiration) common to all cells. Some genes are expressed as a cell enters a particular pathway of differentiation. Some genes are expressed all the time in only those cells that have differentiated in a particular way. For example, a plasma cell expresses continuously the genes for the antibody it synthesizes. Some genes are expressed only as conditions change in and around the cell. For example, the presence or absence of a hormone may turn on, or off, certain genes in that cell.

Question

How many genes are estimated to be in each human cell?

- B 2,500
- C 25,000
- D 250,000

☑ **Answer**

C is the correct answer. The latest research shows that human cells have about 25,000 active genes.

Question

There is about 1,000 times as much DNA in a human cell as in an *E. coli* cell, but only about 10 — 20 times as many genes. How can this be?

- A A human cell has more non-coding DNA.
- B The DNA packaging is much more complex in a prokaryotic cell.
- C Most of the genes in a human cell are turned off.
- D *E. coli* is less able to respond to its environment than humans.

☑ **Answer**

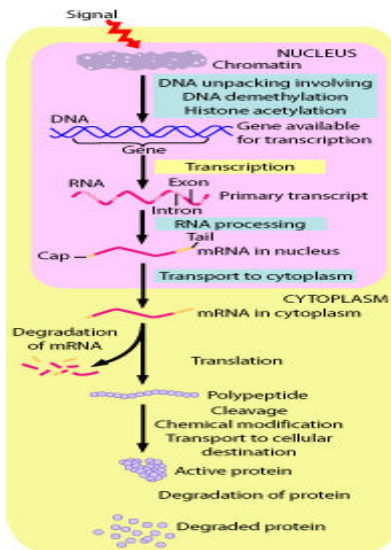
A is the correct answer. Most of the human DNA strand consists of non-coding introns. Choice B is incorrect because DNA packaging is simpler in a prokaryotic cell. Choice C is incorrect; although the genes in specialized cells may be inactivated, they are still present. Choice D is incorrect because *E. coli* is able to respond readily to its environment.

Genetics & Physiology: Gene Regulation

Eukaryotic Gene Regulation Mechanisms

There are several methods used by eukaryotes to regulate genes. The primary method is by altering the rate of transcription of the gene. Secondary methods include:

- altering the rate at which RNA transcripts are processed while still within the nucleus;
- altering the stability of mRNA molecules; that is, the rate at which they are degraded
- altering the efficiency at which the ribosomes translate the mRNA into a polypeptide.



Question

Where in the cell does gene transcription take place?

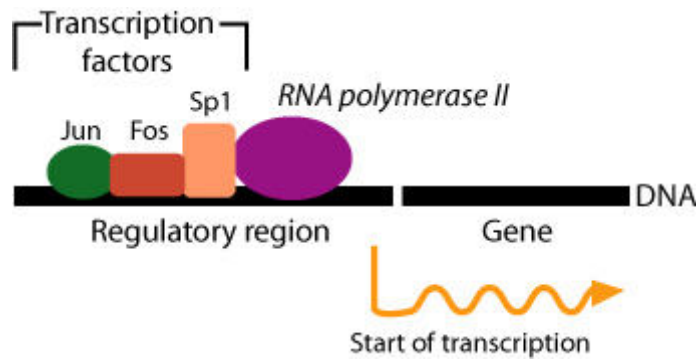
- A Mitochondria
- B Cytoplasm
- C Ribosome
- D Nucleus

Answer

The correct answer is D, because transcription is the process of writing the code to an mRNA molecule. Choice A is incorrect; although mitochondria contain genetic information, they are separate from nuclear genetic information. Choice B is not correct because the cytoplasm only serves to transport mRNA to the ribosome. Choice C is not correct because the ribosome is the location of translation, not transcription.

Altering Gene Transcription Rate

Regulation of gene transcription is the most important means by which gene expression is regulated in eukaryotes, as it was in prokaryotes. However, there are important differences between transcriptional regulation in prokaryotes and eukaryotes. Because of the complexity of eukaryotic patterns of gene expression, each eukaryotic gene is controlled by a separate promoter. Unlike prokaryotes, eukaryotic genes are not organized into operons. Prokaryotic genes are regulated primarily by repressors while eukaryotic genes are primarily regulated by transcriptional activators. These activators are called transcription factors.



Question

Which of the following is the primary method of regulating gene expression in eukaryotes?

- A Controlling transcription of a gene
- B Controlling translation of mRNA into protein
- C Degrading proteins in the cytoplasm
- D Making mRNA molecules more unstable

Answer

A is the correct answer. Regulation of gene expression is accomplished through changing the rate of transcription. Choices B, C, and D are methods of lesser importance.

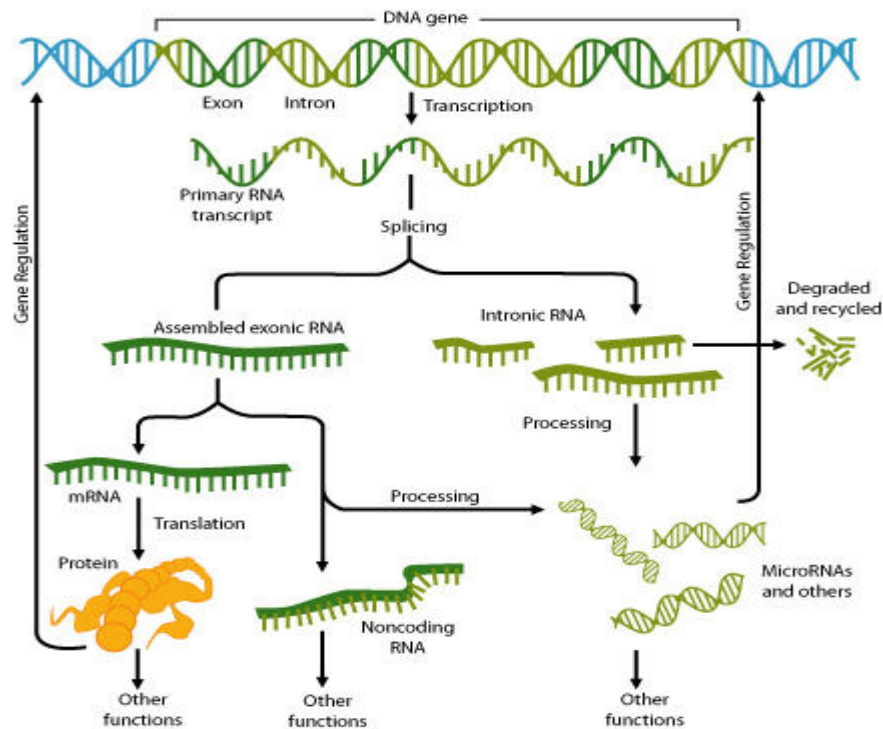
Genetics & Physiology: Gene Regulation

RNA Processing

After transcription, the RNA must be processed before it can be translated. RNA processing involves the addition of a 5' cap, addition of a 3' poly (A) tail, and removal of introns. Regulation of gene expression can also occur during RNA processing in two different ways: whether an RNA gets processed at all, and which exons are retained in the mRNA (or which introns are excised).

The first type of regulation can determine whether or not an mRNA gets translated. If RNA is not processed, it will not be transported out of the nucleus, and will not be translated.

The second type of regulation can affect the function of the protein produced. Some genes have exons that can be arranged in several different orders, a process called exon shuffling. When the exons are rearranged, the polypeptide produced could have a different function. For example, in mammals the calcitonin gene produces a hormone in one cell type and a neurotransmitter in another cell type, because of exon shuffling.



mRNA Longevity Regulation

Molecules of mRNA can usually produce many copies of a polypeptide before becoming degraded. If a molecule lasts for only a short time, it will produce only a few copies of the polypeptide. A different mRNA molecule might last an hour or more; in the process producing thousands of its polypeptide molecule.

Prokaryote mRNA typically only lasts for a few minutes, which is one reason bacteria and other prokaryotes can respond so rapidly to environmental changes by varying their protein synthesis. Eukaryote mRNA typically lasts much longer; hours, days, or even weeks.

The mRNAs for the hemoglobin polypeptides (alpha-globin and beta-globin) found in developing human red blood cells are unusually stable. This is the principle behind the regulation of mRNA longevity. mRNAs from different genes have their approximate lifespan encoded in them. This serves to help regulate how much of each polypeptide is produced.

The information for lifespan is found in the untranslated trailer region (UTR) at the 3' end. The sequence AUUUA, when found in the 3' UTR, is a signal for early degradation (and therefore a short lifespan). The more times the sequence is present, the shorter the lifespan of the mRNA. Because the approximate lifespan of a strand of mRNA is encoded in the nucleotide sequence, this is a set property of each different mRNA; the longevity of an mRNA cannot be varied.

Genetics & Physiology: Gene Regulation

Translation Control

Translation of the mRNA molecule can also be regulated. Translation control mechanisms typically block the initiation stage of polypeptide synthesis. Regulatory proteins can bind to specific sequences within the leader region and the 5' end of the mRNA strand, effectively preventing ribosomes from attaching. Global control of all or most of the translation of mRNA can be initiated by protein factors. For example, if **hemes** are in short supply in a developing red blood cell for some reason, a

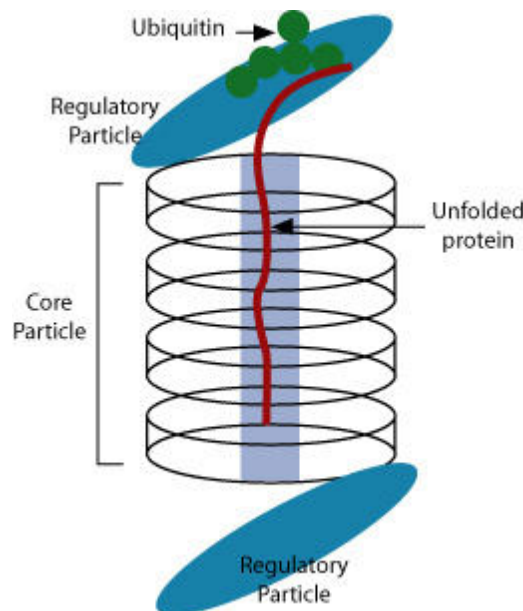
regulatory protein can inactivate a translation initiation factor by phosphorylating it. This halts all translation, but mainly affects the translation of hemoglobin mRNA since the developing red blood cell is primarily engaged in hemoglobin production.

Global control of translation is important during development of embryos. For example, many animals sequester large amounts of mRNA in their eggs, and those mRNA molecules are not translated unless the egg is fertilized. At that point, translation is triggered by the sudden activation of translation initiation factors, resulting in a burst of protein synthesis.

Protein Processing and Degradation

After translation, there is one more opportunity for a cell to regulate gene expression — through protein degradation. Polypeptides must be further processed to become functional proteins. For example, the protein that will become insulin must be cleaved before it is functional. Other proteins acquire sugars, and phosphate groups activate or deactivate regulatory proteins. Polypeptides frequently must be transported to other parts of the cell. All of these processes could serve as a mechanism for regulation.

Proteins marked for degradation are tagged with a small bit of protein called ubiquitin. It is not clear how proteins are chosen for destruction. Once marked, the tagged proteins are recognized by a large structure called a proteasome. The proteasome unfolds the tagged protein, sequesters it in its interior, and chops it into small peptide bits that are recycled. The ubiquitin and proteasome are also recycled.



Steroid Hormones and Signal Transduction Pathways

In prokaryotes, genes that work together to produce a set of related enzymes are grouped together into an operon. Eukaryotic cells do not have operons, so they require some other mechanism for controlling several genes at the same time. This coordinated gene expression probably depends on a specific control element or set of elements that are associated with every gene in a dispersed group. A single key sets all of the genes to turn off or on at the same time.

In prokaryotes, an example of this sort of coordinated gene expression is the activation of a variety of genes by a steroid hormone. These steroid hormones (sex hormones are one example) have a

variety of effects on the body. A steroid hormone acts like a chemical signal, entering each cell and binding to a specific receptor protein in the cell. When turned on, these receptors act like transcription activators. Every gene that will be turned on by that hormone has a control element that recognizes the transcription activator.

Genetics & Physiology: Gene Regulation

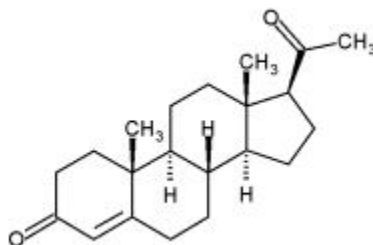
Tissue-Specific Gene Expression

Genes may be turned on in one type of cell and not in another, depending on whether the transcription factor for the gene's enhancer is active or not. For example, consider a cell in muscle tissue and a cell in skin tissue from the same person. Both have the exact same set of genes. In the muscle tissue cell, a particular set of transcription factors has become active causing the set of genes needed by muscle cells to be expressed. In the epidermal tissue cell, a different set of transcription factors is active, causing a different set of genes to be expressed.

How does the body know which transcription factors to send to which cell types and how do they get there? This is a difficult question with a very complicated answer. Many of the details have not yet been worked out by biologists. However, there are a number of mechanisms by which transcription factors can be regulated.

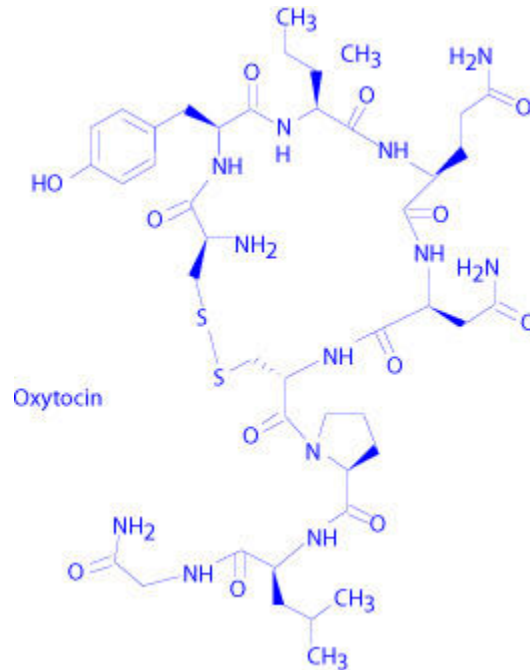
- The presence or absence of a transcription factor in a cell is the determining step. If the factor is present, the gene is transcribed. If not, then the gene is not transcribed. The presence of a transcription factor, of course, depends on the activity of the gene encoding that transcription factor.
- Different cells in the body have somewhat different environments. This can cause different transcription factors to be activated. For example, all cells in many organisms have a set of genes that encode proteins to help the organism survive heat stress. These genes are activated under heat stress, under the control of a specific transcription factor. This factor is always present, but is only activated when the organism is experiencing heat stress.
- Hormones and growth factors can activate transcription factors. These hormones are produced by other cells in the same organism. Hormones must bind to a specific receptor on the target cell, and the receptor mediates the cellular effects of the signal. Steroid hormones and peptide hormones have different receptors.

Steroid hormones, such as testosterone and progesterone, are derived from lipids (specifically cholesterol). Because they are derived from lipids, they can easily pass through cytoplasmic membrane into a cell, where they bind to their specific receptor. Steroid receptors are transcription factors that become activated when they bind to their ligand>>. Once activated, they initiate transcription of a specific set of genes.



Since **peptide hormones** cannot easily cross the cytoplasmic membrane, their receptors are found on the surface of the cell. When bound to its ligand, these receptors initiate a complex series of

biochemical reactions inside the cell, with the ultimate result being the activation of a transcription factor (often by phosphorylation>>, which initiates transcription of a specific set of genes.



Question

Why are human muscle cells and bone cells different?

- A They contain different sets of genes.
- B They contain different sets of operons.
- C Different genes are switched on or off.
- D Similar genes produce different proteins in different cells.

Answer

C is the correct answer. Only 2 to 5 percent of the genes in a specialized cell are activated. Choice A is incorrect because all of the gene sets are the same. Choice B is incorrect because eukaryotic cells are not known to contain operons. Choice D is incorrect because each specific gene produces a specific protein, unless the mRNA is damaged or reshuffled.

Genetics & Physiology: Gene Regulation

Review of Vocabulary and Concepts

- The control of gene expression allows bacteria to respond to changing environmental conditions.
- Cells control metabolism by regulating enzyme activity or by regulating enzyme synthesis.
- Repressors are usually activated by end products of anabolic pathways, while inducible enzymes usually function in catabolic processors.
- Eukaryotic gene expression can be regulated through a variety of different mechanisms, including transcription, processing, mRNA stability, and translation.
- Some RNA molecules can undergo differential splicing, producing different mRNA molecules encoding slightly different polypeptides.
- Transcription requires a promoter and at least one enhancer. Enhancers increase transcription of a gene over basal level, and are responsible for tissue-specific gene transcription. Enhancers are bound by specialized transcription factors.
- Transcription factor activity in a cell can be regulated by synthesis of the factor within the cell, by environmental signals, or by chemical signals from other cells.
- Transcription factors have one functional domain for DNA binding and one for transcription activation. Transcription factors can be classified according to the structure of their DNA binding domains.

5. Organization – from Cells to Organ Systems

Genetics & Physiology: Organization – from cells to organ systems

Lesson Objective

In this lesson, we will review the organization of organisms — from cells to organisms.

Previously we covered...

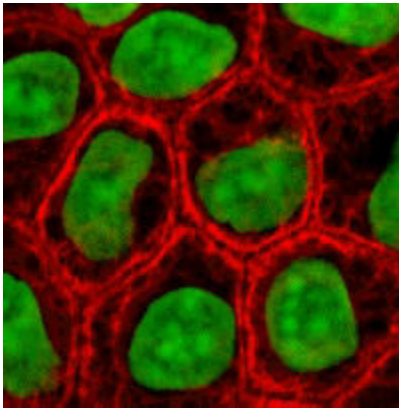
- All organisms consist of cells.
- All organisms use molecules based on a common carbon-based biochemistry.
- All organisms inherit characteristics through genetic material from their parents.
- All organisms use a universal genetic code based on four or five nucleotide bases.

Genetics & Physiology: Organization – from cells to organ systems

From Cells to Organisms

Animals have many different body forms, but all animals must have internal systems that meet a few basic needs: respiration, circulation, excretion, reproduction, and digestion. Comparative physiology is the study of the similarities and differences among animals and their various solutions to meeting those basic needs.

The basic structural unit in all organisms is the **cell**. In multicellular eukaryotes, cells are usually highly specialized and highly differentiated. For example, there are approximately 200 different cell types in the human body.



Cells in turn are grouped into **tissues**. Tissues are composed of cells that are similar in structure and function. In all but the simplest animals, there are four basic types of tissue: epithelial tissue, connective tissue, nervous tissue, and muscle tissue.

Epithelial tissue generally occurs in sheets of tightly packed cells. In vertebrates, it covers the outside of the body and lines body cavities. Epithelial tissue is organized into layers. The outside layer is bathed in air or some fluid, while the innermost layer is attached to a supportive membrane.

Connective tissue binds and supports other tissues. Connective tissue actually contains few cells that are dispersed through an extracellular matrix. The matrix is usually a web of fibers embedded in a uniform foundation. Collagenous fibers are non-elastic bundles of collagen molecules that have been twisted into rope-like structures. Elastic fibers are stretchy fibers made of a protein called elastin. Reticular fibers are thin, branched fibers made from collagen. They form a fabric that supports and connects other tissues. In vertebrates, connective fibers form adipose tissue, loose connective tissue, cartilage, bone, and blood.

Nervous tissue forms the nerve fibers that sense stimuli and transmit signals from one part of the body to another. Nervous tissue is composed of cells called neurons. The neuron consists of a cell body and two or more long extensions or processes called dendrites and axons. In humans a neuron can be over one meter in length.

Muscle tissue is the most abundant tissue in most animals. It is composed of long, thin muscle fibers. These fibers can contract when they receive a stimulus from a neuron bundle. The two contractile proteins actin and myosin are found within the cytoplasm of muscle cells. There are three types of muscle tissue found in vertebrates. **Skeletal muscle** is attached to bones by tendons (a form of connective tissue) and is responsible for voluntary movements of the body. Skeletal muscle is also called striated muscle because overlying layers of muscle give it a striped appearance. **Cardiac muscle** forms the contractile walls of the heart. **Smooth muscle** lacks striations. It is found in the digestive tract, bladder, and other internal organs.

Question

Which tissue type contains few cells?

- A Muscle
- B Nervous

- C Epithelial
- D Connective

👉 Answer

The correct answer is D; connective tissue is a matrix of collagen fibers. Muscle, nervous, and epithelial tissues have many more cells than connective tissue.

The next level of organization in all but the simplest animals is the **organs**. Organs are composed of groups of tissue (sometimes in layers) that work closely together to perform some function. For example, the stomach consists of four layers of tissue: epithelium, connective tissue, smooth muscle, and another layer of connective tissue.

6. Organ Systems

Genetics & Physiology: Organ Systems

Lesson Objective

*For the next lessons, we will review the next highest level of organization for an individual organism, the **organ system**. An organ system consists of two or more organs that work together. In most animals there are 5 to 8 organ systems that are all connected and interrelated. Because we are most familiar with our own systems, the following review will concentrate on vertebrates (mammals specifically, and humans in particular) systems. However, most of these organ systems function similarly in all animals. In this lesson, we will review the structures and functions of the musculoskeletal, circulatory, nervous, digestive, excretory, respiratory, urinary, and reproductive systems.*

Previously we covered...

In the previous lesson, we reviewed the important types of cells found in animals and set the stage for higher orders of organization within the animal body plan.

Genetics & Physiology: Organ Systems

Musculoskeletal System

The musculoskeletal system is an organ system that enables animals to move by using muscles and skeleton in concert. Vertebrate bones also support and protect internal organs, and in many organisms bones also produce blood cells and store fat and minerals.

The human musculoskeletal system consists of the skeleton, made up of bones attached by joints, and skeletal muscle attached to the skeleton by tendons. Many animals have hydrostatic skeletons and move by contracting muscles surrounding a fluid-filled pouch, creating pressure that causes movement. Other animals, most notably the arthropods, have muscles attached to an exoskeleton that coincidentally acts as body armor.

There are three basic kinds of skeletal systems, external (exoskeleton), internal (endoskeleton), and fluid (a hydrostatic skeleton). Because larger external skeletal systems can support less weight than endoskeletons of the same size, many animals like the vertebrates, have evolved internal skeletal systems. Exoskeletons are found in arthropods and many mollusks. An internal skeletal system is made up of bones or cartilage within the body, moved by the muscular system. Some organisms like sharks and rays have a skeleton consisting only of cartilage without calcified bones. Hydrostatic skeletons are similar to a water-filled balloon. Located internally in cnidarians (coral, jellyfish, etc.) and annelids (leeches), among others, these animals can move by contracting the muscles surrounding the fluid-filled pouch, creating pressure within the pouch that causes movement. Animals such as earthworms use their hydrostatic skeletons to change their body shape as they move forward from long and skinny to short and stumpy.

The skeleton functions not only as the support for the body but also in the manufacture of blood cells that takes place in bone marrow. It is also necessary for protection of vital organs and is needed by the muscles for movement.

There are two types of bones in the vertebrate body plan, the axial skeleton and the appendicular skeleton. The axial skeleton consists of bones along the axis, the head, vertebrae, and ribs. The appendicular skeleton, on the other hand, consists of everything else: clavicles, scapulae, pelvis, and the upper and lower limbs. There are also many differences between female and male human skeletons. While men have longer and thicker limbs and digits, women have larger pelvises, narrower ribs, smaller teeth, and less pronounced skull and mandible features. Most notable is the difference in the pelvis, a strongly selected trait that is crucial for women's reproductive success.

Circulatory System

Blood is the body's internal transportation system. The circulatory system connects the various muscles and organs of the body with one another. It consists of the heart, blood, and blood vessels. The circulatory system has four functions:

- Transports nutrients and wastes
- Transports oxygen and carbon dioxide
- Transports hormones
- Distributes heat

Heart

The heart is a hollow, muscular organ that contracts at regular intervals, forcing blood through the circulatory system. The walls are made of three layers of tissue. The outer and inner layers are epithelial tissue. The middle layer is cardiac muscle tissue.

The pattern of circulation in the human body includes two separate circulatory loops. The right side of the heart pumps blood from the body into the lungs, where deoxygenated blood gives up carbon dioxide and picks up oxygen. This is the pulmonary circulation loop. The left side of the heart pumps oxygenated blood from the lungs to the rest of the body. This is the systemic circulation loop.

The heart is enclosed in a protective sac of tissue called the **pericardium**. A **septum** divides the two sides of the heart, preventing the mixing of the deoxygenated blood with the oxygenated blood.

Oxygenated blood flows from the lungs into the left side of the heart through the **pulmonary veins** and empties into the heart's collection chamber, the left **atrium**. From the left atrium, the blood flows into the left **ventricle**. When the heart starts to contract, the atrium contracts first. This pushes the remaining blood into the ventricle. Then the ventricle contracts. The blood is prevented from going back into the left atrium by a one-way valve called the **mitral valve**. Next the blood enters the **aorta**, which is the largest artery in the body. Once in the aorta, the blood is again prevented from moving backwards by another large valve, the **aortic valve**. Many arteries branch from the aorta and carry oxygen-rich blood to the body. The first arteries to branch off are the coronary arteries, which carry oxygenated blood to the heart muscles.

After delivering oxygen to the body's cells, blood returns to the heart through veins. Two large veins collect all the oxygen-poor blood. The **superior vena cava** drains blood from the upper body, while the **inferior vena cava** drains blood from the lower body. These veins empty into the right **atrium** of the heart. The blood then flows into the right **ventricle** through the **tricuspid valve**. As the right ventricle contracts, the blood is sent through the **pulmonary valve** and into the **pulmonary arteries**. These arteries carry the blood to the lungs. The blood then returns to the left atrium, full of oxygen.

Heartbeat

The heart does not contract in a single motion. Instead, the contraction spreads out over the heart like a wave. A smaller cluster of cells, the **sinoatrial node**, embedded in the right atrium, initiates this wave. These cells act as a pacemaker, setting the pace for the heart rate. The impulse travels to the left and right atria, causing both of them to contract almost simultaneously. The right and left ventricles will also contract simultaneously when the impulse reaches them. A tenth of a second usually passes before the lower part of the heart starts to contract.

These contractions cause the chambers to squeeze the blood, pushing it in the proper direction along its path. In most people at rest, the heart rate is between 60 and 80 beats per minute. The heart rate will increase during exercise in order to pump oxygen-rich blood through the body more quickly.

Blood Vessels

Arteries carry blood from the heart to the body tissues. The walls of arteries are thicker than that of veins. Except for pulmonary arteries, all arteries carry oxygenated blood. The wall of an artery is made up of three layers of tissue. This allows the artery to expand as blood is pumped into it. Smaller branches of arteries are called arterioles.

Arterioles branch into networks of **capillaries**, which are tiny blood vessels. The capillaries is where the real work of circulation is done. The walls of capillaries consist of only one layer of cells. This makes it easy for oxygen and nutrients to diffuse from the blood into tissues. Capillaries are extremely narrow — blood cells must move along them in single file.

The flow of blood moves from capillaries into **veins**. Veins collect blood from the body and carry it back to the heart. Veins are lined with smooth muscle; however, the walls are thinner and less elastic than arteries. The walls of veins are able to stretch out, thus reducing the resistance the flow of blood encounters on its way back to the heart. Large veins contain one-way valves that keep blood from flowing backward. The largest vein in the body is the **vena cava**, which leads into the heart.

The cardiovascular system is very leaky. Fluids are forced out of the capillaries by the pressure generated when the heart pumps. A network of vessels, known as the lymphatic system collects the fluid and returns it to the circulatory system. The fluid, called **lymph**, collects in lymph capillaries and

flows into lymph vessels. The fluid is returned to the circulatory system at an opening in a vein located under the left clavicle, just below the shoulder.

Question

The smallest blood vessels are

- A veins.
- B capillaries.
- C lymph vessels.
- D arteries.

Answer

The correct answer is B. Capillaries are so small and narrow, the blood cells have to move through them one-at-a-time. Veins are the next smallest and arteries are the largest. Lymph vessels are not blood vessels.

Blood

Blood is a liquid connective tissue that has multiple functions:

- Transports nutrients, dissolved gases, enzymes, hormones, and waste products
- Regulates body temperature, pH, and electrolytes
- Protects the body from pathogens
- Restricts the loss of fluid from injury

The human body contains four to six liters of blood. Fifty-five percent of blood is made up of a fluid portion called **plasma**. The remaining forty-five percent consists of cells.

Plasma is a yellowish fluid that is 90 percent water and 10 percent dissolved fats, salts, sugars, and proteins. The plasma proteins are divided into three types: **albumins**, **globulins**, and **fibrinogen**. Albumins regulate osmotic pressure. Globulins include antibodies that help fight off infection. Fibrinogen helps the blood to clot. Plasma also carries nutrients, hormones, and waste products.

The cellular portion of the blood includes several types of highly specialized cells and cell fragments. They are red blood cells, white blood cells, and platelets.

Red blood cells, also called erythrocytes, are the most numerous of the blood cells. They are shaped so that they are narrower in the center than along the edges. Erythrocytes are produced from cells in bone marrow that gradually fill with hemoglobin>>. Hemoglobin is the iron-containing protein that carries oxygen from the lungs to the tissues of the body and also gives the erythrocytes their characteristic red color. Red blood cells lack nuclei and organelles and normally stay in circulation for 120 days before they are destroyed by specialized white blood cells in the liver and spleen.

- **White blood cells**, also called leukocytes, are outnumbered by red blood cells almost 500 to 1. They are produced in the bone marrow, are larger than red blood cells, are colorless, and do not contain hemoglobin. The main function of leukocytes is to protect the body against invasion by foreign cells or substances. White blood cells respond quickly to infection.
- **Platelets** are cell fragments. They are formed when pieces of cytoplasm are pinched off megakaryocytic cells in the bone marrow. The life span of a platelet is 5 to 9 days. Platelets play a key role in blood clotting. They clump together and form a plug at the site of a wound. Then they release proteins called clotting factors. The proteins, fibrin, form a netlike covering over the damaged site.

Question

About 90 percent of plasma is composed of

- A salts.
- B sugars.
- C proteins.
- D water.

Answer

D is the correct choice, because plasma is the liquid portion of blood. The other 10 percent of plasma consists of dissolved fats, salts, sugars, and proteins.

Blood Pressure

Blood moves through the vessels because it is under pressure. This pressure is produced by the contraction of the heart and by the muscles surrounding blood vessels. Blood pressure is a measure of the force that blood exerts against a vessel wall. The low pressure that occurs during relaxation of the heart is **diastolic pressure**. The higher pressure that results when a pulse of blood is forced into the arterial system is **systolic pressure**.

Question

What is the function of lymphatic vessels?

- A Blood transport
- B Fluid return to the blood

- C Antibody production
- D Blood clotting control

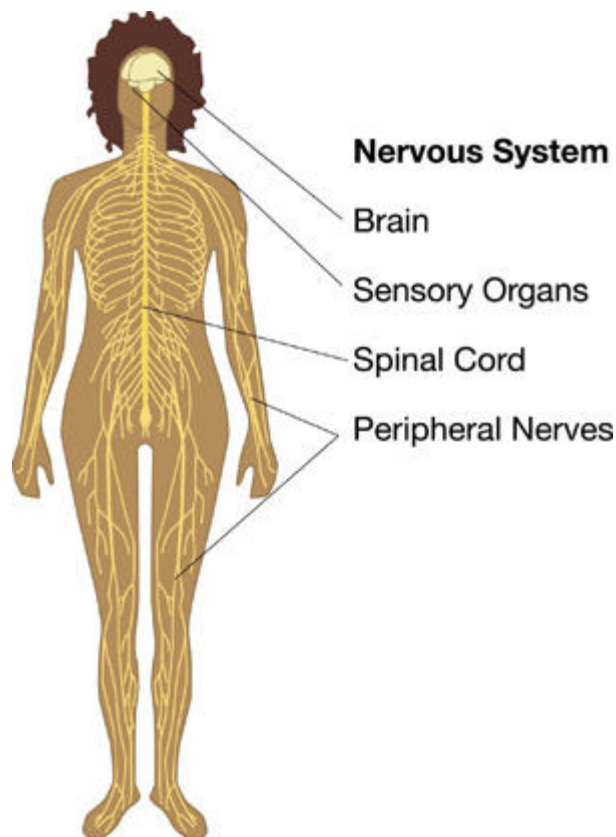
👉 **Answer**

B is the correct choice. The lymphatic system collects the fluid that has leaked out of the circulatory system and returns it to the blood. Blood is transported by the circulatory system. The immune system produces antibodies. Blood clotting is controlled by platelets in the circulatory system.

Genetics & Physiology: Organ Systems

Nervous System

The nervous system controls and coordinates essential functions of the human body. This system receives and relays information about activities within the body, and monitors and responds to internal and external changes.



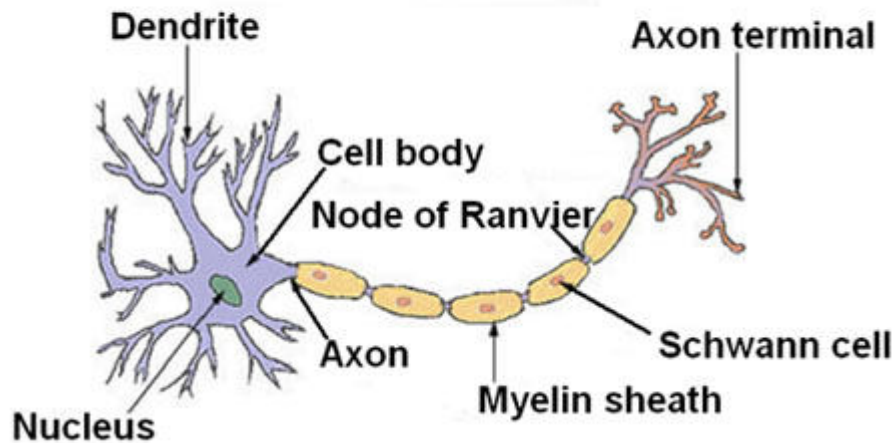
Neuron

Cells that carry messages throughout the nervous system are called neurons. These messages are called nerve impulses. Neurons are classified into three types according to the directions in which the impulses move.

- **Sensory neurons** carry impulses from the sense organs to the brain and spinal cord.
- **Motor neurons** carry impulses from the brain and spinal cord to muscles or glands.

- **Interneurons** connect sensory and motor neurons and carry impulses between them.

Structure of a Typical Neuron



The largest part of the neuron is the cell body. The cell body contains the nucleus and most of the cytoplasm; therefore, most of the cell's metabolic activities occur here. Spreading out from the cell body are branched extensions called dendrites. They carry impulses toward the cell body. The long fiber that carries impulses away from the cell body is the axon, which ends in a series of swellings called axon terminals.

Bundles of neurons are called nerves. The nerves contain a large number of independent communications channels. They are also composed of many supporting cells that form nervous tissue. Schwann cells wrap around axons forming a fatty, insulating covering called a myelin sheath. There are small gaps, called nodes, between the myelin sheaths. As an impulse moves down an axon, it will jump from node to node. This increases the speed of the impulse.

Nerve Impulse

A nerve impulse is a flow of electrical charges along the cell membrane of a neuron. The strength of an impulse is always the same. The minimum level of a stimulus that is required to activate a neuron is the threshold.

At the axon terminals, the neuron may make contact with dendrites of another neuron, with a **receptor** or an **effector**. Receptors are special sensory neurons in sense organs that receive stimuli from the external environment. Effectors are muscles or glands that bring about a coordinated response. The point of contact where an impulse is passed from one cell to another is called a synapse. Tiny vesicles filled with chemicals lie at the synapse. These vesicles are called neurotransmitters, which are used by one neuron to signal another.

Question

Which type of neuron is responsible for transmitting impulses to the central nervous system?

A Sensory neuron

- B Interneuron
- C Receptor neuron
- D Motor neuron

👉Answer

A is the correct choice, because sensory neurons carry signals from sense organs to the brain and spinal cord. Interneurons connect sensory and motor neurons and carry impulses between them. Receptor neurons are special sensory neurons in sense organs that receive stimuli from the external environment. Motor neurons carry impulses from the brain and spinal cord to muscles or glands.

The human nervous system is divided into two major divisions: the central nervous system and the peripheral nervous system. The central nervous system serves as the control center of the body. It consists of the brain and the spinal cord. Its functions are relaying messages, processing information, and comparing and analyzing information. The peripheral nervous system consists of nerves and ganglia, including those of the brain and spinal cord.

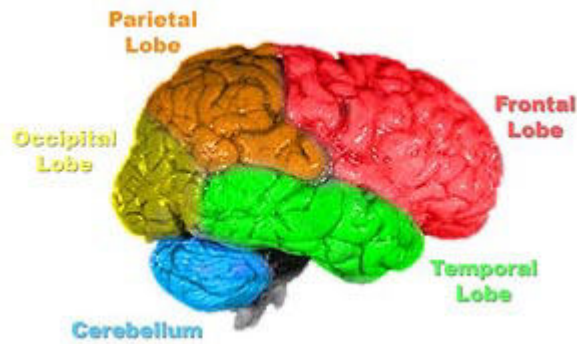
Central	Brain	
	Spinal Cord	
Peripheral	Somatic	
		Sympathetic
	Autonomic	Parasympathetic
		Enteric

Central Nervous System

The brain contains approximately 35 billion neurons and in order for the brain to function, it must have a constant supply of food and oxygen.

The largest part of the brain is the **cerebrum**. It is responsible for all of the voluntary activities of the body. It is also the sight of intelligence, learning, and judgment. The cerebrum is divided into two hemispheres, right and left, by a deep groove known as the corpus callosum. The surface of the cerebrum has numerous folds. Each hemisphere is divided into regions called lobes>>, which are named for the skull bones that cover them.

- frontal lobe
- parietal lobe
- occipital lobe
- temporal lobe

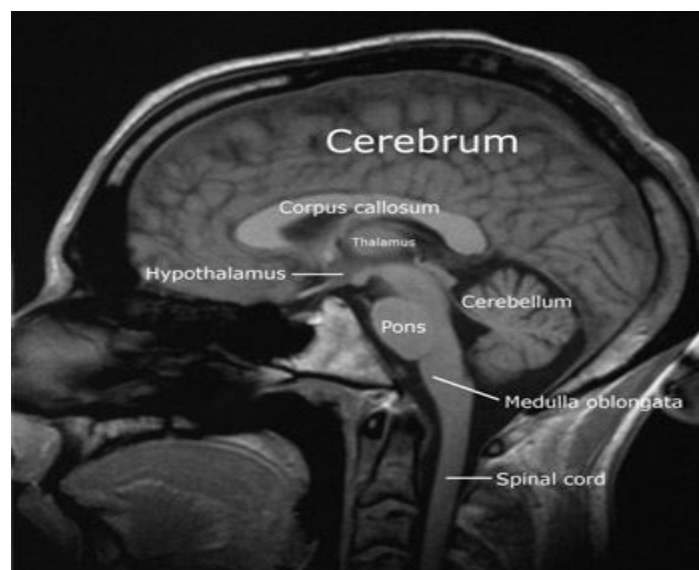


Not surprisingly, the brain is not just uniform gray matter, it has many parts and distinct areas. The right hemisphere is generally associated with creativity, communication, and artistic ability while the left hemisphere is more dedicated to analytical, spatial, and mathematical ability. The cerebrum consists of two surfaces. Much of the activity occurs in the **cerebral cortex**, which is composed of gray matter. The gray matter contains densely packed nerve cells. The other surface of the cerebrum is the **cerebral medulla**. The cerebral medulla is composed of white matter, which contains bundles of axons with myelin sheaths.

The **cerebellum** is the second largest part of the brain and is located at the back of the skull. It controls balance, posture, and voluntary muscle contractions. The **thalamus** and **hypothalamus** are found in the part of the brain between the brain stem and the cerebrum. The egg-shaped thalamus is the main site of sensory processing. Most of the sensory nerves converge on the thalamus. Below the thalamus is the hypothalamus. It is a slender thread of tissue that controls hunger, thirst, fatigue, anger, and body temperature. It also directs the secretions of the pituitary gland.

The **brainstem** connects the brain to the spinal cord. It coordinates and integrates all incoming information, while also serving as the place of entry or exit for 10 of the 12 cranial nerves. The lowest part of the brainstem is the **medulla oblongata**. It controls involuntary functions that include breathing, blood pressure, heart rate, swallowing, and coughing.

The spinal cord emerges from the brain through the opening at the base of the skull, the magnum foramen. It stretches downward and ends just below the ribs and above the pelvis. Like the brain, it is protected by bone and cerebrospinal fluid. Thirty-one pairs of spinal nerves originate in the spinal cord and branch out to the body carrying impulses to and from the brain and regulating reflexes.



Question

Coordination and balance occur principally in the

- A cerebrum
- B cerebellum
- C medulla oblongata
- D corpus callosum

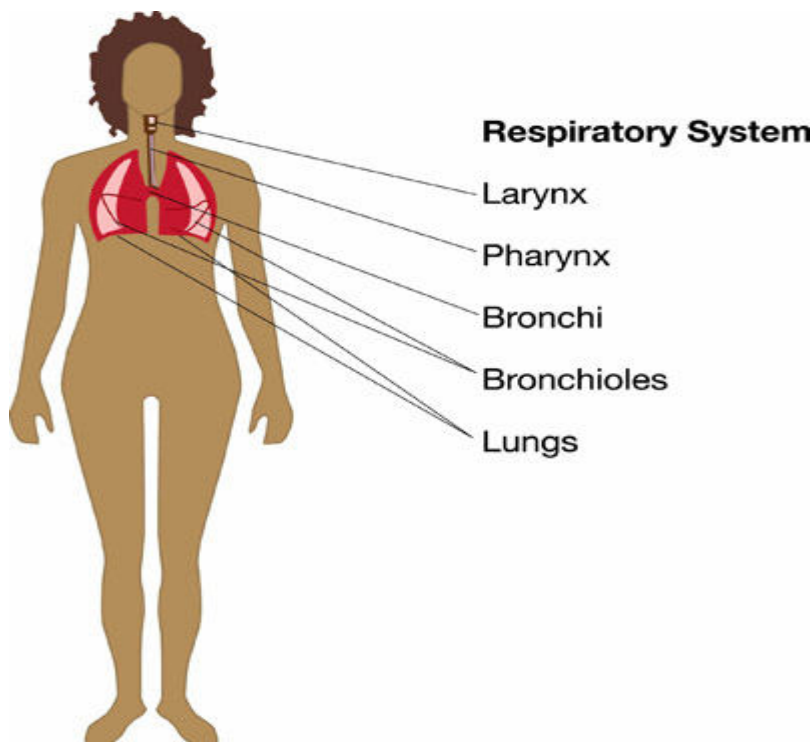
Answer

B is the correct choice, because the cerebellum controls balance and posture. A, the cerebrum is responsible for sight, learning & judgment, while C the medulla oblongata controls autonomic functions. D, the corpus callosum is the deep groove that divides the cerebrum into two hemispheres.

Genetics & Physiology: Organ Systems

Respiratory System

The respiratory system consists of the nose, mouth, pharynx, larynx, trachea, bronchi and lungs. It acts in conjunction with the cardiovascular system to supply oxygen (O_2) and remove carbon dioxide (CO_2) from the blood.

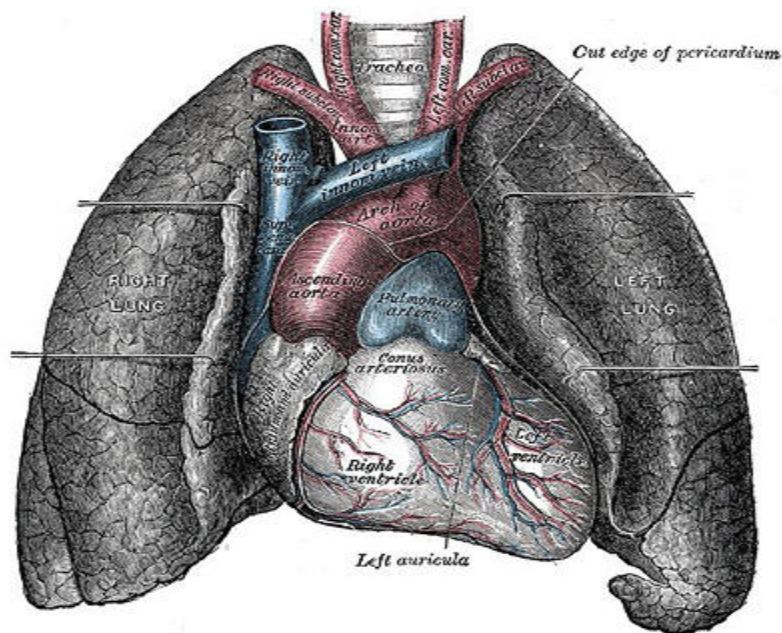


Cells in the body need O_2 for metabolism. They also need to dispose of the by-product CO_2 . The respiratory and cardiovascular systems work together to provide the mechanism for this to occur. The respiratory system takes in the O_2 and disposes of the CO_2 and the cardiovascular system pumps both around the body.

The larynx, or voice box, is a passageway that connects the pharynx with the trachea. It contains the thyroid cartilage (commonly called the "Adam's apple"). At the top of the larynx is the epiglottis, which keeps food from entering the larynx and keeps you from choking.

The trachea is the tube you can feel when you put your hand on the front of your neck. It is reinforced with cartilage rings to prevent it from collapsing. It extends from the larynx and divides into right and left primary (extrapulmonary) bronchi.

Genetics & Physiology: Organ Systems



The respiratory bronchioles and the alveoli are where the actual gas exchange takes place, and they always have a little bit of air in them. The lungs are above the diaphragm in the thorax and are enclosed by a pleural membrane called the pulmonary pleura. The parietal pleura lines the thoracic cavity. Pleural fluid keeps everything lubricated so the lungs can move with little friction as you breathe. The right and the left lungs do not look the same. The right lung has three lobes with two fissures. The left lung is smaller, has two lobes with one fissure, and a cardiac notch, which is where the heart nestles.

Air moves in and out of the lungs through pulmonary ventilation: inspiration (inhalation) and expiration (exhalation). This is an autonomic reflex explained by Boyle's law, which states that the volume of gas (in this case O_2 and CO_2) varies inversely with pressure. As pressure increases, volume decreases; as pressure decreases, volume increases. These changes in pressure occur with the contraction and relaxation of the diaphragm. When the diaphragm contracts it augments the volume of the lungs and decreases the pressure, when the diaphragm relaxes, the lung volume decreases and pressure increases.

Genetics & Physiology: Organ Systems

Gas Exchange

O₂ is transported in red blood cells (RBCs) and is bound to hemoglobin (Hb) to form the compound oxyhemoglobin.

There are three ways CO₂ is transported in blood:

- 7% is dissolved in plasma
- 23% is bound to hemoglobin and forms carboxyhemoglobin (Hb-CO₂)
- 70% is bicarbonate (HCO₃).

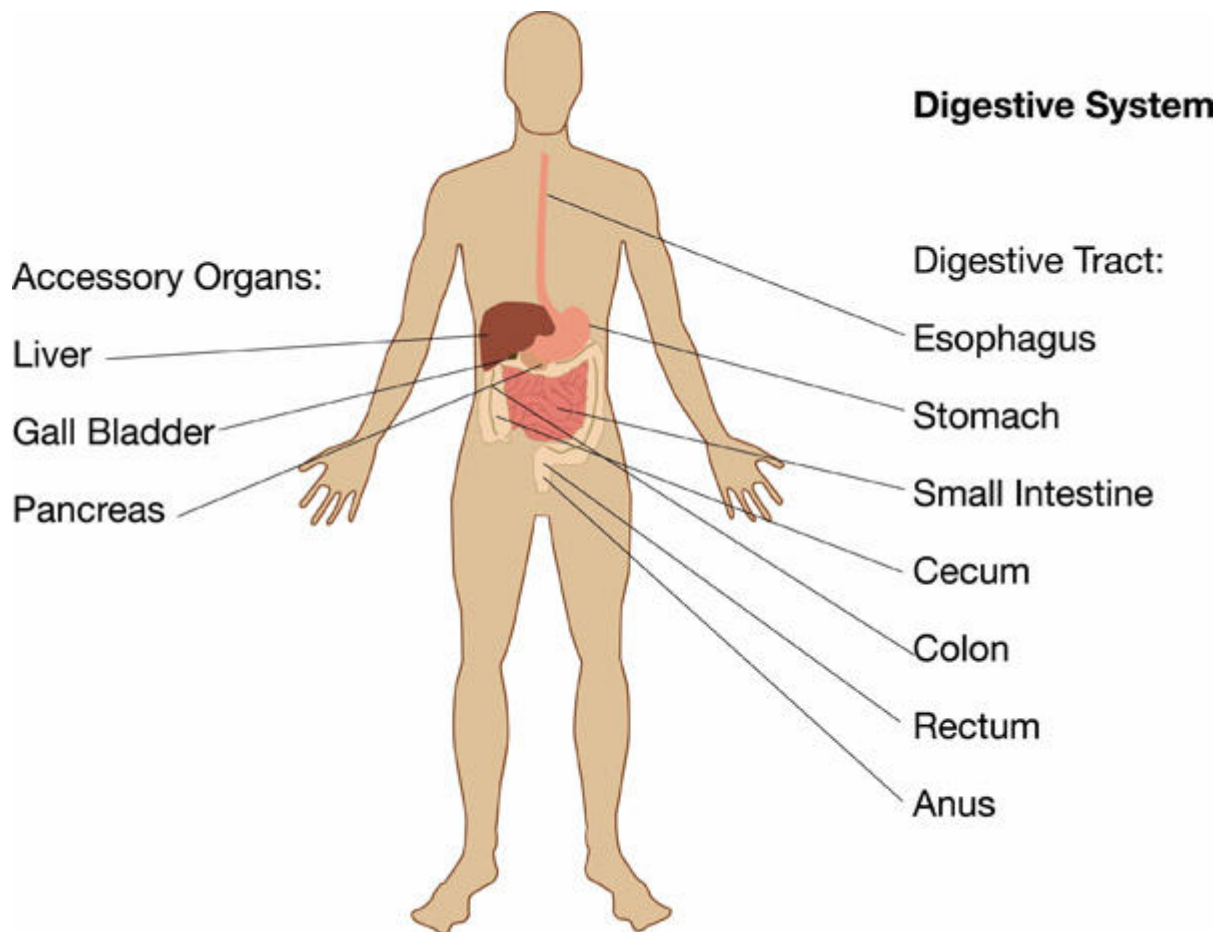
High levels of CO₂ cause blood to become more acidic and this causes Hb to release O₂. When O₂ enters from the airways and is exchanged in the lungs, it then travels in the blood to the heart where it is pumped to the rest of the body and distributed as needed to cells. As cells pick up the O₂ they are also releasing CO₂. CO₂ hitchhikes a ride on Hb and goes back to the lungs where CO₂ is released and exhaled. A rate of flow into and out of the lungs and a high surface area is required for gas exchange to occur. Both O₂ and CO₂ diffuse from an area of higher partial pressure to a lower internal and external respiration.

The brain has two areas that are part of basic life support. One is the medulla oblongata and the other is the pons. Both of these areas set the rhythm for basic breathing and send messages to the nerves that control the diaphragm. As the diaphragm contracts and relaxes, the process of inspiration and expiration occurs. There are times when the body experiences a chemical imbalance that requires a change in normal breathing. If there is too much CO₂ in the body, blood pH drops and it becomes more acidic. The medulla oblongata senses this and modifies the breathing pattern to deep breaths that allow an increase in O₂. If there is too much O₂ in the body, blood pH increases and becomes more alkaline. The saturated Hb does not allow CO₂ to release. The medulla oblongata is alerted and modifies the breathing pattern to shallow breaths. However, if the body continues to take in too much O₂, hyperventilation occurs and can result in unconsciousness.

Genetics & Physiology: Organ Systems

Digestive System

Digestion is the breakdown of food into simpler molecules that can be absorbed by the body. The digestive system is actually a hollow tube called the gastrointestinal tract (GI tract). The first task of the digestive system is to break down the food into a fine pulp. The next task is to chemically act on the food, breaking it down into smaller molecules. The last task is to absorb the molecules and pass them along to the bloodstream for distribution to the rest of the body.



Mouth

The mouth prepares food for entry into the GI tract. The lips, cheeks, and tongue work together to manipulate food for chewing. The teeth begin the process of mechanical digestion, which is the physical breaking up of food. While the teeth cut and grind food into a pulp, the salivary glands secrete the first digestive enzymes of the GI tract. Saliva has three functions:

- Dissolves some food and combines with mucus to speed the passage of food through the digestive system
- Contains enzymes that attack many of the dangerous microbes that can enter the mouth
- Contains the enzyme amylase, which breaks down long starch molecules into sugars

As food is swallowed, the tongue moves the food into the pharynx>>, it presses down on the **epiglottis**. The epiglottis stops entry to the respiratory tract and guides the food to the GI tract.

Esophagus

The food will next pass down the 25cm-wide tube that connects the pharynx to the stomach, the **esophagus**. The esophagus acts as a kind of descending escalator, moving food down to the stomach. It does this by rhythmic waves of contractions called **peristalsis**. The esophagus passes through the **diaphragm** to get to the stomach.

Stomach

The stomach is a thick muscular sac located just below the diaphragm in the abdomen. It temporarily stores food and mechanically breaks down food. It also chemically unravels and breaks down proteins. Three sets of glands in the stomach lining secrete gastric fluids. The stomach mixes its

contents with a churning action. The mixture of food, HCl, and enzymes eventually (after 2 to 3 hours) forms a soupy, semisolid material called **chyme**.

One set of glands produces mucus, which keeps the food lubricated and protects the walls of the stomach from being digested. Another set of glands secretes hydrochloric acid (HCl), which helps break down food. The release of HCl is regulated by the hormone, gastrin. A third set of glands secretes pepsin, a digestive enzyme that breaks proteins into smaller polypeptides. The **pyloric valve** between the small intestine and the stomach opens and the food is forced into the small intestine by peristalsis. At this point, most proteins have been broken down, but sugars and fats have not been chemically altered.

Question

The muscle contractions that move food down the esophagus are called

- A chyme.
- B amylase.
- C gastrin.
- D peristalsis.

Answer

D is correct, because peristalsis is the rhythmic waves of contractions that move food down the esophagus and through the pyloric valve. Chyme is produced in the stomach. Amylase is an enzyme in the mouth. Gastrin is a hormone that regulates the release of HCl in the stomach.

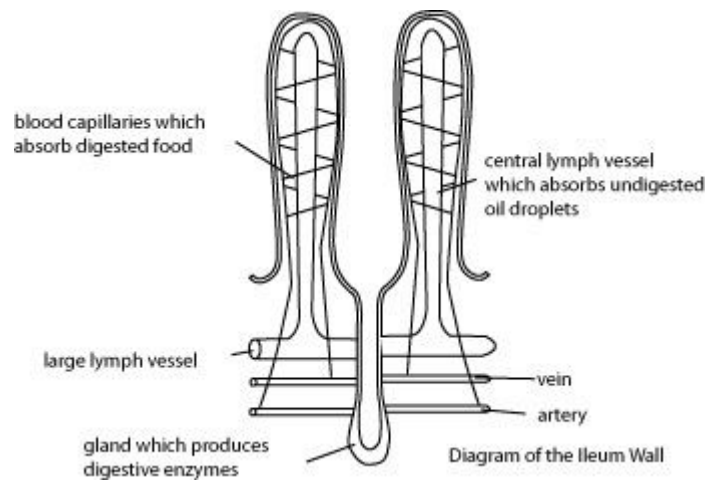
Small Intestine

Food passes through the pyloric valve into the **small intestine**, which is approximately 6m long. The first part of the small intestine is called the **duodenum**. Here, the chyme is flooded with a variety of enzymes and digestive fluids that further break down the food molecules. The enzymes and digestive enzymes come from three sources: the small intestine, pancreas, and liver.

Glands lining the duodenum release enzymes called peptidases, which continue the process of protein digestion. Other enzymes attach to complex carbohydrates, breaking them down into sugars. When chyme enters the small intestine, glands in the **pancreas** are stimulated to release pancreatic fluid. The fluid enters a duct that empties into the duodenum. Enzymes in the fluid aid in digestion of carbohydrates, fats, and proteins. The enzymes include amylase, protease, and lipase. Pancreatic fluid also contains sodium bicarbonate, which neutralizes the hydrochloric acid in the chyme.

As food enters the small intestine, the **liver** is stimulated to release bile through the bile duct into the duodenum. Bile is a yellow-brown liquid that is stored in the gall bladder. Bile does not contain enzymes. It is a mixture of cholesterol, colored pigments, and bile salts. Bile salts aid lipase in properly digesting fats. The complete digestion of carbohydrates, fats, and proteins takes place in the

duodenum, which is the first 25 cm of the small intestine. The rest of the small intestine is devoted to absorbing water and products of digestion into the bloodstream. The lining of the small intestine is covered with fingerlike projections called **villi**, which increase the absorptive surface area of the small intestine. The average surface area is about 300 sq meters.



The Large Intestine

When the food leaves the small intestine, it is essentially nutrient-free. Only water, cellulose, and other indigestible substances are left. The food then passes into the large intestine and colon. The large intestine is about 1m long, but it is about 3 times larger than the small intestine in diameter. Instead of being coiled up, the colon is in three relatively straight segments. The main job of the colon is to remove water from the undigested materials passing through it. The undigested material is then reduced to solid waste products called feces. No digestion takes place in the large intestine. The feces move through the colon by peristalsis and collect at the rectum. At some point, the feces will leave the body through the anus.

Digestive Enzymes

It is important to note that many enzymes aid in the digestion process. Here is a short list:

Enzyme	Organ	Action
Gastrin	stomach	breaks peptide bonds
Trypsin	pancreas	breaks peptide bonds
Chymotrypsin	pancreas	breaks peptide bonds
Carboxypeptidase	pancreas	breaks COOH terminal peptide bonds
Pancreatic lipase	pancreas	breaks triacylglycerols
Intestinal lipase	small intestine	breaks tri-, di- and monoglycerides
Ptyalin	saliva	breaks starch
Amylopsin	pancreas	breaks starch
Intestinal amylase	small intestine	breaks starch
Maltase	small intestine	breaks down maltose
Sucrase	small intestine	breaks down maltose
Lactase	small intestine	breaks down maltose

Question

The part of the digestive system in which digested materials are absorbed is the

- A mouth.
- B small intestine.
- C large intestine.
- D stomach.

👉Answer

The correct choice is B. Villi and macrovilli in the small intestine absorb nutrients. The digestive process begins in the mouth, the large intestine removes water from undigested materials. The stomach breaks food particles down for later absorption.

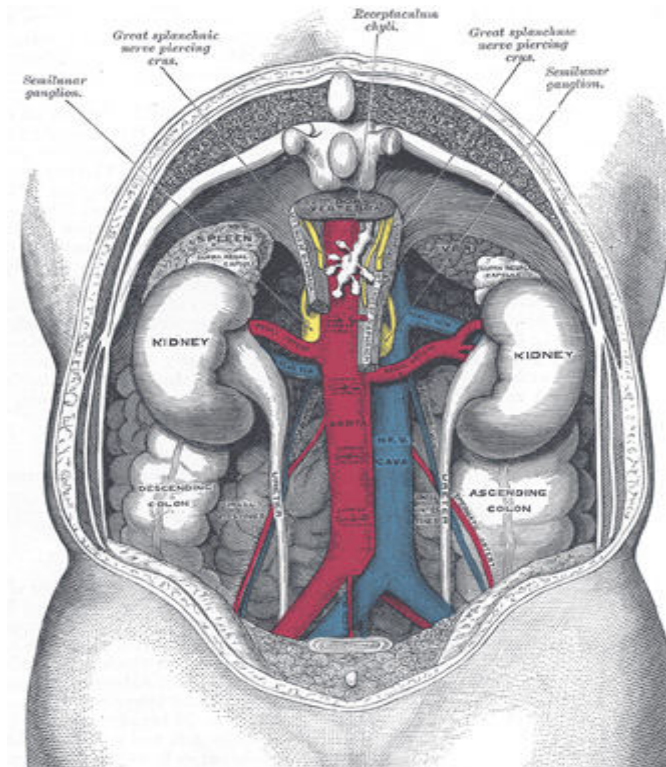
Genetics & Physiology: Organ Systems

Waste Management, the *Excretory System*

The urinary system is efficient in getting rid of byproducts that are not needed. The kidneys and their associated parts all play a role in making sure that the blood is kept clean and that the body does not lose too much water or other essential nutrients. The urinary system also has other important roles in keeping the balance, or homeostasis of the blood. The organs of the urinary system are the kidneys, ureters, urinary bladder, and the urethra. The kidneys do the bulk of the work, while the other parts act as viaducts or storage for what the kidneys produce.

Kidneys

The kidneys filter many liters of blood every day — approximately one-quarter of the body's blood flows through the kidneys each minute! In addition, they regulate the blood volume and the chemical makeup of the blood.



The kidneys help regulate blood pressure with the production of an enzyme called rennin. When blood pressure drops, rennin causes blood vessels to constrict, forcing blood pressure to increase. The kidneys produce the hormone erythropoietin, which stimulates the production of red blood cells. The kidneys also convert Vitamin D into a form that is usable to the body.

In addition, the kidneys have four main roles:

- ***Excretion of nitrogenous wastes***

Nitrogen-containing wastes include:

- urea, which is formed in the liver when the amino acids make ATP
- creatinine, which is a byproduct from the metabolism of creatine in muscles
- ammonia, which results from the breakdown of proteins by bacteria
- uric acid, which is a byproduct of metabolizing nucleic acids

- ***Maintaining an acid-base balance***

- Blood pH is 7.35 to 7.45. When too much CO₂, too much O₂, or as byproducts of lactic acid and fatty acid breakdown increase, the blood can exceed the normal limits of its optimal pH. There are blood buffers that help prevent these changes. These buffers bind to the H⁺ when the pH drops and release H⁺ when the pH increases (the bicarbonate buffer system). The kidneys get rid of acids that are generated during metabolism by excreting or reabsorbing bicarbonate as needed to effect change in the pH.

Genetics & Physiology: Organ Systems

The other roles of the kidneys — water and electrolyte balance — are closely linked. Water makes up 50 to 60 percent of body weight depending on gender. Women tend to have more fat than men, and fat has less water than muscle. Two-thirds of this water is found in cells, while the remaining third is found extracellularly in interstitial fluids, like plasma and cerebrospinal fluid.

The re-absorption of water and electrolytes is regulated mostly by two hormones: anti-diuretic hormone (ADH) and aldosterone (controlled by rennin). If there is high blood loss and blood pressure drops, the filtrate drops. Reacting to this change, osmoreceptors in the hypothalamus release ADH. This allows for the absorption of more water in order to increase blood volume and pressure; therefore, only a small amount of concentrated urine is produced. If there is too little Na^+ or other ions in the blood, the blood becomes diluted, which causes edema or circulatory collapse. Aldosterone regulates the re-absorption of Na^+ . As it is reabsorbed, water passively follows Na^+ .

To review, the kidneys function to regulate these processes:

- blood ionic composition
- blood osmolarity
- blood volume
- blood pressure
- blood pH
- gluconeogenesis
- release calcitriol and erythropoietin
- excrete waste and foreign substances

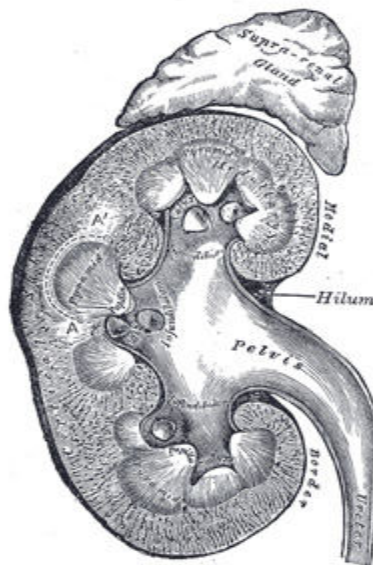
Genetics & Physiology: Organ Systems

Location & Structure

The kidneys are located between T12 and L3 of the spine in the mid- to lower-back and are protected by the ribs. The right kidney is a little lower than the left due to the location of the liver. The indentation in the center of the kidney is called the hilum. Kidneys are encased in a protective sheath called the renal capsule. The renal capsule and some adipose tissue hold the kidney against the muscles of the trunk wall.

A kidney opened lengthwise reveals three regions:

- The cortex (outer layer)
- The medulla (middle layer)
- The triangle-shaped medullary pyramids within the medulla



The pyramids are arranged with the base of the pyramid toward the cortex and the apex towards the inner part of the kidney. At the end of the pyramids are collection vessels called calyces. The calyces drain into the renal pelvis, a cavity that is continuous with the ureters. The pyramids are separated by renal columns, which are structures that are similar in makeup to the cortex.

Since so much blood passes through the kidneys, they have a great blood supply. The renal artery branches from the abdominal aorta that goes to the kidneys. From there it segments into the segmental artery, to the lobular artery, into the interlobular arteries, and then to the cortex.

The major structural unit of the kidney is the nephron. In each kidney there are millions of nephrons producing urine. A nephron has two main parts: the glomerulus and the renal tubule.

The glomerulus is essentially a capillary bed. The blood goes into the glomerulus through the afferent arteriole and leaves via the efferent arteriole. At one end of the renal tubule there is a capsule (called Bowman's capsule) that cups around the glomerulus, forming a porous membrane. Extending from the Bowman's capsule, the renal tubule becomes very convoluted and is surrounded by blood vessels called peritubular capillaries. The renal tubule has three parts: the proximal tubule, the Loop of Henle, and the distal tubule. The proximal tubule ascends down to the Loop of Henle and then ascends back up in the distal tubule.

Question

The major functional part of the kidneys is the

- A hilus.
- B nephron.
- C renal cortex.
- D renal tubule.

👉Answer

B is the correct answer. The hilus is a depression where vessels, nerves, or ducts enter the kidney. The renal cortex contains the glomeruli and the convoluted tubules. Renal tubules are small structures that filter blood and produce urine.

Genetics & Physiology: Organ Systems

Filtration

Filtration occurs between the glomerulus and the Bowman's capsule under high pressure. This pressure basically pushes everything that is small enough — water, ions, vitamins, amino acids, and wastes — into the Bowman's capsule. However, if blood pressure is too low, there is not enough

pressure and filtration will not occur. As this filtrate runs through the renal tubule, most of it is reabsorbed into the peritubular capillaries.

The peritubular capillaries arise from the efferent arterioles. The capillaries envelop the renal tubules before draining into the venules. The peritubular capillaries are porous and have low pressure, yet have a high absorption of solutes and water during reabsorption. The solutes and water are then returned to the bloodstream.

The body needs water, glucose, amino acids, and ions, so the body **reabsorbs** almost everything that was pushed out. Reabsorption begins as soon as the filtrate enters the proximal convoluted tubule. Unlike filtration, which was simple passive transport, reabsorption often uses active transport. There are carriers for the substances that the body needs to keep, like glucose and amino acids. These are usually all removed and are not found in urine. However, there are no carriers for the substances not kept — like creatinine and uric acid. Ions are reabsorbed as necessary.

It is while the filtrate is passing through the nephron that **urine** is formed. Generally, the kidneys filter 150 to 180 liters of plasma in 24 hours, yet produce only 1 to 2 liters of urine.

Genetics & Physiology: Organ Systems

Flushing the System

Under normal conditions, urine is sterile, yet slightly acidic (~6.0 pH). Coloration ranges from clear to dark yellow, the latter due to the urochrome pigment from the breakdown of hemoglobin. Urine can contain Na⁺, K⁺, urea, uric acid, creatinine, ammonia, ions, and vitamins.

Urine needs to leave the body. This is where the other parts of the urinary system come into play.

The ureters are tubes that go from the hilus of the kidney to the urinary bladder. Ureters are smooth muscle and use peristalsis.

The urinary bladder is a smooth, collapsible sac that holds urine. This bladder expands as it fills.

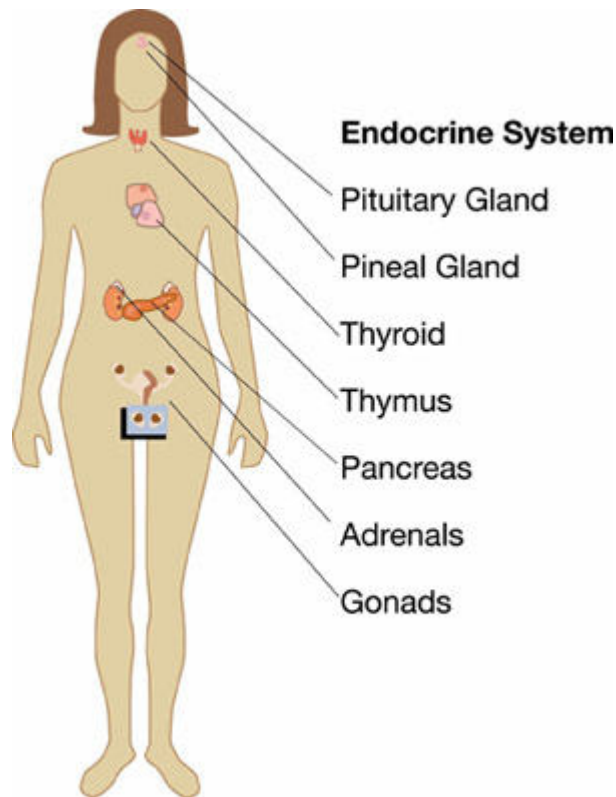
The urethra is a tube that carries the urine from the bladder out of the body. The urethra also operates by peristalsis. It has an internal sphincter that stays closed when urine is not being expelled. Urethra size depends on gender: it is much shorter in females (3 to 4 cm) compared to males (20 cm).

7. Organ Systems II

Genetics & Physiology: Organ Systems

Endocrine System

The endocrine system, like the nervous system, is a regulatory system. It is composed of glands that secrete hormones into the bloodstream. Hormones, which are chemical messengers, bind to receptors on cells and affect the behavior of the cells. A response to hormones is generally slower than a response to a nerve impulse. The major hormone-producing organs are the endocrine glands. Endocrine glands do not have ducts; they release their secretions directly into the bloodstream. Endocrine glands are scattered throughout the body and do not have direct connections to one another.



Hypothalamus

The hypothalamus controls the secretions of the pituitary gland. The activity of the hypothalamus is influenced by the levels of hormones in the blood and sensory information that enters the central nervous system. In the hypothalamus, special neurons extend their axons into the pituitary gland. When the neurons are stimulated, the vesicles at the ends of the axon terminals release their contents into the pituitary gland. The hormones will then be diffused into the capillaries.

Pituitary Gland

The pituitary gland dangles on a slender stalk of tissue at the base of the skull. It is divided into two parts. The front part, the anterior lobe, produces seven major peptide hormones.

- FSH: follicle stimulating hormone.
- LH: luteinizing hormone; both FSH and LH control the growth, development and functioning of the ovaries and testes.
- TSH: thyroid stimulating hormone; stimulates the synthesis and release of thyroxine from the thyroid gland.
- ACTH: adrenocorticotrophic hormone; stimulates the release of hormones from the adrenal cortex.
- GH: somatotropin or growth hormone; stimulates protein synthesis and growth of cells throughout the body; skeletal muscle cells and cartilage cells are particularly sensitive; important during the first 15 years of life.
- Prolactin: plays a role in milk production in pregnant females.
- MSH: melanocyte stimulating hormone; stimulates the melanocytes of skin, increasing their production of melanin.

The back portion of the pituitary, the posterior lobe, releases two other hormones. ADH (antidiuretic hormone) stimulates the kidneys to reabsorb more water from the collecting tubules that comprise them. Oxytocin stimulates the contraction of muscles in the uterus, which helps a mother to push out

a newborn during childbirth. It also causes the release of breast milk of a nursing mother. Oxytocin's function in males is not known.

Pineal Gland

The pineal gland is a pea-sized gland located in the top of the brain. It secretes melatonin>>. Other functions of the pineal gland in humans are not yet known. Melatonin seems to be released as a response to darkness, so the pineal gland is thought to be involved in daily biorhythms. It has also been implicated in mood disorders.

Thyroid Gland

The thyroid gland is located at the base of the neck and wraps around the upper part of the trachea just below the larynx. It produces several hormones, but the most important is thyroxine. Thyroxine increases the body's metabolic rate and promotes the normal growth of the brain, bones, and muscles.

Question

The production of hormones by glands of the endocrine system is initiated by the

- A hypothalamus.
- B medulla of the adrenal glands.
- C thyroid gland.
- D pineal gland.

✔Answer

A is correct, because the hypothalamus acts as the director of the endocrine system by stimulating secretion of hormones by the endocrine glands. The adrenal medulla is a specialized part that secretes neurohormones, adrenaline (or epinephrine), and noradrenaline (norepinephrine). The thyroid gland secretes thyroxine that increases metabolic rate and promotes growth. The pineal gland secretes melatonin in response to darkness.

Parathyroid Glands

The parathyroid glands are attached to the back surface of the thyroid gland. There are usually four parathyroid glands, which secrete parathyroid hormone (PTH). PTH regulates the calcium levels in the blood by increasing the reabsorption of calcium in the kidneys and the digestive system. In addition, PTH is important in promoting proper nerve and muscle function, as well as maintaining bone structure.

Adrenal Glands

The adrenal glands are walnut-shaped structures that sit on top of the kidneys, one gland on each kidney. They produce more than two dozen corticosteroids, which are essential for normal body function. One example is aldosterone. Aldosterone regulates the reabsorption of sodium and the

excretion of potassium by the kidneys. Cortisol helps to control the rate of metabolism of carbohydrates, fats, and proteins. It also helps people cope with stress and acts to reduce inflammation. In addition, they secrete the neurohormones, such as adrenaline (or epinephrine) and noradrenaline (norepinephrine). These hormones prepare the body for emergency action by increasing heart rate, blood pressure, and blood supply to skeletal muscles. They also increase the conversion of glycogen to glucose and stimulate the body's metabolic rate. Noradrenaline stimulates the heart muscle.

Pancreas

The pancreas is located just behind the stomach. The hormone-producing part of the pancreas consists of clusters of cells that resemble islands. They are called islets of Langerhans. Each islet secretes insulin and glucagons, which regulate the metabolism of blood glucose. **Insulin** is a storage hormone that stimulates the ability of its target cells to take up and use glucose. Its major targets are the cells of the liver, skeletal muscles, and fatty tissue. Insulin prevents the level of glucose in blood from rising immediately after a meal. It also ensures that excess glucose will be stored for further use.

Genetics & Physiology: Organ Systems

Reproductive System

The gonads (ovaries and testes) are the body's reproductive glands. The ovaries produce the female sex hormones, estrogen and progesterone. Estrogen is required for the development of eggs and for the formation of the physical characteristics of a female. Progesterone prepares the uterus for the arrival of a developing embryo. The testes produce male sex hormones called androgens. Androgens, such as testosterone, are required for normal sperm production and the development of physical characteristics for a male.

Question

Which gland produces cortisol?

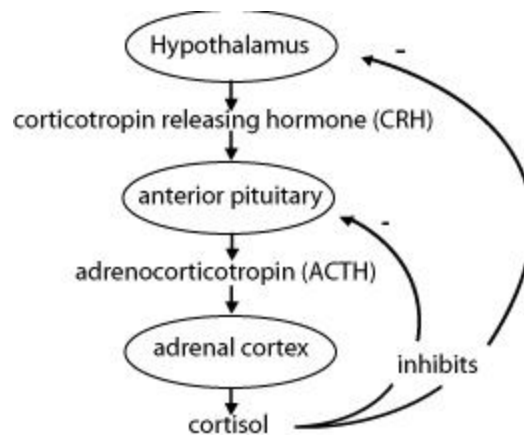
- A Parathyroid
- B Pancreas
- C Thyroid
- D Adrenal

Answer

The correct choice is D, because cortisol is produced and secreted by the adrenal cortex. The parathyroid secretes parathyroid hormone (PTH). The pancreas secretes insulin and glucagons. The thyroid gland produces several hormones, but most importantly thyroxine.

Control of the Endocrine System

The endocrine system is regulated by a negative-feedback mechanism. This mechanism functions to maintain homeostasis in the body.



The hormones produced by endocrine glands fall into two groups: polypeptides and steroids. **Polypeptides**, such as glucagon and thyroxine, are large proteins composed of chains of amino acids. **Steroids**, such as progesterone, are lipids that are produced from **cholesterol**. In addition, some cells and tissue produce local hormones called **prostaglandins**. These hormones are fatty acids.

Question

Secretions from ductless glands are called

- A enzymes.
- B excretory fluids.
- C hormones.
- D digestive fluids.

Answer

The correct choice is C. Endocrine glands are ductless and secrete hormones. Enzymes are proteins that act as catalysts. Excretory fluids come from the urinary system. Digestive fluids come from the digestive system.

Genetics & Physiology: Organ Systems

Reproductive System

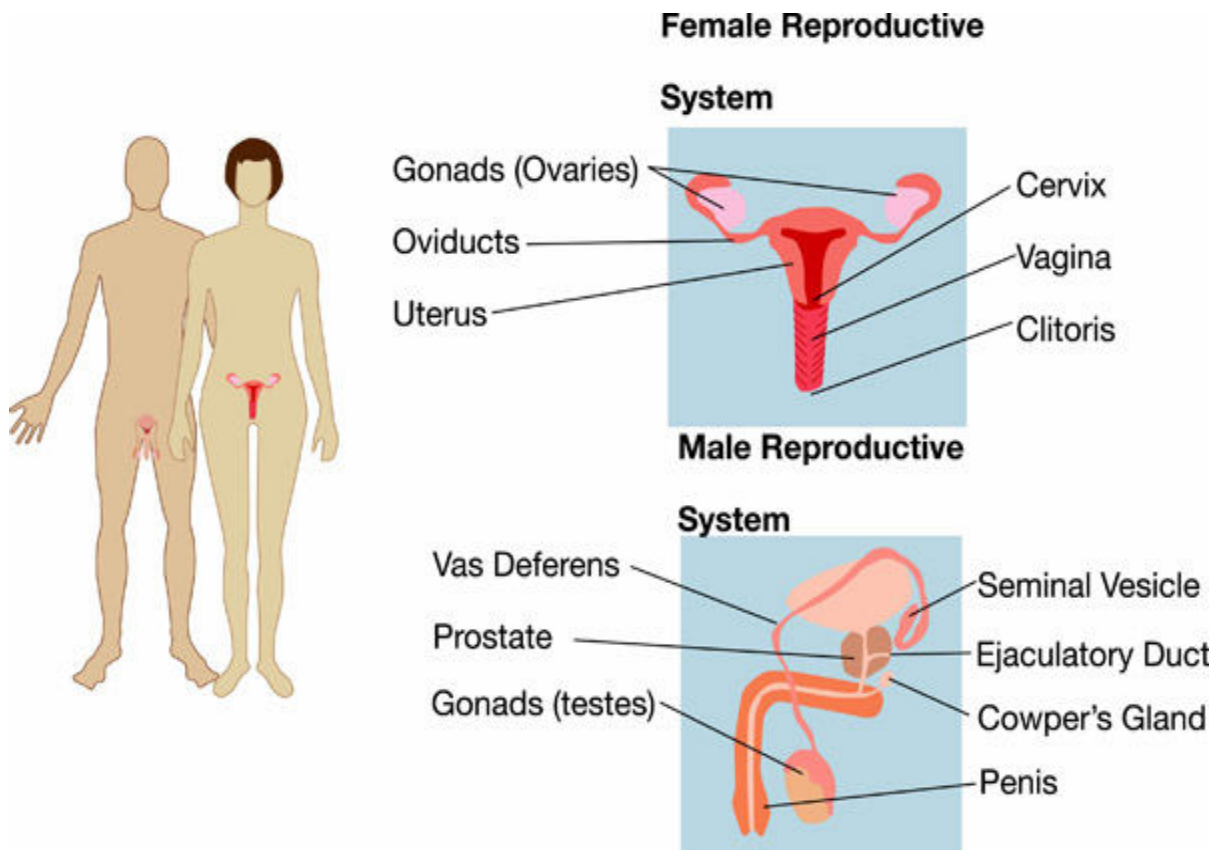
For the combination of parental genotypes during the mating process, and a mixture of genetic materials to take place, the sex cells must first go through a process called meiosis, which results in the gametes (eggs and sperm) containing only half of the parental genetic material. Meiosis only occurs in the testes and ovaries to produce gametes.

Meiosis produces haploid gametes via two nuclear divisions: meiosis I and meiosis II. In meiosis I, homologous chromosomes pair up and cross over. The result is two genetically identical daughter cells. In meiosis II, these daughter cells split to form four haploid cells. You should recall that the gametes have a haploid (n) chromosome number, and the somatic (or body) cells have diploid ($2n$) number of chromosomes.

Gender

While the organs used in reproduction are different in males and females, they have complementary components:

- gonads, which produce gametes
- ducts, which transport and store gametes
- accessory sex glands, which produce materials that support gametes and their supporting structures



Genetics & Physiology: Organ Systems

The Male

The male reproductive system includes: testes, ductus epididymis, ductus (vas) deferens, ejaculatory duct, urethra, seminal vesicles, prostate gland, bulbourethral glands, and penis. The scrotum, which consists of loose skin and superficial fascia, supports and contains the testes. The testes are paired oval glands that contain seminiferous tubules (where sperm is made), sertoli cells (nourishing cells), and Leydig cells (that produce testosterone). The testes descend into the scrotum through inguinal canals during the seventh month of fetal development. The temperature of the testes is regulated by the contraction of the cremaster and dartos muscles. These muscles bring the testes up or down as needed into the pelvic cavity.

Spermatogenesis is when immature spermatogonia develop into mature sperm. Mature sperm consist of a head, a mid-piece, and a tail. Their function is to fertilize a secondary oocyte. During puberty GnRH stimulates secretion of FSH and LH. LH stimulates production of testosterone. FSH and testosterone stimulate spermatogenesis.

Testosterone's role is to control growth and maintenance of sex organs, bone growth, protein anabolism, and sperm maturation. It also stimulates the development of secondary sex characteristics, such as facial hair and deepening of the voice.

The duct system consists of seminiferous tubules, straight tubules and rete testes. Sperm flow out of the testes through efferent ducts. There is also the ductus epididymis, which is a place on the superior portion of the testicle in which the sperm mature. After the sperm mature, they enter the vas deferens, which stores sperm and propels it towards the urethra during ejaculation. Sperm then enter the ejaculatory duct, which is the union of ducts from seminal vesicle and ductus deferens. This duct acts as a passageway way for sperm and secretions of seminal vesicles into the prostatic urethra. There are three parts to the urethra: prostatic, membranous, and spongy (penile).

Accessory sex glands include:

- seminal vesicles, which secrete alkaline, a viscous fluid consisting of approximately 60 percent semen. Alkaline aids sperm viability
- prostate gland, which secretes an acidic fluid consisting of 25 percent semen. This fluid aids sperm motility
- bulbourethral glands, which secrete mucus for lubrication and an alkaline substance to neutralize the acid

Semen is a mixture of sperm and seminal fluid. It provides transportation and nutrients for the sperm, and it helps to neutralize the acidity of the vagina and male urethra (remember, urine also passes through the male urethra).

Genetics & Physiology: Organ Systems

The Female

The main organs of the female reproductive system include: ovaries, uterine (Fallopian) tubes, uterus, vagina and vulva, and mammary glands.

The ovaries are located in the superior part of the pelvic cavity and are lateral to the uterus. Their job is to produce and discharge secondary oocytes (ovulation is the release of an egg for fertilization),

and to secrete estrogens, progesterone, relaxin, and inhibin. An egg is produced through oogenesis, which is the production of haploid secondary oocytes.

The vagina acts as a passageway for menstrual flow, lubricants, and sperm, and serves as the birth canal. External genitalia (vulva) include the mons pubis, labia majora and minora, clitoris, vestibule, vaginal and urethral orifices, hymen, and various glands. The perineum is a diamond-shaped area between the anus and vagina.

Females also have mammary glands, which are modified sweat glands that synthesize, secrete, and release milk, which is regulated by estrogen and progesterone. Milk production is also stimulated by the hormone prolactin, and release is stimulated by the hormone oxytocin.

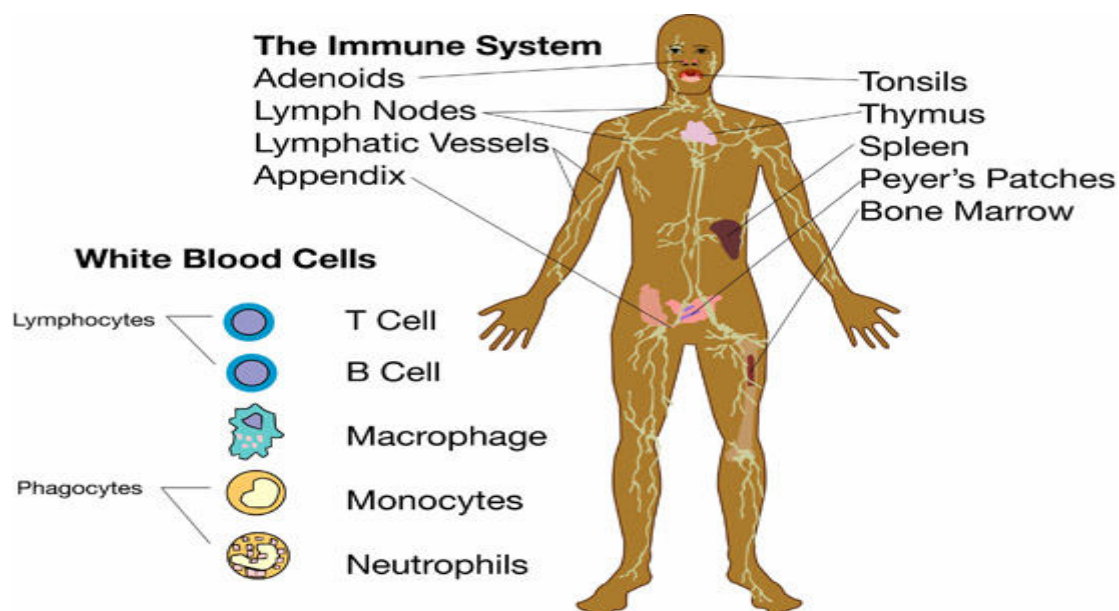
Genetics & Physiology: Organ Systems

Immune and Lymphatic Systems

There are several ways the body protects itself through nonspecific defenses.

- The **skin** provides a barrier to keep out invaders, and oil-secreting glands in the skin increase the effectiveness of this barrier.
- **Mucous membranes** trap microbes. Such membranes line the respiratory and digestive system organs.
- **Cilia** move trapped dirt and microbes. Cilia are tiny, hair-like structures found in the respiratory and digestive tracts. Dirt and microbes are moved into the throat, swallowed, and removed through digestion and excretion.
- **Hydrochloric acid** destroys most bacteria ingested. This acid is found in the stomach and provides a battlefield where "good" bacteria (normal flora) fight "bad" bacteria.

Anything that gets through these four nonspecific defense barriers and threatens the body then encounters the **immune system**. The immune system is the body's defense against invading microbes and foreign cells, as well as the body's own cells that have gone bad.



The immune system consists of cells and some molecules. This system has no organs; instead, it uses the pathways of the lymphatic and circulatory systems to transport immune system cells. These

cells go hunting for foreign invaders that do not belong in the body. They attack these invaders and disable, kill, or remove them from the body.

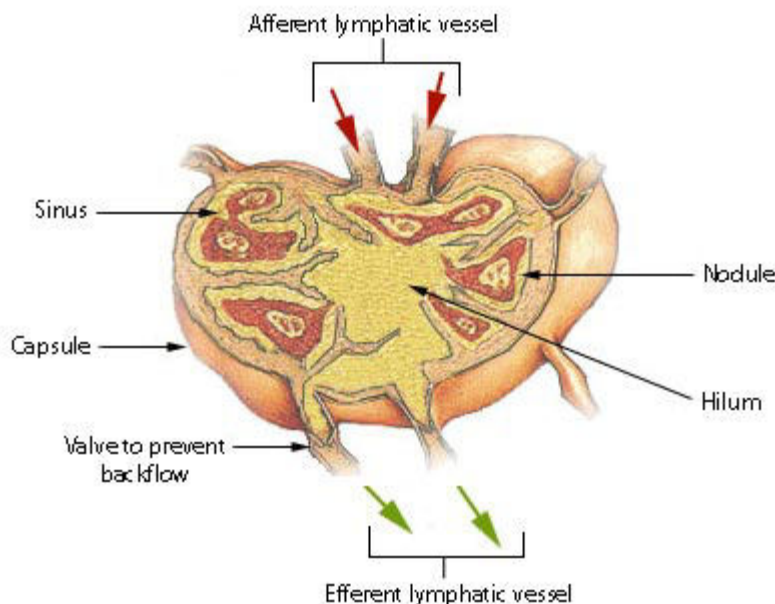
Genetics & Physiology: Organ Systems

Lymphatic System

The **lymphatic system** works in conjunction with the immune system. The main function of the lymphatic system is to keep the body healthy. The tubes that carry lymph fluid throughout the body are the lymphatic vessels. These vessels are structured similarly to the circulatory system's veins. Lymphatic vessels originate as capillaries in spaces between cells. They are found throughout the body, except in avascular tissue, the spleen, bone marrow, or the central nervous system.

Extra tissue fluid surrounds every cell of the body. Excess tissue fluid is called lymph when it is absorbed by the lymphatic vessels. Lymph moves through the lymphatic system, carrying lymphocytes (white blood cells), a few red blood cells, and fat particles. Lymph fluid is prevented from flowing backward by valves; therefore, the system is a one-way track. The lymph is moved by the squeezing action from the movement of arms, legs, and other skeletal muscles. Lymph passes through lymph nodes where it is filtered to remove microbes and impurities.

The lymph nodes are oval-shaped organs that are located in various places along the lymphatic vessels. These nodes are composed of masses of reticular connective tissue and white blood cells. The nodes act as sort of a net to trap bacteria or other harmful substances. As lymph passes through the nodes, it gets strained and cleaned before being returned to the blood stream. When the nodes get full, they become enlarged, which is a sign that they are doing their job of cleansing the blood. The lymph nodes are the only organs that filter lymph. Purified lymph returns to the bloodstream via the circulatory system's veins.



The spleen is a very large lymph node located on the left side of the abdomen, right underneath the diaphragm. It is divided into lobules containing red pulp and white pulp. Red pulp contains red blood cells and white blood cells, including lymphocytes and macrophages. White pulp contains only lymphocytes and macrophages, but no red blood cells.

The spleen serves to filter blood, with the lymphocytes and macrophages filtering out microbes and other foreign material. Excess blood is also stored in the spleen. When the body needs an increase in blood flow, the spleen releases blood.

The thymus gland is located just behind the sternum, overlaying the heart and straddling the trachea. The thymus is large to begin with in life and becomes smaller with age. This gland produces the hormone thymosin, which stimulates the differentiation and maturation of T cells.

The **tonsils** are lymphatic tissue arranged in a ring at the back of the throat. This tissue protects against invasion of inhaled or ingested foreigners. Tonsils "invite infection," which allows for the production of memory cells for later exposure.

Genetics & Physiology: Organ Systems

Immune System Cells

The immune system has a connection with both the skeletal and circulatory systems. White blood cells are created in the red marrow located at the end of long bones, and in the ribs, skull, pelvis, spinal column, clavicles, and sternum. Once created, white blood cells travel throughout the circulatory system.

Specialized cells, called multipotent stem cells, within red bone marrow can potentially differentiate into specific types of blood cells, including white blood cells. There are five types of white blood cells that mount attacks on invaders.

Granular Leukocytes

When these cells are stained, the tiny granules in their cytoplasm can be seen easily.

Basophils release histamines. These cells comprise approximately one percent of all white blood cells in the body.

Eosinophils phagocytize antigens and antibodies before splitting them apart. These cells comprise approximately one to four percent of all white blood cells.

Neutrophils phagocytize bacteria. Forty to seventy percent of all white blood cells are neutrophil cells.

Agranular Leukocytes

The tiny granules in the cytoplasm of agranular leukocytes cannot easily be seen when stained.

Monocytes develop into macrophages. These cells comprise approximately four to eight percent of all white blood cells. Macrophages consume both bacteria and viruses. These cells are involved in the inflammatory, antibody-mediated, and cell-mediated responses. Macrophages play an important role in antigen presentation by engulfing the invader and then putting its antigens on the invaders surface to "present" to T lymphocytes. Macrophages also release proteins that active T cells to release chemicals that will, in turn, transform macrophages into activated macrophages "with a license to kill."

Approximately 20 to 45 percent of all white blood cells are either B or T lymphocytes. B lymphocytes produce antibodies. T lymphocytes mature in the thymus gland upon stimulation from the thymosin hormone. They destroy cells that contain viruses. There are three types of T cells.

Killer T Cells are also known as cytotoxic T cells. These are involved in the cell-mediated response. They directly attack and kill host cells harboring a virus. Killer T cells remove infected cells in order to protect uninfected cells.

Helper T Cells are involved in both the antibody- and cell-mediated responses. These cells produce a compound called interleukin, which stimulates the rapid division of B cells and killer T cells.

Suppressor T Cells prevent any unnecessary immune responses. These cells come into play when the invader has been destroyed or inactivated. They release chemicals that inhibit the helper T cells, and thereby suppress the formation of antibodies and/or killer T cells.

Genetics & Physiology: Organ Systems

Specific Defense Systems

Sometimes the general attack used in the nonspecific immune response is not enough to stop the spread of an invader. When this happens, the host becomes ill and the immune system kicks into overdrive to protect the body. There are three ways the **specific defense system** differs from the nonspecific responses.

- The reaction is systemic — it does not occur in a single place.
(Nonspecific defenses are localized reactions.)
- Responses are specific to the invader.
(The invader type does not matter in nonspecific defenses.)
- A memory of the invader is created, which allows the body to launch a larger attack during the next exposure.

The specific defense response happens after the host has been exposed to the invader. Once exposed the body creates specific antibodies.

Primary Immune Response

This first time encounter with an antigen elicits a primary immune response from lymphocytes and their products. There are two types of primary immune responses.

Antibody-mediated Response

The **antibody-mediated** immune response targets extracellular organisms, such as bacteria, viruses, fungus, protozoa, and other parasites. In order for an antibody to bind to an antigen, the antigen must be present. An antigen cannot be found if the invader is already in one of the body's own cells. The following takes place in a bacterial invasion.

- When bacteria enter the body, their invasion triggers a general inflammatory response and macrophages engulf some of the bacterial cells by phagocytosis. Bacteria are transported via endocytic vesicles into the cytoplasm of the macrophages. The endocytic vesicles fuse with lysosomes and the enzymes digest the bacterial cells without destroying their surface antigens. These antigens are then transported via exocytic vesicles to the macrophages' cell membrane surface. There, the fragments bind to the macrophages' MHC markers, and are not called antigen-MHC complexes.
- Helper T cells make contact with the macrophages and the helper T cells' membrane antigen receptors bind to the macrophage antigen-MHC complexes. The occurrence of this binding causes the macrophages to secrete the compound interleukin that stimulates the helper T cells to secrete their own interleukins. Helper T cell interleukins activate B cells to divide.

- B cells originate and mature in the red bone marrow. While each B cell is maturing, it makes many copies of one type of antibody that no other B cell makes. And each antibody only reacts to one type of antigen. While the B cell is maturing, some of the antibodies it produces become positioned at the cell's surface where they bind to a specific antigen. When a B cell is released into circulation, it is called a virgin B cell, since its antibodies have not yet made contact with an antigen. When a virgin B cell interacts with a specific antigen that matches its antibodies, the B cell is activated. If an activated B cell interacts with the appropriate interleukin-producing helper T cell, the B cell begins dividing quickly, giving rise to a clonal population of identical B cells.
- Part of this clonal population differentiates into plasma cells that secrete thousands of copies of the antibody produced by the initial virgin B cell. These antibodies leave the plasma cells, but do not destroy invaders directly; instead, they attach to the invader's antigens. In doing so, the invader is made visible to macrophages, increasing the chance of attack by the macrophages.
- The other part of the B cell clonal population differentiates into memory B cells, which are used in the secondary immune response.

All B cells have the same genes for coding the amino acids in the chain but each maturing B cell shuffles the genetic code into one of millions of possible combinations, so the sequence of the amino acids is shuffled. This changes the order of the amino acids, which changes the shape of the protein. Because of this ability, B cells can give rise to a virtually unlimited number of shapes of antibodies. So when a virgin B cell comes into contact with "its" antigen, it really just happened to be there. The virgin B cells are not produced because of the invasion; they are already there. It is our genes that determine which specific foreign substances our immune system will be able to recognize and fight.

Cell-mediated Response

The **cell-mediated** immune response deals with viruses and other pathogens that are already in the host cell (intracellular) and hidden from antibodies. In the cell-mediated immune response, the host cells are killed by killer T cells before the pathogens can replicate and spread to the other cells. The following occurs in a viral infection.

- Killer T cells in the thymus produce antigen receptors that become positioned on the surface of the cells. These receptors are not antibodies, yet they are similar.
- The thymus gland releases killer T cells into circulation.
- When a virus infects a cell, viral proteins become associated with the MHC markers on the host cell's surface.
- The receptors on the killer T cells bind to the antigen-MHC complexes of the infected cells or macrophages.
- The killer T cells secrete perforins — a protein that punches holes in the membrane of an infected cell. This kills the infected cell and prevents the reproduction and spread of the virus.

As in the antibody-mediated response, this stimulation of macrophages causes them to produce interleukins, thus stimulating the production of more killer T cells. This again creates a clonal population of killer T-cells — all with the same antigen receptor as the original killer T cell. Some of these clones become memory T cells and become important in the secondary immune response.

When the body rejects an organ transplant or skin graft, killer T cells are one of the reasons why. They recognize the foreign MHC markers on the transplanted organ cells and attack. This is why organ recipients are given immuno-suppressant drugs, which can compromise the body's attempt to mount immune responses to other pathogens.

Secondary Immune Response

The secondary immune response is a response to a previously encountered pathogen. This response can occur in two to three days, is much greater in magnitude than the primary response, and lasts longer. Those B and T cells that were made into memory cells during the primary immune response have been circulating in the body. When a memory cell comes upon the same type of antigen that initiated the primary response, it immediately begins dividing and produces a large clonal population within days. Sometimes the attack commences before the host even knows that it was exposed. This is why you catch any particular cold virus only one time. When people say that they are passing the virus around and keep catching it, they are mistaken. They either never recovered from the first bout, they were exposed to different viruses, or they may have a secondary infection from an opportunistic pathogen.

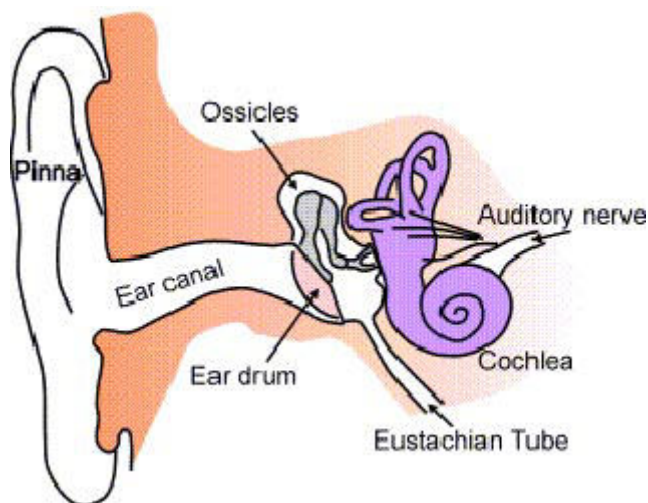
Genetics & Physiology: Organ Systems

Integumentary and Sense Organ System

Ear

Sounds are just vibrations in the air around us. Deep, low-pitched sounds result from slow vibrations, while faster vibrations cause high-pitched sounds. The ear distinguishes the pitch and volume of sounds.

The external auditory meatus (also known as the ear) is the fleshy part that helps to collect sounds and funnel them into the auditory canal. The auditory canal extends into the bones of the head but stops at the eardrum, or **tympanum**. The eardrum is the beginning of the middle ear. Sound waves strike the eardrum and cause it to vibrate. Three small bones behind the eardrum — the **hammer, anvil, and stirrup** — transfer the vibration to a fluid-filled chamber within the inner ear. This chamber, which is shaped like a tightly coiled shell, is the **cochlea**. When the fluid vibrates, tiny hair cells in the cochlea are pushed back and forth, providing stimulation that is turned into nerve impulses. These impulses travel on the auditory nerve to the brain.

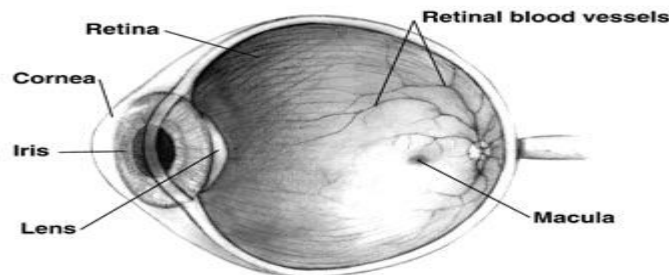


The ears also contain structures for detecting stimuli that make us aware of our movements and allow us to maintain balance. These structures are called semicircular canals.

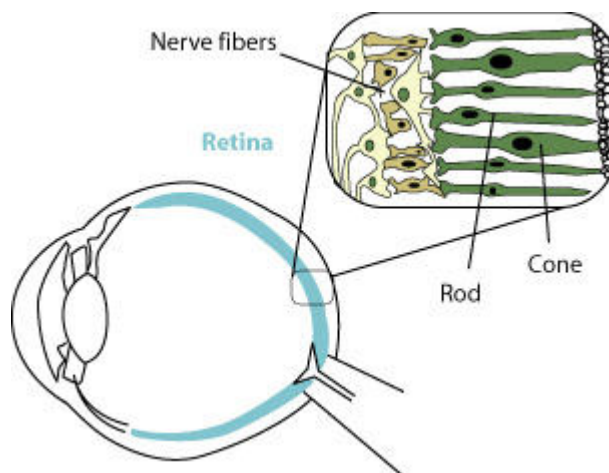
Eye

Each eye is composed of three layers. The outer layer consists of the sclera and the cornea. The **sclera** consists of tough, white connective tissue. It helps maintain the eye's shape and provides a place of attachment for the eye muscles. In the front of the eye, the sclera forms a transparent

layer, the **cornea**. Light will first pass through the cornea, which will focus the light onto the back of the eye. The middle layer of the eye consists of the choroid, ciliary body, and the iris. The **choroid** contains the blood vessels and forms the disk-like iris. The **iris** gives the eye its color and controls the amount of light entering the eye. In the middle of the iris is a small opening, the **pupil**, through which light will enter the eye. Just behind the iris is the **lens**. Small muscles attached to the lens cause it to bend slightly. This bending enables the eye to focus on close and distant objects.



The inner layer of the eye consists of the retina. The retina is the light-sensing portion of the eye. Special photoreceptors are arranged in a layer in the retina. Rods and cones generate nerve impulses, which travel up the optic nerve to the brain. In humans, the field of vision overlaps between the two eyes; each eye sees about one-third of what the other sees. In addition, the two eyes view an object from different angles.



Rods are extremely sensitive to light and can detect various shades of gray, even in dim light. They produce poorly defined images. Cones detect color and are sensitive to edges, so they can detect sharp images.

Question

The outer layer of the eye consists of the

- A choroid, ciliary body, and iris.
- B cochlea.

- C retina.
- D sclera and cornea.

👉 **Answer**

The correct choice is D, the sclera and cornea. Choice A is the middle layer and Choice C is the inner layer. Choice B is part of the ear.

Nose

The sense of smell depends on receptors that detect specific chemicals in the environment. In the nose, receptor cells are located in the upper part of the nasal cavity. These receptors contain cilia that extend into the air passageways of the nose and react to chemicals in the air. This reaction causes impulses to travel up the olfactory nerve to the brain.

Tongue

The sense of taste is also a chemical sense. The organs that detect taste are the taste buds. About 10,000 taste buds are embedded within the surface of the tongue. Taste buds can also be located on the roof of the mouth and on the lips and throat. The taste buds detect four types of chemicals: sugars (sweet), acids (sour), alkaloids (bitter), and metal ions (salty). Generally, the tip of the tongue is sensitive to sweets, while the back of the tongue is sensitive to bitter. The sides of the tongue are sensitive to sour and salty. The taste buds are stimulated when a chemical dissolved in saliva binds to small hairs that protrude from the tip of the taste bud. This generates an impulse that travels to the brain.

Skin

The sense of touch is not found in one particular place. All regions of the skin are sensitive to touch. There are several types of sensory receptors that lie just below the surface of the skin.

- Two respond to heat and cold
- Two respond to touch
- One responds to pain

Sensory receptors for heat and cold are usually scattered. Those for touch are more concentrated in some parts of the body than others. Pain receptors are located throughout the skin.

Question

The largest sense organ is the

- A eye.
- B nose.

C skin.

D ear.

👉Answer

The correct choice is C. The skin has sensory receptors covering the body. Choices A, B, and D are all sense organs smaller than the skin.

Genetics & Physiology: Organ Systems

Review of Vocabulary and Concepts

- The nervous system controls and coordinates essential functions of the human body.
- The endocrine system is a regulatory system like the nervous system. It secretes hormones into the bloodstream, which are targeted to specific organs.
- The digestive system breaks down food into simpler molecules that can be absorbed.
- The circulatory system directs blood; transporting nutrients, wastes, oxygen, carbon dioxide, and hormones. It also distributes heat.
- The respiratory system regulates oxygen intake and carbon dioxide release. It also works in conjunction with the circulatory system.
- The excretory system manages the body's waste. The kidneys do the majority of the work.
- The reproductive system produces new individuals that represent characteristics of both the female and the male.

8. Plants

Genetics & Physiology: Plants

Lesson Objective

We will now cover some of the important aspects of plant biology, culminating in an in depth look at plant physiology.

Previously we covered...

We have reviewed the physiology of animals in depth, going over animal organization and function from cell to tissue to organ to organ system. We will now turn our attention to plants.

Genetics & Physiology: Plants

Classification

Plants have the following characteristics:

- eukaryotic
- multicellular
- cell walls made of cellulose
- roots and shoots
- autotrophic
- reproduce sexually and asexually

Plants are divided into two groups: nonvascular and vascular. Nonvascular plants, which include mosses and liverworts, have simple conducting tissue that does not differentiate into roots, stems, and leaves. Vascular plants have tissue that is differentiated into **roots**, **stems**, and **leaves** to facilitate the movement of water and other materials throughout the body of the plant.

Vascular plants are divided into seedless plants and seed plants. Seedless plants include ferns, horsetails, whisk ferns, and club mosses. These plants live close to water. Over time, as plants developed farther away from water sources, they developed **seeds**. Seeds permit an embryo to survive long periods of time in unfavorable conditions and to disperse an embryo from its parent plant. Seed plants are further divided into gymnosperms and angiosperms. Most living gymnosperms are conifers, producing their seeds in cones. Some examples are: pine, cedar, cypress, redwood, spruce, and fir trees. Angiosperms, such as roses, daisies, grasses, and sunflowers, reproduce with flowers. The flowers promote pollination. Finally, angiosperms are divided into **monocots** and **dicots**. This distinction is based on the number of **cotyledons**, or seed leaves on the plant embryo. Monocots evolved later than dicots.

	Monocots	Dicots
Seed cotyledons	1	2
Roots	Adventitious	Develop from radicle
Stem vascular bundle arrangement	Scattered	In a ring
Leaf venation	Parallel	Reticulated
Secondary growth	Absent	Often present
Flower parts	Multiples of three	Multiples of four or five
Pollen	Single furrow or pore	Three furrows or pores

Question

The first land plants, still alive today, are

- A gymnosperms.
- B angiosperms.
- C algae.
- D ferns.

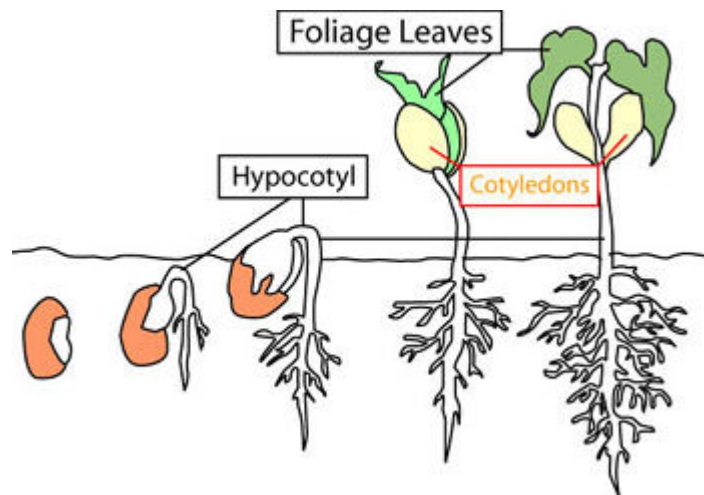
👉 **Answer**

The correct answer is C, because A and B are seed plants, which came much later. Choice D is also incorrect because ferns also came much later, but between algae and seed plants. The first land plants were algae.

Genetics & Physiology: Plants

Flowering Plants: Seeds

A **seed** is a sporophyte plant embryo surrounded by a protective coat. The parts of the embryo are named according to their point of attachment to the **cotyledons**. The **epicotyl** is the stem above the cotyledon, and develops into the plant stem. Below the cotyledon is the **hypocotyl**, which has a region, called the **radicle**, at its base. The radicle develops into the plant's roots. The rest of the embryo consists of the food supply.

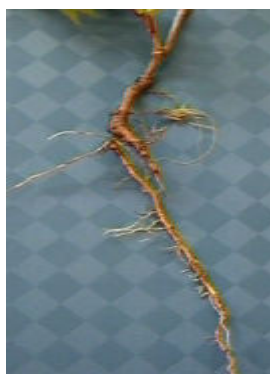


Genetics & Physiology: Plants

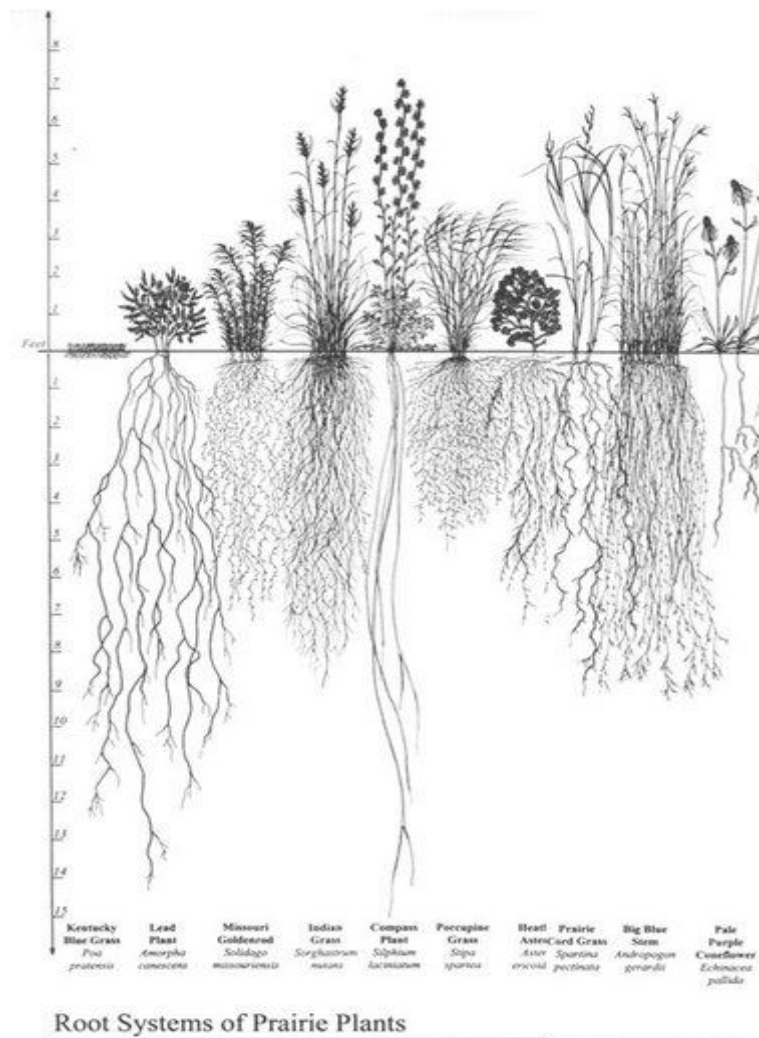
Flowering Plants: Roots

Roots have a simple structure. They lack external features and **pith**. The **vascular bundles** are at the center of the root. Epidermal cells cover the end of the root and those near the root tip produce slender projections called root hairs. Root hairs increase the surface area of the root and absorb water and minerals from the soil. There are three types of root systems:

A taproot system has a large central root called a taproot. The roots that branch from the taproot are usually much smaller. Most dicots have a taproot system. This root system can store sugars or starches. Some examples include carrots, radishes, beets, dandelions, oak trees, and hickory trees.



A fibrous root system is highly branched with roots that are about the same size. Most monocots have fibrous root systems. These systems are important in holding topsoil so that rain does not wash it away. Some examples include grasses and onions.



Adventitious roots grow above ground and provide support, as well as absorbing water. Two types of this root system are prop roots and aerial roots. Some examples include corn, mangroves, and orchids.



Question

A primary root that grows longer and thicker is

- A root hair.
- B a tap root.
- C a fibrous root.
- D an adventitious root.

Answer

The correct answer is B. A taproot is long and thick with shorter roots that branch off it. Choice A refers to the slender projections off root tips. Choice C and D are types of root systems.

Genetics & Physiology: Plants

Flowering Plants: Stems

Stems vary in size and shape from one plant species to another but all stems have two basic functions: holding leaves up in the sunlight and conducting various substances between roots and leaves. In addition, some stems store water and nutrients.

Stems have four basic types of tissue:

- parenchyma (pith)
- vascular tissue (**xylem** and **phloem**)
- **cambium** tissue (vascular **cambium** and cork cambium)
- cork tissue (outer bark).

Vascular tissue in stems conducts water, nutrients, and other materials throughout the plant. The arrangement of this tissue in the stem differs in monocots and dicots. In monocots vascular tissue is scattered in bundles throughout the stem. In dicots it is arranged in a ring.

The places where leaves attach to a stem are called nodes. Internodes are the areas of stem between the nodes. Also at the nodes are lateral buds that grow into branches of the stem. There are two main types of stems: **herbaceous** and **woody**.

Herbaceous stems are flexible, relatively soft, and usually green in color.



Woody stems are stiff, contain layers of wood, and usually are not green in color.



Some stems are modified for other functions and include rhizomes, tubers, and bulbs.

Rhizomes are thick, fleshy, creeping stems that grow either alongside or beneath the surface of the ground. When winter frost kills the above-ground parts of plants, the rhizomes survive to grow again

the following springs. Examples of plants with rhizomes are irises, canna lilies and some species of grasses.



Tubers are modified underground stems that are swollen with stored food, usually starch. The most common example of a tuber is the potato.



Bulbs have underground stems. The stem at the center is small. Most of the food stored is located in layers of leaves that wrap around and protect the stem. Examples of plants with bulbs include daffodils and tulips.



Question

Which of the following is a modified stem?

- A Cactus spine
- B Pine needle
- C Irish potato
- D Carrot

Answer

C is the correct answer, because the potato has a modified stem called a tuber. Choices A and B are modified leaves. Choice D is a modified root.

Genetics & Physiology: Plants

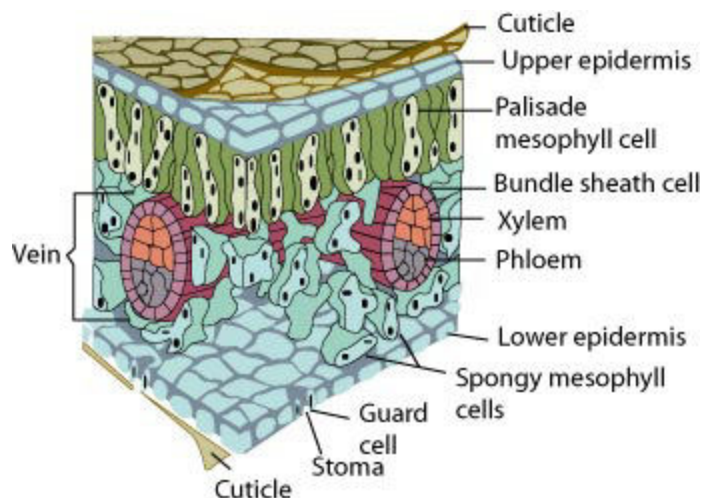
Flowering Plants: Leaves

The leaves of a plant are the world's most important manufacturers of food. Most leaves have a basic structure of a large, flattened surface called the blade that is attached to the stem by a **petiole**.

Leaves with a single blade and petiole are simple leaves. Compound leaves have several blades, or leaflets.

Veins, which are strands of xylem and phloem tissue, run along the leaves.

Leaves are covered by a layer of tough epidermal cells and a waxy cuticle. Within the epidermis are small openings called **stomata**, which are formed by two specialized epidermal cells called **guard cells**. Gas exchange takes place through the stomata.



Most leaf tissue is composed of specialized cells called **mesophyll**. This tissue contains chloroplasts and performs most of the plant's photosynthesis. The mesophyll is divided into two layers. The top layer consists of rows of closely packed, columnar cells and is called the **palisade layer**. The lower layer has loosely packed, spherical cells and is called the **spongy layer**.

Some plants have modified leaves specialized for protection, water conservation, climbing, and reproduction. Remember that most plant parts are basically modified leaves.

Question

Openings that permit gases to enter and leave the leaf are called

- A cuticles.
- B stomata.
- C palisade cells.
- D chloroplasts.

✓Answer

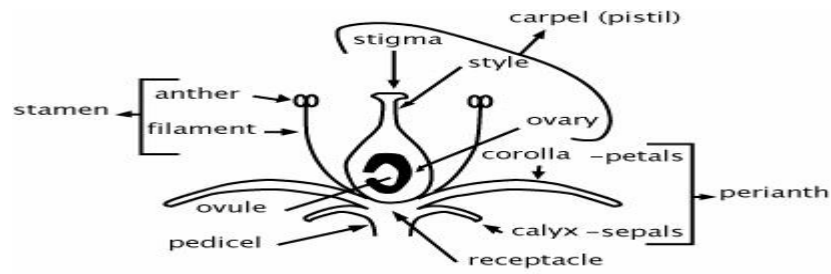
The correct answer is B. Stomata are formed from guard cells and control gas exchange in leaves.

Genetics & Physiology: Plants

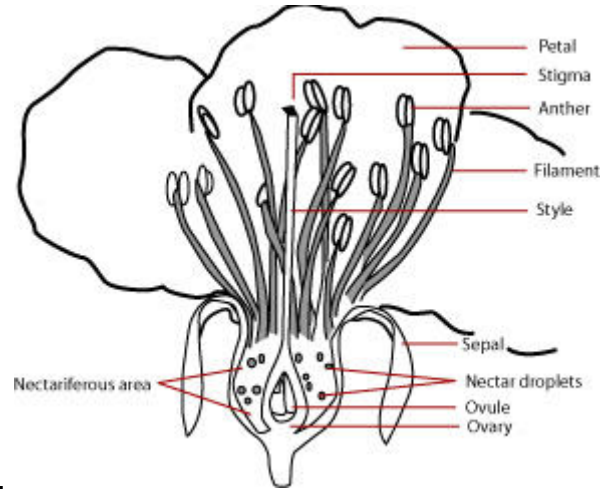
Flowering Plants: Flowers

Flowers are the reproductive organs of angiosperms and usually produce both male and female gametes. Flowers are actually miniature stems that produce four kinds of specialized leaves: sepals, petals, stamens, and carpels. These leaves are arranged in circles and have been modified to serve different purposes.

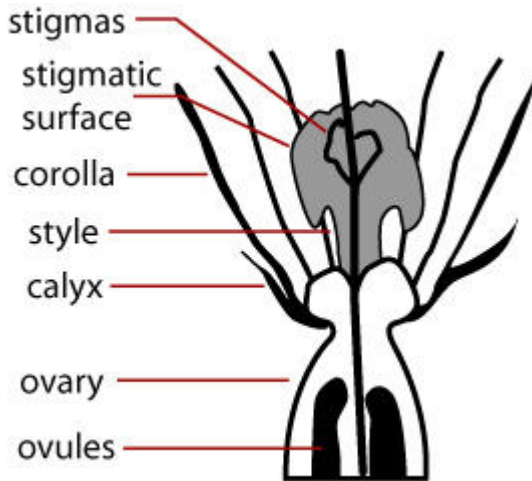
- **Sepals** are the outermost circle of flower parts. They are green and actually resemble leaves. Sepals enclose a flower bud before it opens and protect the developing flower. The sepals held together form the **calyx**.
- **Petals** are the second circle of flower parts. They are inside the sepals and are usually brightly colored. The petals together form the corolla. The corolla often produces bright pigments and fragrances to attract pollinators.
- **Stamens** are the first circle of fertile leaves. Each stamen has a long, thin filament that supports an **anther**. The anthers contain pollen grains, which are the male gametes.
- **Carpels** are the centermost circle of flower parts and are produced from fertile leaves that are rolled up. One or more carpels form the **pistil**, which consists of a base called the **ovary**, a slender stalk called the **style**, and a swollen, sticky tip called the **stigma**. The ovaries contain **ovules**, which are the female gametes. The thickened part of the ovary wall that holds the seeds is called the fruit.



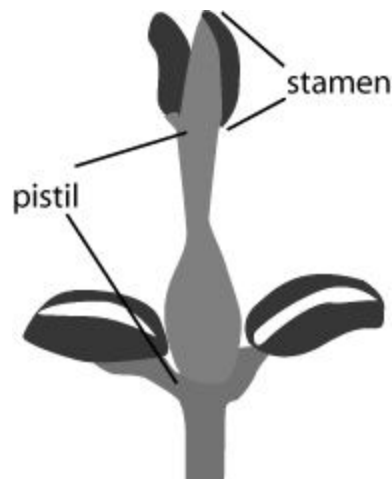
Flowers may or may not have all four parts, which classifies flowers into one of four categories:



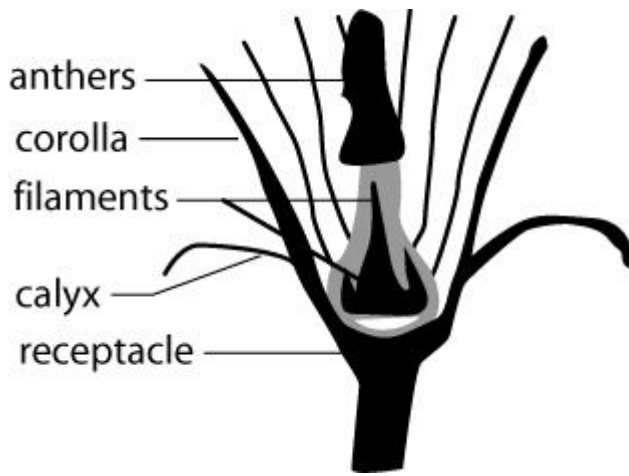
Complete flowers have all four whorls of leaves.



Incomplete flowers lack any one of the four whorls of leaves.



Perfect flowers have both stamens and pistils.



Imperfect flowers lack either stamens or pistils.

Question

Flower parts most involved with attracting pollinators are the

- A pistils.
- B seeds.
- C anthers.
- D petals.

Answer

The correct answer is D, because the petals are usually brightly colored and have a fragrance to attract pollinators. Choice A is a female flower part and choice C is a male flower part, both of which have no qualities for attracting pollinators. Choice B, seeds, is the product of fertilization — long after pollinators are gone.

9. Plant Growth

Genetics & Physiology: Plant Growth

Lesson Objective

In this lesson we will review plant growth, covering fertilization, cell division, secondary growth, and, finally, photosynthesis.

Previously we covered...

We looked at some of the important aspects of

Genetics & Physiology: Plant growth

Beginning and Primary Growth

A plant begins life after double fertilization occurs within the flower's ovary. As cells divide by mitosis, an embryo and **endosperm** are formed. Then the layers of tissue surrounding the embryo and endosperm toughen and become impermeable to water and oxygen. This causes the embryo to stop growing and start forming a mature seed.

At some point, the plant embryo will begin growing again. This is called **germination**. Before germination can occur at all, water and oxygen must penetrate the seed coat. This results in the breaking of the seed coat. Many plants require heat or cold to germinate; still others require exposure to light. The first visible evidence of this process is the emergence of the embryonic root. Then the shoot will elongate and emerge from the soil. The leaves will then push through, unfurl, and begin to photosynthesize. Eventually the food supply stored in the cotyledons is used up, causing them to shrivel up and fall off.

Genetics & Physiology: Plant growth

Plants grow by cell division that occurs in **meristems** located at the tips of the shoots and roots. This type of growth is called primary growth. It occurs in apical meristems, which are located at the tips of stems and roots, just behind the root cap. Primary growth also pushes roots through the soil. The root tip is covered by a root cap. Growth in length is concentrated near the root tip where meristems give rise to primary tissues:

- Protoderm gives rise to the epidermis.
- Procambium gives rise to the stele, which is where the xylem and phloem develop.
- Ground meristems give rise to the ground tissue system; ground tissue fills the region between the stele and the epidermis; and ground tissues store food.

Question

The first sign of germination of a bean seed is the emergence of the embryo's

- A hooked shoot
- B protected shoot
- C root
- D cotyledons

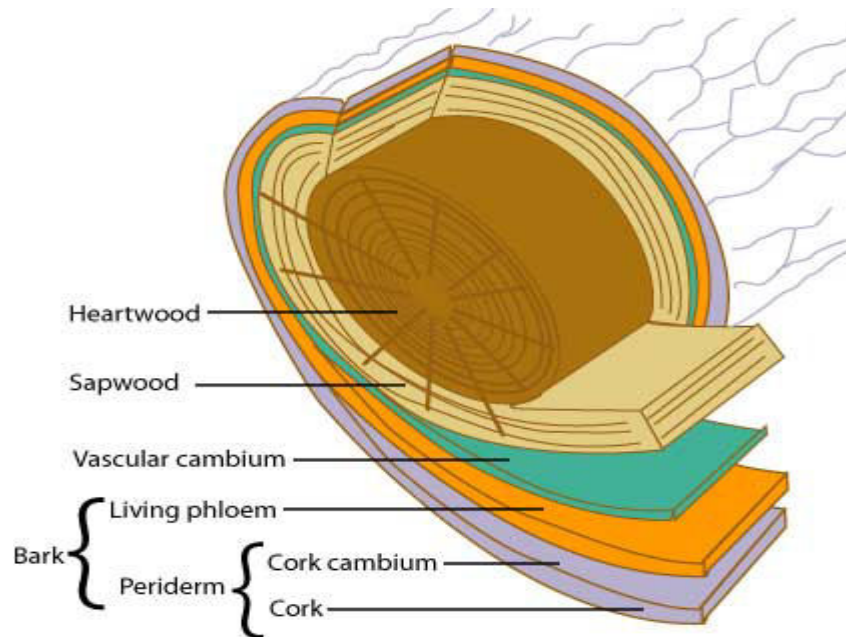
Answer

The correct answer is C. The embryonic root emerges from the seed first and is called the radical.

Genetics & Physiology: Plant growth

Secondary Growth

Most plants undergo secondary growth, in which the plant increases in width as well as length. The tissues that result from this growth are secondary tissues. The effects of secondary growth are most dramatic in woody plants. Two lateral meristems function in this process: vascular cambium and cork cambium. Cell division in the lateral meristems adds layers of new cells around the outside of the plant's body.



The vascular cambium produces xylem (wood) and phloem. This layer is just beneath the bark. Xylem is produced in the interior of the stem and phloem is produced in the exterior. The new ring of xylem tissue formed every growing season and the older xylem become the wood of trees. Older xylem layers are dead, yet can still conduct water for several years. The phloem layer is never as thick as the xylem layer. Phloem tissue forms the inner half of tree bark.

The cork cambium lies within the bark of a woody stem. It produces the cork cells of the outer bark. Cork tissue functions as a barrier that helps protect the stem from physical damage and pathogens. The layers of cork tissue and the cork cambium make up the periderm, which is the protective coat of the secondary plant body that replaces the epidermis of the primary plant body.

The lateral meristems also develop and produce secondary growth in the roots. The vascular cambium forms within the stele and produces xylem and phloem. As the stele grows, the epidermis is split and shed. A cork cambium forms from the pericycle of the stele and produces periderm, which will become the secondary dermal tissue.

Question

Cell division that results in the increased width of a tree occurs in the

- A lateral meristems.

- B apical meristems.
- C primary tissues.
- D sieve tube vessels.

👉Answer

The correct answer is A. Cell division in the lateral meristems occurs in secondary growth which increases the length and width of a tree.

Genetics & Physiology: Plant growth

Growth Hormones

Hormones control the division, growth, maturation, and differentiation of plant cells. They are manufactured primarily in apical meristems, in young leaves, and in growing seeds and developing fruits. Plant hormones control a plant's branching pattern, the rate at which its stems elongate, and its responses to environmental conditions.

Auxin in the stems causes the stem to grow toward light and away from the pull of gravity. High concentrations of auxin stimulate young stem cells to elongate. Auxin in the roots causes the roots to grow away from light and toward the pull of gravity. High concentrations of auxin inhibit root cell elongation. Auxin also can cause cell division in meristematic regions to stop or start. Finally, the high concentration of auxin produced by the apical meristem inhibits the growth of lateral buds near the tip of the shoot.

Cytokinins are manufactured by the growing roots. They stimulate cell division and cause dormant seeds to sprout. Several of the effects produced by cytokinins are the opposite of effects produced by auxins.

Gibberellin is manufactured by all higher plants. It stimulates growth in leaves and stems, but not in the roots. In stems, gibberellin stimulates cell elongation and cell division. It can also signal seeds to break from dormancy and begin germination.

Question

A chemical that directs the growth of a plant is called a (an)

- A apical meristem.
- B hormone.
- C androstrone.

D citric acid.

👉Answer

The correct answer is B. All the other choices are not plant growth chemicals.

Genetics & Physiology: Plant growth

Photosynthesis

Plants convert the energy of sunlight into the energy in the chemical bonds of carbohydrates (sugars and starches) in a process called photosynthesis. The overall process can be summarized by the following chemical equation:



Photosynthesis occurs primarily within leaves. Cells in the leaves contain chloroplasts, which contain chlorophyll. Chlorophyll is the light absorbing substance needed for photosynthesis.

Photosynthesis requires:

- Sunlight
- Pigments
- Carbon dioxide
- Water
- Energy storing compounds

The stages of photosynthesis are:

- Energy is captured from sunlight.
- Light energy is converted to chemical energy.
- Chemical energy powers the synthesis of organic molecules, using carbon from carbon dioxide.

Question

Photosynthesis produces

- A carbon dioxide.
- B water.
- C alcohol.
- D glucose.

🟩Answer

The correct answer is D, because the products of photosynthesis are glucose and oxygen.

Genetics & Physiology: Plant growth

Light Reactions

The process of photosynthesis is divided into two parts: **light reactions** and **dark reactions**. The light reactions require light. In these reactions, the energy of sunlight is captured and used to make energy storing compounds. The light reactions occur in the photosynthetic membranes of chloroplasts. The light reactions can be divided into four basic processes: light absorption, electron transport, oxygen production, and ATP formation. These processes are closely linked and dependent on each other.

- **Light Absorption**

The photosynthetic membrane contains clusters of pigment, or **photosystems**. There are two photosystems in green plants. Each one contains hundreds of chlorophyll molecules, as well as other pigments. The other pigments absorb light in the regions of the spectrum that chlorophyll does not. This causes electrons in pigment molecules to be raised to an excited state. Only a special pair of chlorophyll molecules can process the light energy.

- **Electron Transport**

The high-energy electrons produced in the previous process travel from a special pair of chlorophyll molecules to an adjacent molecule called an electron carrier. This begins electron transport. The high-energy electrons are transferred along a series of electron-carrier molecules in the photosynthetic membrane. At the end of the chain, an enzyme passes the high-energy electrons to an electron carrier called **NADP+**, which is converted into NADPH. Adding a pair of electrons to this electron carrier requires energy. The energy and electrons stored in the bonds of NADPH will be used later on in the overall process.

- **Oxygen Production**

As the light continues to shine, the photosynthetic membrane contains a system that provides new electrons to chlorophyll to replace the ones that converted to NADPH. These electrons are taken from water. Four electrons are removed from two water molecules, leaving four hydrogen ions and two oxygen atoms. The two oxygen atoms combine to form oxygen gas that is eventually released into the air.

- **ATP Formation**

The hydrogen ions left behind when water is “split” are released into the photosynthetic membrane. In addition, more hydrogen ions are pumped across the membrane as electrons are passed from chlorophyll to NADP+. Eventually, an enzyme attaches a phosphate molecule to ADP, forming ATP. This is the second way in which the energy of sunlight is trapped in chemical form. These energy storing molecules will be converted to a more convenient form during the dark reactions.

Question

The oxygen that results from photosynthesis comes directly from the

- A splitting of carbon dioxide molecules by the Calvin cycle.

- B splitting of water molecules to provide electrons for photosystem II.
- C action of proton pumps in the electron transport chain.
- D absorption of photons by carotenoids in the photosystems.

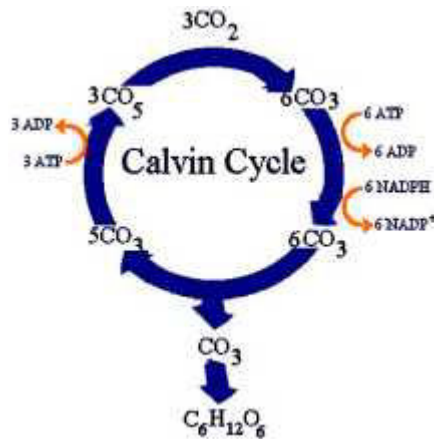
☑Answer

B is correct. After the water molecules are split, the resulting 2 oxygen atoms combine to form oxygen gas.

Genetics & Physiology: Plant growth

Dark Reactions

The dark reactions generally take place in sunlight; however, light does not play a role in the dark reactions. In this part of photosynthesis, carbon dioxide is used to make a complex organic molecule. The dark reactions form a cycle, or circular series of reactions. The dark reactions are also known as the **Calvin cycle**.



The Calvin cycle employs a complex battery of enzymes that are found in the stroma>> of a chloroplast. Photosynthesis itself usually occurs in the thylakoid membranes>> of a chloroplast. A total of six carbon dioxide molecules must enter the Calvin cycle to produce one six-carbon sugar molecule. The Calvin cycle takes place in five steps.

- The cycle begins when a carbon atom from a CO_2 molecule is added to a five-carbon molecule (the starting material).
- The resulting six-carbon molecule is unstable and immediately splits, forming two three-carbon molecules. These first two steps tend to be relatively slow. In order to compensate, the chloroplast has an enzyme that catalyzes the reaction.
- Then energy in the form of a phosphate group from ATP is added to the three-carbon molecules, and they are reduced by the addition of hydrogen from NADPH.
- The reduced three-carbon molecules may combine to make glucose, a six-carbon sugar, or may be used to make other organic molecules.

- Most of the reduced three-carbon molecules are used to regenerate the five-carbon starting material, thus completing the cycle.

Finally, photosynthesis and another process called cellular respiration form a continuous cycle, because the products of one process are the starting materials for the other.

Question

Which of these is produced by the dark reactions?

- A Oxygen
- B Water
- C ATP
- D Glucose

Answer

D is the correct answer, because the final end product of the dark reaction is glucose.

Further Reading in Genetics and Physiology

Biology: Genetics & Physiology: Further Reading

Classical Genetics & Molecular Biology

DNA: The Secret of Life (James D. Watson, Andrew Berry): 2003

The Way of the Cell: Molecules, Organisms and the Order of Life (Franklin M. Harold): 2003

Instant Notes in Molecular Biology (Instant Notes Series) (A. G. McLennan, et al): 2004

Physiology

Physiology (Robert M. Berne, Editor, et. al.): 2004

Physiology (Board Review Series) (Linda S. Costanzo): 2003

Anatomy and Physiology for Dummies (Donna Rae Siegfried): 2002

Plant Physiology

Plant Physiology (Lincoln Taiz, Eduardo Zeiger): 2002

Plants and Microclimate : A Quantitative Approach to Plant Physiology (H. G. Jones): 1992

Chapter: Evolution & Ecology

1. Evolution

Evolution & Ecology: Evolution

Lesson Objective

This lesson will concentrate on the theory of evolution, the foundation for all the biological sciences. We will cover the principle components and forces of evolution. As Theo Dobzhansky once said, "Nothing in biology makes sense, except in the light of evolution."

Previously we covered...

We have reviewed classical genetics, molecular biology, and the basics of plant and animal physiology, to set the background for topics to follow.

Evolution & Ecology: Evolution

Microevolution

Microevolution is a concept that refers to any evolutionary change below the level of species, the changes in gene frequency within a population or a species, and the resulting effects on the phenotype of organisms that comprise that population or species. Microevolution occurs within a short timescale, often allowing direct observation as it is happening. Processes that affect changes in a population include natural selection, mutation, genetic drift and migration.

Natural selection, mutation, genetic drift and migration

Both Charles Darwin and Alfred Russel Wallace, independently and together, deduced the theory of evolution that has become the cornerstone of all biological sciences. Although we now have a new understanding of the genetic mechanics of evolution, the theory developed by Wallace and Darwin remains one of the most important human achievements and has undoubtedly changed the world. It is crucial to our understanding of evolution to review the basics and then come back to them in more depth.

Selection

One of the most important mechanisms of evolution is natural selection, where inheritable biological traits subject to selection are passed on to the next generation in proportion to how strongly they affect an organism's survival and/or reproduction. Individuals with advantageous traits tend to be more successful reproductively than other individuals without the advantageous trait (by definition). Selection increases the frequency of these traits in a population through time, because offspring inherit traits from their parents (who produced more offspring because of the trait). Under strong selection, adaptive traits can become fixed in a population or species.

How and why selection takes place is contingent on many conditions including limited resources (e.g., food, habitat, mates), negative stressors (e.g., predators, pathogens, competition, ambient conditions), and many other factors. Natural selection is what occurs in nature, but there are other types of selection as well. Breeding of domesticated plants and animals is called artificial selection and there are ecological, directional, disruptive, sexual, and stabilizing selections that are also very important. Selection occurs when individuals in a population have at least a threshold level of variation in traits affecting survival or reproduction. Absence of variation or variation that does not impact survival or reproduction effectively precludes selection.

A considerable misconception is that selection guarantees advantageous traits will become prevalent within a population. This is not necessarily true because there are many other factors that balance evolutionary forces and effects. One of the other forces of evolution that often balances effects of selection is genetic drift. Through simple chance of genetic drift, traits that would otherwise be positively selected for can become less common or disappear entirely from a population.

Mutation

Mutations are one of the other driving forces of evolution, where deleterious mutations are usually deleted from the gene pool by natural selection, and more advantageous mutations tend to accumulate. The process of mutation involves any permanent change to DNA or RNA and is caused by many factors. Copying errors that occur during cell division, exposure to radiation, chemicals, or certain bacteria and viruses, can also occur during regular cellular processes like meiosis or mitosis. The vast majority of mutations have no real effect on the organism.

There are many types of mutations that take place and they are classified into broad groups. For example, mutations that affect one or just a few nucleotides are some of the most common. Point mutations simply exchange one nucleotide for another. Insertions augment the DNA or RNA by adding one or more extra nucleotides. Insertions often alter the proteins produced. Deletions remove one or more nucleotides and usually alter the protein that is coded by the gene.

Other mutations can affect nucleotides, chromosomal structure, and include amplifications and duplications that lead to multiple copies of chromosome regions. In contrast, deletions of large chunks of chromosomes lead to loss of multiple genes, and sometimes can affect other chromosomes as well. There are also chromosomal translocations which mix up DNA from different chromosomes, or rather chromosome inversions that switch the orientation of different parts of a chromosome and rearrange chromosomal proximity. All of these can also effectively disrupt heterozygosity with the loss of one (of a pair) allele, effectively making the new genetics homozygous. Another way to categorize mutations is by how they change the genetic functioning or the expression of the gene product.

Genetic Drift

Genetic drift is a statistical stochastic factor in biological evolution, where traits in a population (not under selection) can change over time primarily caused by randomness and chance. Basically, a random sampling of traits that do not affect reproduction or survival can become fixed or removed from a population. Because genes of every generation are not simply copied directly from the reproductively successful ancestors (they are a sample), there are statistical anomalies. Genetic drift is a cumulative effect of this sampling error on the neutral allele frequencies in the population over time. Like selection, genetic drift acts on populations, changing allele frequencies and traits. Because it is an artifact of sampling, drift is most important in small populations and can result in changes that are not adaptive.

Drift and selection

Genetic drift and natural selection are not mutually exclusive and they often occur simultaneously. Alleles are affected by drift and selection in varying ways and depending on many factors. In larger populations, for example, genetic drift would occur only slowly, and even extremely weak selection affects allele frequencies in a much stronger and faster manner. On the other hand, in smaller populations, drift can be much more pervasive. When this happens, selection may have no effect on changes in allele frequency because it is overshadowed by drift and its random sampling of alleles. At the logical extreme, in a bottleneck event where the population shrinks quickly and then

regains its former numbers, genetic drift can change allele frequencies that occur independently of selection thereby eliminating many beneficial adaptations or inherent variability.

Migration

Migration (also known as gene flow) is the physical movement of genes from one population to another via individual organisms that are able to breed in a new population. Migration in or out of populations can drastically change in allele frequencies and the number of individuals with certain traits). There are a number of factors that can affect gene flow among and between populations. One of the most important is simple mobility; an individual's mobility tends to give it greater gene flow potential.

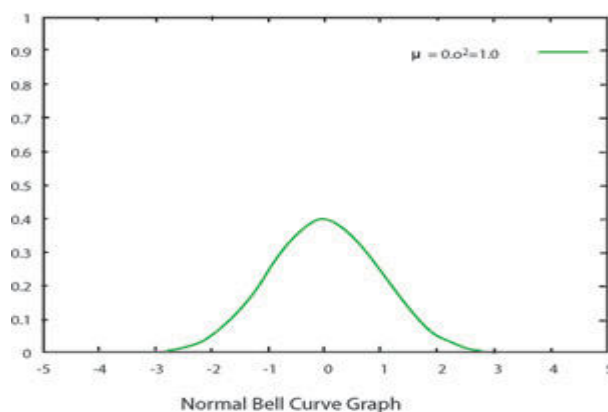
Today we categorize four main fundamental forces that allow evolution to happen: migration, mutation, natural selection, and genetic drift. While all of these forces are important, central to this historical theory is the concept of natural selection.

Evolution & Ecology: Evolution

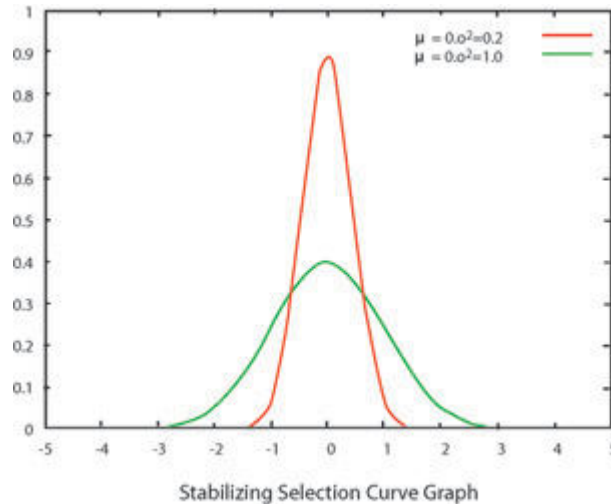
Natural selection describes the process of reproductive success in organisms best adapted for their environment. Darwin and Wallace developed this concept after observing life in the tropical rain forests of the world. Darwin's examples were brought to life dramatically by his illustrations of the finches on the Galapagos Islands. On the islands, he identified 13 species of finches. This intrigued him since he had observed only a single finch species living on mainland South America.

Darwin observed that the Galapagos finches had a wide variety of beaks and although they broadly overlapped in habitat use, they seemed to spend most of their time in completely different microhabitats. The beaks seemed adapted to different feeding habits in the diverse environmental conditions of the different microhabitats. Claw-like beaks enabled finches to eat buds and fruit. Extended beaks enabled finches to extract grubs from the ground. Heavy beaks provided the means for crushing and consuming seeds. Darwin surmised that over time, finches' beaks evolved in order to be best suited for diverse functions, feeding on different foods. The finches with better adaptations to their environment had survived and reproduced. They had passed along their adaptations to offspring who were also more successful.

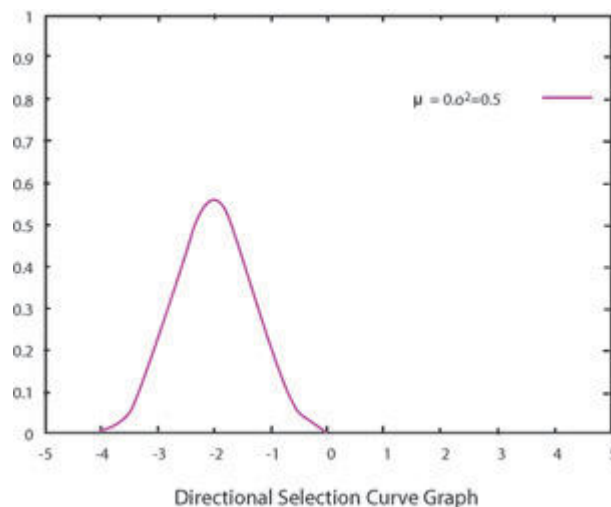
Scientists have identified many types of natural selection. Without any outside selective pressure on organisms, population traits will vary. For example, the height of adult sunflower plants varies around a mean. While most sunflower plants are around average height, others are extremely tall or extremely short. A normal bell curve reflects this trait distribution.



Stabilizing selection occurs when selective pressures limit variation at the extremes of the population. With the sunflower example, taller plants might not survive windy conditions, whereas shorter individuals might not survive excessive drought. In this case, the more average-height plants would become more numerous than the two extremes. As the range of traits decreases in the process of stabilizing selection, genetic diversity for that trait also decreases. Most good examples of stabilizing selection are morphological traits that seem to balance biomechanical performance and exact some sort of cost (like increased predation or caloric expenditure).

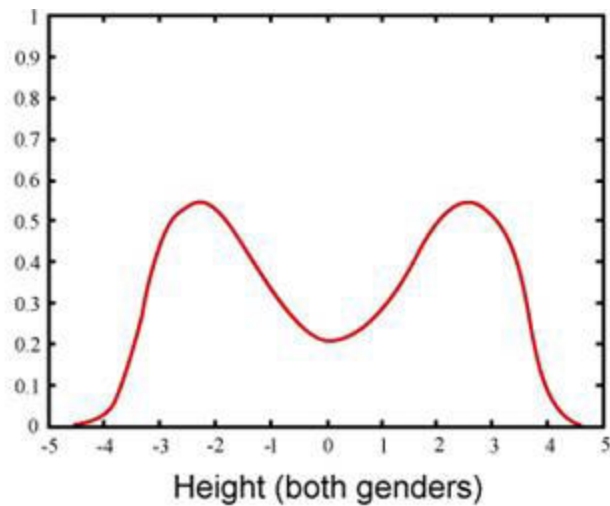


A giraffe's long neck serves as an example of **directional selection**. At some time in the past, animals with short necks came under selection pressure due to competition for limited resources (leaves). After all the low leaves were eaten, animals with shorter necks were less able to reach the leafy food while animals with longer necks could reach the leaves higher up. Over time, neck length shifted in favor of individuals with longer necks because of this advantage. Therefore, one extreme of the trait distribution (shorter necks) is selected against in the process of directional selection. The trait distribution shifts to the other extreme. Just like with all forms of selection, as the range of traits decreases, genetic diversity for that trait also decreases.



Selection pressures of **disruptive selection** act in the middle of the trait distribution. Let's use an example of birds with a normal distribution of beak sizes that experiences severe declines in food availability. After a single generation, the birds in the middle of the normal curve for beak size have starved. The birds underwent extreme selection either for beaks that could fit into the tiniest nooks of a plant's fruit to extract seeds or for beaks that were large enough to crack open nuts, for example.

Those with the medium sized beaks were both unable to extract the seeds from the tiny fruits and were unable to crack open the nuts that were available to them. This is another type of selection that is theoretically possible.



Darwin had other ideas about natural selection. He thought that mate shortages produced selection pressure on species resulting in the evolution of **sexually dimorphic** characteristics. Previously described forms of selection have focused on the ability to survive and reproduce. Sexual selection concentrates on the mating part. Traits that improve an individual's ability to locate, attract, mate with, or fight for access to a mate are the keys to sexual selection. Sexual dimorphism is defined as a difference in form between the sexes of a given species and is a sure sign of sexual selection.

Many species display sexual dimorphism. Male mammals are frequently larger and more colorful than females. In contrast, female insects and amphibians are often larger because they need a large body size to support egg production and carrying. Other types of sexual dimorphism include horns, antlers, eye size, coloration, and body weaponry used to acquire access to females.

The mating system of a species can affect sexual dimorphism. For primates, species that are monogamous, smaller in size, and arboreal tend to be less sexually dimorphic compared to those that are polygamous, larger in size, and terrestrial. In societal groups such as sea lions where a single male breeds with a harem of females, body and canine size are important defensive tools. On the other hand, in multi-male social groups, intelligence and communication ability are more important than sheer body size. These social groups often display cooperation to defeat dominant individuals and improve access to mating for a small group.

Sexual dimorphism, like any type of advertisement, can come with some risks. Although a brightly colored, male Northern Cardinal may attract a female quicker than dull colored competitor, it will also have higher visibility to predators. Coloration may be a competitive advantage for mating success and a survival disadvantage at the same time. White-tailed deer provide another example. The male expends significant energy growing a rack of antlers for mating season. The male burns more calories carrying the rack throughout breeding season. Antlers provide the needed weaponry to improve access to breeding. In the bigger evolutionary picture, an individual's reproductive success is more important than longevity. If the individual is successful in attracting, fighting for, and mating with a female, it will be passing on those adaptive characteristics to the next generation even if it only breeds for a single season.

Evolution & Ecology: Evolution

Population Genetics

A **gene** is a physical unit of heredity passed on from one generation to the next. The details of passing on genetic information happen at the **allele** level. An allele is one variant of a gene. Located at a specific spot on a chromosome, alleles are responsible for characteristics such as hair color, eye color, blood type and many other inherited traits. Expressed traits represent a dominant allele while an individual may also carry an unexpressed or recessive trait.

From one generation to the next, allele diversity shifts and changes. A large, viable population of a species is able to adapt to changing conditions through genetic variability. The more alleles present, the greater the variation the building block of evolution and adaptation. Loss of genetic variation reduces a population's sustainability. Genetic drift is the result of random sampling that is exacerbated by geographic isolation, changes in migration, and the establishment of new populations (founder effect).

Punnett Squares can be used to graphically show how genetic variability in breeding pairs affects their offspring. The Punnett square shown below reflects breeding pairs of adults with the heterozygous gene (Ss). Offspring of these adults display **genotypes** (SS), (Ss) and (ss) in different proportions. The genotypes reflect all possible combinations of alleles based on the parental traits. While individual breeding pairs might not produce all of the genotypes across these percentages, a large population size could compensate for missing allele distributions.

	S	S
S	SS	SS
s	Ss	Ss

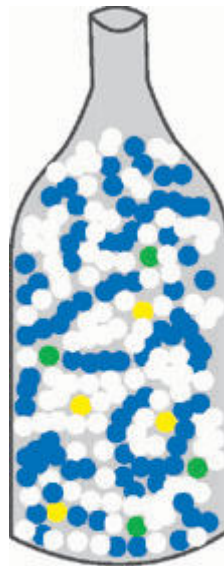
Under the same heterozygous breeding conditions, a very small population of adults could have significantly different results. If there were no offspring born with the (ss) genotype, the genetic information could be lost. Without a population size to compensate for individual reproductive differences genetic drift would begin. The small population could lose the (ss) genotype within a single generation.

	S	s
S	SS	Ss
s	Ss	ss

Founded in the late 1700's the Amish communities of North America are facing some consequences of genetic drift. From microcephaly to dwarfism to other inherited disorders, Amish families have very little genetic variation from the individuals who were their founders several generations ago. Amish people are an example of genetic drift and are part of another small population effect called the **founder effect**. A small number of individuals migrated to North America to establish the Amish community. The migrants were representatives of much larger population in Europe. However, they became geographically isolated. They isolated themselves further by being a closed breeding group. New genetic information has not been added. Although members of a larger population, their limited

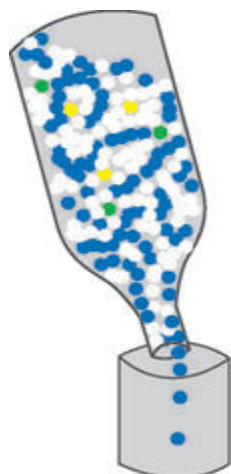
numbers in North America determined the genetic information passed on to later generations. Over time, inbreeding has led to the loss of genetic variation within the community. When compared to blood groups of North Americans in general, the Amish display distinctly limited allele frequencies. Inbreeding is resulting in not only genetic limitations but also a rise in inherited disease.

What do the elephant seal and the cheetah have in common? These animals have survived the **bottleneck effect**. Caught in the bottleneck by hunting, habitat loss, illness, natural selection, disasters such as floods, fires and earthquakes, and separation through migration, a species may be reduced to a very small population size. The northern elephant seal and cheetah are both bottleneck effect survivors.



Original
Population

A small surviving population will be limited to the genetic information of its members. Genetic makeup of the survivors will be significantly less diverse than the original population. Both the northern elephant seal and cheetah reflect the DNA of genetically related individuals. While their populations have recovered from very low numbers, the limited genetic variation in current generations puts them at risk.



Bottleneck
Effect

Wild cheetah populations currently exist in southern and eastern Africa. Genetic research indicates that cheetahs display classic characteristics of inbreeding. At one time, cheetah populations must have been reduced to very low numbers because of a genetic signature that has since been imprinted on the current populations. In order to survive, individuals bred with closely related individuals, a process called inbreeding. As animals inbreed, they pass along potentially deleterious recessive alleles that accumulate because of inbreeding. Today the worldwide population of cheetahs is nearly homogeneous genetically. The cheetah population has rebounded in size, but it is vulnerable to anything that can take advantage of this low variability, like disease, genetic defects, and sudden environmental changes.

Northern elephant seals suffer a similar plight. These animals were hunted to the brink of extinction because of their valuable reserves of blubber. The population was reduced to less than 100 individuals and these individuals became the source of genetic information for the future of the northern elephant seal. Slowly the populations began to recover and the implementation of the Marine Mammal Protection Act of 1972 enhanced the animal's recovery potential. Today the population size may be as large as 150,000 individuals. Their limited genetic variation, however, could easily strip away all success achieved so far, and decimate the population.

As scientists observe other species that have survived the bottleneck effect they have begun to gather data about its overall impact. While species may survive and return to significantly large populations, the genetic variation remains significantly reduced. This decline in genetic variation reduces overall fitness because species have less adaptive potential. Species such as the black-footed ferret, northern elephant seal, cheetah, songbirds, whooping cranes, California condor, most whale and shark species, and many others remain at extreme genetic risk even though their numbers may be increasing.

2. Speciation

Evolution & Ecology: Speciation

Lesson Objective

After review of the micro-evolutionary processes, we will now turn our attention to the processes of macro-evolution, namely, speciation.

Previously we covered...

We reviewed the ideas of natural selection and the various types of selection: stabilizing, directional, and disruptive. We also covered the principles behind population bottlenecks and how they affect populations long after numerical recovery.

Evolution & Ecology: Evolution

Balancing speciation: Extinction

Macro-evolution describes the large-scale changes to an entire species. Occurring at the pace of geologic time, macro-evolutionary change may go unobserved in a human lifetime. Macro-evolution describes the loss or gain of species.

The loss or extinction of entire species has occurred throughout the course of Earth's history. Extinction is a natural part of the ebb and flow of life. From fossil records scientists have determined that many species have lived, thrived, and ultimately become extinct. Species extinction generally occurs through a process of slow change.

Fossil records also indicate that there have been at least five periods of mass extinction. These extinctions involved the catastrophic loss of species. For example, at the end of the Cretaceous period 85% of Earth's species disappeared. **Adaptive radiation** is the process of new species development following a mass extinction. Conditions created by the global change that led to the mass extinction, open the way for new ecological opportunities and creative bursts of species development.

Many factors influence the general extinction process. Natural disasters such as volcanic eruptions, earthquakes, and hurricanes can wipe out entire species. Climate change, habitat destruction, and competition between species contribute to extinction pressure. Changes in predators, parasites, and disease may also affect an entire species.

Extinction can be brought about by biological characteristics of species themselves. Species that are highly specialized, such as the koala, rely on a very specific food supply. The loss of certain eucalyptus species to deforestation has adversely affected koala populations. By comparison, coral reef species rely on precise habitat conditions. Commercial development of coastal areas has put extinction pressures on certain coral species. The corals themselves are unable to migrate or relocate to better habitat conditions. Additional risk factors include low species population numbers and slow reproductive growth capacities.

Finally, human population growth has put a significant strain on species survival. Increases in human populations have created competition over space. Construction destroys habitat needed by endangered species. At the same time it divides the space already used by some species; isolating animals and plants into small pockets making access to mates difficult. These conditions create isolation that leads to genetic drift, bottlenecks, and extinction. Humans have also begun introducing non-native species into new environments. In many cases these introduced species out-compete existing native plants and animals. Introduced species cause devastating affects on local wildlife populations. Human impact on species may be increasing extinction rates throughout the world.

Evolution & Ecology: Evolution

How species come into being

Speciation is the formation of new species, an ongoing evolutionary process. New species develop out of changes in pre-existing populations. As organisms change through the forces of evolution (mutation, migration, selection, and drift), they also become unable to interbreed with their predecessors.

Speciation is one of the most important and least understood processes of biology. Although there are quite a number of definitions, the most generally used definition of species refers to groups of (actually or potentially) interbreeding natural populations that are reproductively isolated from other groups.

In scientific nomenclature, species have a unique two-part scientific name. To denote the scientific name, we either **italicize** or underline the genus and species names. The genus is listed first followed by the species epithet. For example, humans belong to the genus ***Homo***, and the species ***sapiens***, so their full scientific species name is ***Homo sapiens***.

Speciation is the evolutionary process by which new biological species arise. There are three main types of theoretical mechanisms for the creation of new species, all based on the geographic isolation

between the parent and daughter species. They range along a rough continuum from allopatric speciation (furthest) to sympatric speciation (closest), with parapatric speciation being in the middle.

Allopatric speciation happens when a population divides into two geographically isolated populations. The two different and isolated populations undergo differential divergence as they encounter and adapt to different environments. This happens because they are encountering distinct selective pressures, there is a difference in their connectivity to other populations, and/or they are independently experiencing genetic drift in different trajectories. If or when the two new species come back into contact, they have either evolved enough that they are reproductively isolated and are no longer capable of exchanging genes, or they are unable to produce viable offspring that can also interbreed.

In **sympatric speciation**, species diverge while remaining in close proximity and are not geographically isolated from each other. Sympatric speciation usually happens in complex biological contexts and can be found in insects that are dependent on different host plants, for example. Polyploidy is also a mechanism attributing speciation events in sympatry. Of the three different types of speciation outlined here, sympatric speciation is undoubtedly the least common and perhaps least likely to occur.

Parapatric speciation happens when the areas of two diverging populations are contiguous but do not overlap. This is only partial geographic separation, so individuals of each species may still encounter each other from time to time. This form of speciation is theoretically possible, but would take longer than pure allopatric speciation because of the potential for extended periods of interbreeding, effectively making the two populations closely related.

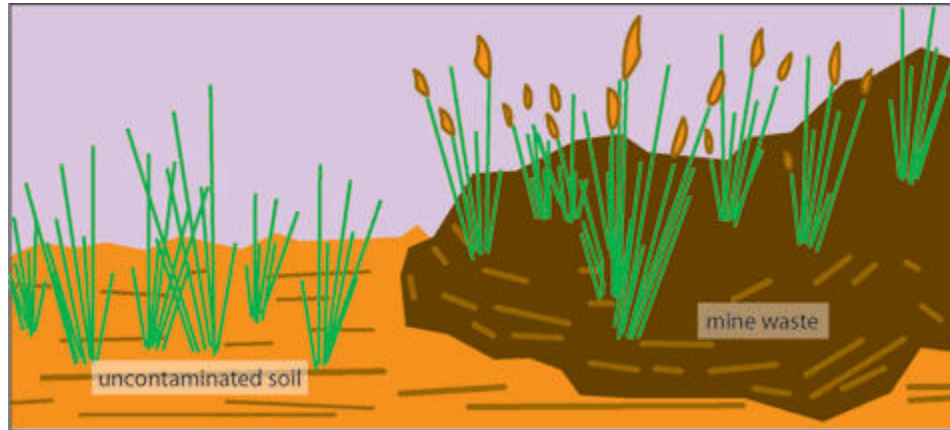
These types of speciation have undoubtedly taken place over the immense timescale of evolution, but it still remains a subject of debate about the relative importance of each mechanism in driving or maintaining biodiversity.

Lemurs are a primitive group of primates found on the island of Madagascar. When this island separated from mainland Africa, lemurs became isolated from other centers of primate evolution. The Madagascar lemurs now represent an **endemic** group of primates and they are an example of very early **allopatric speciation** that helped to set the stage for their subsequent adaptive radiation. Allopatric speciation occurs when individuals become geographically isolated. Over time the lemurs of Madagascar have developed adaptations making them distinctly different from the other primates in Africa. The lemurs have adapted specific traits to the diverse habitats of the island itself and have radiated to fill all potential niches of Madagascar forests.



In contrast, **parapatric speciation** occurs without geographic barriers for reproduction. Populations of species may share bordering territory without sharing genetic information. An example of this has been observed in an area where soil has become contaminated by heavy metals. **Anathoxan**

odoratum is a grass species with divergent populations that have adapted by becoming tolerant to the soil's otherwise lethal contamination. Some of the original populations of grass still grow successfully in neighboring uncontaminated soil. By growing in close range, they could fertilize one another. Through evolution, however, one population has developed an earlier flowering time than the other. Gene flow is beginning to be cut off between the tolerant and intolerant grass neighbors. This could be the start of parapatric speciation.



Evolutionary change to a species leading to the formation of another species within the same geographic area is called **sympatric speciation**. Sympatric speciation is a relatively rare evolutionary process in which new species develop within the range of its ancestral species. The East African Great Lakes have provided some of the few natural opportunities for researching how and why sympatric speciation occurs.



The small, deep, crater lakes in East Africa have incredibly diverse populations of cichlid fish. Sequencing the DNA of the cichlid species has revealed that many of the different species found within an individual lake are more closely related than fish from other lakes. Because the lakes are isolated from other water supplies by the natural crater rims, it is thought that cichlid species diversity developed from within. Founder individuals served as the basis for current, widely diverse but genetically similar populations. The cichlids move throughout the lake encountering the diversity of microhabitats and prey items. Most species within a lake demonstrate ecological isolation in feeding styles and diet preferences ranging from open water predators to bottom detritus feeders. These ecological differences may have provided the beginning of selective mating, reproductive isolation, and finally, speciation.

Sympatric speciation is much more prevalent in plant species. Yellow bananas, cultivated wheat, rhododendron, and Appalachian spleenwort ferns are all examples of new plant species arising as a result of sympatric speciation. The acquisition of extra sets of chromosomes (polyploidy) is a major process supporting plant sympatric speciation. Sympatric speciation occurs in the range of the parent species and, as mentioned with cichlids, is a relatively rare evolutionary trajectory. Whatever the ultimate mechanism of speciation, however, there must be some type of reproductive isolation in order to maintain the separation of species' genotypes.

Evolution & Ecology: Speciation - Developing the Theory of Evolution

Lesson Objective

In this lesson we will review the major players that helped to develop the theory of evolution, review an evolutionary timeline, and explain the gradualism and punctuated equilibrium schools of speciation. We will also review evolutionary connections determined by convergent evolution, and homologous and analogous structures.

Previously we covered...

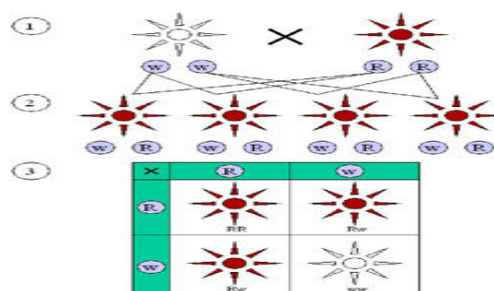
We reviewed the main ideas behind the theory of evolution, originally proposed by Wallace and Darwin over 150 years ago. We described the four forces of evolution (mutation, migration, selection, and drift) and compared and contrasted the extremes of macro-evolution and micro-evolution. We also discussed the effects of genetic drift, population bottlenecks, and outlined two types of speciation (allopatric and sympatric).

Evolution & Ecology: Evolution

Timing

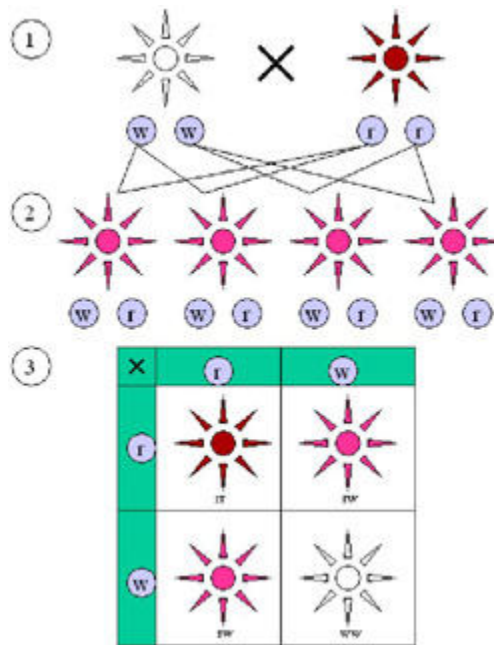
Darwin and Wallace's work with evolution undeniably launched a scientific revolution of research, discovery, and debate. Publishing his book, ***On the Origin of Species*** in 1859, Darwin repeatedly gave undeniably strong evidence for the concept of natural selection — first introduced in a paper he and Wallace had published nearly a year before publication of the book. Darwin and Wallace proposed the idea that those with adaptations best suited for survival and reproduction would be more successful in passing on their traits to the next generation. They knew that evolution was a gradual process in which the changes of adaptation happened slowly over many generations. According to their theory, species are always in a state of transition or continuous evolution.

At almost the same time, working with peas in a monastery garden, Gregor Mendel observed variations in plants across generations. Prior to Mendel's work, scientists thought that a blending occurred between parents to produce the traits of the offspring. The blending passed on an "essence" to form the offspring's new characteristics. Studying more than 28,000 plants gave Mendel the information needed to develop two important new generalizations about inheritance. Mendel's observations led to an understanding of how inheritance worked. He discovered that discrete traits are passed along in units of inheritance. Through his research, Mendel identified the fundamental laws of inheritance and set the stage for modern genetics.



Dominant and recessive phenotypes.

(1) Parental generation. (2) F1 generation. (3) F2 generation. Dominant (red) and recessive (white) phenotypes look alike in the F1 generation and show a 3:1 ratio in the F2 generation.

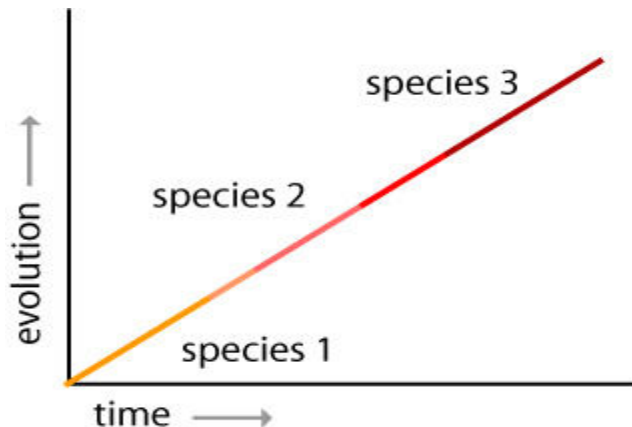


*The color alleles of **Mirabilis jalapa** are not dominant or recessive.*

(1) Parental generation. (2) F1 generation. (3) F2 generation. The "red" and "white" allele together make a "pink" phenotype, resulting in a 1:2:1 ratio of red:pink:white in the F2 generation.

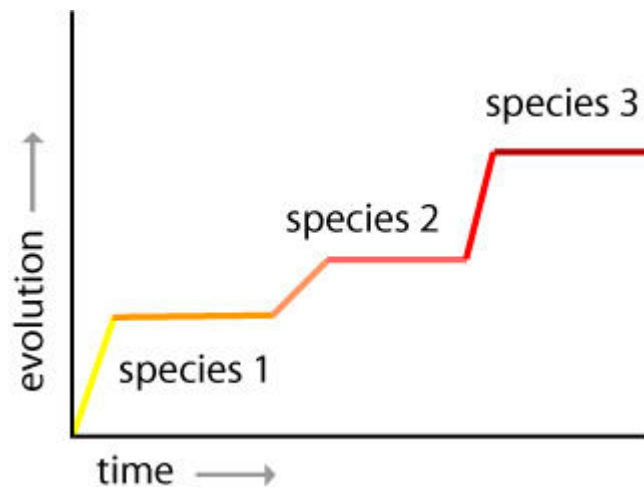
Mendel's inheritance laws changed the way scientists thought about inheritance. His work was published in 1865, but it did not receive serious attention until it was re-evaluated around 1900.

Geneticist Theodosius Dobzhansky and systematist Ernst Mayr were the next key thinkers in updating ideas about evolution. In the 1930s and 1940s, they introduced a few new twists on the original theory that became known as the Modern Synthesis. Reconciling the work of both Darwin and Mendel, the Modern Synthesis shifts from a focus on individual organisms and speciation to more of an emphasis on populations, genetics, and phenotypes. The scientists argued that geographic isolation of a small sub-population would gradually lead to the evolution of new genetic traits. Through this **gradualism**, the changed populations become unable to interbreed with each other. Mayr clarified by saying: "Without speciation, there would be no diversification of the organic world, no adaptive radiation, and very little evolutionary progress. The species, then, is the keystone of evolution."



Evolution & Ecology: Evolution

During the 1960s and 1970s, geologically trained paleontologists brought even more new research to bear on evolution. Niles Eldredge and Stephen Jay Gould reintroduced ideas about patterns of species' stability over time. They formulated an argument around the idea of **stasis** where species remained in the same form with little or no change for millions of years. Eldredge and Gould thought that stasis was punctuated by bursts of rapid change when new species develop. As a result of these rapid changes, little fossil information was left behind. They called the periods of rapid change **punctuated equilibrium**. Eldredge and Gould demonstrated that most speciation occurred on the fringes of populations. They hypothesized that changes in species were not visible in fossil records because they occurred in very small, isolated populations. The scientists suggested that only species that were successful could leave behind enough fossil evidence to ensure a good fossil record.



In 1985, paleontologist Elisabeth Vrba introduced the turnover pulse hypothesis. She suggested that changes in environmental conditions initiate rapid periods of extinctions and new species development. According to Vrba, external factors, such as climate changes, produce major evolutionary shifts. She studied turnover pulse events that occurred 2.5 million years ago in Eastern and Central Africa. She identified global cooling as the cause of significant African ecosystem change. Drier, cooler conditions resulted in a decline of wet woodland habitat and led to large expanses of grasslands. Species like the impala were successful in surviving the change because they were generalists. Other species were not so lucky.

Vrba also described the process of habitat tracking in which species successfully migrated into the changed habitat. She is credited with explaining that ecosystem decay and fragmentation leads to speciation and extinction.

Concurrent with all of this research has been significant breakthroughs in understanding population genetics. In 1952, Frederick Sanger uncovered the first complete protein sequence in insulin. Through his groundbreaking work, science has seen advances in DNA techniques leading to the successful conclusion of the Human Genome Project in 2001. This project set out to map the complete sequence of human chromosomes. While it seemed an impossible task, the first human DNA sequence was published in 1999 and many variations and genotypes have been added to this initial template.

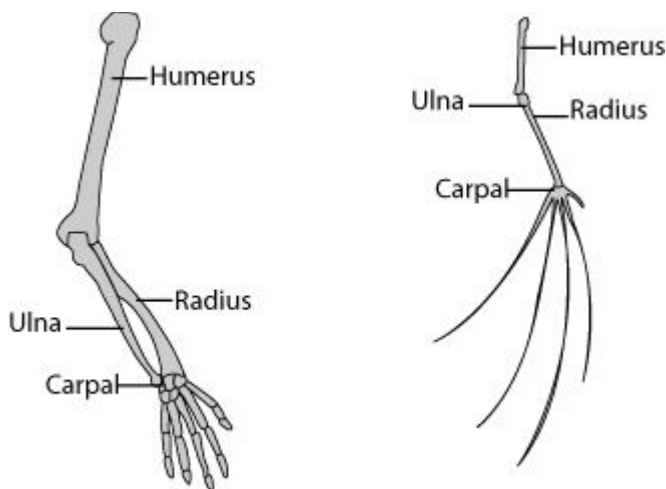
Evolution & Ecology: Evolution

Form and Function

Closely related to evolutionary biology and phylogeny is the study of differences and similarities between organisms, or comparative biology. Comparative biology has seen tremendous growth in the last 10 years and we now have sophisticated methods of teasing apart the evolutionary and ecological aspects that make up all life's diversity.

Prior to Darwin's time, Georges Cuvier was working toward significant leaps forward in our understanding of anatomy. In the late 1700s, Cuvier argued that every structure of an organism was integral to its survival. Formulating the process of comparative anatomy, Cuvier studied elephants. He compared African and Indian elephants to fossil remains of mammoths and his research led him to believe that some species that evolved between mammoths and modern elephant species became extinct. His work became the basis for modern vertebrate paleontology.

Paleontology and comparative anatomy have provided further evidence in the case for evolution. Through comparative anatomy, scientists have observed that some animals share similar structures. **Homologous structures** are those features shared among a set of related species. The structures are shared because they have been inherited from a common ancestor. For example, the bone structure in a human arm and a bat's wing are homologous. While each organism has a different use for the limb (writing and flight) the general structure is similar. Scientists agree that this similarity can best be explained by common descent.



Homologous structures are the result of **divergent evolution**. Whales, cats, birds, bats, and humans all share this limb-structural similarity. There are many uses for the same bone structure. Locomotion strategies for swimming, flying, jumping, and writing reflect divergent evolutionary paths. Over the course of evolution then, related species become increasingly dissimilar even though they do share many traits.

Analogous structures, however, do not reflect common ancestry. Analogous structures may be superficially similar but are observed in organisms that are completely unrelated. These structures evolved in response to similar environmental factors and they evolved independently. While the structures may have similar functions, they are not the result of a common ancestor. For example, the structure of an insect wing is vastly different from a bird wing. Both will have a competitive advantage by virtue of flight. With the ability to fly an organism gains greater access to food, potential to seasonally migrate, increased access to a safe nesting space, and the ability to flee predators.

Analogous structures are an example of **convergent evolution** that ultimately is affected by similar selective pressures in similar ecological contexts. Unrelated species have converged upon a common feature that probably accrues some competitive advantage or an adaptation that affords some success in their environment. Dolphins and sharks are good examples, where convergent evolution has shaped their bodies in extremely similar ways. Although they are not at all closely related (one is a fish and the other a mammal), they are both strongly affected by their marine environment and the selective pressures placed on their body plans is virtually the same. Another good example is the major split within mammals — the placentals and the marsupials. Although they have lived on different continents separated for more than 55 million years, they have evolved many broad similarities. For example, the groundhog (a placental) has a strong resemblance to the wombat (a marsupial). Additionally, there are both placental and marsupial anteaters, mice, top predators, and moles. With very similar body characteristics, the main difference between these groups of mammals is how they rear their young. The marsupial's young are born much less developed than placental young. Marsupial young develop to maturity in an external pouch. The placental mammals carry their young internally much longer. When the placental young are born, they still require significant parental care, though they are more mature than are marsupial young.

3. Ecology

Evolution & Ecology: Ecology

Lesson Objective

In this lesson we will review the discipline of ecology, looking at specifically at the study of population ecology.

Previously we covered...

In the last lesson we discussed reasons for, and causes of, extinction; the formation new species; and the development of the theory of evolution.

Evolution & Ecology: Ecology

The scope and science of "the house".

Ecology is the science of our house; the word is derived from the Greek ***oikos*** ("house") and ***logos*** ("to study") so "ecology" literally means "to study the house". In this case our house is Earth. Ecology focuses on the distribution and abundance of living organisms, how these are affected by interactions between the organisms and their environment, and the relationships of organisms with each other. The ecology of an organism includes the physical properties of its environment, local abiotic factors like geology and climate, and other organisms that share its habitat. The term ecology (***oekologie***) was originally conceived in 1866 by German biologist Ernst Haeckel who is considered to be one of the forefathers of the discipline.

Ecology is one of the broadest branches of biology because organisms can be studied at a myriad of different levels, from biomolecules like proteins and nucleic acids, to cells, to tissues, to organs, to organ systems, to individuals, and culminating with populations, communities, ecosystems, and ultimately to the biosphere. Most of ecology focuses on the last half of that list, and because of its concentration on these higher levels of organization and the interrelations between organisms and their environment, ecology draws heavily from many other branches of science. Most notable of these are geology, geography, meteorology, chemistry, and physics.

Ecology can also be subdivided into many sub-disciplines that include:

- Behavioral ecology: the ecological and evolutionary basis for animal behavior and the role of behavior in animal adaptation.

- Community ecology: the interactions between species within a community.
- Ecosystem ecology: the flow of both energy and matter through ecosystems.
- Global ecology: the macro-ecological questions focused at a global level.
- Landscape ecology: the interactions between the elements of a landscape.
- Physiological ecology: the adaptation of individuals to their environment and the influence of biotic and abiotic factors on the physiology of the individual.
- Population ecology: the dynamics of populations and the interactions of populations with environmental factors (both biotic and abiotic).
- Ecology can also be studied at several levels: population, community, ecosystem, and all the way up to the biosphere. Moreover, there are particular branches that focus on specific aspects of ecology like tropical ecology, animal ecology, island ecology, pollination ecology, and others.

Evolution & Ecology: Ecology

Populations

Considering the dynamics of entire populations of organisms points to the study of population ecology and its implications for humans and wildlife. Many of the ideas about natural selection are based on the thinking of Thomas Malthus who noticed that more offspring were produced by organisms than could actually survive. In particular, Malthus considered the capabilities of populations to overproduce. He suspected that a population could not grow unchecked indefinitely.

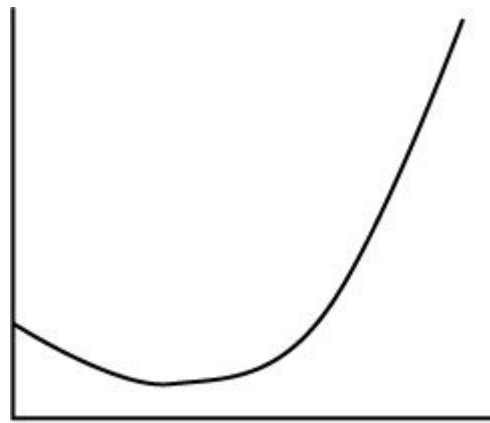
Today the study of population ecology examines individuals in populations and how they change over time. Birth rate and death rate are the most basic factors of population growth. The **intrinsic rate of increase** is measured as the birth rate minus the death rate. The capacity of organisms to reproduce under ideal conditions is called **biotic potential**. The age an organism reaches sexual maturity, the frequency of reproductive opportunities, and the offspring produced are factors that affect biotic potential.

Humans, elephants, whales, gorillas, and many other large species have low biotic potential. These species take several years to reach sexual maturity. Long gestation periods are needed. Low numbers of offspring are produced as the result. Parental care requires a considerable amount of energy. Offspring often remain under the care of the parents for many years. Low biotic species typically live a long time.

On the other hand, most insects, amphibians, rodents, marine invertebrates, bacteria, and parasites are examples of species with high biotic potential. High biotic potential is distinguished by a short time to reach sexual maturity, and large numbers of offspring. Many offspring are needed because not all will live to reproduce. In these cases, little to no parental investment is spent caring for offspring after hatching. At or shortly after birth, offspring need to be ready to provide for their own needs. High biotic species generally have short generation times and, consequently, higher mutation rates than species with lower biotic potentials.

Evolution & Ecology: Ecology

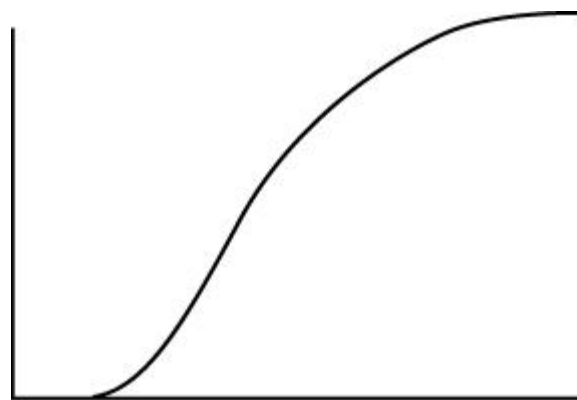
Under ideal conditions a population may exhibit **exponential growth** rates, or growth at its biotic potential. Exponential growth is a mathematical expression of increasing values. For example, an arithmetic progress would look like 2, 4, 6, 8, 10, 12; while an exponential progression is 2, 4, 8, 16, 32. Each time the population grows the number doubles. On a graph, exponential growth is expressed as a J-curve.



The J-shaped curve

Without limiting factors a population of organisms could double rapidly. However, in the natural world, this is rare. There are many factors that affect the growth rate of a population. Predators, disease, availability of food, water, shelter or space, and natural disasters are all factors that limit a population's success. These environmental factors help define the **carrying capacity (K)** of a habitat. The carrying capacity is the population size an environment or place is able to support indefinitely.

The carrying capacity is different for every environment and its resident organisms. In nature, carrying capacities tend to stabilize over time. Increased death rates result from too many individuals. Too few individuals can lead to increasing population sizes. The carrying capacity of a habitat can limit the population's potential. If a habitat's natural resources become limited by drought conditions, for example, population growth also becomes limited. In a graph representing the limiting factors of carrying capacity, the population curve would be reflected as an S. Over time the influence of a habitat's carrying capacity would act on the population size.



The S-shaped curve

Evolution & Ecology: Ecology

Review of Vocabulary and Concepts

- Comparative anatomy has provided valuable information confirming theories of evolution.
- The structures of species provide insight to different evolutionary processes.
- Population ecology is the study of the dynamics of population growth.
- Biotic potential is an organism's ability to reproduce under ideal conditions.

- Carrying capacity refers to the size of a population that an environment can support indefinitely.

4. Ecological Growth & Limits

Evolution & Ecology: Ecological Growth and Limits

Lesson Objective

In this lesson, we will review population growth and the factors that limit and support such growth. You will also review the biological roles species play in their environment.

Previously we covered...

We have reviewed the main players in the development of the theory of evolution and how population growth is limited by different factors, including the ability to reproduce and carrying capacity.

Evolution & Ecology: Ecological Growth and Limits

Respect Your Elders

Many variables limit population growth. Environmental factors, such as natural predators, disease, food, water, shelter or space, and natural disasters contribute to population success. These factors help determine the carrying capacity of a natural place.

From 1979 to 1989, the African elephant population drastically declined. Environmental factors did not contribute to this decline. Rather, the elephants were heavily hunted by humans to support the worldwide demand for ivory. In 1990, the Convention on International Trade in Endangered Species (CITES) established a ban on the international ivory trade.

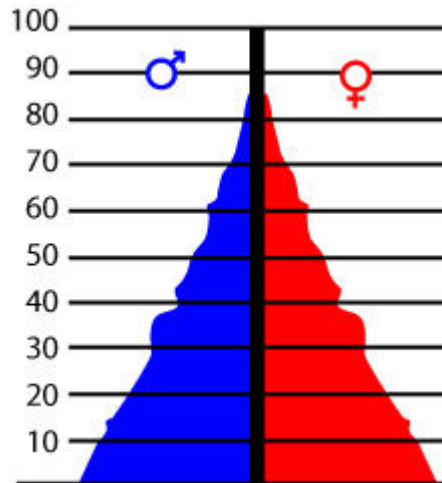
While elephant populations in Africa have shown a steady increase, there are still survival concerns. African elephants live in matriarchal herds. The social structure of the herds plays a significant role in survival. For example, the senior females carry historical knowledge relevant to the herd's success. All senior herd members play an important role in the care and growth of younger animals. Knowledge about travel over long distances or locating food or water during drought conditions may also be a responsibility of elder herd members. Senior elephants also have the largest tusks.

In the late 1980s and early 1990s, scientists began observing herds without any senior members. Destroying the larger, more mature animals yielded the most ivory. It also left herds in the position of being led by younger and younger females. Scientists worried about the impact of these juvenile herds on long-term elephant survival.

The **age structure** of a population can be an indicator of its growth rate. It is a reflection of the number of individuals in each age group in a population. Scientists study the number of individuals who are pre-reproductive, reproductive, and post-reproductive to make predictions about a population's success. In the case of the African elephant, poaching significantly altered the age structure of the wild population. While the size of the population may be growing, the post-poaching age structure may have successful implications for African elephants.

Evolution & Ecology: Ecological Growth and Limits

Age structure is measured in three ways. Population pyramids are a graphic reflection of age and sex.



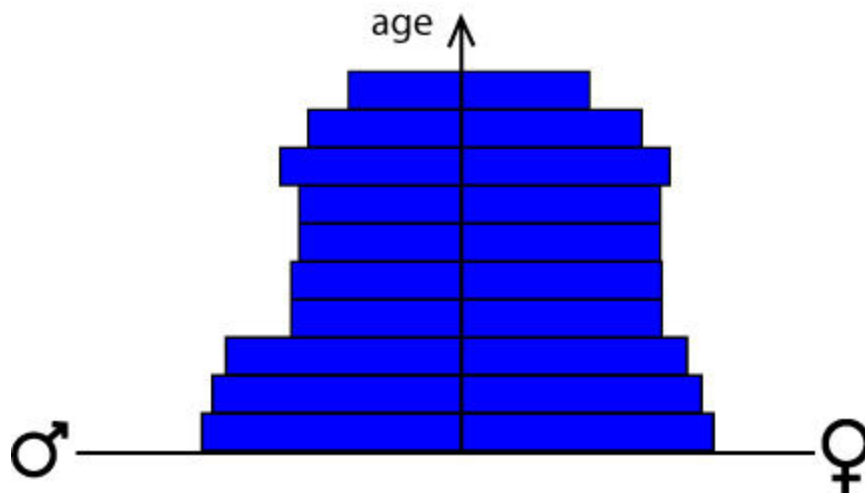
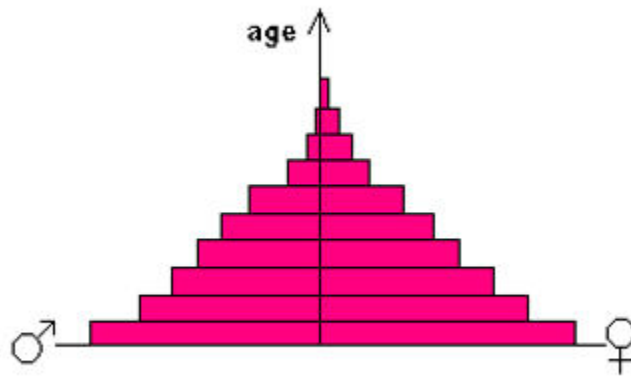
An average may be assembled reflecting the median age of a population, or the population may be differentiated by a dependency ratio. The dependency ratio is determined by summing the number of youth (ages 0 to 15) and the number of adults (ages 65+) and dividing their total $[(0 \text{ to } 15) + (65+)]$ by the number of people in the mid-range (15 to 64). The product is then multiplied by 100 to determine the dependency ratio.

Age structure is important because it is a reflection of the number of living individuals in a population. Age structure is affected by births, deaths, **emigration**, and **immigration**. Individuals leaving or breaking off from the originating population represents emigration. Individuals immigrating into or joining an existing population increase its size. There are many factors affecting population shifts. **Density dependent factors** include variables such as competition, territorial behavior, stress, and decreases in births, predation, and disease. As a population grows denser these factors increase death rates or reduce birth rates. Anything that reduces the potential for individual survival in a dense population is a density dependent factor.

Variables such as fire, avalanche, drought, and human impact fall into the category of **density independent factors**. For example, plant and animal populations could be significantly diminished by long-term and unexpected drought conditions. Density independent factors affect a population regardless of its size. In the case of extended drought conditions, entire populations would be affected.

The study of society and population is called **demography**. The human population has grown at an exponential rate. Advances in technology, food production, and resource acquisition have enabled further expansion. In 1987 the human population was approximately five billion. By 1999 the population had exceeded six billion. Eventually though, the human population will reach physical and biological limitations. These could include competition for space and food, as well as the impact of density dependent factors.

The age structure of North Americans will have long-term implications. For example, the population known as "baby boomers" represents a significant increase in births following World War II. The baby boomer group makes up more than half of the United States population. This group is expected to live longer than their parents. As humans continue to live longer they work longer, consume more resources, and require more medical care. The baby boomers are followed by a bust generation (born after 1965) who will be responsible for caring for the boomers and supporting them. By comparison the demographic bulge is quite different in developing countries.



Consider the population structures and their implications for humans over time. Humans have developed the capability to alter limitations on population size. With fewer growth limitations, populations have exploded worldwide. This has also led to significant competition for habitat space previously used by wildlife. Humans have also developed the technology to control insect species once considered to be a nuisance, to grow more food per acre, and to maximize the resources that people consume. Human-influenced habitat destruction is the primary reason species around the world are threatened and becoming extinct.

Evolution & Ecology: Ecological Growth and Limits

Dynamics and stability

Ecological factors that interact with populations or species in a given environment are usually divided into two groups: abiotic and biotic. Abiotic factors range from geological, geographical, and hydrological, to climatological. Specific abiotic factors include:

- Water is an essential compound for all life
- Air provides oxygen, nitrogen, and carbon dioxide as well as being a medium for the diffusion of pollen, pheromones, gametes, and spores.
- Soil is a source of nutrients, a type of microhabitat, and a physical foundation.
- Soil characteristics like pH, nutrient content, the ability to retain water, and density are all important factors.

- Temperature is crucial for all biochemical reactions.
- Sunlight provides nearly all energy to Earth.
- Natural disasters such as hurricanes, earthquakes, floods, droughts, tornadoes, and other conditions can be catastrophic abiotic factors for most organisms.

Biotic ecological factors are also considered to be an important aspect within ecology. Biotic relationships are broken down into either intraspecific or interspecific. Intraspecific relationships are established between individuals of the same species in a population and can range from cooperation, mating, or competition. Interspecific relations, on the other hand, are interactions between different species, and are described by their beneficial, detrimental or neutral effects. For example, these relationships can range from both species obtaining a benefit (**e.g.**, mutualism is a +/+ relationship) or both species experiencing negative effects (**e.g.**, competition is usually a -/- relationship). One of the most important and prevalent relationships is predation (a +/- relationship), which also defines the cascade of energy and mass in ecosystems.

The interactions among living organisms and with their environment occur as part of a larger cyclical mixing of elements (most importantly carbon, oxygen and nitrogen) and water, which are called biogeochemical cycles. These processes provide relative stability to the biosphere and maintain the conditions necessary for life to continue. This self-regulation, supported by negative feedback controls, ensures the natural longevity of ecosystems worldwide. Unfortunately, because of tremendous human population growth and the parallel problems of pollution and unsustainable natural resource use, we are creating an unbalanced biosphere.

Evolution & Ecology: Ecological Growth and Limits

Competition

The **Law of the Minimum** states that population growth limitations are set by the environmental resource in shortest supply. Access to food, water, space, shelter, soil, and light could limit population size. At the same time, species play a biological role in the environment. This role is called a **niche**. From reviewing evolution theory it is evident that reproductive success is a survival indicator. The ability to acquire nutritional resources and avoid predators also supports survival. The combination of environmental requirements and physical conditions determine an organism's ability to live abundantly in any given place. This combination also culminates in what represents an organism's niche. Therefore, an organism's niche refers to its use of environmental resources, as well as its "fit" into the ecosystem.

Useable forms of energy, space, and locations for the activities of living are all factors in the competition to survive. In the case of **interspecific competition** members of diverse species are competing with each other. **Intraspecific competition** occurs when members of the same species compete. Intraspecific competition is made more intense because of the shared requirements for food and space within a species population. However, plants and animals have developed strategies for coping with these forms of competition.

Intraspecific competition is avoided when adult plants create shade so that seedlings are unable to germinate under them. Seed dispersal strategies such as animals, wind, and water keep plants from competing for the same space. Some plants secrete substances into the soil, thereby making it impossible for seedlings to grow.

Animals also have strategies for coping with intraspecific competition. Utilizing different niches, having feeding habits specific to developmental stages, and territorialism are all strategies animals utilize. Both plants and animals benefit from these strategies as offspring move into adjacent areas.

Scientists make another distinction related to niche. **Theoretical niche** refers to a species' potential to use available resources, without predation or interspecific competition from other species. By contrast, a species' **realized niche** is one that is occupied by the species and varies from place to place (in response to interactions with other species, such as predators and competitors).

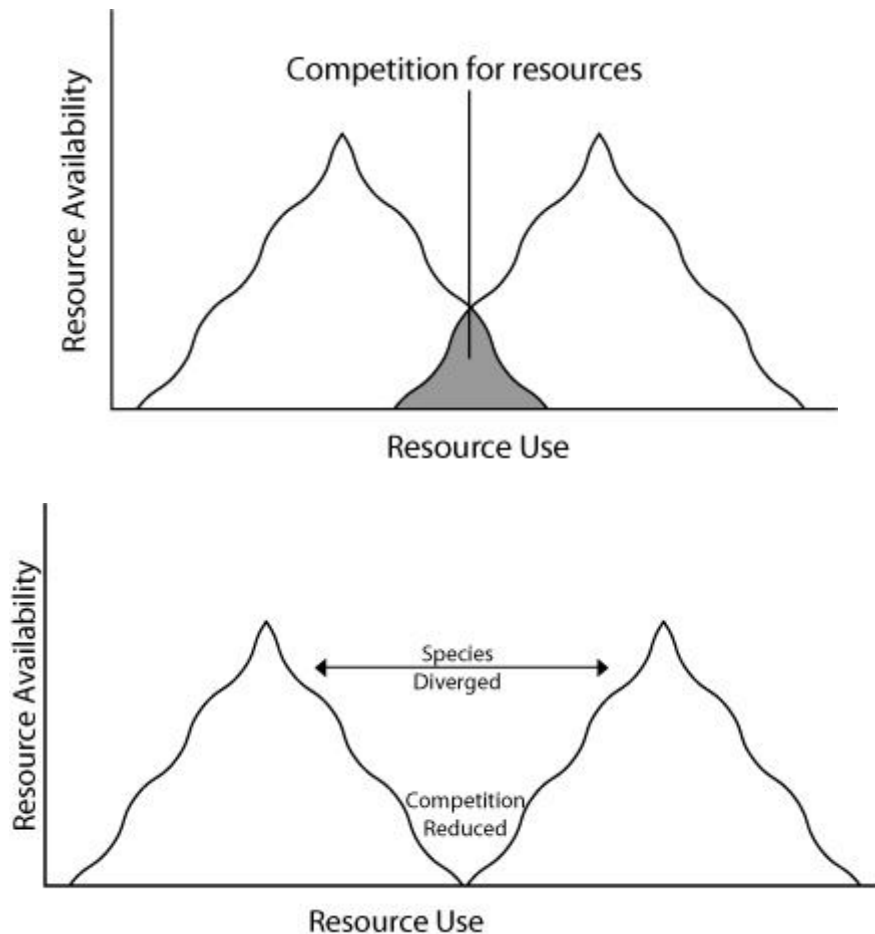
Gause's Law of Competitive Exclusion focuses on the competition between diverse species. A Russian biologist Georgyi F. Gause (1910 – 1986) promoted the idea that two or more species could not coexist when they were competing for the exact same resources. Gause believed that one species would gain access to more resources and have a subsequent competitive advantage over the other species. Under these conditions the second competitor would eventually become extinct. Not all biologists completely agree with Gause's law, pointing to examples such as plankton. Plankton species all rely primarily on water-soluble minerals and solar energy. Contrary to the Law of Competitive Exclusion, large numbers of plankton species successfully share resources in the open ocean.

Evolution & Ecology: Ecological Growth and Limits

Species do not live in isolation. Instead, diverse species share **ecosystems**. In this sharing, some species develop adaptations that enable them to survive while minimizing competition for primary resources. **Resource partitioning** enables different species to utilize the same resource by accessing it differently. For example, several tropical bird species are fruit eaters. Some eat only a particular fruit. Others in the same niche may eat at a different time of day or may eat the same fruit but from a different location on the tree (*e.g.*, higher or lower on the tree). Still others may feed on fruit at different stages of its development. This partitioning allows many different species to share the same resource and successfully survive.



At the same time, resource partitioning is an aspect of the evolutionary process. Subpopulations of a species assume behavioral adaptations to avoid competition. These adaptations create a divergence from the parent population. Over time, the subpopulation diverges into its own species.



As a consequence of resource partitioning, some species exhibit **character displacement**. Character displacement occurs when two species share the same niche. If they were not competing, the two species would not need to evolve differently. For example, on the Galapagos Islands, the finches *Geospiza fuliginosa* and *Geospiza fortis* share the same niche. *G. fortis* has a larger beak for consuming larger seeds. The two finch subspecies have developed resource partitioning strategies. These finches have been observed on separate islands, as well. Under those conditions, both species have intermediate-sized beaks enabling them to consume a broader range of seeds. Character displacement differences are an evolutionary response to interspecific competition.

Evolution & Ecology: Ecological Growth and Limits

Why can't we all just get along?

Competition is an important process for species survival and evolution. Other biological processes also support and influence survival. **Symbiotic relationships** form when organisms of different species interact in ways that benefit at least one of the species involved. In some cases, these relationships are important aspects of community structure. Several different types of symbiotic relationships exist.

Mutualism is the symbiotic relationship whereby both organisms benefit (+/+). Through mutualistic relationships, organisms are safe from predation or share in the acquisition of food. In **facultative mutualism**, both organisms benefit through living in close association. The organisms may rely on one another in proximity. For example, small fish like the wrasse consume parasites or small organisms that attach to larger fish. The wrasse benefits from a ready food supply and the larger fish are cleaned of unwanted organisms.

Obligate mutualism is a necessary survival connection between organisms. Honeybees are responsible for pollination of certain flowers. The bees can see blue, yellow, and ultraviolet. Bee-pollinated flowers are most likely to have these colors. Collecting pollen from flowers enables bees to feed the growing brood inside the hive. Moving from bloom to bloom, the bees support plant reproduction by carrying pollen along with them.



Evolution & Ecology: Ecological Growth and Limits

Commensalism is another type of symbiosis. The literal translation of commensalism is "at table together." In commensalism only one of the organisms receives benefit from the relationship. The other organism neither benefits nor harmed (+/0). The family of orchids called epiphytes lives in the branches of rainforest trees. The trees do not receive a benefit from the epiphytes' presence. However, living high in rainforest trees, the epiphytes benefit from access to more air and sunlight.



Another type of symbiotic relationship benefits one organism while harming or destroying the other (+/-). **Parasitic relationships** benefit the parasite that harms or destroys its host. Lice, tapeworms, fleas, ticks, and malaria are all examples of parasites. These parasites work externally or internally to benefit their own survival. The parasite lives in or on a host organism and may weaken the host's ability to survive. Parasites demonstrate two survival strategies: one is living in or on the host without

killing it, while surviving long enough to reproduce successfully; the other needs the host species to die in order to complete the stages of their own life cycle.

All of these interactions are examples of **co-evolution**. The species have evolved through influential relationships. Some of the relationships are beneficial. Some are not. Either way, genetic change has occurred in both species as a result of the relationship. Each species has exerted selective pressure on the other to the extent that they both evolve. Some species co-evolve into very limited symbiosis. Yucca plants are totally dependent upon the yucca moth for pollination. The plant bloom has evolved into a shape only accessible by the moth. If the moth population went extinct, the yucca population would be affected, as well.

Evolution & Ecology: Ecological Growth and Limits

Review of Vocabulary and Concepts

- The availability of abundant natural resources supports exponential population growth.
- Many variables can limit population growth. These include environmental, age, movement, and competition.
- Species interact in different ways for food, water, and shelter. Competition can be either interspecific or intraspecific.
- Resource partitioning is a strategy that different species use to share the same resource differently.

5. Environmental Cycles

Evolution & Ecology: Environmental Cycles

Lesson Objective

In this lesson, we will review environmental cycles, energy flow, primary and secondary succession, climax communities, abiotic and biotic factors, and biomes.

Previously we covered...

We have reviewed the basics of population growth, how it can be supported by abundant natural resources or limited by various factors, including environment, age, movement, and competition. We also covered how species interact and compete in various ways, like resource partitioning or through competition for resources.

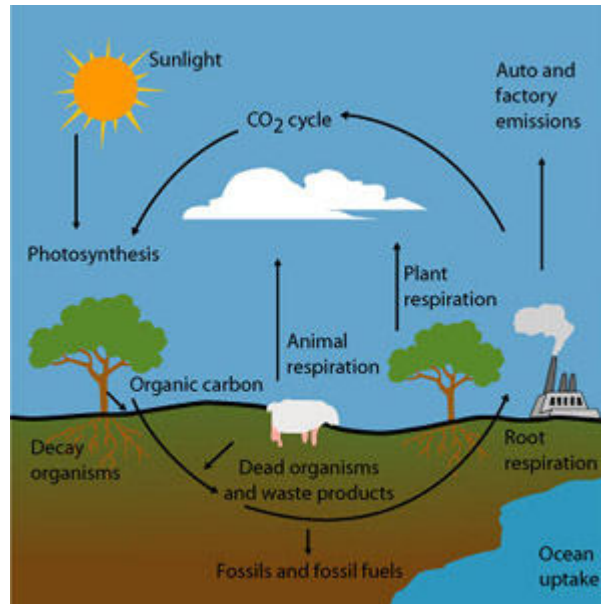
Evolution & Ecology: Environmental Cycles

Cycles

Understanding evolution, niches, ecosystems, and relationships between living things includes behind-the-scenes processes. These background events of all living systems is the movement of nutrients. Nutrients are central to the systemic survival of Earth's ecosystems. Biogeochemistry is the study of nutrient movement through both the biological and geological layers of the ecosystem.

Nutrients, such as nitrogen (N), phosphorus (P), and carbon (C), are among the 16 chemical elements necessary for growth. Plants, microbes, animals, and organic matter are the **biotic** locations of nutrients. The atmosphere, water, and soil represent the **abiotic** locations. Nutrients are also stored in sediments, rocks, and oceans. Nutrients are constantly cycling through biotic and abiotic systems. Biological, chemical, and geological processes transform nutrients into resources beneficial to living things.

Carbon is one of the primary biogeochemical cycles studied by scientists. Earth stores carbon in dead and living organisms, in the atmosphere as carbon dioxide gas, and in soil as organic matter. Carbon is present in fossil fuels, rock deposits, and marine organisms. The movement of carbon is a complex cycle. The most familiar process in the carbon cycle is photosynthesis. During photosynthesis terrestrial plants take in atmospheric carbon dioxide. Through respiration plants release oxygen. Humans have had a significant impact on the carbon cycle. Burning fossil fuels releases carbon dioxide into the atmosphere as greenhouse gases. Agricultural practices including deforestation, soil cultivation for food production, and reforestation also have a significant impact on atmospheric carbon dioxide levels.



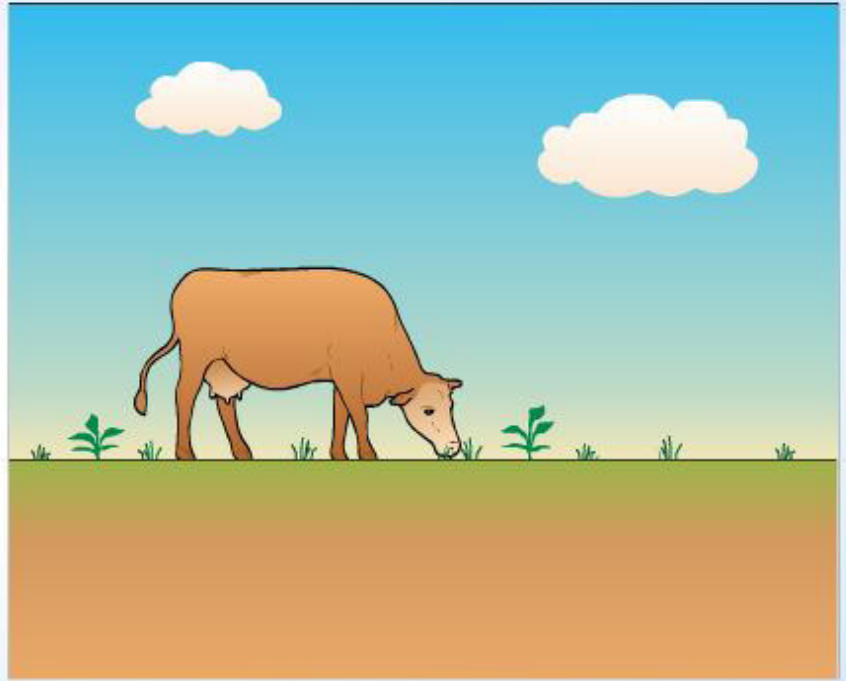
Evolution & Ecology: Environmental Cycles

The nitrogen cycle is another biogeochemical cycle. It is also one of the most important cycles in terrestrial ecosystems. Nitrogen is used by living things to produce organic molecules, such as proteins, nucleic acids, and amino acids. Soil, oceans, and the atmosphere hold stores of nitrogen. The largest nitrogen store is the Earth's atmosphere. Plants take up nitrogen as nitrates and ammonium. By consuming dead or living organic matter, animals obtain the nitrogen they need for growth, reproduction, and metabolism.

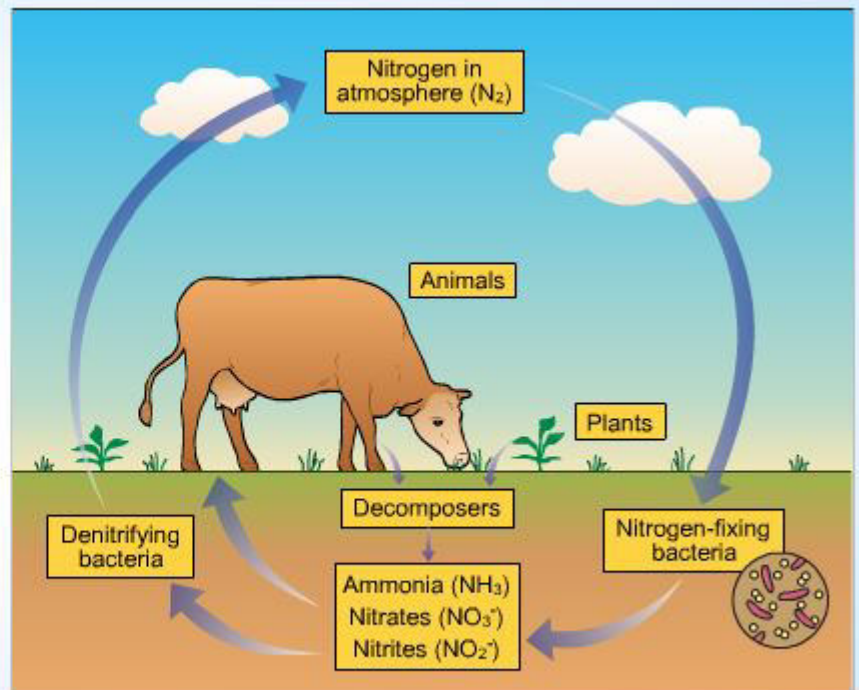
Human activity has significantly altered the nitrogen cycle. The following are some human practices that have affected the nitrogen cycle:

The Nitrogen Cycle

The nitrogen cycle is a process that involves many different members of an ecosystem, including plants and bacteria that live in soil – even dead and decaying plants and animals. Click “Next” to review how the nitrogen cycle works.

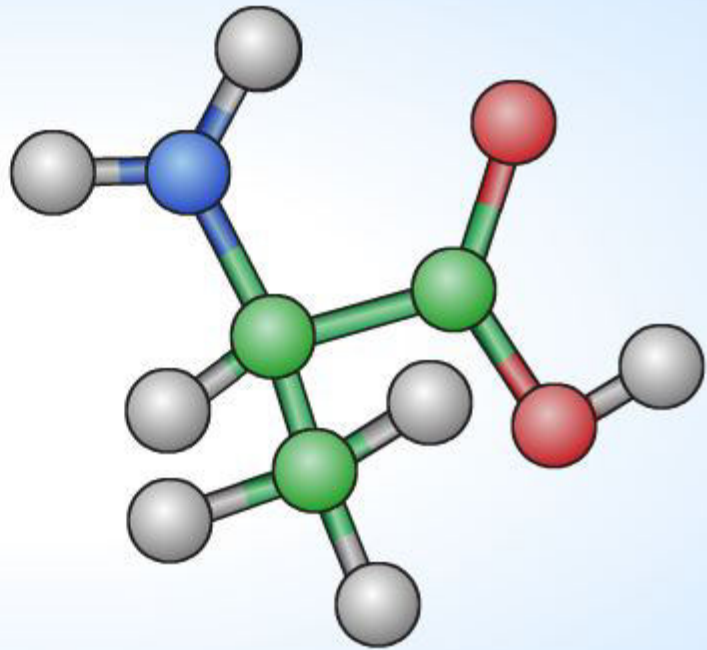


Nitrogen (N_2) is an abundant element in the atmosphere, but for most plants and animals, it is unusable in that form. There are several different ways in which nitrogen is made usable, though the decomposition of organic materials is the most prominent.



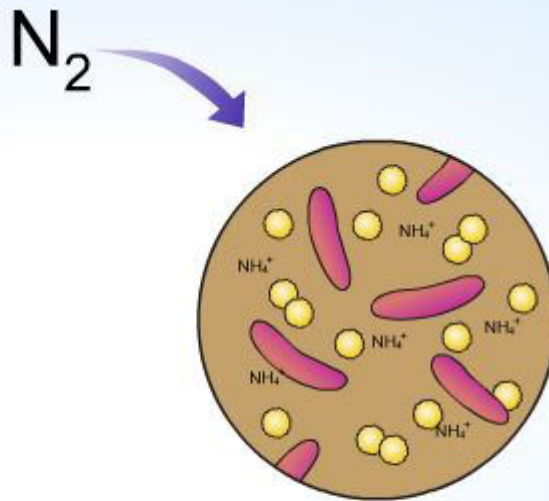
The decomposition of organic materials – like dead plants and animals – provides the soil with complex compounds, such as proteins, amino acids, and nucleic acids.

Rollover the different molecules to see what each one is.

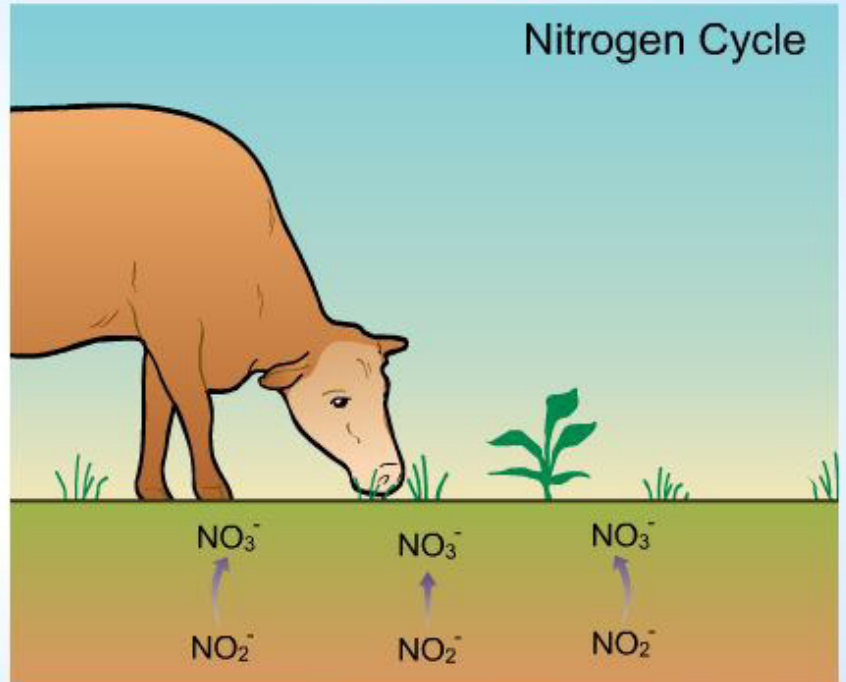


Example of Amino Acid - Alanine

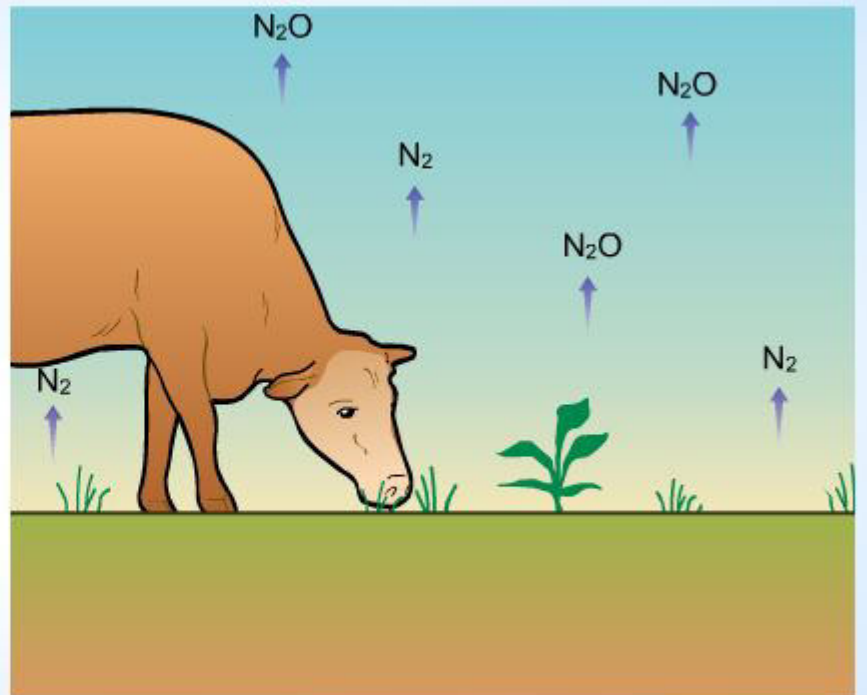
Microorganisms, such as bacteria, then use these compounds to form usable proteins. During this process, called ammonification, excess nitrogen is released in the form of ammonium ions (NH_4^+).



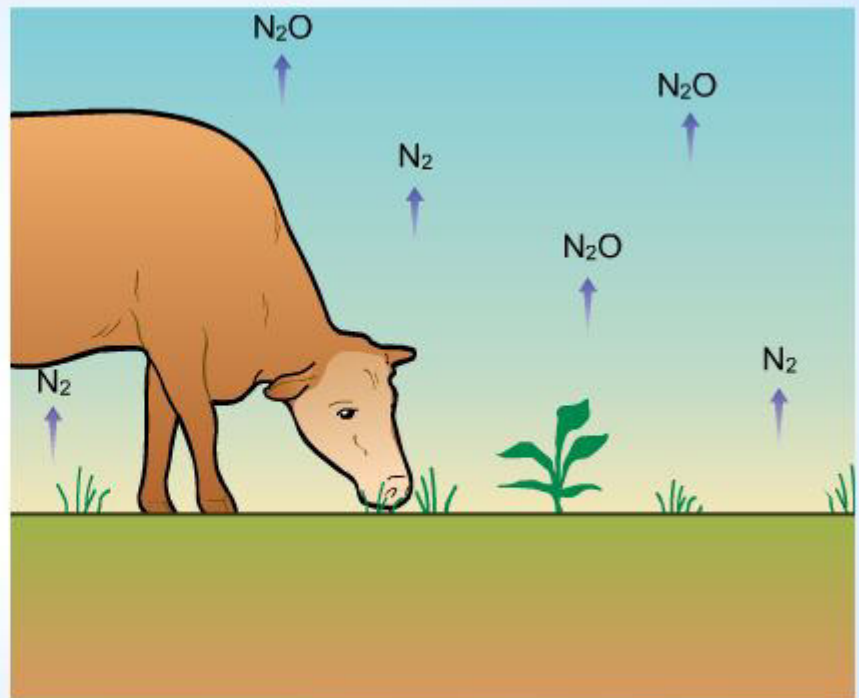
Certain bacteria in the soil then oxidize the ammonia and ammonium ions in a process called nitrification. The ammonia is converted into nitrite (NO_2^-). However, nitrite is toxic to many plants. Bacteria known as nitrobacteria then oxidize the nitrite into nitrate (NO_3^-), the form of nitrogen that most plants and animals use. Plants will receive the nitrates directly from the soil, while animals will get nitrates by eating plants.



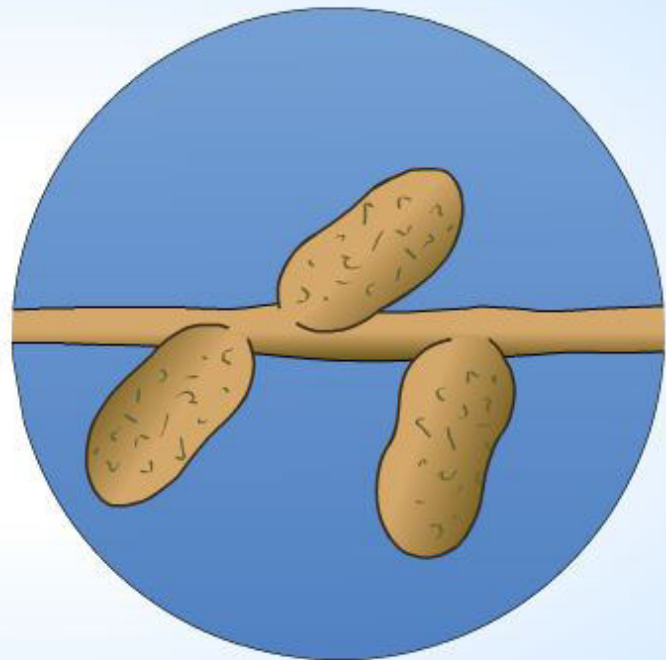
Denitrification is the process that helps return nitrogen to the atmosphere. Anaerobic bacteria reduce nitrates in gaseous forms, including nitrogen gas (N_2) and nitrous oxide (N_2O). Though nitrogen will return to the soil in the decay of plants and animals, there are other ways of replenishing the ecosystem with nitrogen.



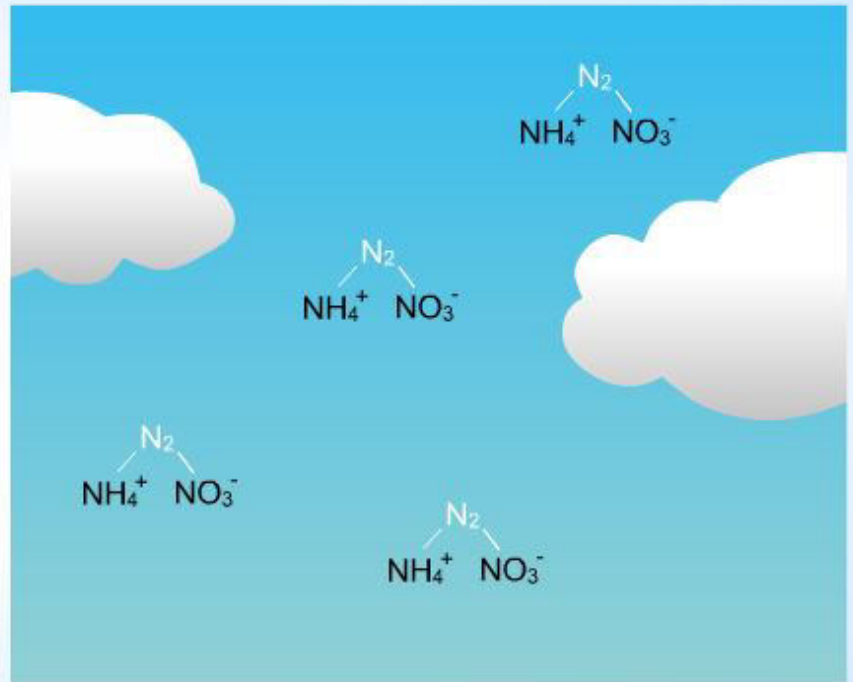
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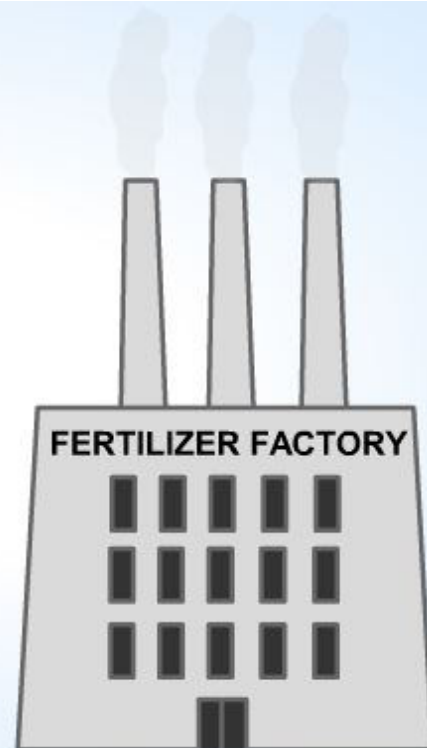
Symbiotic biological fixation requires a certain type of bacterium, called a rhizobium, and leguminous plants, like beans or alfalfa. Rhizobia enter the legume through the root and form growths called nodules. The relationship between the legume and rhizobium is symbiotic because the bacteria receives carbon compounds allowing it to perform nitrogen fixation while the plant itself receives nitrogen. Farmers capitalize on this process by rotating legume crops with other plants.



Atmospheric nitrogen fixation occurs when lightning splits N_2 into ammonia (NH_4^+) and nitrates (NO_3^-). Rain then helps bring the fixed nitrogen to the soil. However, this process accounts for very little of the biosphere's total nitrogen fixation – only about 5 to 8%.



Humans have also developed methods for nitrogen fixation. These processes produce ammonia (NH_3) that is used for fertilizer or turned into ammonium nitrate (NH_4NO_3).



Question 1:

The process that returns nitrogen to the atmosphere is called:

- a** Ammonification
- b** Nitrogen fixation
- c** Denitrification
- d** Nitrification

Question 2:

What provides the most amount of nitrogen for the nitrogen cycle?

- a** Lightning
- b** Industrial processes
- c** The decomposition of plants and animals
- d** The symbiotic relationship of legumes and rhizobia

Question 3:

Which form of nitrogen is most useful to plants and animals?

- a** Nitrite
- b** Nitrate
- c** Nitrogen Gas
- d** Nitrous Oxide

Question 4:

Which step of the nitrogen cycle does not directly involve bacteria?

- a** Decomposition of plants and animals
- b** Nitrification
- c** Denitrification
- d** Ammonification

- Enhancing crop growth with the use of nitrogen-based fertilizers. Nitrogen-based fertilizers do not remain on agricultural soils; they end up in groundwater systems. Estuaries, streams, rivers, and lakes all show evidence of nitrogen including the effects of **eutrophication** which can alter or even destroy many aquatic ecosystems.
- Earth's atmosphere shows increasing levels of nitrogen as a consequence of burning forests and fossil fuels. Many of these are greenhouse gases that have affected global climate and are melting polar ice caps. Left unchecked these trends of pollution will lead to drastic changes in climate all around the world and the potential for rising sea levels and more powerful storms.

- The process of livestock ranching releases massive amounts of ammonia and methane. Entering the soil and atmospheric systems, these nitrogen sources also leach into waterways and are changing the natural balance of nitrogen cycles.
- Human sewage from septic tanks also leaches nitrogen into the soil.

In addition to human factors, there are other causes that reduce the amount of nitrate available to plants. Erosion is the process of soil particles being carried away by wind or water. Nutrients are carried away in the eroding soil. As water percolates through soil, it carries dissolved nutrients with it. Water may leach the nutrients out of the reach of roots. Water plays an important role in both the carbon and nitrogen cycles. Water movement enhances the cycling of nutrients in the leaching process, as it is responsible for dissolving and carrying nutrients to and from plants. Soil organisms and plants need water to survive. The movement of water can also cause problems. The power of water can be a destructive force, contributing to runoff, erosion, and soil compaction.

Evolution & Ecology: Environmental Cycles

Amazonian rainforests provide an example of the complexity of nutrient cycling. Based on the enormous diversity of vegetation of these tropical rainforests, it was once thought that their soils were rich. Scientists now know, however, that most rainforest soils are actually quite nutrient poor and high in potentially toxic chemicals like aluminum. The yellow and red clay-like soils of tropical rainforests worldwide are relatively nutrient poor, most of them considered to be old and weathered. The Amazon does not have the benefit of volcanic activity that could bring significant nutrients to the soil. As a result, the soils lack critical mineral resources, such as calcium, magnesium, phosphorus, and potassium. It turns out that the abundance of nutrients in rainforests is stored in the plant matter itself. Vital minerals are constantly being processed and reabsorbed into the system. Everything is constantly breaking down and returning to the system to maintain the massive volume of living plant material. Some plant species are so highly adapted for this process that they have root systems forming mats on the forest floor to efficiently obtain nutrients.



Vast expanses of rainforests have been cleared for agricultural use. Agricultural practices have quickly depleted the minor reserves of minerals present in the soil, rendering them useless for further agriculture. These tracts of land have been exhausted without the contributions of water and nutrient cycling. No longer viable for agriculture, they have been abandoned in favor of newly deforested land. The process of reforesting these large tracts of land has met with limited success. Many rainforest species need the systemic combination of many factors like decomposition, nutrient cycling, symbiotic bacteria and mycorrhizae, and deep shade of more mature plants to grow. Too much sun, stripped soil, and the lack of incoming nutrients make it difficult for rainforests to recover to their former level of

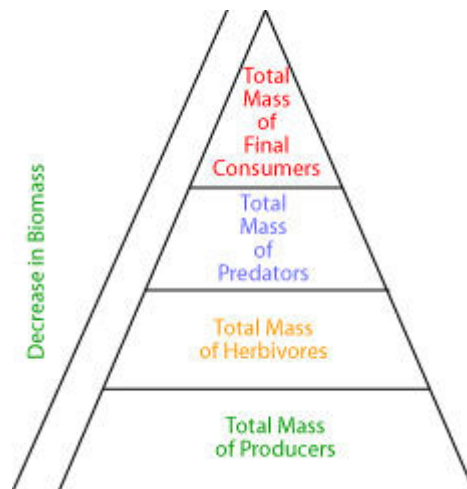
diversity. Smaller tracts of deforested land have recovered with some success because they have adjacent areas with enough surrounding rainforest to contribute vital nutrients, seeds, and symbiotic organisms vital to the recovery process.

Evolution & Ecology: Environmental Cycles

Going with the Flow

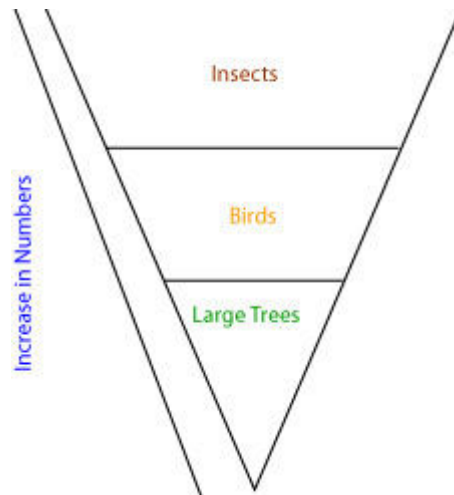
Sunlight, water, and carbon are central to the energy conversion that is photosynthesis. Plant production of simple sugars becomes the energy of growth and reproduction. The sun's energy converted by plants into simple sugars is the starting point of any food chain. Plants are the primary **producers**, which are organisms that create their own food. Animals obtain converted energy by eating plants. Animals are **consumers**. As consumers they cannot create their own food. **Herbivores** are consumers that rely entirely on plants for their food. **Omnivores** are animals that obtain their energy from both plant matter and other animals. **Carnivores** obtain all of their energy by consuming other animals.

Each level of consumption in the food chain is called a **trophic level**. Producers are the first trophic level and are the beginning point for transfer of the sun's energy to all other living things. As it is transferred from one trophic level to the next some energy is lost as heat. A biomass pyramid is one expression of the movement of energy through the trophic levels. The lower trophic levels contain the most energy. Energy is lost as it is transferred from one level to the next. The upper levels of the **biomass pyramid** have less total biomass as a result of the lower energy availability.

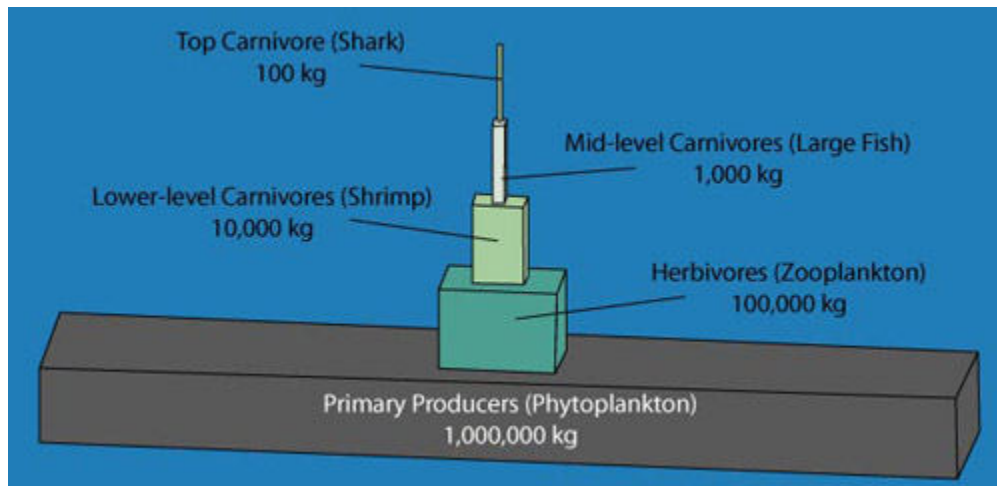


Evolution & Ecology: Environmental Cycles

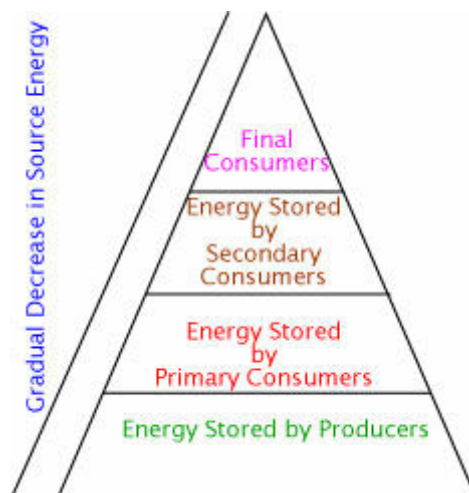
A **pyramid of numbers** is an expression of the amount of organisms in a trophic level. The type of ecosystem determines the shape of the pyramid. For example, a forest ecosystem may have a limited number of large trees. However, the trees successfully support a number of bird species and an even greater number of insects.



In contrast an ocean pyramid of numbers would reflect an enormous number of algae, fewer herbivores, and even fewer carnivores.



A **pyramid of energy** reflects the production rates in each trophic level. Using the ocean example again, consider the rapid reproduction rate of algae. Algae populations take only a few days to double. Zooplankton feed on the algae and may double in population in a few months. The fish feeding on the zooplankton may only reproduce a single time each year. A pyramid of energy reflects the turnover rate of a population. This pyramid cannot be inverted.



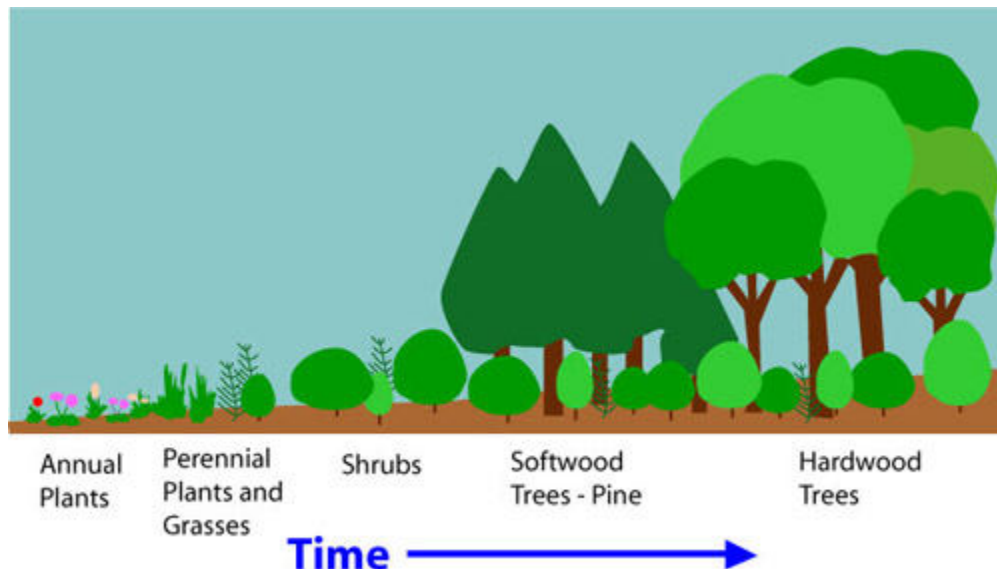
Across the trophic levels, some energy remains unconsumed or is excreted as undigested material. This potential energy does not go unused. **Detritivores** survive on the waste products of the ecosystem. Detritivores include the scavengers, such as vultures, who consume carrion or the matter of dead animals, and the **decomposers**, such as ants and worms, that consume organic matter. They all serve as recyclers breaking down nitrogenous waste products and dead organisms. Consumers of detritivores access the energy of their clean-up work and bring it further into the food web.

Vast expanses of rainforests have been cleared for agricultural use. Agricultural practices have quickly depleted the minor reserves of minerals present in the soil, rendering them useless for further agriculture. These tracts of land have been exhausted without the contributions of water and nutrient cycling. No longer viable for agriculture, they have been abandoned in favor of newly deforested land. The process of reforesting these large tracts of land has met with limited success. Many rainforest species need the systemic combination of many factors like decomposition, nutrient cycling, symbiotic bacteria and mycorrhizae, and deep shade of more mature plants to grow. Too much sun, stripped soil, and the lack of incoming nutrients make it difficult for rainforests to recover to their former level of diversity. Smaller tracts of deforested land have recovered with some success because they have adjacent areas with enough surrounding rainforest to contribute vital nutrients, seeds, and symbiotic organisms vital to the recovery process.

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The Only Constant: Change

As species change and evolve over time, so do ecosystems. Ecosystems go through constant, observable processes of change and restructuring. Over time, some species may become more abundant while others decline or even disappear. As time marches on so does the composition of inhabitants of an ecosystem resulting in **ecological succession**.



Succession processes are frequently recognized by the presence of certain species. During particular parts of the orderly series of changes, certain species will be more prevalent. This prevalence enables scientists to roughly identify the stage of succession that is underway in a community.

The concept of succession is an important ecological idea and hinges on the ideas of colonization, pioneer species, and climax communities. Whenever there is a disturbance (fire, landslide, flood,

etc.), there exists an opportunity for succession to occur. In regular turnover that accompanies the replacement of these communities, the species that make up each stage in succession are similar in their abilities to colonize, reproduce, and disseminate. Moreover, there are striking similarities in these communities' longevity, area of reproduction, and their placement in the succession arena.

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More recently, scientists have identified two types of succession. **Primary succession** occurs in places previously unoccupied by vegetation. Lava flows, newly emerged volcanic islands, soil rubble exposed by major landslides, the remnants of open-pit mining, and receding glaciers are all locations for primary succession. Characterized by exposed rock and soil, these locations take hundreds of years to change species communities towards a climax community.

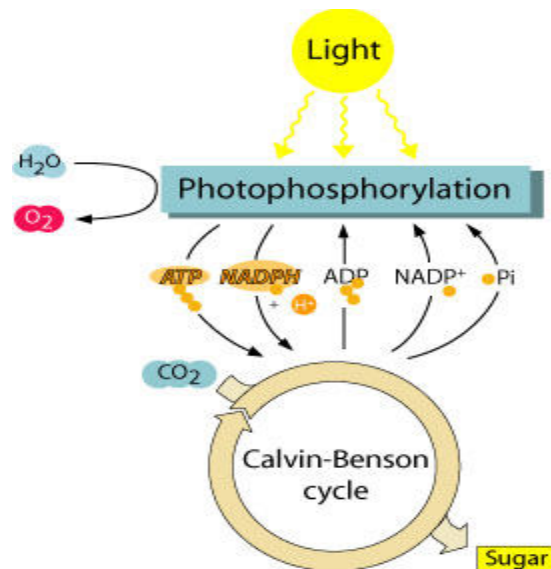
Secondary succession occurs as the re-establishment of viable, stable communities following deforestation, abandonment of agricultural sites, and flooding or hurricane conditions. Secondary succession is expressed in a similar sequence except with a different starting point. As a result of any of these disturbances, secondary succession maximizes the remaining topsoil and organic life to begin anew.

In primary and secondary succession the re-vegetation process is driven by new species out-competing existing species. For example, the extensive root systems of tall grasses enable access to nutrients and moisture needed by wildflowers. Eventually the tall grasses put the wildflowers out of business. Later the tall grasses will be overpowered by the increased shade produced by incoming tree growth. With plant species transitions come new influxes of animal species. Animals arrive on the attributes of plant species that provide food or shelter. Slowly the entire system moves towards increasing stability known as a **climax community**. In the absence of climate or land changes, a climax community can support a consistent species composition. Eventually the community becomes so well-established it is self-sustaining. These climax communities are the foundation of Earth's diverse biomes.

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Abiotic Factors and Biomes

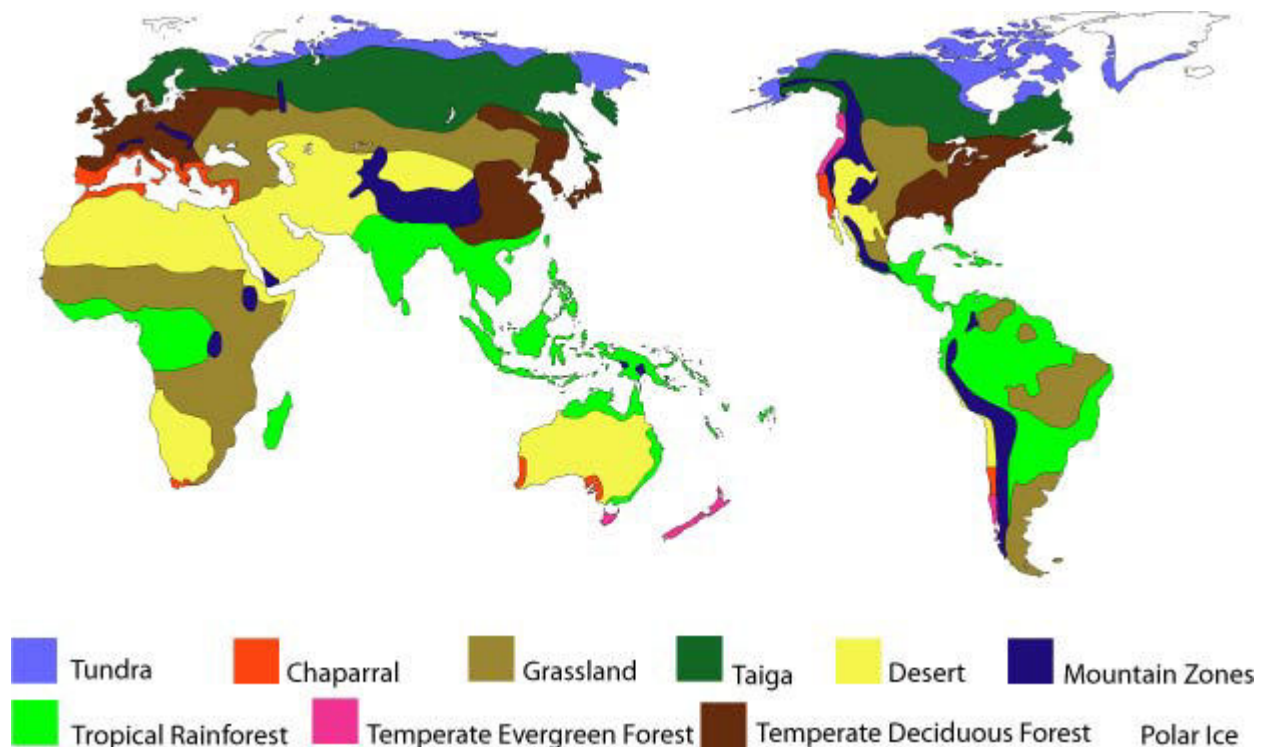
Evolution, interdependent relationships, symbiosis, competition, and reproductive success are the biotic factors influencing all living things. But this is only half of the bigger picture. The other half relates to abiotic factors. that have a direct affect on global and local species distribution. Wind, water, sunlight, temperature, soil, rocks, and periodic disturbances are all abiotic factors. These factors affect species where they live. For example, wind can speed the evaporation of moisture from soil or increase dehydration in animals. Freezing or extreme heat can quickly affect an entire population of species. Those unable to migrate are affected by temperature extremes. Soil is necessary for all plant growth. This makes it an important abiotic factor for the success of any ecosystem. Sunlight is the first element of any food chain. Sunlight launches plant photosynthesis, contributes to productivity in aquatic habitats, determines vegetation in all layers of the forest, and for some animals, determines breeding cycles and lifestyle.



Fire is an example of an abiotic periodic disturbance. Fire is part of a natural cycle of transforming accumulated leaf litter and undergrowth into nutrients in the soil, and making way for new growth. Some species of plants need fire to trigger seed dispersal or initiate germination. In the past, humans have mistakenly controlled fires in the western United States. Controlling the natural process of forest fires has meant an increase in the amount of leaf litter and undergrowth. Subsequent fires burn hotter, consuming the abundant fuel available from fewer previous fires. Less frequent fires negatively impact plants that rely upon them for reproduction and growth.

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Abiotic factors are one aspect of the physical definition of **biomes**. A biome is a large geographic region and the distribution of plants and animals within it. Biomes are heavily dependent upon the combination of geography and climate. Climax communities are the foundation of biomes. Forests, deserts, grasslands, and aquatic regions are considered to be some of Earth's major biomes.



Forests are perhaps the most ecologically complex biomes. Plants, trees, microorganisms, insects, invertebrates, amphibians, reptiles, and mammals are all found in the varying climatic conditions of Earth's forests. Found along the Earth's equator, tropical rainforests contain richly diverse communities.

A rainforest basks in 12 hours of daylight and has virtually no winter season. Characterized by a dry season and a rainy season, vegetation growth is abundant. Rainforests are capable hosts of well-adapted plant and animal species. Diverse adaptations — giant leaf size, enormous buttress roots, camouflage, mimicking coloration, and symbiotic relationships — enable rainforests to be highly productive, self-sustaining climax communities.

Temperate broadleaf deciduous forests can be observed in eastern North American, eastern Asia, and western and central Europe. These climax communities receive up to 152 centimeters of rain distributed throughout the seasons. They experience winter months including the implications of snow and ice. Cooler fall weather causes many tree species to drop their leaves, adding nutrient resources to the rich soil of the forest floor. Temperate broadleaf deciduous forests are characterized by tree species such as elm, linden, walnut, oak, maple, hickory, and chestnut. Squirrels, raccoons, opossums, and black bears are among the mammal inhabitants. Insects are abundant and are connected to the bird species present in this biome, including thrushes, warblers, hummingbirds, wrens, woodpeckers, and chickadees. Birds migrate out of this biome to warmer temperatures during the winter months, returning to the highly productive biome for breeding during the summer season.

Question

What would the principles of ecological succession predict?

- A A climax community is slowly out-competed by secondary plants, the secondary plants are likewise marginalized by pioneer species, and then the process would start all over again.
- B Pioneer species are the first to invade new habitat and they are slowly out-competed by secondary plants; finally the secondary plants give rise to the climax community.
- C After a disturbance, secondary species are the first to invade new habitat and they are slowly out-competed by pioneer plants; finally they give rise to the climax community.
- D Invasive exotic species disturb the habitat, making it unfit for the secondary species who then are replaced by pioneer species that change the habitat back to an environment suitable for the secondary species.

Answer

The correct answer is B. Pioneer species are the first members of the first communities that take over new habitats. The pioneer species are short-lived and are out-competed by other species, called secondary species that (if conditions are right) are then further out-competed by the climax community, until there is another disturbance.

Evolution & Ecology: Environmental Cycles

About 20% of the Earth is covered by desert biomes. The extremely low rainfall these biomes receive each year makes them deserts. In a setting where water is at a premium, high temperatures cause evaporation that is not replenished by rainfall. Consequently, vegetation is sparsely distributed in desert biomes, with adaptations to maximize moisture storage while minimizing the impact of evaporation. Where forest trees have leaf sizes ranging from medium to enormous, desert plants are thrifty minimalists. Some desert plant and animal species are annuals with short life cycles that take full advantage of brief wet periods and have dormant life stages during the hot and dry periods.

Deserts can be geographically and climatically defined. Ranging from arid to semi-arid, to coastal, to cold and high deserts, soil make-up combined with heat and rainfall determine the exact type of desert and environmental factors. In turn, these factors limit plant and animal life to a few species with highly specialized adaptation strategies. Animals take advantage of nightfall and come out in the cooler darkness to access food resources and to breed. Many live in burrows to avoid the extreme daytime heat.

South African veldt, Asian steppes, South American pampas, and North American prairies are all grassland biomes. All are inland and receive 10 to 20 cm of precipitation annually. Perennial grasses; grazing, migratory herd mammals; herbivorous rodents; and ground nesting bird species take advantage of the characteristics of grassland habitat. Humans have exploited grasslands extensively for agricultural development.

Seventy-five percent of Earth is covered by water. Billions of years ago, life began in the ocean. From deep ocean floors to rocky mountain streams, aquatic biomes support a diverse array of species adapted for life in the water. The largest and most diverse ecosystems are oceanic. Oceans are home to abundant algae that contribute most of the oxygen in Earth's atmosphere, as well as marine species that take advantage of the open ocean, intercoastal, tidal, coral reef, and estuarine habitats. Inland freshwater lakes, wetlands, ponds, and rivers are aquatic ecosystems. Each is characterized by water and geologic features that can support life. We still have much to learn about the productivity and abundance of the aquatic ecosystems.

Further Reading in Evolution and Ecology

Biology: Evolution & Ecology: Further Reading

Evolution

The Ancestor's Tale: A Pilgrimage to the Dawn of Evolution (Richard Dawkins): 2004

Origin of Species (Charles Darwin): 1995

Darwin 's Dangerous Idea: Evolution and the Meanings of Life (Daniel C. Dennett): 1996

What Evolution Is (Ernst Mayr): 2002

The Complete Idiot's Guide to Biology (Glen Moulton): 2004

Ecology

A Citizen's Guide to Ecology (Lawrence B. Slobodkin): 2003

A Dictionary of Ecology, Evolution and Systematics (R. J. Lincoln, et. al.): 1998