flexbook
next generation textbooks

CK-12 Biology Advanced Concepts

CK-12 Biology Advanced Concepts

next generation textbooks

To access a customizable version of this book, as well as other interactive content, visit www.ck12.org

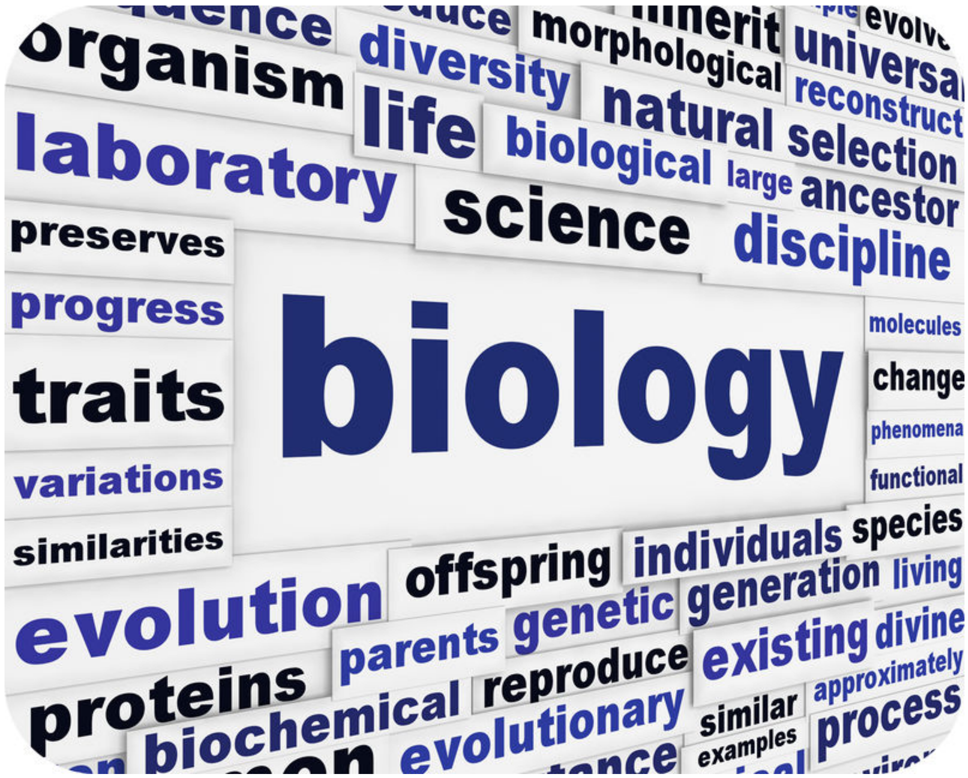
CK-12 Foundation is a non-profit organization with a mission to reduce the cost of textbook materials for the K-12 market both in the U.S. and worldwide. Using an open-content, web-based collaborative model termed the **FlexBook®**, CK-12 intends to pioneer the generation and distribution of high-quality educational content that will serve both as core text as well as provide an adaptive environment for learning, powered through the **FlexBook Platform®**.

Printed: October 2, 2013

flexbook
next generation textbooks

EDITOR
Douglas Wilkin, Ph.D.

Foreword



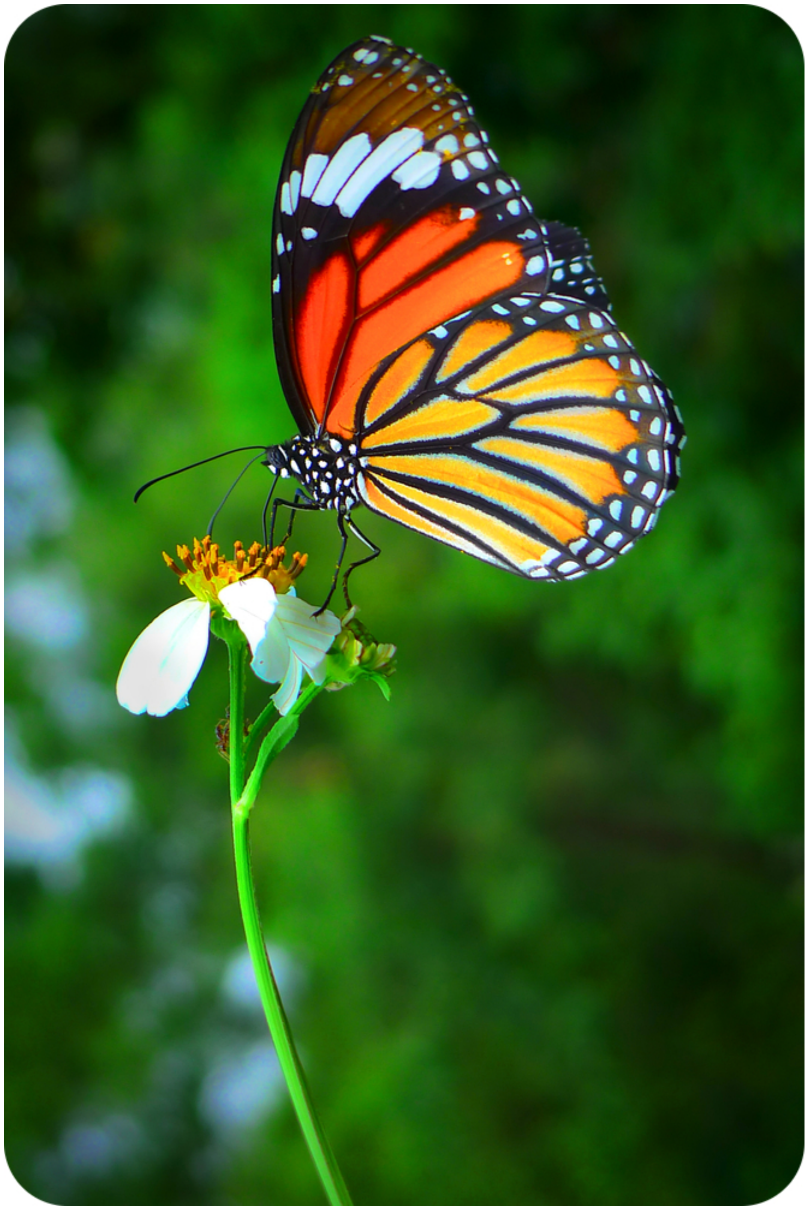
The study of biology is the study of life. Concept Biology Advanced is CK-12s most extensive material describing the study of life. Concept Biology Advanced presents biology as a set of 18 concepts, with each concept centered around a specific category, such as cell biology or plants. Each concept is comprised of a series of lessons, with each lesson focusing on one specific topic. The complete Concept Biology Advanced is comprised of over 550 lessons. This material has been developed to complement the most advanced secondary-level biology course.

Contents

CHAPTER 1 The Study of Life - Advanced

Chapter Outline

Introduction



Is there a way to define *life*?

Scientifically, there is an actual definition of *life*. Living organisms must have certain characteristics. If they do not have these characteristics, are they living? This butterfly, like all other insects, animals, plants, and every other living organism, shares common characteristics with all life. What exactly does it mean to be *alive*? This concept will answer this question. These lessons will serve as an introduction to biology, discussing *The Study of Life* and fundamental *Principles of Biology.*

1.1 Goals of Science

- Define *science.*
- List the principles that should guide scientific research.

What is science?

The goal of science is to learn how nature works by observing the natural and physical world, and to understand this world through research and experimentation. **Science** is a distinctive way of learning about the world through observation, inquiry, formulating and testing hypotheses, gathering and analyzing data, and reporting and evaluating findings. We are all part of an amazing and mysterious phenomenon called "life" that thousands of scientists everyday are trying to better explain. And it's surprisingly easy to become part of this great discovery. All you need is your natural curiosity and an understanding of how people use the process of science to learn about the world.

Goals of Science

Science involves objective, logical, and repeatable attempts to understand the principles and forces working in the natural universe. Science is from the Latin word, *scientia*, which means "knowledge." Science is an ongoing process of testing and evaluation, and is guided by an universal set of principles. One of the intended benefits of these concepts is to become more familiar with the scientific process.

Humans are naturally interested in the world we live in. Young children constantly ask "why" questions. Science is a way to get some of those "whys" answered. You may not realize it, but you are performing **experiments** all the time. For example, when you shop for groceries, you may end up carrying out a type of scientific experiment (**Figure** 1.1). If you like Brand X of salad dressing, and Brand Y is on sale, perhaps you will try Brand Y. And then if you like Brand Y, you may buy it again even when it is not on sale. If you did not like Brand Y, then no sale will get you to try it again. Your conclusions are essentially based on an experiment. To find out *why* a person makes a particular purchasing choice, you might examine the cost, ingredient list, or packaging of the two salad dressings.

FIGURE 1.1
Shopping sometimes involves a little scientific experimentation. You are interested in inventing a new type of salad that you can pack for lunch. You might buy a vegetable or salad dressing that you have not tried before, to discover if you like it. If you like it, you will probably buy it again. That is a type of experiment.

There are many different areas of science, or *scientific disciplines*, but all scientific study involves:

- asking questions
- making observations
- relying on evidence to form conclusions
- being skeptical about ideas or results

Skepticism is an attitude of doubt about the truthfulness of claims that lack empirical evidence. **Scientific skepticism**, also referred to as skeptical inquiry, questions claims based on their scientific verifiability rather than accepting claims based on faith or anecdotes. Scientific skepticism uses critical thinking to analyze such claims and opposes claims which lack scientific evidence.

Vocabulary

- **experiment**: A test that is used to rule out a hypothesis or validate something already known; a test that is used to eliminate one or more of the possible hypotheses until one hypothesis remains.
- **science**: A distinctive way of learning about the natural world through observation, inquiry, formulating and testing hypotheses, gathering and analyzing data, and reporting and evaluating findings.
- **scientific skepticism**: Questioning claims based on their scientific verifiability rather than accepting claims based on faith or anecdotes.

Summary

- Scientific skepticism questions claims based on their scientific verifiability rather than accepting claims based on faith or anecdotes. Scientific skepticism uses critical thinking to analyze such claims and opposes claims which lack scientific evidence.

Practice

Use this resource to answer the question that follows.

- **The Aim of a Good Scientist** at http://www.5min.com/Video/The-Aim-of-a-Good-Scientist-291035149.

1. Describe the goals of the scientist in this video.

Review

1. What is science? What is the goal of science?
2. What is an experiment? Why are experiments performed?
3. Describe scientific skepticism.

1.2 Scientific Perspectives

- Examine a scientist's view of the world.

What would be a *scientific view of the world*?

It could be said that the *scientific view of the world* is based on proven answers to specific questions. "How old are recently identified fossils? What are the consequences of mutations in a certain gene? How does the endocrine system help maintain homeostasis?" These are questions in which definite answers can be sought. These answers help expand the scientific view of the world. Questions that cannot be answered with definitive answers, questions that cannot be proved with evidence, are not based on science. The scientific view of the world would not include answers to such questions.

A Scientific View of the World

Science is based on the analysis of things that humans can observe either by themselves through their senses, or by using special equipment. Science therefore cannot explain anything about the natural world that is beyond what is observable by current means. The term *supernatural* refers to entities, events, or powers regarded as being beyond nature, in that such things cannot be explained by scientific means. They are not measurable or observable in the same way the natural world is, and so considered to be outside the realm of scientific examination.

When a natural occurrence which was once considered supernatural is understood in the terms of natural causes and consequences, it has a scientific explanation. For example, the flickering lights sometimes seen hovering over damp ground on still evenings or nights are commonly called *Will-o'-the-wisp*. This phenomena looks like a lamp or flame, and is sometimes said to move away if approached. A great deal of folklore surrounds the legend, such as the belief that the lights are lost souls or fairies attempting to lead travelers astray. However, science has offered several potential explanations for Will-o'-the-wisp from burning marsh gases to glowing fungi, or animals that glow in a similar way to lightning bugs.

When trying to answer scientific questions, there is no fixed set of steps that scientists always follow and there is no single path that leads to scientific knowledge. There are, however, certain features of science that give it a very specific fashion of investigating. You do not have to be a professional scientist to think like a scientist. Everyone, including you, can use certain features of scientific thinking to think critically about issues and situations in everyday life.

Science assumes that the universe is a vast single system in which the basic rules are the same, and thus nature, and what happens in nature, can be understood. Things that are learned from studying one part of the universe can be applied to other parts of the universe. For example, the same principles of motion and gravitation that explain the motion of falling objects on Earth also explain the orbit of the planets around the sun, and galaxies, as shown in the **Figure** 1.2. As discussed below, as more and more information and knowledge is collected and understood, scientific ideas can change. And even though scientific knowledge usually stands the test of time, it cannot answer all questions.

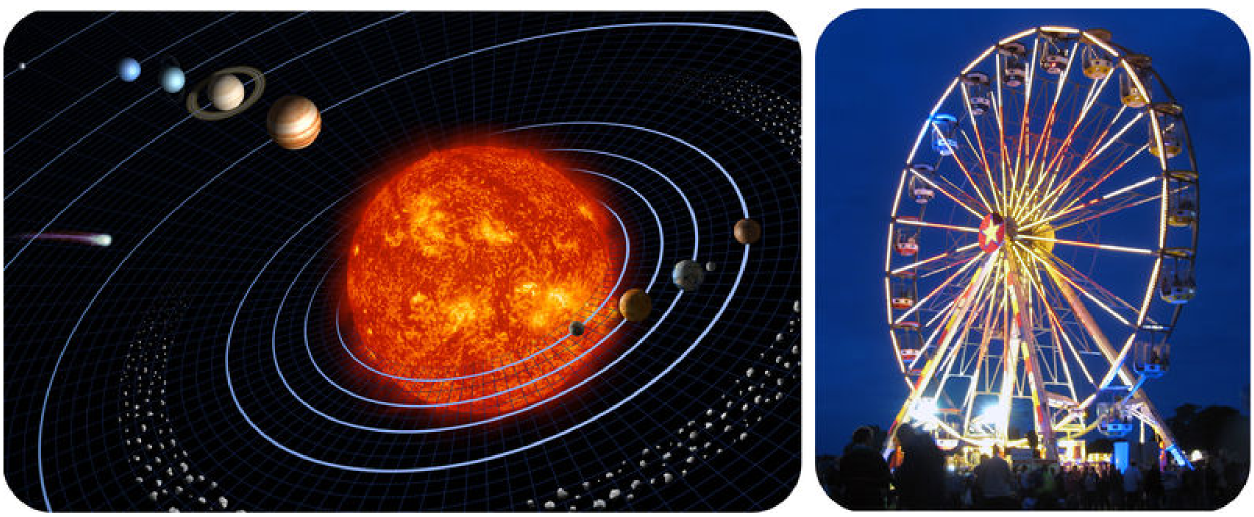


FIGURE 1.2
With some changes over the years, similar principles of motion have applied to different situations. The same scientific principles that help explain planetary orbits can be applied to the movement of a Ferris wheel.

Nature Can Be Understood

Science presumes that events in the universe happen in patterns that can be understood by careful study. Scientists believe that through the use of the mind, and with the help of instruments that extend the human senses, people can discover patterns in all of nature that can help us understand life, the world and the universe.

Scientists think of nature as a single system controlled by natural laws. By discovering natural laws, scientists strive to increase their understanding of the natural world. Laws of nature are expressed as scientific laws. A **scientific law** is a statement that describes what always happens under certain conditions in nature.

An example of a scientific law is the law of gravity, which was discovered by Sir Isaac Newton (see **Figure** 1.3). The law of gravity states that objects always fall towards Earth because of the pull of gravity. Based on this law, Newton could explain many natural events. He could explain not only why objects such as apples always fall to the ground, but he could also explain why the moon orbits Earth. Isaac Newton discovered laws of motion as well as the law of gravity. His laws of motion allowed him to explain why objects move as they do.

FIGURE 1.3
Did Newton discover the law of gravity when an apple fell from a tree and hit him on the head? Probably not, but observations of nature are often the starting point for new ideas about the natural world.

Scientific Ideas Can Change

Science is a process for developing knowledge. Change in knowledge about the natural world is expected because new observations may challenge the existing understanding of nature. No matter how well one theory explains a set of observations, it is possible that another theory may fit just as well or better, or may fit a still wider range of observations. In science, the testing and improving of theories goes on all the time. Scientists know that even if there is no way to gain complete knowledge about something, an increasingly accurate understanding of nature will develop over time.

The ability of scientists to make more accurate predictions about the natural world, from determining how the smallest living organisms develop antibiotic resistance to how "non-living" viruses continue to evolve, from how a cancerous tumor develops its own blood supply to how mutations lead to cancer and other diseases, from trying to predict earthquakes to calculating the orbit of an asteroid, provides evidence that scientists are gaining an understanding of how the world works.

Scientific Knowledge Can Stand the Test of Time

Continuity and stability are as much characteristics of science as change is. Although scientists accept some uncertainty as part of nature, most scientific knowledge stands the test of time. A changing of ideas, rather than a complete rejection of the ideas, is the usual practice in science. Powerful ideas about nature tend to survive, grow more accurate and become more widely accepted.

For example, in developing the theory of relativity, Albert Einstein did not throw out Issac Newton's laws of motion but rather, he showed them to be only a small part of the bigger, cosmic picture. That is, the Newtonian laws of motion have limited use within our more general concept of the universe. For example, the National Aeronautics and Space Administration (NASA) uses the Newtonian laws of motion to calculate the flight paths of satellites and space vehicles.

The theory of evolution by natural selection is a classic example of a biological theory that has withstood the test of time. Developed over 150 years ago, myriad data has been identified to support Charles Darwin's theory. So far, no scientific information has been uncovered to contradict or counteract this scientific theory.

Science Cannot Offer Answers to All Questions

There are many things that cannot be examined in a scientific way. There are, for instance, beliefs that cannot be proved or disproved, such as the existence of supernatural powers, supernatural beings, or the meaning of life. In other cases, a scientific approach to a question and a scientific answer may be rejected by people who hold to certain beliefs.

Scientists do not have the means to settle moral questions surrounding good and evil, or love and hate, although they can sometimes contribute to the discussion of such issues by identifying the likely reasons for certain actions by humans and the possible consequences of these actions.

Vocabulary

- **science**: A distinctive way of learning about the natural world through observation, inquiry, formulating and testing hypotheses, gathering and analyzing data, and reporting and evaluating findings.
- **scientific law**: A principle which can be used to predict the behavior of the natural world.
- **scientist**: An individual who uses the scientific method; a person who engages in a systematic activity to acquire knowledge.

Summary

- Science is based on the analysis of things that humans can observe either by themselves through their senses, or by using special equipment. Science therefore cannot explain anything about the natural world that is beyond what is observable by current means. Supernatural things cannot be explained by scientific means.

Practice

Use this resource to answer the question that follows.

- **E.O. Wilson: Advice to young scientists** at http://www.ted.com/talks/e_o_wilson_advice_to_young_scientists.html.

MEDIA
Click image to the left for more content.

1. Summarize the principles of biologist's E.O. Wilson's presentation.

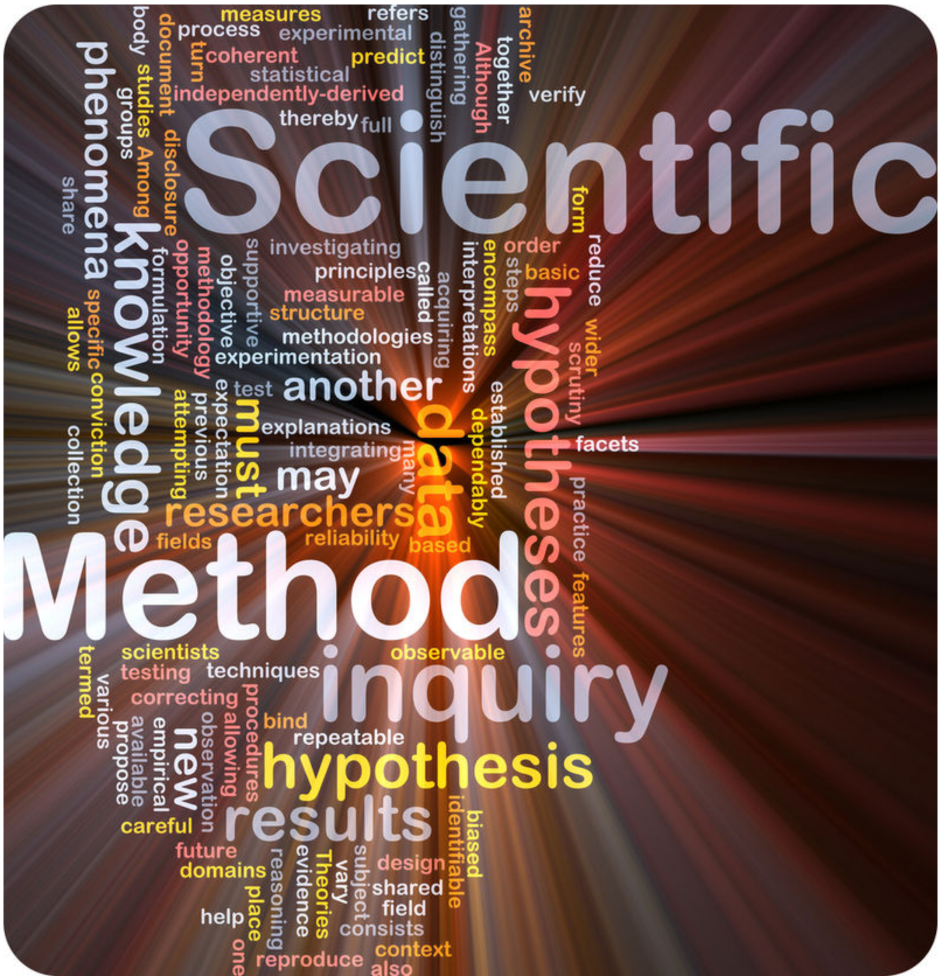
Review

1. What makes someone a "scientist?"
2. Describe a scientific law.

3. What is meant by *nature can be understood*?
4. Discuss why science cannot answer all questions.

1.3 Scientific Methods - Advanced

- Outline a set of steps that are used in the scientific method of investigating a problem.
- Explain why a control group is used in an experiment.



What is the method of science?

How is science "done?" It can be difficult sometimes to define research methods in a way that will clearly distinguish science from non-science. However, there is a set of core principles that make up the “bones” of scientific research. These principles are widely accepted within the scientific community. Although there is no fixed set of steps that scientists always follow during an investigation, and there is no single path that leads scientists to knowledge, there are certain features of science that give it a distinct way of investigating.

Scientific Methods

Scientific investigations examine, gain new knowledge, or build on previous knowledge about phenomena. A **phenomenon**, is any occurrence that is observable, such as the burning match shown in the **Figure** 1.4, as well as the structure of a cell and the prey of a lion. A phenomenon may be a feature of matter, energy, or time. For example, Isaac Newton made observations of the phenomenon of the moon’s orbit, Galileo Galilei made observations of phenomena related to swinging pendulums and Charles Darwin made observations of unique plant and animal species. Although procedures vary from one field of scientific inquiry to another, certain features distinguish scientific inquiry from other types of knowledge. **Scientific methods** are based on gathering observable, empirical (produced by **experiment** or observation), and measurable **evidence** that is critically evaluated.

FIGURE 1.4
The combustion of this match is an observable event and therefore a phenomenon.

The Scientific Method Video can be seen at http://www.youtube.com/watch?v=KZaCy5Z87FA (3:36).

MEDIA
Click image to the left for more content.

Scientific Investigations

The scientific method is not a step by step, linear process. It is a way of learning about the world through the application of knowledge. Scientists must be able to have an idea of what the answer to an investigation should be. To do this, many investigations are going to be based on previous knowledge, with the notion of extending that knowledge. Scientists will often make an observation and then form a hypothesis to explain why a phenomenon occurred. They use all of their knowledge and a bit of imagination in their journey of discovery.

A **hypothesis** is a suggested explanation of a question or problem, based on evidence that can be tested by observation or experimentation. Scientists may test and reject several hypotheses before solving a problem. A hypothesis must be testable; it gains credibility by being tested over and over again, and by surviving attempts to prove it wrong.

Scientific investigations involve the collection of data through observation, the formation and testing of hypotheses by experimentation, and analysis of the results that involves reasoning. Scientific investigations begin with observations that lead to questions. Questions can be as varied as how does a certain disease form to what does the product of a certain gene do?

We will use an everyday example to show what makes up a scientific investigation. Imagine that you walk into a room, and the room is dark.

- You observe that the room appears dark, and you question why the room is dark.
- In an attempt to find explanations to this phenomenon, you develop several different hypotheses. One hypothesis might state that the room does not have a light source at all. Another hypothesis might be that the lights are turned off. Still, another might be that the light bulb has burnt out. Worse yet, you could be going blind.
- To discover the answer, you experiment. You feel your way around the room and find a light switch and turn it on. No light. You repeat the experiment, flicking the switch back and forth; still nothing.
- This means your first two hypotheses, that the room is dark because (1) it does not have a light source; and (2) the lights are off, have been rejected.
- You think of more experiments to test your hypotheses, such as switching on a flashlight to prove that you are not blind.
- In order to accept your last remaining hypothesis as the answer, you could predict that changing the light bulb will fix the problem. If your predictions about this hypothesis succeed (changing the light bulb fixes the problem), the original hypothesis is valid and is accepted.
- However, in some cases, your predictions will not succeed (changing the light bulb does not fix the problem), and you will have to start over again with a new hypothesis. Perhaps there is a short circuit somewhere in the house, or the power might be out.

The general process of a scientific investigation is summed up in **Figure** 1.6.

TABLE 1.1: Common Terms Used in Scientific Investigations

Term	Definition
Scientific Method	The process of scientific investigation.
Observation	The act of noting or detecting phenomenon by the senses. For example, taking measurements is a form of observation.
Hypotheses	A suggested explanation based on evidence that can be tested by observation or experimentation.
Scientific Reasoning	The process of looking for scientific reasons for observations.
Experiment	A test that is used to rule out a hypothesis or validate something already known.
Rejected Hypothesis	An explanation that is ruled out by experimentation.
Confirmed Hypothesis	An explanation that is **not** ruled out by repeated experimentation, and makes predictions that are shown to be true.
Inference	Developing new knowledge based upon old knowledge.

TABLE 1.1: (continued)

Term	Definition
Theory	A widely accepted hypothesis that stands the test of time. Theories are often tested, and usually not rejected.

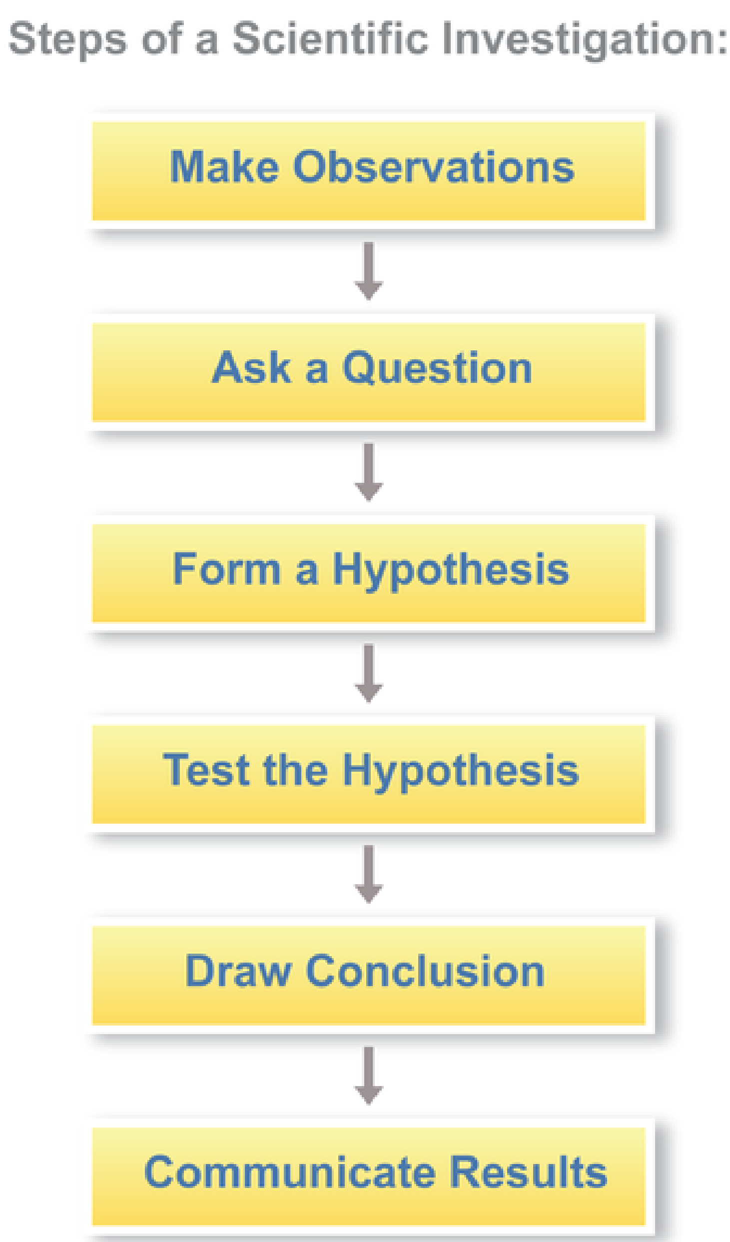


FIGURE 1.5
Steps of a Scientific Investigation. A scientific investigation typically has these steps.

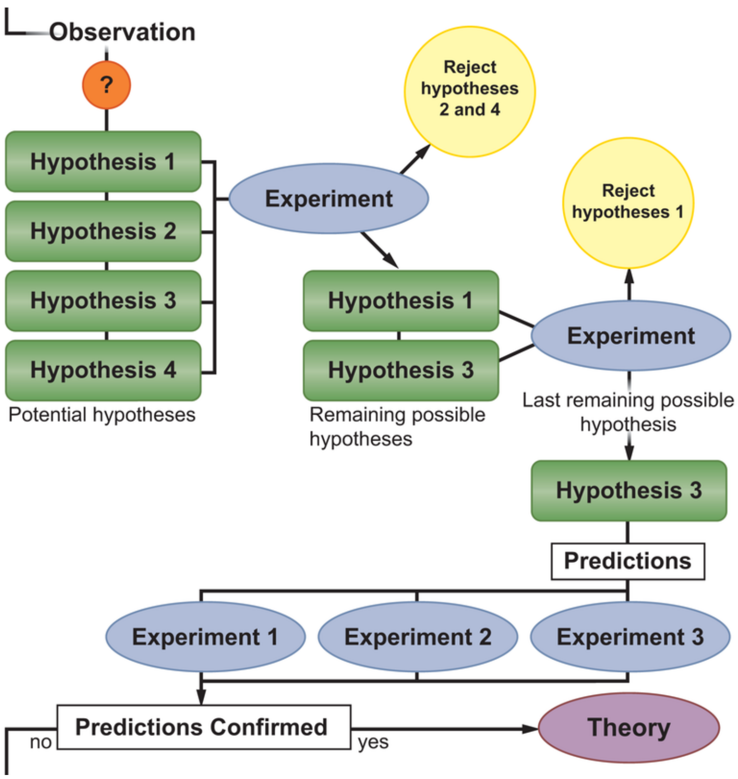


FIGURE 1.6

The general process of scientific investigations. This diagram illustrates how scientific investigations moves from observation of phenomenon to a theory. The progress is not as straightforward as it looks in this diagram. Many times the hypothesis is falsified, which means the investigator will have to redevelop/revise a hypothesis.

The Scientific Method Made Easy explains the scientific method: http://www.youtube.com/watch?v=zcavPAFiG14 (9:55).

MEDIA
Click image to the left for more content.

Making Observations

Scientists first make observations that raise questions. An **observation** is the act of noting or detecting phenomenon through the senses. For example, noting that a room is dark is an observation made through sight.

Developing Hypotheses

In order to explain the observed phenomenon, scientists develop a number of possible explanations, or hypotheses. A hypothesis is a suggested explanation for a phenomenon or a suggested explanation for a relationship between many phenomena. Hypotheses are always based on evidence that can be tested by observation or experimentation. Scientific investigations are required to test hypotheses. Scientists mostly base hypotheses on prior observations or on extensions of existing scientific explanations.

Though many people describe an hypothesis as an "educated guess," that definition is not scientifically accurate. To define a hypothesis as "an educated guess" is like calling a tricycle a "vehicle with three." The definition leaves out the tricycles most important and characteristic feature: the wheels. The "educated guess" definition of a hypothesis also leaves out the concept's most important and characteristic feature: the purpose of the hypotheses. People generate hypotheses as early attempts to explain patterns observed in nature or to predict the outcomes of experiments. For example, in science, one could correctly call the following statement a hypothesis: identical twins can have different personalities because the environment influences personality.

Evaluating Hypotheses

Scientific methods require hypotheses that are **falsifiable**, that is, they must be framed in a way that allows other scientists to prove them false. Proving a hypothesis to be false is usually done by observation and experimentation. However, confirming or failing to falsify a hypothesis does not necessarily mean the hypothesis is true.

For example, a person comes to a new country and observes only white sheep. This person might form the hypothesis: “All sheep in this country are white.” This statement can be called a hypothesis, because it is falsifiable - it can be tested and proved wrong; anyone could falsify the hypothesis by observing a single black sheep, shown in **Figure** 1.7. If the experimental uncertainties remain small (could the person reliably distinguish the observed black sheep from a goat or a small horse), and if the experimenter has correctly interpreted the hypothesis, finding a black sheep falsifies the "only white sheep" hypothesis. However, you cannot call a failure to find non-white sheep as proof that no non-white sheep exist.

Vocabulary

- **evidence**: Any type of data that may be used to test a hypothesis.

FIGURE 1.7
The statement “there are only white sheep in this country” is a hypothesis because it is open to being falsified. However, a failure to see a black sheep will not necessarily falsify the hypothesis. A better scientific hypothesis may be that "only white sheep can survive in this country because of the existing ecosystems."

- **experiment**: A test that is used to rule out a hypothesis or validate something already known; a test that is used to eliminate one or more of the possible hypotheses until one hypothesis remains.
- **falsifiable**: Can be proved false.
- **hypothesis** (plural, **hypotheses**): A suggested explanation based on evidence that can be tested by observation or experimentation.
- **observation**: The act of noting or detecting phenomenon through the senses.
- **phenomenon**: Any occurrence that is observable.
- **scientific investigation**: A plan for asking questions and testing possible answers.
- **scientific methods**: Procedures based on gathering observable, empirical (produced by experiment or observation) and measurable evidence that is critically evaluated.

Summary

- Scientific investigations involve the collection of data through observation, the formation and testing of hypotheses by experimentation, and analysis of the results that involves reasoning.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **How Do Biologists Study?**

1. How is *biology* described in this animation?
2. What are the steps of the scientific method described here?
3. Define *hypothesis*. What was the hypothesis in this animation?
4. What is meant by *causation*?
5. What were the observations described in this animation?
6. What is a *correlation*? Why was a high correlation observed in this animation?
7. What is meant by "correlation does not equal causation?"
8. What is a *theory*? What are the characteristics of a theory?

9. What is a *controlled scientific experiment*?
10. What causes Lyme disease? How is this disease transmitted?

Review

1. Describe the scientific method.
2. What is an hypothesis?
3. How is a hypothesis developed and evaluated?
4. What is meant by falsifiable?
5. What happens if a hypothesis is false?

1.4 Scientific Reasoning - Advanced

- Outline the role that reasoning plays in examining hypotheses.

What does it mean *to reason*?

"What does the data show? Did the experiment work? Is the hypothesis correct?" Reasoning is the human process used to make sense of things. Reasoning is also used to establish and verify facts. Scientific reasoning is no different than everyday reasoning - it is used to make sense of things related to the scientific process, such as conclusions based on the results of an experiment.

Scientific Reasoning

Any useful hypothesis will allow predictions based on reasoning. Reasoning can be broken down into two categories: deduction and induction. Most reasoning in science is done through induction.

Deductive Reasoning: Deduction

Deduction involves determining a single fact from a general statement; it is only as accurate as the statement.

For example, if we know that all organisms are made of cells, need to maintain homeostasis and must reproduce to stay alive, and that humans are organisms, then humans are made of cells, maintain homeostasis and reproduce.

Deductions are intended to have reasoning that is valid. The reasoning in the following argument is valid, because there is no way in which the reasons 1 and 2, could be true and the conclusion, 3, be false:

- Reason 1: All humans are mortal.
- Reason 2: Albert Einstein is a human.
- Conclusion: Albert Einstein is mortal (**Figure** 1.8).

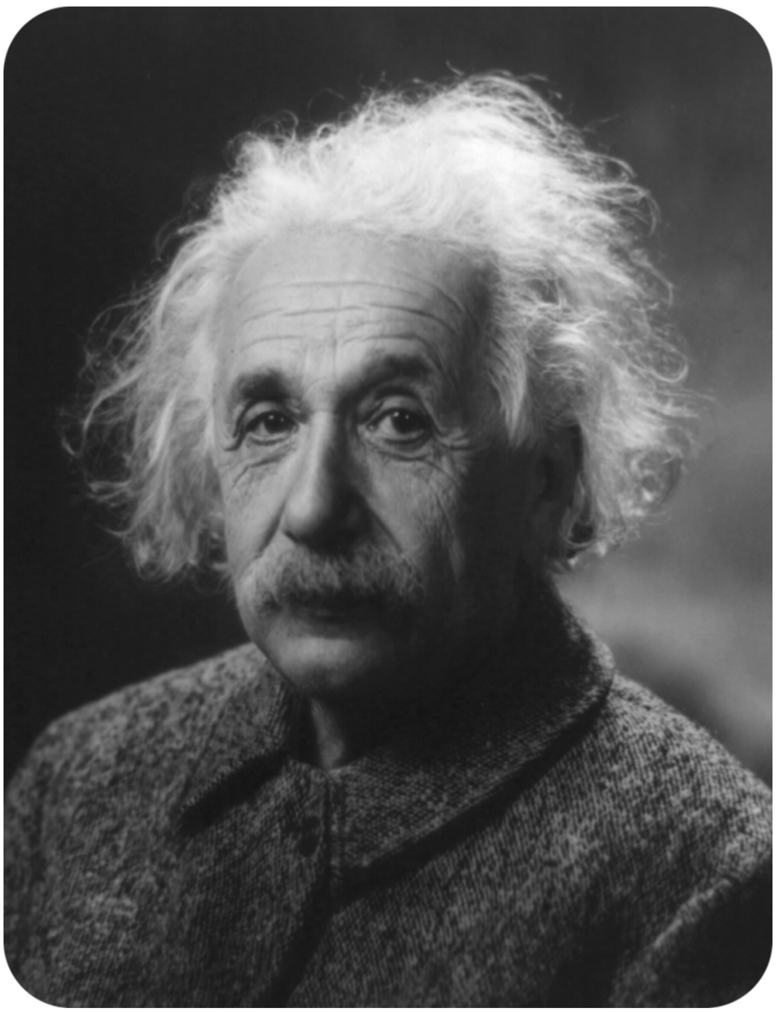


FIGURE 1.8
Albert Einstein (1879–1955) Deductive reasoning has helped us determine that Albert Einstein is a mortal being.

Inductive Reasoning: Induction

Induction involves determining a general statement that is very likely to be true from several facts.

For example, if we have had a test every Tuesday for the past three months, we will have a test next Tuesday (and every Tuesday after that).

Induction contrasts strongly with deduction. Even in the best, or strongest, cases of induction, the truth of the reason does not guarantee the truth of the conclusion. Instead, the conclusion of an inductive argument is very likely to be true; you cannot be fully sure it is true because you are making a prediction that has yet to happen.

A classic example of inductive reasoning comes from the philosopher David Hume:

- Reason: The sun has risen in the east every morning up until now.
- Conclusion: The sun will also rise in the east tomorrow.

Inductive reasoning involves reaching conclusions about unobserved things on the basis of what has been observed already. Inferences about the past from present evidence, such as in archaeology, are induction. Induction could also be across outer space, as in astronomy, where conclusions about the whole universe are drawn from the limited number of things we are able to observe.

Vocabulary

- **deduction**: Involves determining a single fact from a general statement.
- **induction**: Involves determining a general statement that is very likely to be true, from several facts; the relief of repression for a gene or set of genes under negative control.

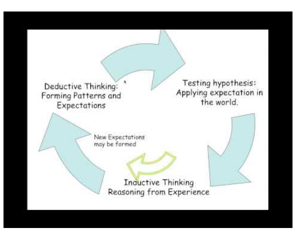
Summary

- Any useful hypothesis will allow predictions based on reasoning. Reasoning can be broken down into two categories: deduction and induction. Most reasoning in science is formed through induction.

Practice

Use this resource to answer the questions that follow.

- **INDUCTIVE AND DEDUCTIVE REASONING** at http://www.youtube.com/watch?v=J0OVCgruWDo.



MEDIA

Click image to the left for more content.

1. What is the difference between inductive and deductive reasoning?
2. What is confirmation bias?
3. Why did investors expect Shrek 3 to be a box office hit?

Review

1. What is meant by scientific reasoning?
2. Outline the difference between inductive and deductive reasoning.

1.5 Experiments - Advanced

- Describe what defines a scientific experiment.
- Examine the function of the control, dependent and independent variables in an experiment.

So what exactly is an experiment?

Observing lions in their natural habitat. Analyzing DNA for mutations to a particular disease, such as Tay-Sachs disease or cystic fibrosis. Studying the species of the Galápagos Islands. Are these all experiments? Do all experiments have to be done in a laboratory? The answers to these questions are yes and no. Yes, observing lions in their natural habitat, analyzing DNA for mutations and studying the species of the Galápagos Islands can all be considered experiments, especially if the scientists involved are trying to answer specific questions and the experiments are based on a hypothesis. And no, all experiments do not have to be done in a laboratory.

Experiments

An **experiment** is a test that is used to eliminate one or more of the possible hypotheses until one hypothesis remains. A scientific experiment must have the following features:

- a control, so variables that could affect the outcome are reduced,
- the variable being tested reflects the phenomenon being studied,
- the variable being tested can be measured accurately, to avoid experimental error,
- the experiment must be reproducible.

The experiment is a cornerstone in the scientific approach to gaining deeper knowledge about the natural world. Scientists use the principles of their **hypothesis** to make predictions, and then test them to see if their predictions are confirmed or rejected.

FIGURE 1.9
A laboratory experiment studying plant growth. What might this experiment involve?

Scientific experiments involve **controls**, or subjects that are not tested during the investigation. In this way, a scientist limits the factors, or *variables* that can cause the results of an investigation to differ. A **variable** is a factor that can change over the course of an experiment. **Independent variables** are factors whose values are controlled by the experimenter to determine its relationship to an observed phenomenon (the dependent variable). **Dependent variables** change in response to the independent variable. **Controlled variables** are also important to identify in experiments. They are the variables that are kept constant to prevent them from influencing the effect of the independent variable on the dependent variable.

For example, if you were to measure the effect that different amounts of fertilizer have on plant growth, the independent variable would be the amount of fertilizer used (the changing factor of the experiment). The dependent variables would be the growth in height and/or mass of the plant (the factors that are influenced in the experiment). The controlled variables include the type of plant, the type of fertilizer, the amount of sunlight the plant gets, the size of the pots you use. The controlled variables are controlled by you, otherwise they would influence the dependent variable.

In summary:

- The independent variable answers the question "What do I change?"
- The dependent variables answer the question "What do I observe?"
- The controlled variables answer the question "What do I keep the same?"

Experimental Design

Controlled Experiments

In an old joke, a person claims that they are snapping their fingers "to keep tigers away," and justifies their behavior by saying, "See, it works!" While this experiment does not falsify the hypothesis "snapping your fingers keeps tigers away," it does not support the hypothesis either, because not snapping your fingers will also keep tigers away. It also follows that not snapping your fingers will not cause tigers to suddenly appear (**Figure** 1.10).

FIGURE 1.10

Are tigers really scared of snapping fingers, or is it more likely they are just not found in your neighborhood? Considering which of the hypotheses is more likely to be true can help you arrive at a valid answer. This principle, called **Occam's razor** states that the explanation for a phenomenon should make as few assumptions as possible. In this case, the hypothesis "there are no tigers in my neighborhood to begin with" is more likely, because it makes the least number of assumptions about the situation.

To demonstrate a cause and effect hypothesis, an experiment must often show that, for example, a phenomenon occurs after a certain treatment is given to a subject, and that the phenomenon does not occur in the absence of the treatment.

One way of finding this out is to perform a controlled experiment. In a **controlled experiment,** two identical experiments are carried out side-by-side. In one of the experiments the independent variable being tested is used, in the other experiment, the control, or the independent variable is not used.

A controlled experiment generally compares the results obtained from an experimental sample against a control sample. The control sample is almost identical to the experimental sample except for the one variable whose effect is being tested. A good example would be a drug trial. The sample or group receiving the drug would be the experimental group, and the group receiving the placebo would be the control. A placebo is a form of medicine that does not contain the drug that is being tested.

Controlled experiments can be conducted when it is difficult to exactly control all the conditions in an experiment. In this case, the experiment begins by creating two or more sample groups that are similar in as many ways as possible, which means that both groups should respond in the same way if given the same treatment.

Once the groups have been formed, the experimenter tries to treat them identically except for the one variable that he or she wants to study (the independent variable). Usually neither the patients nor the doctor know which group receives the real drug, which serves to isolate the effects of the drug and allow the researchers to be sure the drug does work, and that the effects seen in the patients are not due to the patients believing they are getting better. This type of experiment is called a **double blind experiment**.

Controlled experiments can be carried out on many subjects other than people; some are even carried out in space! The wheat plants in **Figure** 1.11 are being grown in the International Space Station to study the effects of microgravity on plant growth. Researchers hope that one day enough plants could be grown during spaceflight to feed hungry astronauts and cosmonauts. The investigation also measured the amount of oxygen the plants can produce in the hope that plants could become a cheap and effective way to provide oxygen during space travel.

FIGURE 1.11
Spaceflight participant Anousheh Ansari holds a miniature wheat plant grown in the Zvezda Service Module of the International Space Station.

Experiments Without Controls

The term *experiment* usually means a controlled experiment, but sometimes controlled experiments are difficult or impossible to do. In this case researchers carry out natural experiments. When scientists conduct a study in nature instead of the more controlled environment of a lab setting, they cannot control variables such as sunlight, temperature, or moisture. Natural experiments therefore depend on the scientist's observations of the system under study, rather than controlling just one or a few variables as happens in controlled experiments.

For a natural experiment, researchers attempt to collect data in such a way that the effects of all the variables can be determined, and where the effects of the variation remains fairly constant so that the effects of other factors can be determined. Natural experiments are a common research tool in areas of study where controlled experiments are difficult to carry out. Examples include:

- astronomy - the study of stars, planets, comets, galaxies and phenomena that originate outside Earth's atmosphere,
- paleontology - the study of prehistoric life forms through the examination of fossils,
- meteorology - the study of Earth's atmosphere.

In astronomy it is impossible, when testing the hypothesis "suns are collapsed clouds of hydrogen", to start out with a giant cloud of hydrogen, and then carry out the experiment of waiting a few billion years for it to form a sun. However, by observing various clouds of hydrogen in various states of collapse, and other phenomena related to the hypothesis, such as the nebula shown in **Figure** 1.12, researchers can collect data they need to support (or maybe falsify) the hypothesis.

An early example of this type of experiment was the first verification in the 1600s that light does not travel from place to place instantaneously, but instead has a speed that can be measured. Observation of the appearance of the moons of Jupiter were slightly delayed when Jupiter was farther from Earth, as opposed to when Jupiter was closer to Earth. This phenomenon was used to demonstrate that the difference in the time of appearance of the moons was consistent with a measurable speed of light.

Natural Experiments

There are situations where it would be wrong or harmful to carry out an experiment. In these cases, scientists carry out a natural experiment, or an investigation without an experiment. For example, alcohol can cause developmental

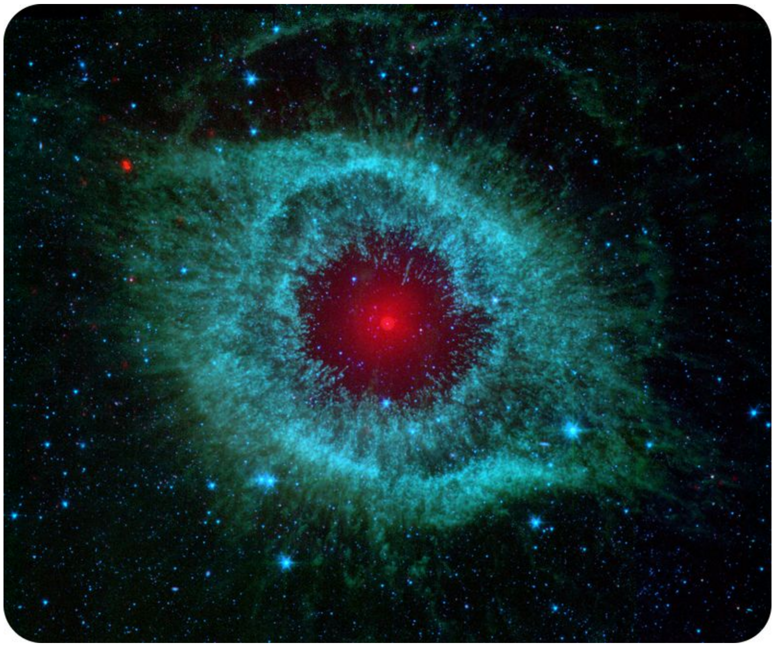


FIGURE 1.12
The Helix nebula, located about 700 light-years away in the constellation Aquarius, belongs to a class of objects called **planetary nebulae**. Planetary nebulae are the remains of stars that once looked a lot like our sun. When sun-like stars die, they puff out their outer gaseous layers. These layers are heated by the hot core of the dead star, called a white dwarf, and shine with infrared and visible colors. Scientists can study the birth and death of stars by analyzing the types of light that are emitted from nebulae.

defects in fetuses, leading to mental and physical problems, through a condition called fetal alcohol syndrome.

Certain researchers want to study the effects of alcohol on fetal development, but it would be considered wrong or *unethical* to ask a group of pregnant women to drink alcohol to study its effects on their children. Instead, researchers carry out a natural experiment in which they study data that is gathered from mothers of children with fetal alcohol syndrome, or pregnant women who continue to drink alcohol during pregnancy. The researchers will try to reduce the number of variables in the study (such as the amount or type of alcohol consumed), which might affect their data. It is important to note that the researchers do not influence or encourage the consumption of alcohol; they collect this information from volunteers.

Field Experiments

Field experiments are so named to distinguish them from lab experiments. Field experiments have the advantage that observations are made in a natural setting rather than in a human-made laboratory environment. However, like natural experiments, field experiments can get contaminated, and conditions like the weather are not easy to control. Experimental conditions can be controlled with more precision and certainty in the lab.

An introduction to the *Prince William Sound Field Experiment* can be seen at http://www.youtube.com/watch?v=OpQngP9HmKo (4:49).

MEDIA
Click image to the left for more content.

Predictions

A **prediction** is a statement that tells what will happen under specific conditions. It can be expressed in the form: *If A is true, then B will also be true.* Predictions are based on confirmed hypotheses shown to be true or not proved to be false.

For researchers to be confident that their predictions will be useful and descriptive, their data must have as few errors as possible. **Accuracy** is the measure of how close a calculated or measured quantity is to its actual value. Accuracy is closely related to **precision**, also called reproducibility or repeatability, which is the degree to which repeated measurements under unchanged conditions show the same results. Reproducibility and repeatability of experiments are cornerstones of scientific methods. If no other researcher can reproduce or repeat the results of a certain study, then the results of the study will not be accepted as valid. Results are considered valid only if they are both accurate and precise.

A useful tool to help explain the difference between accuracy and precision is a target, shown in **Figure** 1.13. In this analogy, repeated measurements are the arrows that are fired at a target. Accuracy describes the closeness of arrows to the bulls eye at the center. Arrows that hit closer to the bulls eye are more accurate. Arrows that are grouped together more tightly are more precise.

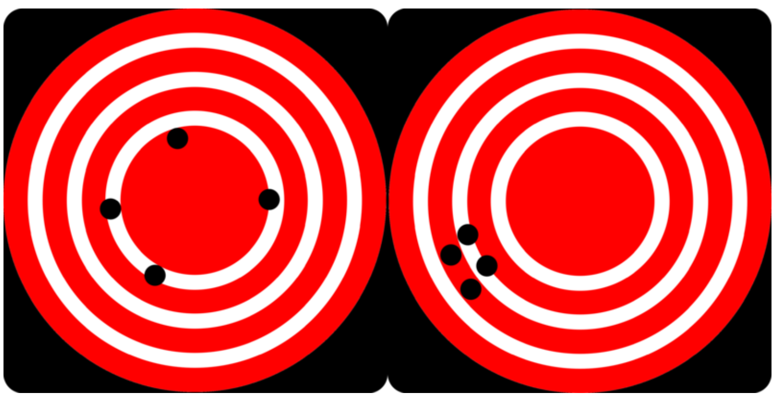


FIGURE 1.13

A visual analogy of accuracy and precision. Left target: High accuracy but low precision; Right target: low accuracy but high precision. The results of calculations or a measurement can be accurate but not precise; precise but not accurate; neither accurate nor precise; or accurate and precise. A collection of bulls eyes right around the center of the target would be both accurate and precise.

Experimental Error

An **error** is a boundary on the precision and accuracy of the result of a measurement. Some errors are caused by unpredictable changes in the measuring devices (such as balances, rulers, or calipers), but other errors can be caused by reading a measuring device incorrectly or by using broken or malfunctioning equipment. Such errors can have an impact on the reliability of the experiment's results; they affect the accuracy of measurements. For example, you use a balance to obtain the mass of a 100 gram block. Three measurements that you get are: 93.1 g, 92.0 g, and 91.8 g. The measurements are precise, as they are close together, but they are not accurate.

If the cause of the error can be identified, then it can usually be eliminated or minimized. Reducing the number of possible errors by careful measurement and using a large enough sample size to reduce the effect of errors will improve the reliability of your results.

Vocabulary

- **accuracy**: The measure of how close a calculated or measured quantity is to its actual value.
- **control**: Something that is not tested during the investigation.

- **controlled experiment**: Two identical experiments are carried out side-by-side; in one of the experiments the independent variable being tested is used, in the other experiment, the control, or the independent variable is not used.
- **controlled variables**: Variables that are kept constant to prevent influencing the effect of the independent variable on the dependent variable.
- **dependent variable**: Variable that changes in response to the independent variable.
- **double blind experiment:** Experiment in which neither the researcher not subjects know who receives the independent variable; common in drug trials.
- **error**: A boundary on the precision and accuracy of the result of a measurement.
- **experiment**: A test that is used to rule out a hypothesis or validate something already known; a test that is used to eliminate one or more of the possible hypotheses until one hypothesis remains.
- **hypothesis** (plural, **hypotheses**): A suggested explanation based on evidence that can be tested by observation or experimentation.
- **independent variable**: Factor(s) whose values are controlled by the experimenter to determine its relationship to an observed phenomenon (the dependent variable).
- **Occam's razor**: States that the explanation for a phenomenon should make as few assumptions as possible.
- **precision**: The degree to which repeated measurements under unchanged conditions show the same results; reproducibility or repeatability.
- **prediction**: A statement that tells what will happen under specific conditions.
- **variable**: A factor that can change over the course of an experiment.

Summary

- A variable is a factor that can change over the course of an experiment. Independent variables are factors whose values are controlled by the experimenter to determine its relationship to an observed phenomenon (the dependent variable). Dependent variables change in response to the independent variable.

Practice

Use this resource to answer the questions that follows.

- **Science Experiment** at http://www.youtube.com/watch?v=OgS46ksAawk.

MEDIA
Click image to the left for more content.

1. What is the hypothesis of this experiment?
2. Why does the experiment need a control?
3. What were the results of the experiment?
4. What is the next step of the experiment?

Review

1. What is an experiment? Give an example.

2. Why are controls important?
3. In taking measurements, what is the difference between accuracy and precision?
4. Why is it a good idea to try to reduce the chances of errors happening in an experiment?
5. To ensure that their results are not due to chance, scientists will usually carry out an experiment a number of times, a process called replication. Devise a practical experimental approach, incorporating replication of the experiment.

1.6 Scientific Theories - Advanced

- Define what is meant by a scientific theory and compare this to the meaning of hypothesis.

Theory vs. theory. Is a scientific *theory* different from the everyday use of the word *theory?*

The Big Bang Theory. The Theory of Gravity. The Plate Tectonic Theory. The Modern Atomic Theory. The Cell Theory. The Theory of Evolution by Natural Selection. These are all classic scientific theories. So, without a doubt, yes, a scientific *theory* is very different from the everyday use of the word *theory.* A scientific theory is accepted as a scientific *truth,* supported by evidence collected by many scientists. Lots of data has been collected to support the theory, and no data has been identified to prove the theory incorrect. That does not mean that evidence does not exist, it means that no one has been able to identify it.

Scientific Theories

Scientific theories are hypotheses which have stood up to repeated attempts at falsification and are thus supported by a great deal of data and evidence. Some well known biological theories include the theory of evolution by natural selection, the cell theory (the idea that all organisms are made of cells), and the germ theory of disease (the idea that certain microbes cause certain diseases). The scientific community holds that a greater amount of evidence supports these ideas than contradicts them, and so they are referred to as theories. In fact, no evidence has been identified to disprove these or other scientific theories.

In every day use, people often use the word *theory* to describe a guess or an opinion. For example, “I have a theory as to why the light bulb is not working.” When used in this common way, “theory” does not have to be based on facts. It does not have to be based on a true description of reality. This usage of the word theory often leads to a misconception that can be best summed up by the phrase, "It’s not a fact, it’s only a theory." In such everyday usage, the word is most similar to the term hypothesis.

Scientific theories are the equivalent of what in everyday speech we would refer to as *facts*. In principle, scientific theories are always subject to corrections or inclusion in another, wider theory. As a general rule for use of the term, theories tend to deal with broader sets of phenomena than do hypotheses, which usually deal with much more specific sets of phenomena or specific applications of a theory.

A video discussing the difference between a hypothesis and a theory can be viewed at http://www.youtube.com/watch?v=jdWMcMW54fA (6:39).

MEDIA

Click image to the left for more content.

Constructing Theories

In time, a confirmed hypothesis may become part of a theory or may grow to become a theory itself. Scientific hypotheses may be mathematical models. Sometimes they can be statements, stating that some particular instance of the phenomenon under examination has some characteristic and causal explanations. These theories have the general form of universal statements, stating that every instance of the phenomenon has a particular characteristic.

A hypothesis may predict the outcome of an experiment in a laboratory or the observation of a natural phenomenon. A hypothesis should also be falsifiable, and one cannot regard a hypothesis or a theory as scientific if it does not lend itself to being falsified, even in the future. To meet the "falsifiable" requirement, it must at least in principle be possible to make an observation that would disprove the hypothesis. A falsifiable hypothesis can greatly simplify the process of testing to determine whether the hypothesis can be proven to be false. Scientific methods rely heavily on the falsifiability of hypotheses by experimentation and observation in order to answer questions. Philosopher Karl Popper suggested that all scientific theories should be falsifiable; otherwise they could not be tested by experiment.

A **scientific theory** must meet the following requirements:

- it must be consistent with a pre-existing theory in that the pre-existing theory has been experimentally verified, though it may often show a pre-existing theory to be wrong in an exact sense,
- it must be supported by many strands of evidence rather than a single foundation, ensuring that it is probably a good approximation, if not totally correct.

Also, a theory is generally only taken seriously if it:

- allows for changes to be made as new data are discovered, rather than claiming absolute certainty,
- is the most straight forward explanation, and makes the fewest assumptions about a phenomenon (commonly called "passing the Occam's razor test").

This is true of such established theories as those of special relativity, general relativity, quantum mechanics, plate tectonics, and evolution. Theories considered scientific meet at least most, but ideally all, of these extra criteria.

In summary, to meet the status of a scientific theory, the theory must be falsifiable or testable. Examples of scientific theories in different areas of science include:

- **Astronomy**: Big Bang Theory
- **Biology**: Cell Theory; Theory of Evolution; Germ Theory of Disease
- **Chemistry**: Atomic Theory; Kinetic Theory of Gases
- **Physics**: General Relativity; Special Relativity; Theory of Relativity; Quantum Field Theory
- **Earth Science**: Giant Impact Theory; Plate Tectonics

Unverifiable Theories

The term theory is sometimes stretched to refer to theoretical speculation which is currently unverifiable. Examples are string theory and various theories of everything. String theory is a model of physics, which predicts the existence of many more dimensions in the universe than the four dimensions that current science understands (length, width, height, and space-time). The theory of everything is a hypothetical theory in physics that fully explains and links together all known physical phenomena.

For a scientific theory to be valid it must be verified experimentally. Many parts of the string theory are currently untestable due to the large amount of energy that would be needed to carry out the necessary experiments as well as the high cost of conducting these experiments. Therefore string theory may not be tested in the foreseeable future. Some scientists have asked if it even deserves to be called a scientific theory because it is not falsifiable.

Superseded Theories

A **superseded,** or obsolete, scientific theory is a theory that was once commonly accepted, but for whatever reason is no longer considered the most complete description of reality by mainstream science. It can also mean a falsifiable theory which has been shown to be false. Giraffes, shown in **Figure** 1.14, are often used in the explanation of Lamarck's superseded theory of evolution. In Lamarckism, a giraffe is able to lengthen its neck over the course of its life, for example by stretching to reach higher leaves. That giraffe will then have offspring with longer necks. The theory has been superseded by the understanding of natural selection on populations of organisms as the main means of evolution (Darwin's theory of evolution by natural selection), not physical changes to a single organism over its lifetime.

FIGURE 1.14

Superseded theories like Lamarck's theory of evolution are theories that are now considered obsolete and have been replaced by newer theories that have more evidence to support them; in Lamarck's case, his theory was replaced by Darwin's theory of evolution and natural selection, which will be further discussed in additional concepts.

Scientific Laws

Scientific laws are similar to scientific theories in that they are principles which can be used to predict the behavior of the natural world. Both scientific laws and scientific theories are typically well-supported by observations and/or experimental evidence. Usually scientific laws refer to rules for how nature will behave under certain conditions. Scientific theories are more overarching explanations of how nature works and why it exhibits certain characteristics.

A **physical law** or law of nature is a scientific generalization based on a sufficiently large number of empirical observations that it is taken as fully verified.

Isaac Newton's law of gravitation is a famous example of an established law that was later found not to be universal—it does not hold in experiments involving motion at speeds close to the speed of light or in close proximity of strong gravitational fields. Outside these conditions, Newton's laws remain an excellent model of motion and gravity.

Scientists never claim absolute knowledge of nature or the behavior of the subject of the field of study. A scientific theory is always open to falsification, if new evidence is presented. Even the most basic and fundamental theories may turn out to be imperfect if new observations are inconsistent with them. Critical to this process is making every relevant part of research publicly available. This allows peer review of published results, and it also allows ongoing reviews, repetition of experiments and observations by many different researchers. Only by meeting these expectations can it be determined how reliable the experimental results are for possible use by others.

Vocabulary

- **law of nature**: A scientific generalization based on a sufficiently large number of empirical observations that it is taken as fully verified; physical law.
- **physical law**: A scientific generalization based on a sufficiently large number of empirical observations that it is taken as fully verified; law of nature.
- **scientific law**: A principle which can be used to predict the behavior of the natural world.
- **scientific theory**: A hypothesis which has stood up to repeated attempts at falsification; supported by a great deal of data and evidence.
- **superseded theory**: A theory that was once commonly accepted, but is no longer considered the most complete description of reality by mainstream science.

Summary

- Scientific theories are hypotheses which have stood up to repeated attempts at falsification and are thus supported by much data and evidence.
- Scientific laws are similar to scientific theories in that they are principles which can be used to predict the behavior of the natural world.
- A scientific theory must be supported by many strands of evidence rather than a single foundation, ensuring that it is probably a good approximation, if not totally correct.
- A superseded scientific theory is a theory that was once commonly accepted, but is no longer considered the most complete description of reality by mainstream science.

Practice

Use this resource to answer the questions that follow.

- **Concepts and Methods in Biology** – Non-Majors Biology –*Theories and Laws* at : http://www.hippocampus.org/Biology.

1. Describe scientific theories and laws. Give examples.
2. What is meant by the following statement: *Theories can never be proven absolutely...*

Review

1. Identify two features that a theory must have, to qualify as a scientific theory.
2. Give an example of a superseded theory.
3. What is meant by the following statement: *A hypothesis should be falsifiable.*

4. Distinguish between a scientific theory and a scientific law.
5. Give examples of scientific theory from a variety of scientific fields.

1.7 Scientific Models in Biology

- Outline the importance of scientific models.

What is a scientific model?

Looks like a human head, but it is obviously missing certain parts. Of course, this would be a model, and it could be considered a scientific model, as it represents the anatomy of the head and skull. It can obviously be used to teach about this anatomy.

Scientific Models

To describe particular parts of a phenomenon, or the interactions among a set of phenomena, it is sometimes helpful to develop a model of the phenomenon. **Scientific models** are representations of reality. They can be a physical, mathematical, or logical representation of a system, phenomenon, or process, and they allow scientists to investigate a phenomenon in a controlled way. For instance, a scale model of a house or of a solar system is clearly not an actual house or an actual solar system; the parts of an actual house or an actual solar system represented by a scale model are, only in limited ways, representative of the actual objects (**Figure** 1.15).

Scientific modeling is the process of making abstract models of natural phenomena. An **abstract model** is a theoretical construct that represents something. Models are developed to allow reasoning within a simplified framework that is similar to the phenomena being investigated. The simplified model may assume certain things that are known to be incomplete in some details. Such assumptions can be useful in that they simplify the model, while at the same time, allowing the development of acceptably accurate solutions. These models play an important role in developing scientific theories.

A **simulation** is a model that runs over time. A simulation brings a model to life and shows how a particular object or phenomenon will behave. It is useful for testing, analysis or training where real-world systems or concepts can be represented by a model. For the scientist, a model also provides a way for calculations to be expanded to explore

FIGURE 1.15
A model of planets of the solar system. This model is clearly not a real solar system; it is a representation of the planets Mercury, Venus, Earth, Mars, Jupiter, Saturn, and Uranus. Scientists use representations of natural things to learn more about them. Also, the visitors to the Griffith Observatory in Los Angeles, California can get a better idea of the relative sizes of the planets by observing this model.

what might happen in different situations. This method often takes the form of models that can be programmed into computers. The scientist controls the basic assumptions about the variables in the model, and the computer runs the simulation, eventually coming to a complicated answer.

Examples of models include:

- Computer models
- Weather forecast models
- Molecular models
- Climate models
- Ecosystem models
- Geologic models

One of the main aims of scientific modeling is to allow researchers to quantify their observations about the world. In this way, researchers hope to see new things that may have escaped the notice of other researchers. There are many techniques that model builders use which allow us to discover things about a phenomenon that may not be obvious to everyone. The National Weather Service Enhanced Radar Images web site (http://radar.weather.gov/) is an excellent example of a simulation. The site exhibits current weather forecasts across the United States.

Evaluating Models

A person who develops a model must be able to recognize whether a model reflects reality. They must also be able to identify and work with differences between actual data and theory.

A model is evaluated mostly by how it reflects past observations of the phenomenon. Any model that is not consistent with reproducible observations must be modified or rejected. However, a fit to observed data alone is not enough for a model to be accepted as valid. Other factors important in evaluating a model include:

- its ability to explain past observations,
- its ability to predict future observations,
- its ability to control events,
- the cost of its use, especially when used with other models,
- ease of use and how it looks.

Some examples of the different types of models that are used by science are shown in **Figures** 1.17 and 1.18.

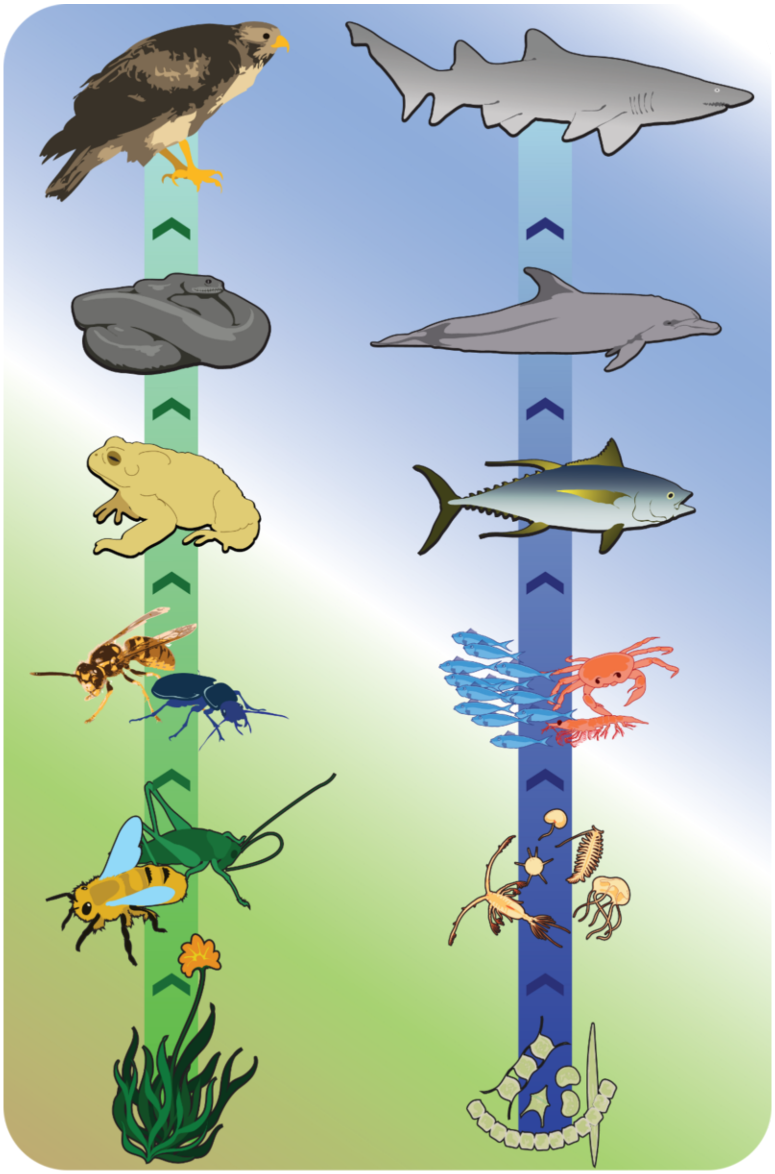


FIGURE 1.16
These two food chains represent the flow of energy in complex systems in nature. These conceptual models make the systems easier to understand. Models of very complex systems are often based on mathematical equations or computer simulations.

Theories as Models

Scientific theories are constructed in order to explain, predict and understand phenomena. For example, this could include the movement of planets, weather patterns, or the behavior of animals. In many instances we are constructing models of reality. A theory makes generalizations about observations and is made up of a related set of ideas and models. The important difference between theories and models is that the first is explanatory as well as descriptive, while the second is only descriptive and predictive in a much more limited sense.

Model Organisms

A **model organism** is a non-human species that is extensively studied to understand particular biological processes and concepts. These organisms are chosen because it is believed that discoveries made in the model organism will provide insight into the workings of other organisms, including humans. Model organisms range from single-celled bacteria to complex multi-cellular organisms. Even some viruses are utilized as models, though technically a virus

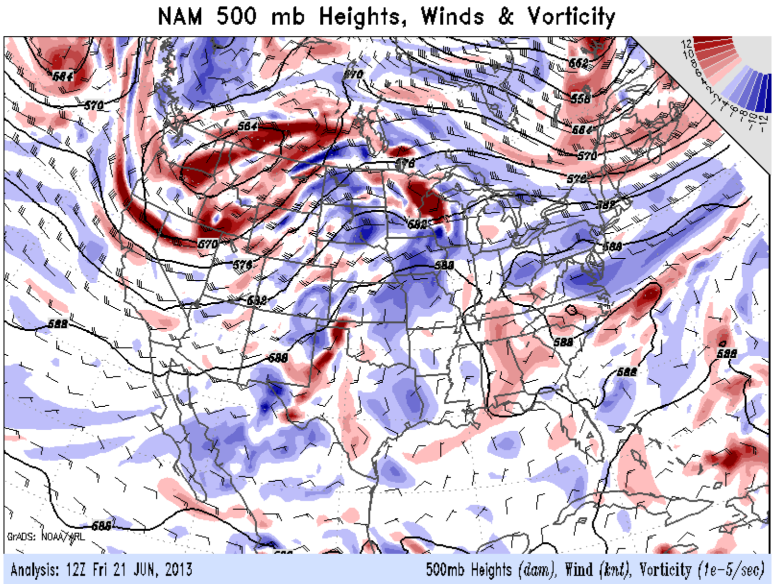


FIGURE 1.17
A computer model of wind patterns across the continental United States for 19 November, 2007. This model is used to forecast wind speeds and directions. Data on wind speed, direction, and related data are entered into a computer which then produces this simulation. This visual model is much easier for a person to understand than a large table of numbers.

FIGURE 1.18
Biosphere 2 is an example of a very large three-dimensional model which biologists built to attempt to recreate a self-sustaining biome. To learn more about biomes and ecosystems, see *Ecology - Advanced*.

is not considered an organism.

The **Table** 1.2 lists some common model organisms. All of these organisms listed have had their complete genomes sequenced.

TABLE 1.2: Common Model Organisms

	Organism	Common Name
Prokaryote	*Escherichia coli*	*E. coli* bacteria
Eukaryote, unicellular	*Saccharomyces cerevisiae*	Yeast

TABLE 1.2: (continued)

	Organism	Common Name
Eukaryote, multicellular	*Neurospora crassa* *Caenorhabditis elegans* *Drosophila melanogaster* *Arabidopsis thaliana*	bread mold nematode fruit fly thale cress
Vertebrate	*Danio rerio* *Mus musculus* *Xenopus laevis* *Macaca mulatta*	zebrafish house mouse African clawed frog rhesus monkey

Vocabulary

- **abstract model**: A theoretical construct that represents something.
- **model organism**: A non-human species that is extensively studied to understand particular biological phenomena.
- **scientific model**: A physical, mathematical, or logical representation of a system, phenomenon, or process; allow scientists to investigate a phenomenon in a controlled way.
- **scientific modeling**: The process of making abstract models of natural phenomena.
- **simulation**: A model that runs over time.

Summary

- Scientific models are representations of reality. They can be a physical, mathematical, or logical representation of a system, phenomenon, or process, and they allow scientists to investigate a phenomenon in a controlled way.
- A simulation is a model that runs over time.

Practice

Use this resource to answer the questions that follow.

- **!!Flu Viruses!! (Scientific Model)** at http://www.youtube.com/watch?v=_Fh2wjHSPXI.

MEDIA

Click image to the left for more content.

1. Why is the "virus" developed in this video considered to be a "scientific model?"
2. How and why does the flu virus make you sick?

Review

1. What is a scientific model? Give two examples.

2. Discuss the importance of scientific models.
3. What is a model organism? Give three examples.
4. Why are simulations useful?
5. What are factors important to evaluating a model?

1.8 What is a Scientist? - Advanced

- Identify the benefits of studying science, even if you do not intend on becoming a scientist.
- List three things that can influence scientific research.
- Examine how ethics are applied to communicating ideas and research.

What is a scientist?

It could be said that a scientist is someone who uses a systematic approach to acquire new knowledge. A scientist can also be defined as someone who uses the scientific method. A scientist may be an expert in one or more areas of science, such as biology, or more specifically biochemistry, genetics or ecology. Whatever the speciality of the scientist is, all scientists perform research toward a more comprehensive understanding of nature.

What Is a Scientist?

Science and Society

Biology literally means "the study of life." It is also a science that is consistently used in our everyday lives. Biology is a very broad field, covering the intricate workings of chemical processes inside our cells, to the more broad concepts of ecosystems and global climate change. **Biologists** study minute details of the human brain, the make up of our genes, and even the functioning of our reproductive system. For example, biologists recently finished decoding the human genome, the sequence of deoxyribonucleic acid (DNA) bases that may determine much of our abilities and predispositions for certain illnesses and can also play a major role in many court cases. For example, criminals have been caught, victims identified, and wrongly imprisoned people have been freed based on DNA evidence.

We are blitzed with headlines about possible health risks from certain foods as well as possible benefits of eating other foods. Commercials try to sell us the latest “miracle” pill for easy, fast weight loss. Many people are turning to herbal remedies to ease arthritis pain, improve memory, as well as improve their mood. Other people may choose the conventional medicines that can be bought at the pharmacy. It is important to know the effects such supplements, such as the ones shown in **Figure** 1.19, and medicines can have on the body.

FIGURE 1.19
Nutritional supplements. Understanding how your body works and how nutrients work will help you decide whether you need to take a nutritional supplement. It will also help you make sense of the large amount of information available about regular medicines, if and when you need to take them.

Can just one biology course give you the answers to these everyday questions? No, but it will enable you to learn how to sift through the biases of investigators, the press, and others in a quest to critically evaluate the question. To be honest, five years after you are finished with this biology course, it is doubtful you would remember all the details of metabolism. However, you will have a better idea about where to look for the answer. Knowing about the process of science will also allow you to make a more informed decision. Will you be a scientist? Yes, in a way. You may not be formally trained as a scientist, but you will be able to think critically, solve problems, have some idea about what science can and cannot do, as well as an understanding of the role of biology in your everyday life.

Biology and You

So why should you study biology? Because you are surrounded by it every day! It is about what happens in your brain as you read the words on this page, and about how hippopotamuses know to come up to the surface to breath even while sleeping. Biology is about why a person with hook worms doesn't sneeze as much and about why Velcro works. From understanding the benefits of the vitamin-enriched milk or juice that you have at breakfast, to discerning commercials that promise a fuller head of hair, or snack foods that announce they are the "healthier option for you," you cannot be fully informed about such claims unless you understand the science behind them, or can think like a scientist to analyze them. For example, you would need to know the types of fats you need to get from your food to know why eating salmon, or other foods such as flax seeds and kiwi fruit may be good for your health.

You may also become a stronger advocate for your community. For example, if a tree planting initiative has begun in your neighborhood, you can investigate the plan for your area and find out what you can do. You could then explain what the program is about to your friends and family.

Or, perhaps a city park has fallen into disrepair, and city officials are looking for feedback from the public about what to do with it. You could use scientific thinking to analyze the issue and options, and develop possible solutions.

FIGURE 1.20
Salmon has recently been touted as "super-brain food," but do you know why it is so good for you? Educating yourself on how science affects your life is important. It will help you analyzing the validity of such claims, help you take better care of your health, be a wiser healthcare consumer, and make you more science literate in general.

What Is a Scientist?

What exactly makes a person a **scientist** and what is their role in society? First, we should start with what scientists are not. They are not crazed geniuses with bad hair and a fondness for hysterical laughter. Although they may not be on the cutting edge of fashion, they are regular people. They went to school like you, they studied math, reading, and science like you, and they probably exhibited at science fairs.

Being a scientist does not require you to learn everything in these over 500 concepts or any other science book by heart, but understanding the important concepts really helps. Instead, being a scientist begins by *thinking* like a scientist. Scientists are curious about how the world works; they have many questions and go about answering those questions using the scientific methods.

If you are fascinated by how things work and why they work a certain way, you too could become a scientist! **Research scientists** are the people that do the investigations and make the discoveries that you read or hear about. To work as a research scientist, a person usually needs an advanced degree in science. An advanced degree is obtained by attending graduate school after getting a Bachelor of Science, Engineering, or Arts degree. A Bachelor degree normally takes four years to complete; graduate degrees usually take two years for a Masters degree and four or more years to complete a Doctorate degree.

Scientific research offers much more to a person than just discovering new things. Researchers have the opportunity to meet with other people (scientists and non-scientists) who care about the same subjects that the scientists research such as cancer research, marine ecology, or human nutrition. Many researchers also teach students who will become the next generation of scientists. Scientists have many opportunities to work with different people, explore new fields, and broaden their expertise.

Scientists are part of a community that is based on ideals of trust and freedom, and their work can have a direct effect on society. As a result, the public usually has an interest in the results of research that will directly affect them. Therefore it is important that you can understand the meaning of a science story when you read it, see it, or hear about it and become an engaged and active member of the public when making decisions involving science.

I Am A Scientist video and song can be viewed at http://www.youtube.com/watch?v=fpOYWdalzTU (3:14).

MEDIA

Click image to the left for more content.

Science As a Human Endeavor

Conducting science requires part human creativity and part scientific skepticism. Researchers make new observations and develop new ideas with the aim of describing the world more accurately or completely. These observations and ideas are often based on existing theories and observations that were made by earlier scientists.

For example, the history of **molecular biology**, the study of molecules that make up living things, is a good example of how scientific knowledge builds on earlier knowledge.

Researchers from chemistry and physics were involved in the early investigations to discover what was responsible for heredity. Scientists in the late 19^{th} and early 20^{th} century knew that organisms inherited certain characteristics such as hair color from their parents. What we now call "genes" were then called "units of heredity." Scientists did not know exactly how these heredity units were inherited or what they were made of, however. Following the development of the Mendelian theory of heredity in the 1910s and the development of atomic theory and quantum mechanics in the 1920s, such explanations seemed within reach. Researchers from chemistry and physics turned their attention to this biological question. Still, in the 1930s and 1940s it was not clear which, if any, area of research would be most successful.

In 1940, geneticists George Beadle and Edward Tatum demonstrated a relationship between genes and proteins. In 1944, physician and researcher Oswald Avery further elaborated on that finding by demonstrating that genes are made up of DNA. In 1952, geneticist Alfred Hershey and lab assistant Martha Chase confirmed that the genetic material of a virus that infects bacteria is made up of DNA. And in 1953, biologist James Watson and biophysicist Francis Crick, with the help of X-ray crystallographer Rosalind Franklin, worked out the three dimensional structure of DNA and built a model of the double helix structure of the molecule.

There have been many additional discoveries about DNA and heredity since then, which will be discussed in additional concepts.

Influences on Scientific Research

To nonscientists, the competition, frustration, cooperation, and disagreement between research scientists can seem disorganized. Scientific knowledge develops from humans trying to figure things out. Scientific research and discoveries are carried out by people—people who have virtues, values, shortcomings, and limitations—just like everyone else. As a result, science and research can be influenced by the values of the society in which the research is carried out. How do such values influence research?

This question is of interest to more than just the scientific community. Science is becoming a larger part of everyone's life, from developing more effective medicines to developing more productive crops and to designing innovative air conditioning systems that are modeled after the self-cooling nests of termites. The public has become more interested in learning more about the areas of science that affect everyday life. As a result, scientists have become more accountable to a society that expects to benefit from their work.

It costs money to carry out scientific studies. Things such as the cost of equipment, transportation, rent, and salaries for the people carrying out the research all need to be considered before a study can start. The systems of financial support for scientists and their work have been important influences of the type of research and the pace of how that research is conducted. Today, funding for research comes from many different sources, some of which include:

- government, for example, through the National Institutes of Health (NIH), Center for Disease Control and Prevention (CDC), and the Food and Drug Administration (FDA),
- military funding, such as through the Department of Defense,
- corporate sponsorship,
- non-profit organizations, such as the Muscular Dystrophy Association, the American Cancer Society and American Heart Association,
- private donors.

When the economy of a country slows down, the amount of money available for funding research is usually reduced, because both governments and businesses try to save funds by reducing certain non-essential expenses.

Many pharmaceutical companies are heavily invested in research and development, on which they spend many millions of dollars every year. The companies aim to research and develop drugs that can be marketed and sold to treat certain illnesses, such as diabetes, cancer, or heart disease. Areas of research in which the companies do not see any hope of a return on their huge investments are not likely to be studied.

For example, two researchers, Evangelos Michelakis and Steven Archer of the University of Alberta, Canada, recently reported that a drug that has been used for in the treatment of rare metabolic disorders could be an effective drug for the treatment of several forms of cancer. Dichloroacetic acid, (DCA), is a chemical compound that appears to change the way cancer cells get energy, without affecting the function of normal cells. The researchers found that DCA killed cancer cells that were grown in the lab and reduced the size of tumors in rats.

However, DCA is non-patentable as a compound. A **patent** is a set of rights granted to a person or company (the patentee) for a certain period of time which allows the patentee the exclusive right to make, use, sell, or offer to sell the patented item. Because DCA cannot currently be patented, concerns are raised that without the financial security a patent would ensure, the financial incentive for the pharmaceutical industry to get involved in DCA-cancer research would be reduced, and therefore clinical trials of DCA may not be funded.

But, other sources of funding exist; previous studies of DCA have been funded by government organizations such as the National Institutes of Health (NIH), the Food and Drug Administration (FDA), the Canadian Institutes of Health Research and by private charities such as the Muscular Dystrophy Association. Recognizing the possible challenges to funding, Dr. Michelakis's lab took the unusual step of directly asking for online donations to fund the research. After six months, his lab had raised over $800,000, which was enough to fund a small clinical study. Dr. Michelakis and Dr. Archer have nonetheless applied for a patent on the use of DCA in the treatment of cancer.

Funding for research can also be influenced by the public and by social issues. An intense amount of public interest was raised by the DCA study. The story received much media attention in early 2007. As a result, the American Cancer Society and other medical organizations received a large volume of public interest and questions regarding DCA. A few months later, the Department of Medicine of Alberta University reported that after the trial funding was secured, both the Alberta local ethics committee and Health Canada approved the first DCA Clinical Trial in Cancer.

Government funding of research can be indirectly influenced by the public. Funding priorities for specific research can be influenced by the ethical beliefs or reservations of elected public officials, or influenced by the public during constitutional amendment elections. Celebrities often campaign to bring public attention to issues that are important to them.

Science and Ethics

Ethics, also called moral philosophy, is the discipline concerned with what is morally good and bad, right and wrong. The term is also applied to any system or theory of moral values or principles. Personal ethics is the moral code that a person adheres to, while social ethics includes the moral theory that is applied to groups. **Bioethics** is the social ethics of biology and medicine; it deals with the ethical implications of biological research and applications, especially in medicine. **Bioethicists** are concerned with the ethical questions that arise in the relationships among biology, biotechnology, medicine, politics, law, and philosophy.

While scientific research has produced social benefits, it has also posed some troubling ethical questions. For example, when is it alright to test an experimental cancer drug on people? Developing a new drug takes a long time, maybe as much as 10 years, or more. There are many rules and regulations that drug researchers need to follow while developing drugs to treat specific illnesses.

Generally, drugs cannot be tested on people until researchers have evidence that the drug does what they claim it does, but also that the drug will not make patients more ill or cause death. However, if the drug has tested successfully in earlier experiments, and scientists are quite confident that the drug does what it is intended to do, is it ethical to allow patients with a terminal disease, who have no other treatment options, to try the experimental drug?

With new challenges in public health and health policy, and with advances in biotechnology, bioethics is a fast-growing academic and professional area of inquiry. Some recent bioethical debates include:

- Refusal of medical treatment: the choice of a patient to refuse certain life-saving medical procedures such as a blood transfusion, or refusal by a parent or guardian for medical treatment for the patient.
- Euthanasia: the choice by a terminally ill person to have medical assistance in dying.
- Stem cell research: research involving stem cells, which can be harvested from human embryos.
- Animal cloning: the ability and usefulness of scientists cloning animals for various needs, such as vaccine development, tissues for transplant into humans such as heart valves, and increased food production. Dolly the sheep is probably the most famous animal clone to date.

Because research may have a great effect on the well-being of individual people and society in general, scientists are required to behave ethically. Scientists who conduct themselves ethically treat people (called *subjects*) who are involved in their research respectfully. Subjects are not allowed to be exploited deliberately, exposed to harm, or forced to do something they do not agree to.

Vocabulary

- **bioethicists**: Individuals concerned with the ethical questions that arise in the relationships among biology, biotechnology, medicine, politics, law, and philosophy.
- **bioethics**: The social ethics of biology and medicine; deals with the ethical implications of biological research and applications, especially in medicine.
- **biologists**: Scientists who study biology.
- **biology**: The study of life.
- **ethics**: The discipline concerned with what is morally good and bad, right and wrong.
- **molecular biology**: The study of molecules that make up living organisms.
- **patent**: A set of rights granted to a person or company (the patentee) for a certain period of time; allows the patentee the exclusive right to make, use, sell, or offer to sell the patented item.
- **research scientist**: People that do the scientific investigations and make scientific discoveries.
- **scientist**: An individual who uses the scientific method; a person who engages in a systematic activity to acquire knowledge.

Summary

- Biology is the study of life.
- Scientists are regular people who chose to study science. They are experts in done or more fields of science.
- Science can be influenced by numerous agencies and organizations.
- Ethics has a significant role in the science of today.

Practice

Use this resource to answer the questions that follow.

- **Symphony of Science - the Quantum World!** at http://www.youtube.com/watch?v=DZGINaRUEkU.

MEDIA

Click image to the left for more content.

1. What aspects of science do the actors and scientists in this video discuss?
2. According to this video, what is a main goal of science?

Review

1. What is a scientist?
2. What would a molecular biologist study?
3. List three potential influences on science.
4. Where does most funding for research come from in the United States?
5. Discuss the role of ethics in science.

1.9 Units of Measurement - Advanced

- Identify the units of measurement that scientists use.

How do you measure something really really small?

If we are talking about a cell, then not with a ruler. Units must exist that can describe sizes many times smaller than the smallest marking on a ruler.

Units of Measurement

The measurements that scientists use are based on the **International System of Units (SI),** which is a form of the metric system. The term *SI* is shortened from the French term *Le Système international d'unités*. It is the world's most widely used system of units, both in science and business. It is useful to scientists because it is based on multiples of 10. The SI was developed in 1960 from an older metric system and is used in almost every country.

The SI is not static, as the technology of measurement progresses, units are created and definitions are changed through international agreement among many nations. The international system of units is made up of a seven base units, shown in the **SI Base Units Table** 1.3. From these seven base units several other units are derived.

TABLE 1.3: **SI Base Units**

Name	Symbol	Quantity
meter	m	length
kilogram	kg	mass
second	s	time

TABLE 1.3: (continued)

Name	Symbol	Quantity
ampere	A	electric current
kelvin	K	thermal energy (temperature)
mole	mol	amount of substance
candela	cd	uminous intensity

A prefix may be added to SI units to make a multiple of the original unit. An **SI prefix** is a name or symbol that is put before a unit of measure (or its symbol) to form a decimal or a multiple of the unit. For example, *kilo-* is a multiple of a thousand and *milli-* is a multiple of a thousandth, so there are one thousand *millimeters* in a meter, and one thousand meters in a *kilometer*. All prefixes are multiples of 10, as you can see from the **SI Prefixes Table** 1.4. The prefixes are never combined; a millionth of a kilogram is a *milligram* not a *microkilogram*.

TABLE 1.4: SI Prefixes

Name	Symbol	Factor of 10	
tera-	T	1,000,000,000,000 (10^{12})	trillion (thousand billion)
giga-	G	1,000,000,000 (10^{9})	billion (thousand million)
mega-	M	1,000,000 (10^{6})	million
kilo-	k	1000 (10^{3})	thousand
hecto-	h	100 (10^{2})	hundred
deca-	da	10 (10^{1})	ten
deci-	d	1 (10^{-1})	tenth
centi-	c	0.1 (10^{-2})	hundredth
milli-	m	0.01 (10^{-3})	thousandth
micro-	μ	0.00001 (10^{-6})	millionth
nano-	n	0.00000001 (10^{-9})	billionth
pico-	p	0.00000000001 (10^{-12})	trillionth

Vocabulary

- **International System of Units (SI)**: The modern form of the metric system; a system of units of measurement devised around seven base units and the convenience of the number ten.
- **SI prefixes**: A name or symbol that is put before a unit of measure (or its symbol) to form a decimal or a multiple of the unit.

Summary

- The measurements that scientists use are based on the International System of Units (SI), which is form of the metric system. Based on multiples of ten, It is the world's most widely used system of units, both in science and business.

Practice

Use this resource to answer the questions that follow.

- **International System of Units** at http://www.mashpedia.com/International_System_of_Units.

1. When was the SI system established?
2. What is the SI system based on?

Review

1. What is SI?
2. Why is it important that scientists use common units of measurement?
3. Which one of the following units of measurement would be the most appropriate in determining the mass of a banana? Kilograms, micrograms, or grams.
4. What is the standard SI unit for measuring volume, weight, time, and length?
5. What is the shorthand unit for .000056 grams, 5600000000 seconds, .56 liter, and 560 meter.

1.10 Laboratories

- Identify three items that are common to science labs.
- Contrast light microscopes and electron microscopes.
- Outline what students and researchers can do to stay safe while working in the lab.

What is a laboratory?

When most people think of a scientific laboratory, they picture images similar to those shown here. And it's true that a laboratory must be a controlled environment, but what if certain studies cannot be done in that environment. How do you observe penguins or elephants in their natural environments? What is the lab then?

The Laboratory

A **laboratory** is a place that has controlled conditions in which scientific research, experiments, and measurement may be carried out. Scientific laboratories can be found in schools and universities, in industry, in government facilities, and even aboard ships and spacecraft, such as the one shown in **Figure** 1.21.

Because of the different areas of science, there are many different types of science labs that each include different scientific equipment. For example, a physics lab might contain a particle accelerator, in which the particles that

FIGURE 1.21
Labs are not always Earth-bound, like the biochemistry lab to the left is. This astronaut is working in a lab on the International Space Station (right).

make up atoms are studied. A chemistry or biology lab most likely contains a fume hood where substances with poisonous fumes can be worked. A particle accelerator and a fume hood are both shown in **Figure** 1.22. Despite the great differences among labs, some features are common in them.

Most labs have workbenches or countertops at which the scientist may sit or stand to do work comfortably. This is important because scientists can spend all day working in the lab. A scientist usually records an experiment's progress in a lab notebook, but modern labs almost always contain a computer for data collection and analysis. In many labs computers are also used for lab simulations (modeling or imitating an experiment or a natural process), and for presenting results in the form of graphs or tables.

FIGURE 1.22
Different fields of science need different types of equipment, such as the particle accelerator at left, found in a physics lab, and the fume hood, at right, found in chemistry labs, but also sometimes in biology labs.

View http://www.nasa.gov/centers/dryden/aircraft/DC-8/index.html to read about a flying DC-8 laboratory.

Lab Equipment

Lab techniques include the procedures used in science to carry out an experiment. Lab techniques follow scientific methods, and while some of them involve the use of simple laboratory equipment such as glassware (shown on the shelves in **Figure** 1.21), others use more complex and expensive equipment such as electrical and computerized machines such as the particle accelerator shown in **Figure** 1.22, or use expensive supplies.

Equipment commonly found in biology labs include microscopes, weighing scales or balances, water baths, glassware (such as test tubes, flasks, and beakers), Bunsen burners, pipettes shown in **Figure** 1.23, chemical reagents, and equipment such as centrifuges and PCR machines.

Light Microscopes

Microscopes are instruments used to view objects that are too small to be seen by the naked eye. **Optical microscopes**, such as the one shown in **Figure** 1.24, use visible light and lenses to magnify objects. They are the simplest and most widely used type of microscopes. **Compound microscopes** are optical microscopes which have a series of lenses, the ocular lens (in the eyepiece) and the objective lenses (close to the sample). These microscopes have uses in many fields of science, particularly biology and geology. The scientist in **Figure** 1.25 is looking through a stereo microscope (notice the two lenses). This type of microscope uses the two lenses to produce a three-dimensional visualization of the sample being examined.

FIGURE 1.23
Pipettes are small, but important tools in many biology labs. Micropipettes, such as these here, are calibrated to measure very small amounts of liquids. For example, 100 microliters (100 μL) which is about half the volume of your little finger tip; or even 1 μL, which is much smaller than a drop of water.

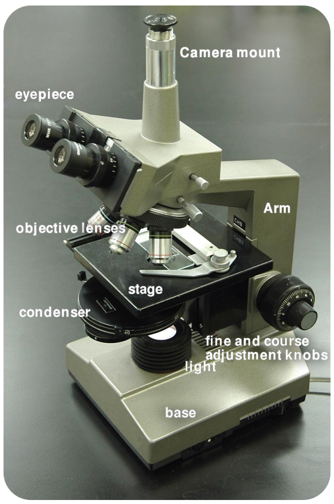


FIGURE 1.24
Compound light microscopes use lenses to focus light. Typical magnification of a light microscope is up to 1500x. The various parts of the microscope are labeled. This specifically is a phase contrast microscope. Phase contrast microscopy is particularly important in biology, as it reveals many cellular structures that are not visible with a simpler bright field microscope.

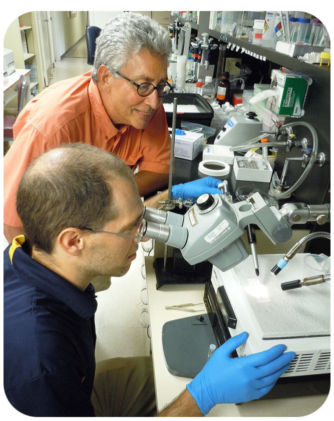


FIGURE 1.25
This scientist is using a stereo microscope, which is a light microscope with two ocular lenses.

Resolution is a measure of the clarity of an image; it is the minimum distance two points can be separated and still be distinguished as two separate points. Because light beams have a physical size, which is described in wavelengths, it is difficult to see an object that is about the same size or smaller than the wavelength of light. Objects smaller than about 0.2 micrometers appear fuzzy, and objects below that size cannot be seen.

Magnification involves enlarging the image of an object so that it appears much bigger than its actual size. Magnification also refers to the number of times an object is magnified. For example, a lens that magnifies 100X, magnifies an object 100 times larger than its actual size. Light microscopes have three objective lenses that have different magnifications, as shown in **Figure** 1.26. The ocular lens has a magnification of 10X, so a 100X objective lens and the ocular lens together will magnify an object by 1000X.

FIGURE 1.26
Objective lenses of a light microscope.

Visible light has wavelengths of 400 to 700 nanometers, which is larger than many objects of interest such as the insides of cells. Scientists use different types of microscopes in order to get better resolution and magnification of objects that are smaller than the wavelength of visible light. Objects that are to be viewed under an electron microscope may need to be specially prepared to make them suitable for magnification.

Electron Microscopes

Electron microscopes use electrons instead of photons (light), because electrons have a much shorter wavelength than photons and thus allow a researcher to see things at very high magnification, far higher than an optical microscope can possibly magnify.

There are two general types of electron microscopes: the Transmission Electron Microscope that shoots electrons through the sample and measures how the electron beam changes because it is scattered in the sample, and the Scanning Electron Microscope that scans an electron beam over the surface of an object and measures how many electrons are scattered back.

Transmission electron microscopy (TEM) is an imaging method in which a beam of electrons is passed through a specimen. An image is formed on photographic film or a fluorescent screen by the electrons that scatter when passing through the object. TEM images show the inside of the object.

The **scanning electron microscope (SEM)** is a type of electron microscope capable of producing high-resolution images of a sample surface. Due to the manner in which the image is created, SEM images have a characteristic three-dimensional appearance and are useful for judging the surface structure of the sample. Sometimes objects need to be specially prepared to make them better suited for imaging under the scanning electron microscope, as shown with the insect in **Figure** 1.27.

Electron microscopes work under low pressures and usually in a vacuum chamber to avoid scattering the electrons in the gas. This makes the microscopes considerably larger and more expensive than optical microscopes. The different types of images from the two electron microscopes are shown in **Figure** 1.28. *Zoom into a Leaf* at http://www.dailymotion.com/video/x4mtsz_zoom-into-a-leaf_tech.

Aseptic Technique

In the microbiology lab, **aseptic technique** refers to the procedures that are carried out under sterile conditions. Scientists who study microbes are called microbiologists. Microbiologists must carry out their lab work using the aseptic technique to prevent microbial contamination of themselves, contamination of the environment they are working in, including work surfaces or equipment, and contamination of the sample they are working on. Bacteria live on just about every surface on Earth, so if a scientist wants to grow a particular type of bacterium in the lab, he or she needs to be able to sterilize their equipment to prevent contamination by other bacteria or microorganisms. The aseptic technique is also used in medicine, where it is important to keep the human body free of contamination.

FIGURE 1.27

This fish has been coated in gold, as part of the preparation for viewing with an SEM.

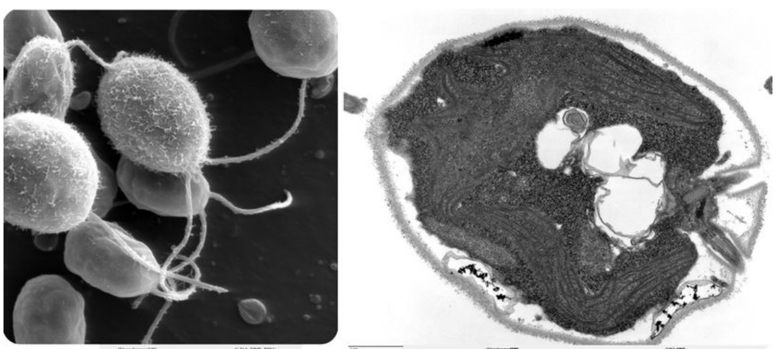


FIGURE 1.28

SEM and TEM images of the algae *Chlamydomonas*. The SEM image, shown at the right, is a three-dimensional image of the surface of the organism, whereas the TEM image is a two-dimensional image of the interior of the organism.

Aseptic technique is used whenever bacteria or other microbes are transferred between nutrient media or in the preparation of the nutrient media. Some equipment that is used in the aseptic technique include a Bunsen burner, an autoclave (**Figure** 1.29), hand and surface sanitizers, neoprene gloves, and a fume hood.

Students of microbiology are taught the principles of aseptic technique by hands-on laboratory practice. Practice is essential in learning how to handle the lab tools without contaminating them.

Lab Safety

In some laboratories, conditions are no more dangerous than in any other room. In many labs, though, additional hazards are present. Laboratory hazards are as varied as the subjects of study in laboratories, and might include poisons, infectious agents, flammable, explosive, or radioactive materials, moving machinery, extreme temperatures, or high voltage. The hazard symbols for corrosive, explosive, and flammable substances are shown in **Figure** 1.30. In laboratories where conditions might be dangerous, safety precautions are important. Lab safety rules minimize a person's risk of getting hurt, and safety equipment is used to protect the lab user from injury or to help in responding to an emergency.

Some safety equipment that you might find in a biology lab includes:

FIGURE 1.29
A worktop autoclave. Autoclaves commonly use steam heated to 121 ℃ (250 ℉), at 103 kPa (15 psi) above atmospheric pressure. Solid surfaces are effectively sterilized when heated to this temperature. Liquids can also be sterilized by this process, though additional time is required to reach sterilizing temperature.

FIGURE 1.30
The hazard symbols for corrosive, explosive, and flammable substances.

FIGURE 1.31
Immediate disposal of used needles, and other sharp equipment into a sharps container is standard procedure.

- **Sharps Container**: A container that is filled with used medical needles and other sharp instruments such as blades, shown in **Figure** 1.31. Needles or other sharp items that have been used are dropped into the container without touching the outside of the container. Objects should never be pushed or forced into the container, as damage to the container or injuries may result.
- **Laminar Flow Cabinet**: A carefully enclosed bench designed to prevent contamination of biological samples. Air is drawn through a fine filter and blown in a very smooth, laminar (streamlined) flow towards the user. The cabinet is usually made of stainless steel with no gaps or joints where microorganisms might collect.
- **Gloves**: Due to possible allergic reactions to latex, latex gloves are not recommended for lab use. Instead, vinyl or nitrile gloves, shown in **Figure** 1.32, are often used. Gloves protect the wearers hands and skin from getting contaminated by microorganisms or stained or irritated by chemicals.

FIGURE 1.32
A nitrile glove. Latex gloves are no longer recommended so vinyl gloves or nitrile gloves, which are usually green or blue in color, are preferred.

- **Lab Coat**: A knee-length overcoat that is usually worn while working in the lab. The coat helps to protect the researcher's clothes from splashes or contamination. The garment is made from white cotton or linen to allow it to be washed at high temperature and make it easy to see if it is clean.

Safe Laboratory Practice

Safety precautions are in place to help prevent accidents. Always wear personal protective equipment such as goggles and gloves when recommended to do so by your teacher.

- Tell your teacher immediately if an accident happens.
- The production of aerosols due to poor technique such as squirting the last drop out of pipettes, and the spread of contamination due to spills is completely avoidable and especially important if you are handling infectious material or chemicals.
- Wear enclosed toe shoes, instead of sandals or flip flops, or thongs (**Figure** 1.33). Your feet and toes could easily get hurt or broken or if you dropped something.
- Do not wear loose, floppy clothes in the lab; they can get caught in or knock over equipment, causing an accident.
- If you have long hair, tie it up for the same reasons listed above.
- Do not eat or drink in the lab.
- Do not use cell phones in the lab, even if you are only sending a text message. You can easily contaminate your phone with whatever you have been working with. Consider where your hands have been, and where your face will be the next time you talk on the phone.

- Sweep up broken glass immediately and dispose in a designated area or container, or notify your teacher.
- Always listen carefully to your teacher's instructions.

FIGURE 1.33
Although they may be comfy and casual, flip-flops and other open-toed shoes are not suitable footwear in the lab.

Accidents

In the case of an accident, it is important to begin by telling your teacher and to know where to find safety equipment.

Some common safety equipment in a school lab:

- Fire Extinguishers
- Fire Blanket
- Eye-Wash Fountain (**Figure** 1.34)
- First-Aid Kit

Through the first three lessons, we have discussed what science is and how science is done. Now we need to turn our attention to Biology. Biology is the study of life. As the 'study of life,' a knowledge of biology is an extremely important aspect of your education. Biology includes the identification and analysis of characteristics common to all living organisms. What is known about biology is discovered or identified through the same processes as all other sciences, including the scientific method and peer review process.

FIGURE 1.34
Symbol for the eyewash fountain.

Vocabulary

- **aseptic technique**: Laboratory procedures that are carried out under sterile conditions.
- **compound microscope**: An optical microscopes that has a series of lenses; has uses in many fields of science, particularly biology and geology.
- **electron microscope**: A microscope that uses electrons instead of light; allows a researcher to see things at very high magnification, far higher than an optical microscope can possibly magnify.
- **lab techniques**: The procedures used in science to carry out an experiment.
- **laboratory**: A place with controlled conditions in which scientific research, experiments, and measurement can be carried out.
- **magnification**: Enlarging an image of an object so that it appears much bigger than its actual size; also refers to the number of times an object is magnified.
- **microscope**: An instrument used to view objects that are too small to be seen by the naked eye.
- **optical microscope**: A microscope that uses visible light and lenses to magnify objects.
- **resolution**: A measure of the clarity of an image; the minimum distance that two points can be separated and still be distinguished as two separate points.
- **scanning electron microscope (SEM)**: Electron microscope that scans an electron beam over the surface of an object; measures how many electrons are scattered back.
- **transmission electron microscope (TEM)**: Electron microscope that shoots electrons through the sample; measures how the electron beam changes because it is scattered in the sample.

Summary

- Equipment commonly found in a biology labs include microscopes, weighing scales or balances, water baths, glassware (such as test tubes, flasks, and beakers), Bunsen burners, tongs, pipettes, chemical reagents, lab

coats, goggles, and biohazard waste containers.
- Always wear personal protective equipment such as goggles and gloves, wear enclosed shoes, and do not eat or drink in the lab.

Practice

Use this resource to answer the question that follows.

- **Science Lab Safety Rules** at http://www.youtube.com/watch?v=yclOrqEv7kw.

MEDIA
Click image to the left for more content.

1. List the laboratory rules described in this video.

Review

1. What is a laboratory? Where can they be found?
2. What is the main difference between a light microscope and an electron microscope.
3. What is an aseptic technique and what equipment does it require?
4. Name three pieces of safety equipment that you should wear while carrying out an investigation in the lab.
5. What should you first do if an accident happens in the lab?
6. If you saw this hazard sign on a chemical container, what do you think it might mean?

1.11 Characteristics of Life - Advanced

- Identify the seven characteristics of living things.

What do a bacterium and a whale have in common?

Do they share characteristics with us? All living organisms, from the smallest bacterium to the largest whale, share certain characteristics of life. For example, all living things are made of cells and they must reproduce to make the next generation. Without these characteristics, there is no *life*.

Characteristics of Life

Biology examines the structure, function, growth, origin, evolution, and distribution of living things. It classifies and describes organisms, their functions, how species come into existence, and the interactions they have with each other and with the natural environment. Four unifying principles form the foundation of modern biology: cell theory, evolution, genetics and homeostasis.

A powerful introductory video, *Characteristics of Life,* choreographed to dramatic music, highlighting the wonder of life, and how it is defined can be seen at http://vimeo.com/15407847.

Most biological sciences are specialized areas of study. Biology includes biochemistry, cell biology, microbiology, immunology, genetics, physiology, zoology, ecology, evolutionary biology, and botany. Biochemistry is the study of the chemicals that make up life. Cell biology is the study of life at the level of the cell. Microbiology is the study of microscopic organisms. Immunology is the study of an organism's resistance to disease. Genetics is the study of how organisms pass traits to their offspring. The study of how the human body works is called physiology. Zoology is the study of animals. The study of how organisms interact with their environment and each other is called ecology. Evolutionary biology is the study of how populations and species change over time. Botany is the study of plants. The four unifying principles are important foundations for each and every field of biology. Applied fields of biology such as medicine and genetic research involve many specialized areas of study.

What is Life?

Not all scientists agree exactly about what makes up life. Many characteristics describe most living things. However, with most of the characteristics listed below we can think of one or more examples that would seem to break the rule, with something non-living being classified as living or something living classified as non-living.

There is not just one distinguishing feature that separates a living thing from a non-living thing. A cat moves but so does a car. A tree grows bigger, but so does a cloud. A cell has structure, but so does a crystal. Biologists define life by listing characteristics that living things share. Something that has all of the characteristics of life is considered to be alive. The duck decoy in **Figure** 1.35 may look like a duck, act like a duck in that it floats about, but it is not alive. The decoy cannot reproduce, respond to its environment, or breathe.

FIGURE 1.35
Is it a duck? Both of these objects move across the water's surface. But, how can you tell which one is alive and which is not? You can tell by seeing which of them have all of the characteristics of life.

An individual living creature is called an **organism**. There are many characteristics that living organisms share. They all:

- respond to their environment
- grow and change
- reproduce and have offspring
- have a complex chemistry
- maintain homeostasis
- are built of structures called cells
- pass their traits onto their offspring

Responding to the Environment

All living organisms respond to their environment. If you step on a rock, it will just lie there, but if you step on a turtle, it may move or even snap at you. Living things know what is going on around them, and respond to changes in the environment. An **adaptation** refers to the process of becoming adjusted to an environment. Adaptations may include structural, physiological, or behavioral traits that improve an organism's likelihood of survival, and thus, reproduction.

Growth and Change

All living organisms have the ability to grow and change. A seed may look like a pebble, but under the right conditions it will sprout and form a seedling that will grow into a larger plant. The pebble of course will not grow. Even the smallest bacteria must grow. This bacteria will reproduce by dividing into two separate bacterium. If the parent bacterium does not grow, then each subsequent generation will just be smaller then the previous generation. Eventually the bacteria will be too small to function properly.

Reproduction

All living organisms must have the ability to reproduce. Living things make more organisms like themselves. Whether the organism is a rabbit, or a tree, or a bacterium, life will create more life. If a species cannot create the next generation, the species will go extinct. **Reproduction** is the process of making the next generation. Reproduction

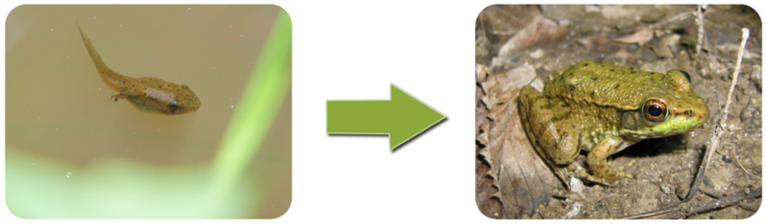


FIGURE 1.36
Tadpoles, like those shown here, go through many changes to become adult frogs.

may be sexual or asexual. **Sexual reproduction** involves two parents and the fusion of **gametes**, haploid sex cells from each parent. Sexual reproduction produces offspring that are genetically unique and increases genetic variation within a species. **Asexual reproduction** involves only one parent. It occurs without a fusion of gametes and produces offspring that are all genetically identical to the parent.

Have Complex Chemistry

All living organisms have a complex chemistry. A flower has a complicated and beautiful structure. So does a crystal. But if you look closely at the crystal, you see no change. The flower, on the other hand, is transporting water through its petals, producing pigment molecules, breaking down sugar for energy, and undergoing a large number of other biochemical reactions that are needed for living organisms to stay alive. The sum of all the chemical reactions in a cell is **metabolism**.

Maintain Homeostasis

A human body has a temperature of 37 degrees Celsius, (about 98.6 degrees Fahrenheit). If you step outside on a cold morning, the temperature might be below freezing. Nevertheless, you do not become an ice cube. Your shiver and the movement in your arms and legs allow you to stay warm. Eating food also gives your body the energy to keep warm. Living organisms keep their internal environments within a certain range (they maintain a stable internal condition), despite changes in their external environment. This process is called **homeostasis**, and is an important characteristic of all living organisms.

Built of Cells

If you look closely at any organism you can see that it is made of structures called **cells**. Organisms that are very different such as ferns, fish, and elephants all look similar at the cellular level. A cell is the basic unit of structure and function of all living organisms. All living organisms are made of one or more cells: a simple bacterium will consist of just one cell, whereas you are made of trillions of cells.

Organisms are organized in the microscopic level from atoms up to cells. The matter is structured in an ordered way. Atoms are arranged into molecules, then into macromolecules, which make up organelles, which work together to form cells. Beyond this, cells are organized in higher levels to form entire multicellular organisms, as shown in **Figure** 1.38. Cells together form tissues, which make up organs, which are part of organ systems, which work together to form an entire organism. Of course, beyond this, organisms form populations which make up parts of an ecosystem. All of Earth's ecosystems together form the diverse environment that is Earth.

Vocabulary

- **adaptation**: The process of becoming adjusted to an environment; a characteristic which helps an organism

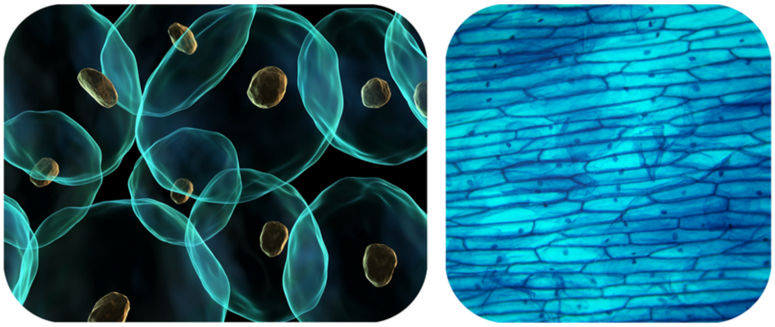


FIGURE 1.37
Representations of human cells (left) and onion cells (right). If you looked at human and onion cells under a microscope, this is what you might see.

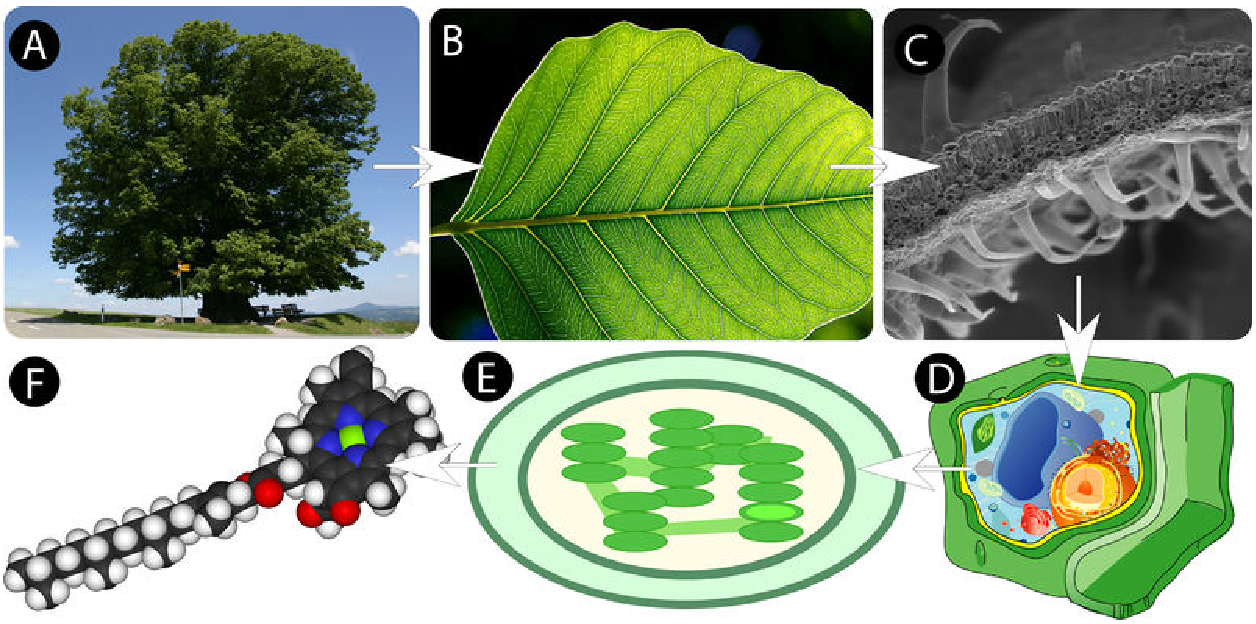


FIGURE 1.38
Levels of organization in a tree. (a) The tree is the organism; (b) a leaf is an organ, (c) a leaf tissue is made up of different types of cells; (d) a plant cell; (e) chloroplast is an organelle inside a plant cell; (f) chlorophyll is the photosynthetic molecule that is found in chloroplasts.

survive in a specific habitat.

- **asexual reproduction**: Reproduction involving only one parent; occurs without a fusion of gametes; produces offspring that are all genetically identical to the parent.
- **cell**: The basic unit of structure and function of all living organisms.
- **gamete**: A sexually reproducing organism's reproductive cells, such as sperm and egg cells.
- **homeostasis**: The process of maintaining a stable environment inside a cell or an entire organism.
- **metabolism**: The sum of all the chemical reactions in a cell and/or organism.
- **organism**: An individual living creature; a life form consisting of one or more cells.
- **reproduction**: Process by which living organisms give rise to offspring; making the next generation.
- **sexual reproduction**: Reproduction involving the joining of haploid gametes, producing genetically diverse individuals.

Summary

- The seven characteristics of life include: responsiveness to the environment; growth and change; ability to reproduce; have a metabolism and breathe; maintain homeostasis; being made of cells; passing traits onto offspring.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology. → Non-Majors Biology → Search: **Defining Biology**

1. What does "biology" encompass?
2. What characteristics define life?
3. Define metabolism and homeostasis
4. Are viruses living? Explain your answer.

Review

1. What are the four unifying principles that form the foundation of modern biology?
2. Identify three of the seven characteristics of living things.
3. What is adaptation?
4. Distinguish between metabolism and homeostasis.
5. What is a cell?

1.12 Unifying Principles of Biology

- Identify and explain the four unifying principles of modern biology.

What is a biological principle?

The word *principle* can be defined as "a fundamental truth or proposition that serves as the foundation for a system of belief or behavior or for a chain of reasoning." So a principle of biology is a fundamental concept that is just as true for a bee or a sunflower as it is for us. All life, including that sunflower and bee, is made of at least one cell, the traits of that organism are embedded within its genes, that organism must maintain homeostasis to survive, and that organism has evolved from previously existing species.

Unifying Principles of Biology

There are four unifying principles of biology that are important to all life and form the foundation of modern biology. These are:

1. the cell theory,
2. the gene theory,
3. homeostasis,
4. evolutionary theory.

The Cell Theory

The **cell** is the basic unit of structure and function of all organisms. The Cell Theory states that all living things are made of one or more cells, or the secretions of those cells, such as the organisms shown in **Figure** 1.39. For example, shell and bone are built by cells from substances that they secrete into their surroundings. Cells come from cells that already exist, that is, they do not suddenly appear from nowhere. In organisms that are made of many cells (called multicellular organisms), every cell in the organism's body derives from the single cell that results from a fertilized egg. You will learn more about cells and the Cell Theory in *The Cell Theory - Advanced* concept.

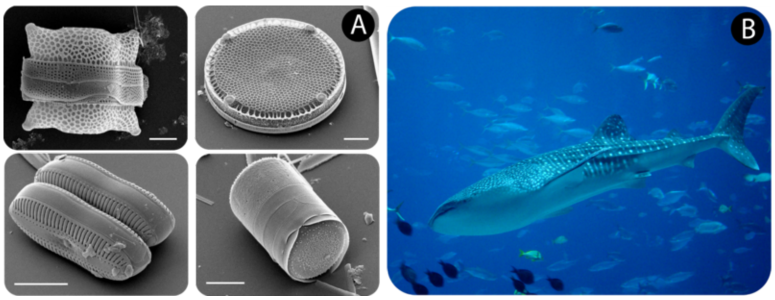


FIGURE 1.39

Tiny diatoms and whale sharks are all made of cells. Diatoms are about 20 μm in diameter and are made up of one cell, whereas whale sharks can measure up to 12 meters in length, and are made up of billions of cells.

Gene Theory

An organism's traits are encoded in their **DNA**, the large molecule, or macromolecule, that holds the instructions needed to build cells and organisms. DNA makes up the **genes** of an organism. Traits are passed on from one generation to the next by way of these genes. Information for how the organism appears and how its cells work come from the organism's genes. Although the appearance and cell function of the organism may change due to the organism's environment, the environment does not change its genes. The only way that genes can change in response to a particular environment is through the process of evolution in populations of organisms. You will learn more about DNA and genes in *Molecular Biology - Advanced*.

Homeostasis

Homeostasis is the ability of an organism to control its body functions in order to uphold a stable internal environment even when its external environment changes. All living organisms perform homeostasis. For example, cells maintain a stable internal acidity (pH); and warm-blooded animals maintain a constant body temperature. You will learn more about homeostasis in the *Homeostasis - Advanced* concept.

Homeostasis is a term that is also used when talking about the environment. For example, the atmospheric concentration of carbon dioxide on Earth has been regulated by the concentration of plant life on Earth, because plants remove more carbon dioxide from the atmosphere during the daylight hours than they emit to the atmosphere at night.

Evolution

Evolution by **natural selection**, is the theory that maintains that a population's inherited traits change over time, and that all known organisms have a common origin. Evolutionary theory can explain how specialized features, such as the geckos sticky foot pads shown in **Figure** 1.40, develop in different species. More about evolution is discussed in *Evolution - Advanced*.

FIGURE 1.40

A Tokay Gecko. The pads at the tip of the Tokay gecko's foot are covered in microscopic hairs, each split into hundreds of tips that measure about 200 nanometers in diameter. By using these tiny hairs that can cling to smooth surfaces, the geckos are able to support their entire body weight while climbing walls, definately a product of evolution.

KQED: Bio-Inspiration: Nature as Muse

For hundreds of years, scientists have been using design ideas from structures in nature. Now, biologists and engineers at the University of California, Berkeley are working together to design a broad range of new products, such as life-saving milli-robots modeled on the way cockroaches run and adhesives based on the amazing design of a geckos foot. This process starts with making observations of nature, which lead to asking questions and to the additional aspects of the scientific process. *Bio-Inspiration: Nature as Muse* can be observed at http://www.kqed.org/quest/television/bioinspiration-nature-as-muse.

Adobe Flash

MEDIA

Click image to the left for more content.

Vocabulary

- **cell**: The basic unit of structure and function of all living organisms.
- **DNA (deoxyribonucleic acid)**: Double-stranded nucleic acid that composes genes and chromosomes; the hereditary material.
- **evolution**: The change in the characteristics of living organisms over time; the change in species over time.
- **gene**: A segment of DNA that contains information to encode an RNA molecule or a single polypeptide.
- **homeostasis**: The process of maintaining a stable environment inside a cell or an entire organism.
- **natural selection**: Evolutionary process by which certain beneficial traits becomes more common within a population, changing the characteristics (traits) of a species over time.

Summary

- Four unifying principles form the foundation of modern biology: cell theory, evolutionary theory, the gene theory and the principle of homeostasis. These four principles are important to each and every field of biology.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology. → Non-Majors Biology → Search: **Cell Theory**

1. What is the Cell Theory?
2. What are the three basic tenets of the Cell Theory?
3. Describe the findings of Schwann, Schleiden, and Virchow.
4. What has led to the "modernization" of the Cell Theory?
5. What are the main differences between the classic cell theory and the modern cell theory?

Review

1. Identify and describe the four unifying principles of modern biology.
2. Why do you believe the four unifying principles of modern biology form the foundation of modern biology.

1.13 Interdependence of Living Things - Advanced

- List two different types of interactions that organisms can have with each other.

What does it mean to be *interdependent*?

Do species live alone, or do many live in communities with other organisms? All species rely on other species in some way for their survival. They may rely on other species for food, shelter or to help them reproduce. Here the bee is helping the flower spread its pollen. Species are not independent, they are interdependent.

Interdependence of Living Things

Biological interactions are the interactions between different organisms in an environment. In the natural world, no organism is cut off from its surroundings. Organisms are a part of their environment which is rich in living and non-living elements that interact with each other in some way. The interactions of an organism with its environment are vital to its survival, and the functioning of the ecosystem as a whole.

These relationships can be categorized into many different classes. The interactions between two species do not necessarily need to be through direct contact. Due to the connected nature of ecosystems, species may affect each other through such relationships involving shared resources or common enemies.

The term **symbiosis** comes from a Greek word that means "living together." Symbiosis can be used to describe various types of close relationships between organisms of different species, such as **mutualism** and **commensalism**, which are relationships in which neither organism is harmed. Sometimes the term symbiosis is used only for cases where both organisms benefit, sometimes it is used more generally to describe all kinds of close relationships, even when one organism is killed by another, as shown in **Figure** 1.41. Symbiosis can also be used to describe relationships where one organism lives on or in another, called **parasitism**, or when one organism kills and eats another organism, called **predation**. These relationships will be further described in *Ecology - Advanced*.

FIGURE 1.41
There are many different types of symbiotic interactions between organisms. Clockwise from top left: *Escherichia coli* bacteria live inside your intestines in a mutualistic relationship: the bacteria produce Vitamin K for you, and they get their food from what you eat. Clownfish that live among the tentacles of sea anemones protect the anemone from anemone-eating fish, and in turn the stinging tentacles of the anemone protect the clownfish from its predators (a special mucus on the clownfish protects it from the stinging tentacles). Similar to the *E. coli*, this bee has a mutualistic relationship with the flower, the bee feeds from the flower, and the flower gets pollinated by the bee. Lions are predators that feed on other organisms such as this Cape buffalo.

FIGURE 1.42
A flock of starlings looks out, before searching for parasites on a red deer stag.

Competition is as an interaction between organisms or species, for the same resources such as water, food, or hunting grounds in an environment, shown in **Figure** 1.43. Eventually, the species that is less able to compete for resources will either adapt or die out. According to evolutionary theory, competition for resources plays an important role in natural selection.

Animals that eat decomposing organic material also have an important interaction with the environment. They help to decompose dead matter and assist with the recycling of nutrients. By burying and eating dung, dung beetles, such as the one shown in **Figure** 1.44, improve nutrient cycling and soil structure. They make the dead organic matter

FIGURE 1.43
Competition between organisms and species. These male deer are competing for females during rutting (mating) season. Trees in this Bangladesh forest are in competition for light.

available to bacteria that break it down even further.

FIGURE 1.44
Dung beetles have important interactions with the environment, through which many other organisms benefit.

Organisms are not independent, they are **interdependent**. They cannot live alone; they need other organisms to survive. The same is true for species. All species need other species to survive.

Levels of Organization

In studying how organisms interact with each other, biologists often find it helpful to classify the organisms and interactions into levels of organization. Similar to the way an organism itself has different levels of organization, the ways in which organisms interact with their environment and each other can also be divided into levels of organization. For example:

The **biosphere** includes all living things within all of their environments. It includes every place that life occurs, from the upper reaches of the atmosphere to the top few meters of soil, to the bottoms of the oceans. An **ecosystem** is made up of the relationships among smaller groups of organisms with each other, and with their environment. Scientists often speak of the interrelatedness of living things, because, according to evolutionary theory, organisms adapt to their environment, and they must also adapt to other organisms in that environment.

A **community** is made up of the relationships between groups of different species. For example, the desert communities consist of rabbits, coyotes, snakes, birds, mice and such plants as sahuaro cactus, ocotillo, and creosote bush. Community structure can be disturbed by such dynamics as fire, human activity, and over-population.

A **population** is a group of individuals of a single species that mate and interact with one another in a limited geographic area. For example, a field of flowers which is separated from another field by a hill or other area where none of these flowers occur.

It is thus possible to study biology at many levels, from collections of organisms or communities, to the inner workings of a cell (organelle). More about the interactions of organisms will be discussed in *Ecology - Advanced*.

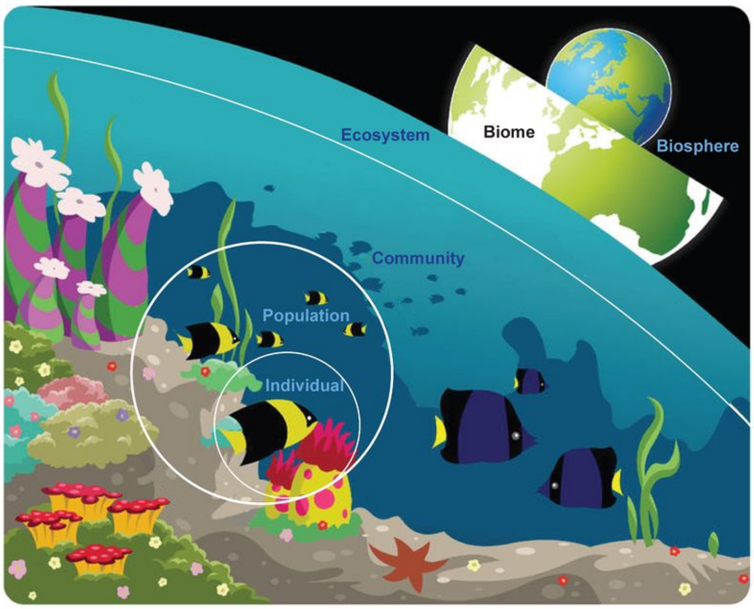


FIGURE 1.45
This picture shows the levels of organization in nature, from the individual organism to the biosphere.

The Diversity of Life

Evolutionary theory and the cell theory give us the basis for how and why organisms relate to each other. The diversity of life found on Earth today is the result of 4 billion years of evolution. Some of this diversity is shown in **Figure** 1.46. The origin of life is not completely understood by science, though limited evidence suggests that life may already have been well-established a few 100 million years after Earth formed. Until approximately 600 million years ago, all life was made up of single-celled organisms.

The level of **biodiversity** found in the fossil record suggests that the last few million years include the period of greatest biodiversity in the Earth's history. However, not all scientists support this view, since there is a lot of uncertainty as to how strongly the fossil record is biased by the greater availability and preservation of more recent fossil-containing rock layers. Some researchers argue that modern biodiversity is not much different from biodiversity 300 million years ago. Estimates of the present global species diversity vary from 5 million to 30 million species, with a best estimate of somewhere near 10 million species. All living organisms are classified into one of the six kingdoms: Archaebacteria (Archaea), Eubacteria (Bacteria), Protista (Protists), Fungi, Plantae (Plants), and Animalia (Animals).

New species are regularly discovered and many, though already discovered, are not yet classified. One estimate states that about 40 percent of freshwater fish from South America are noa few of the many members of the animal kingdom are shown in **Figure** 1.46. The animal kingdom is just a tiny portion ot yet classified. Every year, scientists discover the existence of many hundreds more archaea and bacteria than were previously known. Just f the total diversity of life. More about the diversity of living creatures will be discussed throughout numerous concepts.

FIGURE 1.46

Animal diversity. This figure shows just a fraction of the diversity of life. The diversity of organisms found in the five kingdoms of life, dwarf the number of organisms found in the animal kingdom. The other kingdoms of life are Eubacteria, Archaebacteria, Protista, Fungi, and Plantae.

Vocabulary

- **biodiversity**: The variety of life and its processes; including the variety of living organisms, the genetic differences among them, and the communities and ecosystems in which they occur.
- **biological interactions**: The interactions between different organisms in an environment.
- **biosphere**: The areas of Earth where all organisms live; extends from about 11,000 meters below sea level to 15,000 meters above sea level.
- **commensalism**: A symbiotic relationship in which one species benefits while the other species is not affected.
- **community**: The populations of different species that live in the same habitat and interact with one another; the biotic component of an ecosystem.
- **competition**: The relationship between organisms that strive for the same limited resources.
- **ecosystem**: A natural unit consisting of a community (the biotic factors) functioning together with all the nonliving (abiotic) physical factors of the environment.
- **interdependent**: The notion that organisms (species) cannot live alone; they need other organisms (species) to survive.
- **mutualism**: A type of symbiotic relationship in which both species benefit.
- **parasitism**: A symbiotic relationship in which one species (the parasite) benefits while the other species (the host) is harmed.
- **population**: A group of individuals of a single species that mate and interact with one another in a limited geographic area.
- **predation**: A relationship in which members of one species (the predator) consume members of other species (the prey).

- **symbiosis**: A close relationship/association between organisms of different species in which at least one of the organisms benefits from the relationship.

Summary

- The interactions of an organism with its environment are vital to its survival, and the functioning of the ecosystem as a whole.
- An ecosystem consists of the relationships among smaller groups of organisms with each other, and with their environment.
- Symbiosis can be used to describe various types of close relationships between organisms of different species.
- Competition is as an interaction between organisms or species for the same resources in an environment.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Non-Majors Biology → Search: **Interactions Within Communities**

1. How do organisms within a community interact with each other?
2. Describe and give examples of the two types of competition.
3. How may predation benefit the prey population?
4. Describe the various types of symbiotic relationships. Provide examples of each.

Review

1. What is biological interactions?
2. What is the difference between mutualism and commensalism?
3. What is predation?
4. What are the levels of organization that organisms interact with their environment and explain them.
5. Give an example of how you are interdependent from another organism.

1.14 Evolution of Life - Advanced

- Outline the formation of modern evolutionary theory.

What is a dinosaur?

A dinosaur is from a class of reptiles. They are diverse reptiles that first appeared during the Triassic period, approximately 230 million years ago, and were the dominant land vertebrates for 135 million years, from the beginning of the Jurassic period (about 200 million years ago) until they went extinct, at the end of the Cretaceous period, 65.5 million years ago. They are very strong evidence of evolution, the change in species over time. Dinosaurs went extinct because they could not adapt to a catastrophic environmental change. The ability to adapt to a changing environment is a key feature of natural selection, the process of evolution.

Evolution of Life

Evolution is the process by which populations of organisms change over time. It is a process that began on this planet well over 3.5 billion years ago and continues to this day, as populations of organisms continue to change.

Evolution occurs as organisms acquire and pass on new traits from one generation to the next generation. Its occurrence over large stretches of time explains the origin of new species and the great diversity of the biological world. Extant species are related to each other through common descent, and products of evolution over billions of years. Analysis of the DNA of different organisms indicates there is a similarity among very different organisms in the genetic code that help make proteins and other molecules. This genetic code is used by all known forms of life on Earth. The theory of evolution suggests that the genetic code was established very early in the history of life, and some studies suggest it was established soon after the formation of Earth. The timeline of the evolution of life, shown in **Figure** 1.47, outlines the major events in the development of life.

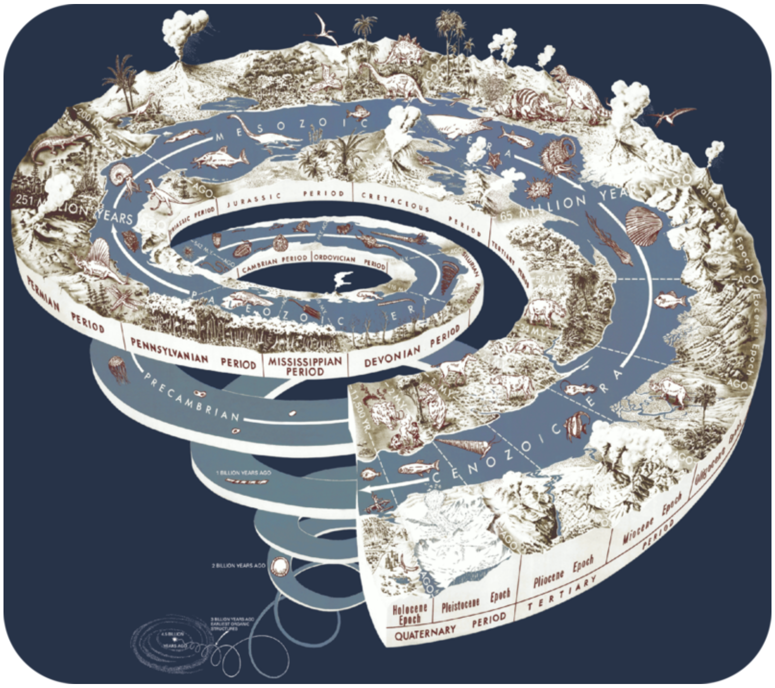


FIGURE 1.47
According to recent estimates, the Earth is about 4.5 billion years old. Most of the evidence for an ancient Earth is contained in the rocks that form the Earth's crust. The rock layers themselves, like pages in thick history book, record the surface shaping events of the past. Buried within them are traces of life, including the plants and animals that evolved from organic structures that existed perhaps as many as 3 to 3.5 billion years ago.

How do scientists know Earth is so old? The answer is in the rocks. Contained in rocks that were once molten, shown in **Figure** 1.48, are chemical elements that act like an atomic clock. The atoms of different forms of elements (called **isotopes**) break down at different rates over time. Parent isotopes within these rocks decay at a predictable rate to form daughter isotopes. By determining the relative amounts of parent and daughter isotopes, the age of these rocks can be calculated—forming the so-called atomic clock.

Thus, the results of studies of rock layers (**stratigraphy**), and of fossils (**paleontology**), along with the ages of certain rocks as measured by atomic clocks (**geochronology**), indicate that the Earth is over 4.5 billion years old, with the oldest known rocks being 3.96 billion years old. More about the history of life on Earth will be discussed in *History of Life - Advanced* concepts.

FIGURE 1.48
Molten rock, called *lava*, is expelled by a volcano during an eruption. The lava will eventually cool to become solid rock. When first expelled from a volcanic vent, it is a liquid at temperatures from 700 °C to 1,200 °C (1,300 °F to 2,200 °F). Not all types of rocks come from cooled lava, but many do.

Additional images/videos of volcanic eruptions can be seen at Hawaii Volcanic Eruption with Lightning and USGS Kilauea Volcano http://hvo.wr.usgs.gov/gallery/kilauea/volcanomovies/.

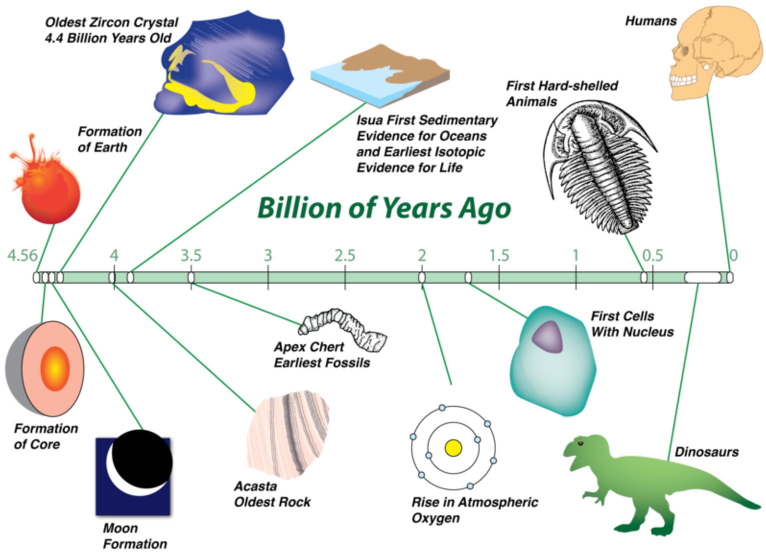


FIGURE 1.49
This timeline shows the history of life on Earth. In the entire span of the time, humans are a relatively new addition.

History of Evolutionary Thought

The theory of evolution by natural selection was proposed at about the same time by both Charles Darwin and Alfred Russel Wallace, shown in **Figure** 1.50, and was set out in detail in Darwin's 1859 book *On the Origin of Species*. **Natural selection** is a process that causes heritable traits that are helpful for survival and reproduction to become more common, and harmful traits, or traits that are not helpful or advantageous for survival to become more rare in a population of organisms. This occurs because organisms with advantageous traits are more "fit" to survive in a particular environment and have "adapted" to the conditions of that environment. These individuals will have greater reproductive success than organisms less fit for survival in the environment. This will lead to an increase in the number of organisms with the advantageous trait(s) over time. Over many generations, adaptations occur through a combination of successive, small, random changes in traits, and natural selection of those variants best-suited for their environment. Natural selection is one of the cornerstones of modern biology.

The theory of evolution encountered initial resistance from religious authorities who believed humans were divinely set apart from the animal kingdom. There was considerable concern about Darwin's proposal of an entirely scientific explanation for the origin of humans. Many people found such an explanation to be in direct conflict with their religious beliefs. A caricature of Darwin as a monkey, shown in **Figure** 1.51, reflects the controversy that arose over evolutionary theory. In the 1930s, Darwinian natural selection was combined with Mendelian inheritance to form the basis of modern evolutionary theory.

The identification of DNA as the genetic material by Oswald Avery and colleagues in the 1940s, as well as the publication of the structure of DNA by James Watson and Francis Crick in 1953, demonstrated the physical basis for inheritance. Since then, genetics and molecular biology have become core aspects of evolutionary biology.

Currently the study of evolutionary biology involves scientists from fields as diverse as biochemistry, ecology, genetics and physiology, and evolutionary concepts are used in even more distant disciplines such as psychology, medicine, philosophy and computer science.

FIGURE 1.50

Charles Darwin, left (1809-1882), and Alfred Russel Wallace, right (1823-1913). Both scientists proposed a process of evolution by natural selection at about the same time. However, Darwin is primarily associated with the theory of evolution by natural selection due to his abundance of data.

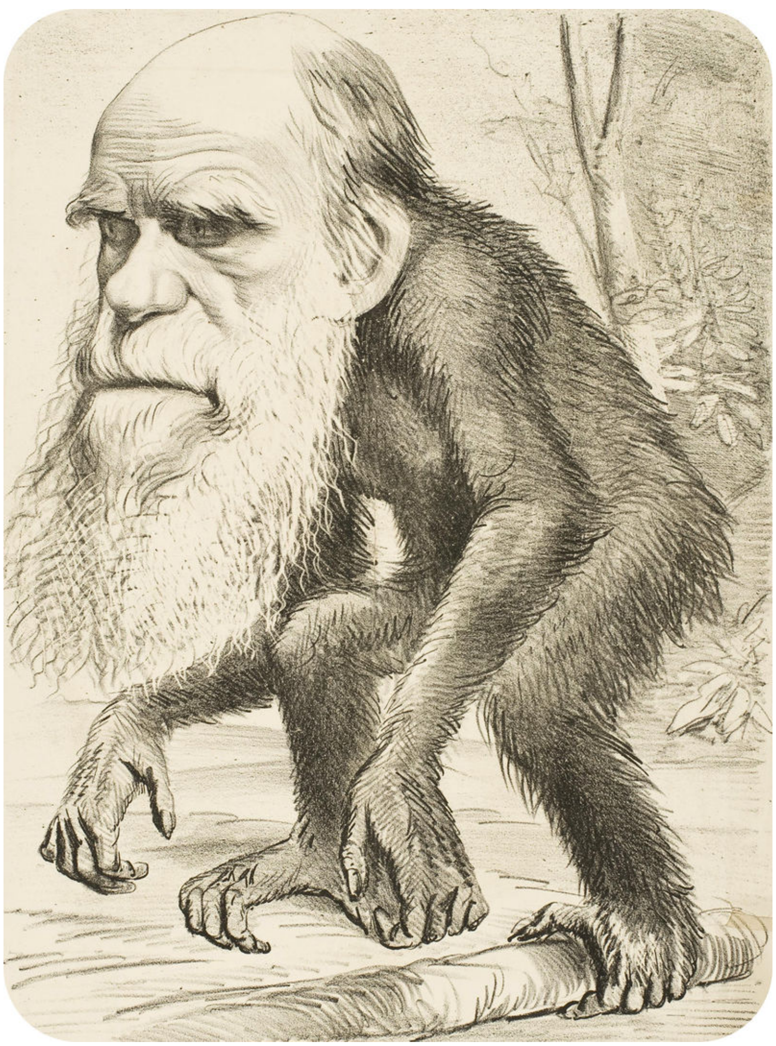


FIGURE 1.51

An 1871 caricature portraying Darwin with an ape body and the bushy beard he grew in 1866. Such satire reflected the cultural backlash against evolution.

Misconceptions About Evolution

The following list includes some common misconceptions about evolution.

- The term evolution describes the changes that occur in populations of living organisms over time. Describing these changes does not address the origin of life. The two are commonly and mistakenly confused. Biological evolution likewise says nothing about cosmology, the Big Bang, or where the universe, galaxy, solar system, or Earth came from.
- Humans did not evolve from chimpanzees or any other modern ape; instead they share a common ancestor that existed around 7 million years ago.
- The process of evolution is not necessarily slow. Millions of years are not required to see evolution in action. Indeed, it has been observed multiple times under both controlled laboratory conditions and in nature.
- Evolution is not a progression from "lower" to "higher" forms of life, and it does not increase in complexity. For example, bacteria have simpler structures and a smaller amount of genetic material than humans do. This does not mean however, that bacteria are "less evolved" than humans are. Bacteria have evolved over many millions of years and are well adapted to their own environments.

After Darwin

Since Darwin's time, scientists have gathered a more complete fossil record, including microorganisms and chemical fossils. These fossils have supported and added more information to Darwin's theories. However, the age of the Earth is now held to be much older than Darwin thought. Researchers have also uncovered some of the preliminary mysteries of the mechanism of heredity as carried out through genetics and DNA, which were areas unknown to Darwin. Another growing subject is the study of comparative anatomy, which looks at how different organisms have similar body structures. Molecular biology studies of slowly changing genes reveal an evolutionary history that is consistent with fossil and anatomical records.

Vocabulary

- **evolution**: The change in the characteristics of living organisms over time; the change in species over time.
- **geochronology**: The study of the age of rocks.
- **isotope**: An atom of a different form of the same element.
- **natural selection**: Evolutionary process by which certain beneficial traits becomes more common within a population, changing the characteristics (traits) of a species over time.
- **paleontology**: The study of fossils.
- **stratigraphy**: The study of rock layers.

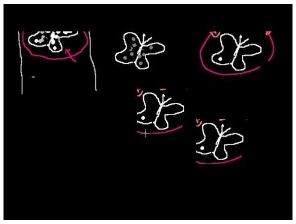
Summary

- Analysis of the DNA of different organisms indicate that there is a similarity in the genetic codes that help make proteins and other molecules in very different organisms.
- The theory of evolution by natural selection is based on the concept of the *survival of the fittest,* where individuals with beneficial traits are better able to survive and reproduce in the environment in which they live.

Practice

Use this resource to answer the questions that follow.

- **Introduction to Evolution and Natural Selection** at http://www.youtube.com/watch?v=GcjgWov7mTM (17:39).



MEDIA

Click image to the left for more content.

1. What is meant by *evolution*?
2. Describe *natural selection.*
3. What is meant by *variation*?
4. Describe the "evolution" of the peppered moth.
5. What is a virus? Do viruses evolve? Why or why not?

Review

1. What is evolution and natural selection?
2. Outline the formation of modern evolutionary theory.
3. How have more recent scientific findings fit with evolutionary theory since Darwin's time?
4. What are the misconceptions about evolution?
5. *Large animals are more evolved than single-celled organisms such as bacteria.* Do you agree with this statement? Explain your answer.

1.15 Nobel Prizes

- Explain what the Nobel Prize is.

What is the highest honor a scientist can be awarded?

The Nobel Prize, awarded each October in six categories, including physiology or medicine and chemistry.

The Nobel Prize

The **Nobel Prize** is an international award given each year to honor outstanding achievements in physics, chemistry, medicine, literature and for work in peace. The award is maintained by the Nobel Foundation in Stockholm, Sweden, named after **Alfred Nobel** (1833-1896), a scientist, inventor, entrepreneur, author and pacifist. At the age of 17, Alfred Nobel spoke five languages fluently. He went on to become an inventor and businessman, and at the time of his death, he had 355 patents worldwide, one which was the patent for dynamite. More importantly, he had started 87 companies world-wide. He had an unprecedented idea for his wealth. See http://www.nobelprize.org for additional information.

In his last will, dated November 27, 1895, Nobel left instructions for the prize. After leaving sums of monies to various friends and relatives, Nobel stated in his will, "The whole of my remaining realizable estate shall be dealt with in the following way: the capital, invested in safe securities by my executors, shall constitute a fund, the interest on which shall be annually distributed in the form of prizes to those who, during the preceding year, shall have conferred the greatest benefit to mankind. The said interest shall be divided into five equal parts, which shall be apportioned as follows: one part to the person who shall have made the most important discovery or invention within the field of physics; one part to the person who shall have made the most important chemical discovery or improvement; one part to the person who shall have made the most important discovery within the domain of physiology or medicine; one part to the person who shall have produced in the field of literature the most outstanding work in an ideal direction; and one part to the person who shall have done the most or the best work for fraternity between nations, for the abolition or reduction of standing armies and for the holding and promotion of peace congresses. The prizes for physics and chemistry shall be awarded by the Swedish Academy of Sciences; that for physiological or medical work by the Caroline Institute in Stockholm; that for literature by the Academy in Stockholm, and that for champions of peace by a committee of five persons to be elected by the Norwegian Storting. It is my express wish that in awarding the prizes no consideration whatever shall be given to the nationality of the candidates, but that the most worthy shall receive the prize, whether he be a Scandinavian or not."

The first five Nobel Prizes were awarded in 1901. In 1969, another prize was added: "The Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel."

Many of the contributions of Nobel laureates are discussed throughout these concepts. The contributions from the physiology or medicine are directly related to the life sciences, as are selected contributions from the chemistry prize.

Physiology or Medicine

TABLE 1.5: Nobel Laureates in Physiology or Medicine, 1950 to present

Year	Laureates	Contribution	Concept
2012	Sir John B. Gurdon, Shinya Yamanaka	*for the discovery that mature cells can be reprogrammed to become pluripotent*	
2011	Bruce A. Beutler, Jules A. Hoffmann, Ralph M. Steinman	*for their discoveries concerning the activation of innate immunity* (BAB, JAH) *and for his discovery of the dendritic cell and its role in adaptive immunity* (RMS)	
2010	Robert G. Edwards	*for the development of in vitro fertilization*	
2009	Elizabeth H. Blackburn, Carol W. Greider, Jack W. Szostak	*for the discovery of how chromosomes are protected by telomeres and the enzyme telomerase*	
2008	Harald zur Hausen, Françoise Barré-Sinoussi, Luc Montagnier	*for his discovery of human papilloma viruses causing cervical cancer* (HzH) and *for their discovery of human immunodeficiency virus* (FB-S, LM)	

TABLE 1.5: (continued)

Year	Laureates	Contribution	Concept
2007	Mario R. Capecchi, Sir Martin J. Evans, Oliver Smithies	*for their discoveries of principles for introducing specific gene modifications in mice by the use of embryonic stem cells*	The Human Genome Project - Advanced
2006	Andrew Z. Fire, Craig C. Mello	*for their discovery of RNA interference - gene silencing by double-stranded RNA*	Types of RNA - Advanced
2005	Barry J. Marshall, J. Robin Warren	*for their discovery of the bacterium Helicobacter pylori and its role in gastritis and peptic ulcer disease*	
2004	Richard Axel, Linda B. Buck	*for their discoveries of odorant receptors and the organization of the olfactory system*	
2003	Paul C. Lauterbur, Sir Peter Mansfield	*for their discoveries concerning magnetic resonance imaging*	
2002	Sydney Brenner, H. Robert Horvitz, John E. Sulston	*for their discoveries concerning genetic regulation of organ development and programmed cell death*	
2001	Leland H. Hartwell, Tim Hunt, Sir Paul M. Nurse	*for their discoveries of key regulators of the cell cycle*	
2000	Arvid Carlsson, Paul Greengard, Eric R. Kandel	*for their discoveries concerning signal transduction in the nervous system*	
1999	Günter Blobel	*for the discovery that proteins have intrinsic signals that govern their transport and localization in the cell*	
1998	Robert F. Furchgott, Louis J. Ignarro, Ferid Murad	*for their discoveries concerning nitric oxide as a signalling molecule in the cardiovascular system*	
1997	Stanley B. Prusiner	*for his discovery of Prions - a new biological principle of infection*	
1996	Peter C. Doherty, Rolf M. Zinkernagel	*for their discoveries concerning the specificity of the cell mediated immune defense*	

TABLE 1.5: (continued)

Year	Laureates	Contribution	Concept
1995	Edward B. Lewis, Christiane Nüsslein-Volhard, Eric F. Wieschaus	*for their discoveries concerning the genetic control of early embryonic development*	Eukaryotic Regulation of Gene Expression - Advanced
1994	Alfred G. Gilman, Martin Rodbell	*for their discovery of G-proteins and the role of these proteins in signal transduction in cells*	
1993	Richard J. Roberts, Phillip A. Sharp	*for their discoveries of split genes*	Gene Cloning - Advanced
1992	Edmond H. Fischer, Edwin G. Krebs	*for their discoveries concerning reversible protein phosphorylation as a biological regulatory mechanism*	
1991	Erwin Neher, Bert Sakmann	*for their discoveries concerning the function of single ion channels in cells*	
1990	Joseph E. Murray, E. Donnall Thomas	*for their discoveries concerning organ and cell transplantation in the treatment of human disease*	
1989	J. Michael Bishop, Harold E. Varmus	*for their discovery of the cellular origin of retroviral oncogenes*	Cancer - Advanced
1988	Sir James W. Black, Gertrude B. Elion, George H. Hitchings	*for their discoveries of important principles for drug treatment*	
1987	Susumu Tonegawa	*for his discovery of the genetic principle for generation of antibody diversity*	
1986	Stanley Cohen, Rita Levi-Montalcini	*for their discoveries of growth factors*	
1985	Michael S. Brown, Joseph L. Goldstein	*for their discoveries concerning the regulation of cholesterol metabolism*	
1984	Niels K. Jerne, Georges J.F. Köhler, César Milstein	*for theories concerning the specificity in development and control of the immune system and the discovery of the principle for production of monoclonal antibodies*	
1983	Barbara McClintock	*for her discovery of mobile genetic elements*	

TABLE 1.5: (continued)

Year	Laureates	Contribution	Concept
1982	Sune K. Bergström, Bengt I. Samuelsson, John R. Vane	*for their discoveries concerning prostaglandins and related biologically active substances*	
1981	Roger W. Sperry, David H. Hubel, Torsten N. Wiesel	*for his discoveries concerning the functional specialization of the cerebral hemispheres* (RWS), and *for their discoveries concerning information processing in the visual system* (DHH, TNW)	
1980	Baruj Benacerraf, Jean Dausset, George D. Snell	*for their discoveries concerning genetically determined structures on the cell surface that regulate immunological reactions*	
1979	Allan M. Cormack, Godfrey N. Hounsfield	*for the development of computer assisted tomography*	
1978	Werner Arber, Daniel Nathans, Hamilton O. Smith	*for the discovery of restriction enzymes and their application to problems of molecular genetics*	Gene Cloning - Advanced
1977	Roger Guillemin, Andrew V. Schally, Rosalyn Yalow	*for their discoveries concerning the peptide hormone production of the brain* (RG, AVS) and *for the development of radioimmunoassays of peptide hormones* (RY)	
1976	Baruch S. Blumberg, D. Carleton Gajdusek	*for their discoveries concerning new mechanisms for the origin and dissemination of infectious diseases*	
1975	David Baltimore, Renato Dulbecco, Howard Martin Temin	*for their discoveries concerning the interaction between tumour viruses and the genetic material of the cell*	Viruses: Classification
1974	Albert Claude, Christian de Duve, George E. Palade	*for their discoveries concerning the structural and functional organization of the cell*	

TABLE 1.5: (continued)

Year	Laureates	Contribution	Concept
1973	Karl von Frisch, Konrad Lorenz, Nikolaas Tinbergen	*for their discoveries concerning organization and elicitation of individual and social behavior patterns*	
1972	Gerald M. Edelman, Rodney R. Porter	*for their discoveries concerning the chemical structure of antibodies*	
1971	Earl W. Sutherland, Jr.	*for his discoveries concerning the mechanisms of the action of hormones*	
1970	Sir Bernard Katz, Ulf von Euler, Julius Axelrod	*for their discoveries concerning the humoral transmittors in the nerve terminals and the mechanism for their storage, release and inactivation*	
1969	Max Delbrück, Alfred D. Hershey, Salvador E. Luria	*for their discoveries concerning the replication mechanism and the genetic structure of viruses*	
1968	Robert W. Holley, Har Gobind Khorana, Marshall W. Nirenberg	*for their interpretation of the genetic code and its function in protein synthesis*	
1967	Ragnar Granit, Haldan Keffer Hartline, George Wald	*for their discoveries concerning the primary physiological and chemical visual processes in the eye*	
1966	Peyton Rous, Charles Brenton Huggins	*for his discovery of tumour-inducing viruses* (PR) and *for his discoveries concerning hormonal treatment of prostatic cancer* (CBH)	
1965	François Jacob, André Lwoff, Jacques Monod	*for their discoveries concerning genetic control of enzyme and virus synthesis*	Regulation of Gene Expression - Advanced
1964	Konrad Bloch, Feodor Lynen	*for their discoveries concerning the mechanism and regulation of the cholesterol and fatty acid metabolism*	

TABLE 1.5: (continued)

Year	Laureates	Contribution	Concept
1963	Sir John Carew Eccles, Alan Lloyd Hodgkin, Andrew Fielding Huxley	*for their discoveries concerning the ionic mechanisms involved in excitation and inhibition in the peripheral and central portions of the nerve cell membrane*	
1962	Francis Harry Compton Crick, James Dewey Watson, Maurice Hugh Frederick Wilkins	*for their discoveries concerning the molecular structure of nucleic acids and its significance for information transfer in living material*	The Double Helix - Advanced
1961	Georg von Békésy	*for his discoveries of the physical mechanism of stimulation within the cochlea*	
1960	Sir Frank Macfarlane Burnet, Peter Brian Medawar	*for discovery of acquired immunological tolerance*	
1959	Severo Ochoa, Arthur Kornberg	*for their discovery of the mechanisms in the biological synthesis of ribonucleic acid and deoxyribonucleic acid*	
1958	George Wells Beadle, Edward Lawrie Tatum, Joshua Lederberg	*for their discovery that genes act by regulating definite chemical events* (GWB, ELT) and *for his discoveries concerning genetic recombination and the organization of the genetic material of bacteria*	
1957	Daniel Bovet	*for his discoveries relating to synthetic compounds that inhibit the action of certain body substances, and especially their action on the vascular system and the skeletal muscles*	
1956	André Frédéric Cournand, Werner Forssmann, Dickinson W. Richards	*for their discoveries concerning heart catheterization and pathological changes in the circulatory system*	

TABLE 1.5: (continued)

Year	Laureates	Contribution	Concept
1955	Axel Hugo Theodor Theorell	*for his discoveries concerning the nature and mode of action of oxidation enzymes*	
1954	John Franklin Enders, Thomas Huckle Weller, Frederick Chapman Robbins	*for their discovery of the ability of poliomyelitis viruses to grow in cultures of various types of tissue*	
1953	Hans Adolf Krebs, Fritz Albert Lipmann	*for his discovery of the citric acid cycle* (HAK) and *for his discovery of co-enzyme A and its importance for intermediary metabolism* (FAL)	
1952	Selman Abraham Waksman	*for his discovery of streptomycin, the first antibiotic effective against tuberculosis*	
1951	Max Theiler	*for his discoveries concerning yellow fever and how to combat it*	
1950	Edward Calvin Kendall, Tadeus Reichstein, Philip Showalter Hench	*for their discoveries relating to the hormones of the adrenal cortex, their structure and biological effects*	

TABLE 1.6: **Selected Nobel Laureates in Physiology or Medicine, 1901-1949**

Year	Laureates	Contribution	Concept
1945	Sir Alexander Fleming, Ernst B. Chain, Sir Howard Florey	*for the discovery of penicillin and its curative effect in various infectious diseases*	Fungi: Uses
1935	Hans Spemann	*for his discovery of the organizer effect in embryonic development*	
1933	Thomas H. Morgan	*for his discoveries concerning the role played by the chromosome in heredity*	Chromosomes - Advanced
1905	Robert Koch	*for his investigations and discoveries in relation to tuberculosis*	Prokaryotes: Disease

TABLE 1.6: (continued)

Year	Laureates	Contribution	Concept
1902	Ronald Ross	*for his work on malaria, by which he has shown how it enters the organism and thereby has laid the foundation for successful research on this disease and methods of combating it*	Animal-like Protists: Diseases

Chemistry

The following are the Nobel Prizes in Chemistry that have significance to the life sciences.

TABLE 1.7: Chemistry

Year	Laureates	Contribution	Concept
2012	Robert J. Lefkowitz, Brian K. Kobilka	*for studies of G-protein-coupled receptors*	
2009	Venkatraman Ramakrishnan, Thomas A. Steitz, Ada E. Yonath	*for studies of the structure and function of the ribosome*	
2006	Roger D. Kornberg	*for his studies of the molecular basis of eukaryotic transcription*	The Chromosome - Advanced
2004	Aaron Ciechanover, Avram Hershko, Irwin Rose	*for the discovery of ubiquitin-mediated protein degradation*	
2003	Peter Agre, Roderick MacKinnon	*for discoveries concerning channels in cell membranes*	
1997	Paul D. Boyer, John E. Walker, Jens C. Skou	*for their elucidation of the enzymatic mechanism underlying the synthesis of adenosine triphosphate* (PDB, JEW) and *for the first discovery of an ion-transporting enzyme,* Na^+, K^+*-ATPase* (JCS)	

TABLE 1.7: (continued)

Year	Laureates	Contribution	Concept
1993	Kary B. Mullis, Michael Smith	*for his invention of the polymerase chain reaction (PCR) method* (KBM) and *for his fundamental contributions to the establishment of oligonucleotide-based, site-directed mutagenesis and its development for protein studies* (MS)	The Polymerase Chain Reaction - Advanced
1989	Sidney Altman, Thomas R. Cech	*for their discovery of catalytic properties of RNA*	
1988	Johann Deisenhofer, Robert Huber, Hartmut Michel	*for the determination of the three-dimensional structure of a photosynthetic reaction centre*	
1982	Aaron Klug	*for his development of crystallographic electron microscopy and his structural elucidation of biologically important nucleic acid-protein complexes*	
1980	Paul Berg, Walter Gilbert, Frederick Sanger	*for his fundamental studies of the biochemistry of nucleic acids, with particular regard to recombinant-DNA* (PB) and *for their contributions concerning the determination of base sequences in nucleic acids* (WG, FS)	Biotechnology - Advanced
1978	Peter D. Mitchell	*for his contribution to the understanding of biological energy transfer through the formulation of the chemiosmotic theory*	

TABLE 1.7: (continued)

Year	Laureates	Contribution	Concept
1972	Christian B. Anfinsen, Stanford Moore, William H. Stein	*for his work on ribonuclease, especially concerning the connection between the amino acid sequence and the biologically active conformation* (CBA) and *for their contribution to the understanding of the connection between chemical structure and catalytic activity of the active centre of the ribonuclease molecule* (SM, WHS)	
1970	Luis F. Leloir	*for his discovery of sugar nucleotides and their role in the biosynthesis of carbohydrates*	
1962	Max Ferdinand Perutz, John Cowdery Kendrew	*for their studies of the structures of globular proteins*	
1961	Melvin Calvin	*for his research on the carbon dioxide assimilation in plants*	
1958	Frederick Sanger	*for his work on the structure of proteins, especially that of insulin*	
1954	*Linus Carl Pauling	*for his research into the nature of the chemical bond and its application to the elucidation of the structure of complex substances*	

- Linus Pauling was also awarded the Nobel Peace Prize in 1962.

Vocabulary

- **Alfred Nobel**: A Swedish chemist, engineer, innovator, and armaments manufacturer who used his fortune to posthumously institute the Nobel Prizes.
- **Nobel Prize**: A set of annual international awards given in recognition of cultural and scientific advances.

Summary

How are the life sciences studied? The scientific method is the process by which biological information, like that of all other sciences, has been identified. This method has produced scientific theories and laws, including the cell theory and the theory of evolution. All life, from the smallest bacteria to the largest whale, and all other prokaryotes, protists, fungi, plants and animals in between, have characteristics of life in common. All life responds to their environment, grows and changes, reproduces and has offspring, has a complex chemistry, maintains homeostasis, is built of structures called cells and passes their traits onto their offspring.

1.16 References

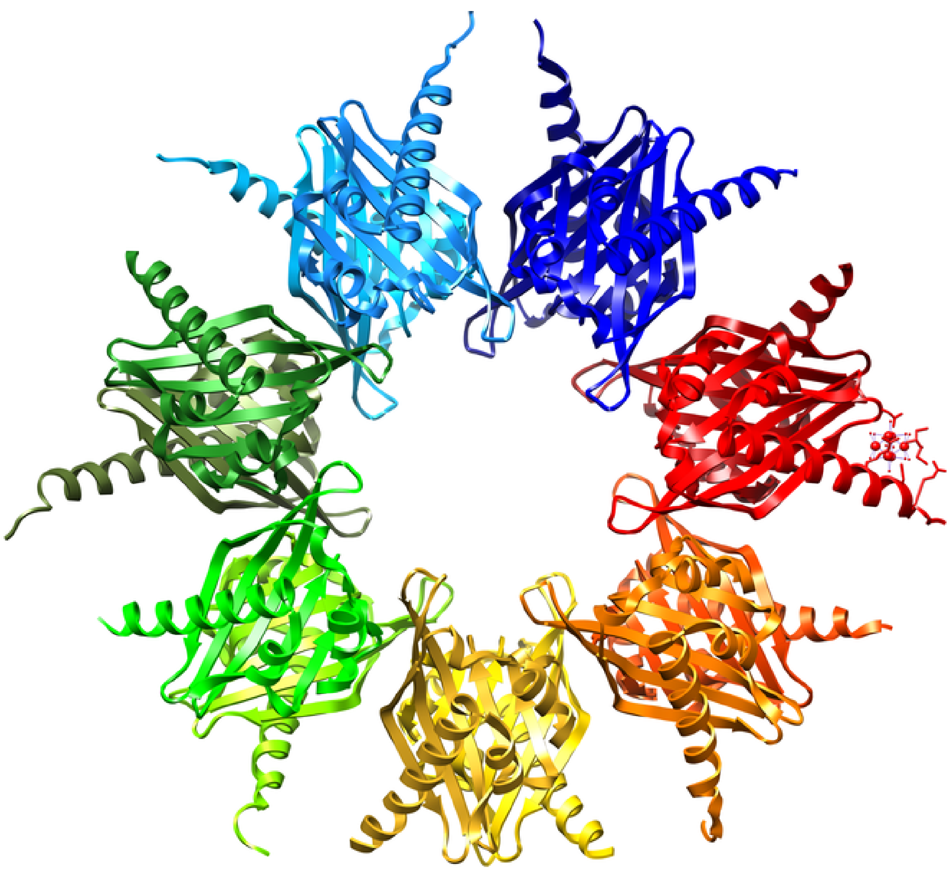
1. Flickr: Polycart. . CC-BY 2.0
2. Solar system: Courtesy of Harman Smith and Laura Generosa (nee Berwin), NASA; Ferris wheel: Flickr: mjtmail (tiggy). . Solar system: Public Domain; Ferris wheel: CC-BY 2.0
3. Image copyright Dennis Cox, 2010. . Used under license from Shutterstock.com
4. Image copyright sergo iv, 2013. . Used under license from Shutterstock.com
5. CK-12 Foundation - Hana Zavadska. . CC-BY-NC-SA 3.0
6. Cnelson, Modified by: CK-12 Foundation. . Public Domain
7. Image copyright Alexander Chaikin, 2010. . Used under license from Shutterstock.com
8. Oren Jack Turner. . Public Domain
9. Image copyright Sebastian Duda, 2010. . Used under license from Shutterstock.com
10. Image copyright Skynavin, 2013. . Used under license from Shutterstock.com
11. Courtesy of NASA. . Public Domain
12. Courtesy of NASA/JPL-Caltech/Univ. of Ariz. . Public Domain
13. User:DarkEvil/Wikimedia Commons. . Public Domain
14. Sergio Cambelo. . Public Domain
15. Rachel Titiriga. . CC-BY 2.0
16. Mariana Ruiz Villarreal (User:LadyofHats/Wikimedia Commons). . Public Domain
17. Courtesy of NOAA - Air Resources Laboratory. . Public Domain
18. Colin Marquardt. . Public Domain
19. Steven Depolo. . CC-BY 2.0
20. Maggie Hoffman. . CC-BY 2.0
21. (left) User:Magnus Manske/Wikimedia Commons; (right) Courtesy of NASA. . (left) CC-BY 1.0; (right) Public Domain
22. (left) Matt Brown (Flickr: Matt from London); (right) User:Deglr6328/Wikimedia Commons. . (left) CC-BY 2.0; (right) Public Domain
23. User:Newbie/Wikimedia Commons. . Public Domain
24. User:GcG/Wikimedia Commons, modified by User:Rozzychan/Wikimedia Commons. . Public Domain
25. Courtesy of Neil Sanscrainte and the ARS/USDA. . CC-BY 2.0
26. Image copyright Leigh Prather, 2013. Objective lenses of a light microscope.. Used under license from Shutterstock.com
27. User:Toutates/Wikimedia Commons. . CC-BY 3.0
28. Elizabeth Smith, Louisa Howard, Erin Dymek. . Public Domain
29. Tom Beatty (Flickr: North Coast Outfitters, Ltd.). . CC-BY 2.0
30. User:Phrood/Wikimedia Commons and User:Matthias M./Wikimedia Commons. . Public Domain
31. William Rafti. . CC-BY 2.5
32. User:Tjwood/Wikimedia Commons. . Public Domain
33. Steve Johnson. . CC-BY 2.0
34. Rafal Konieczny. . The copyright holder of this work allows anyone to use it for any purpose including unrestricted redistribution, commercial use, and modification
35. Ducks: Jürgen from Sandesneben, Germany; Decoy: Peter Shanks (Flickr: BotheredByBees). . CC-BY 2.0
36. Tadpole: Dan Century; Frog: Greg Schechter (Flickr:GregTheBusker). . CC-BY 2.0
37. Human cells image copyright Sebastian Kaulitzki, 2010; onion cells image copyright Jubal Harshaw, 2010. . Used under licenses from Shutterstock.com
38. (a) Taz (Flickr: sporkist); (b) Jon Sullivan, pdphoto.org; (c) Louisa Howard; (d) Mariana Ruiz Villarreal (Wikimedia: LadyofHats); (e) User:Ollin/Wikipedia; (f) Ben Mills (Wikimedia: Benjah-bmm27). . (a) CC-

BY 2.0; (b) Public Domain; (c) Public Domain; (d) Public Domain; (e) Public Domain; (f) Public Domain
39. (a) Mary Ann Tiffany, San Diego State University; (b) Flickr: istolethetv. . (a) CC-BY 2.5; (b) CC-BY 2.0
40. Tokay gecko: Nick Hobgood; Tokay foot: User:Shimbathesnake/Wikipedia. . Tokay gecko: CC-BY 2.0; Tokay foot: Public Domain
41. E. coli: Courtesy of Rocky Mountain Laboratories, NIAID, NIH; Clownfish: Jan Derk; Lions: Flickr: paulshaffner; Bee: Jon Sullivan and pdphoto.org. . E. coli: Public Domain; Clownfish: Public Domain; Lions: CC-BY 2.0; Bee: Public Domain
42. Image copyright Godrick, 2010. . Used under license from Shutterstock.com
43. Deers: Heinz Seehagel (User:HaSee/De.Wikipedia); Forest: Courtesy of USAID. . Public Domain
44. User:LiquidGhoul/Wikimedia Commons. . CC-BY 2.5
45. CK-12 Foundation - Christopher Auyeung, modified by Mariana Ruiz Villarreal. . CC-BY-NC-SA 3.0
46. Bird: Kevin Cole; Moose: Courtesy Hagerty Ryan, US Fish and Wildlife Service; Frog: User:Zandberg/Wikimedia Commons; Snake: Kelley Minars (Flickr: greaterumbrage); Fish: Adrian Pingstone; LadyBug: Jon Sullivan. . Bird: CC-BY 2.0; Moose: Public Domain; Frog: Public Domain; Snake: CC-BY-2.0; Fish: Public Domain; Ladybug: Public Domain
47. Courtesy of the US Geological Survey. . Public Domain
48. Courtesy of Jim D. Griggs, HVO, US Geological Survey. . Public Domain
49. CK-12 Foundation - Zachary Wilson, using images copyright Florian Augustin, 2012; hkannn, 2012; and Denis Barbulat, 2012. . Dinosaur, skull, and trilobite images used under licenses from Shutterstock.com
50. . . Public Domain
51. . . Public Domain

CHAPTER 2 Chemistry of Life - Advanced

Chapter Outline

Introduction

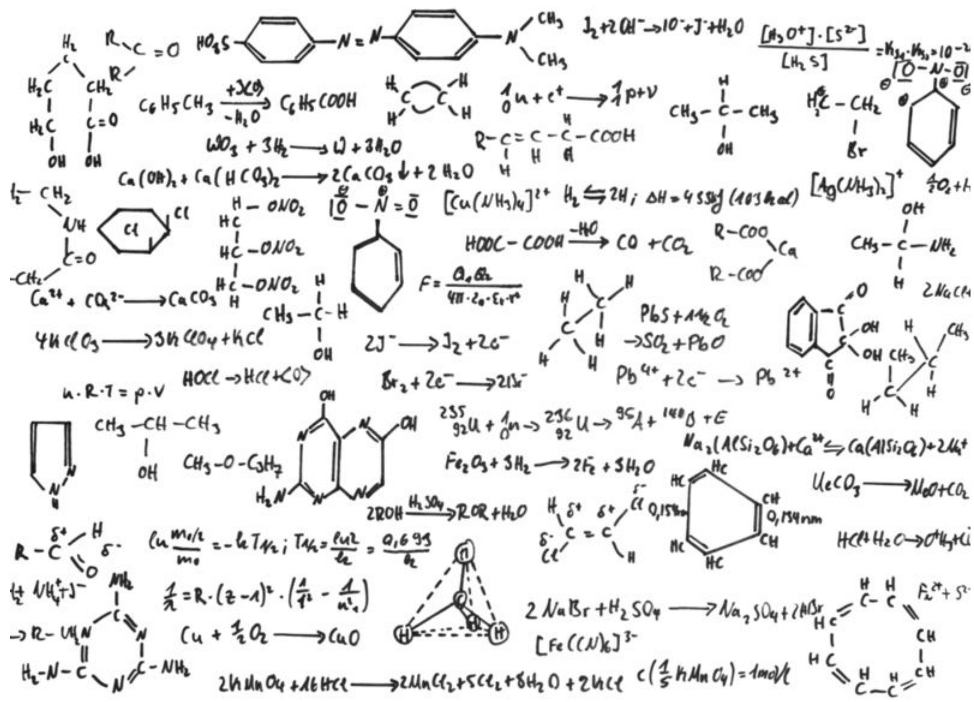


What do you see when you look at this picture? Is it just a mass of tangled ribbons? Look closely. It's actually a complex pattern of three-dimensional shapes. It represents the structure of a common chemical found inside living cells. The chemical is a protein called hemoglobin. It is the protein in red blood cells which transports oxygen around the body.

What are proteins? What other chemicals are found in living things? You will learn the answers to these questions as you read about the chemistry of life.

2.1 Chemical Substances - Advanced

- Describe elements and compounds, and explain how mixtures differ from compounds.



Take some Cs, Hs, Ns, Os, Ps and Ss, combine them in many different combinations, and what do you get?

In just the right combinations, you get life. Carbon, hydrogen, nitrogen, oxygen, phosphorus and sulfur. Some of the most basic of elements, but some of the most important. Together they can form countless combinations of organic compounds. And in just the right combinations, anything can happen.

Chemical Substances

Living things are made of **matter.** In fact, matter is the "stuff" of which all things are made. Anything that occupies space and has mass is known as matter. Matter, in turn, consists of chemical substances. A **chemical substance** is a material that has a definite chemical composition. It is also homogeneous, so the same chemical composition is found uniformly throughout the substance. A chemical substance may be an element or a chemical compound.

Elements

An **element** is a pure substance that cannot be broken down into different types of substances. There are almost 120 known elements (**Figure** 2.1), each with its own personality. The chemical and physical properties of one element differ from any other. Elements are arranged according to their properties in the **Periodic Table**.

Examples of elements include carbon, oxygen, hydrogen, gold, silver and iron. Each element is made up of just one type of atom. An **atom** is the smallest particle of an element that still characterizes the element. As shown in **Figure** 2.2, at the center of an atom is a nucleus. The nucleus contains positively charged particles called protons

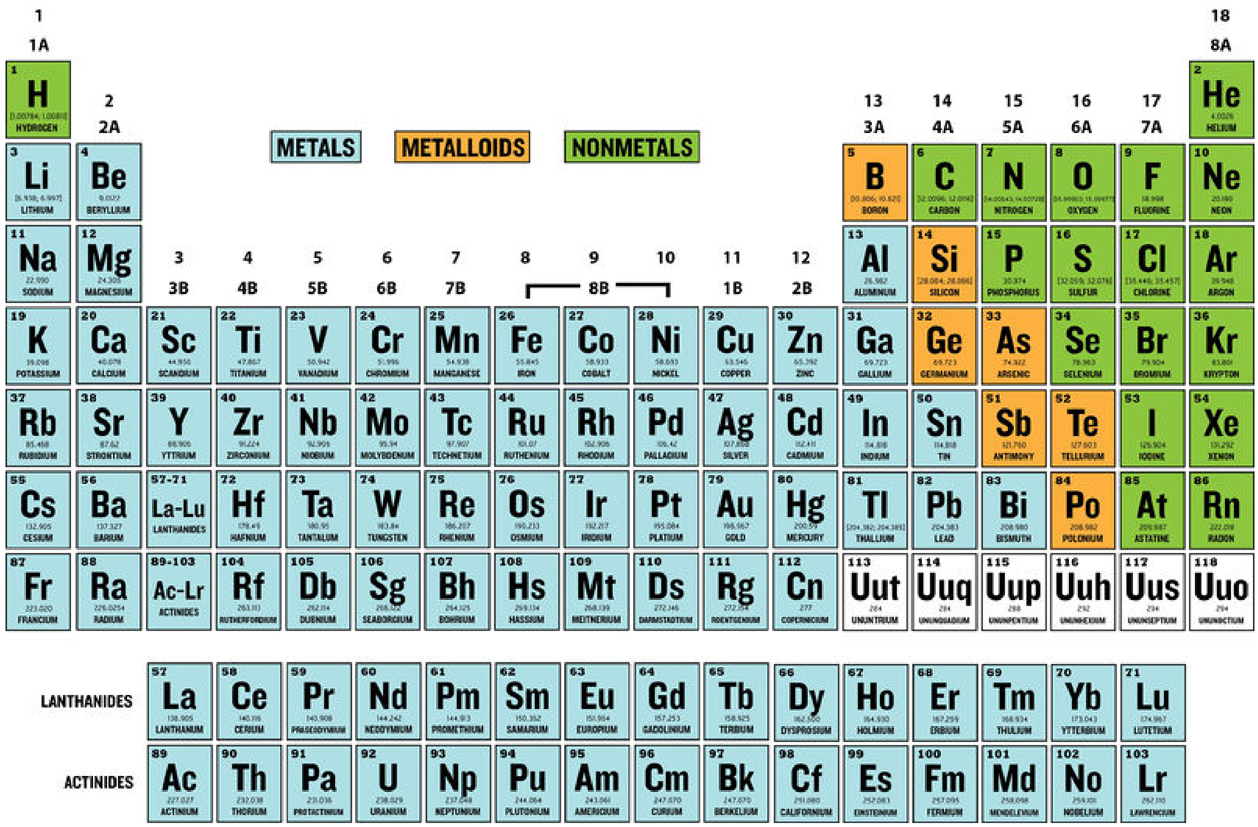


FIGURE 2.1

The Periodic Table.

and electrically neutral particles called neutrons. Surrounding the nucleus is a much larger electron cloud consisting of negatively charged electrons. Electrons are arranged into distinct energy levels, at various distances from the nucleus. An atom is electrically neutral if it has the same number of protons as electrons. Each element has atoms with a characteristic number of protons, which defines the atomic number of the element. For example, all carbon atoms have six protons, and all oxygen atoms have eight protons. A combination of the number of protons and neutrons in the nucleus gives the approximate atomic mass of the atom, measured in an amu, or atomic mass unit. For example, hydrogen has an atomic number of 1 and an atomic mass of 1.00794 amu; carbon has an atomic number of 6 and an atomic mass of 12.0107 amu; oxygen has an atomic number of 8 and an atomic mass of 15.9994 amu. See the *Dynamic Periodic Table* at http://www.ptable.com for additional information.

Over 100 elements can be seen in this video http://www.youtube.com/watch?v=LFsdbLFHgY8 (10:00).

MEDIA

Click image to the left for more content.

The majority of known elements are classified as metals. Metals are elements that are lustrous, or shiny. They

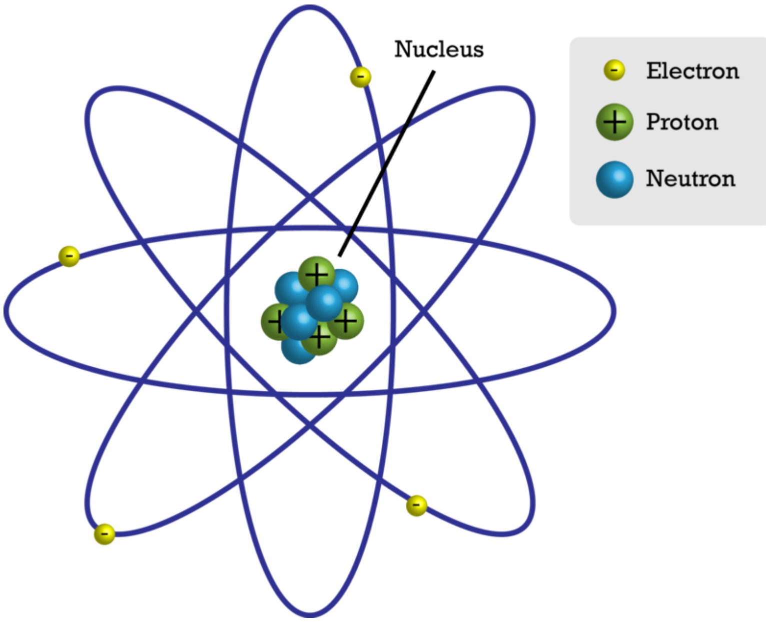


FIGURE 2.2
Model of an Atom. The protons and neutrons of this atom make up its nucleus. Electrons surround the nucleus.

are also good conductors of electricity and heat. Examples of metals include iron, gold, and copper. Fewer than 20 elements are classified as nonmetals. Nonmetals lack the properties of metals. Examples of nonmetals include oxygen, hydrogen, and sulfur. Certain other elements have properties of both metals and nonmetals. They are known as metalloids. Examples of metalloids include silicon and boron.

The Element Song can be heard at http://www.youtube.com/watch?v=DYW50F42ss8 (1:24).

MEDIA
Click image to the left for more content.

Chemical Compounds

A **chemical compound** is a new substance that forms when atoms of two or more elements react with one another. A **chemical reaction** is a process that changes some chemical substances into other chemical substances. A compound that results from a chemical reaction always has a unique and fixed chemical composition. The substances in the compound can be separated from one another only by another chemical reaction. This is covered further in *Biochemistry - Advanced*. Atoms bond with each other through the interactions of their electrons, specifically their outermost or valence electrons.

The atoms of a compound are held together by chemical bonds. Chemical bonds form when atoms share electrons. There are different types of chemical bonds, and they vary in how strongly they hold together the atoms of a compound. Two of the strongest types of bonds are covalent and ionic bonds. **Covalent bonds** form between atoms that have little if any difference in electronegativity, and result when atoms share electrons. **Electronegativity** is the power of an atom to attract electrons toward itself. **Ionic bonds**, in contrast, form between atoms that are significantly different in electronegativity. An **ion** is an atom that has gained or lost at least one electron. Ionic bonds form between ions of opposite charges.

An example of a chemical compound is water. A water molecule forms when oxygen (O) and hydrogen (H) atoms react and are held together by covalent bonds. Like other compounds, water always has the same chemical composition: a 2:1 ratio of hydrogen atoms to oxygen atoms. This is expressed in the chemical formula H_2O. A model of a water molecule is shown in **Figure** 2.3.

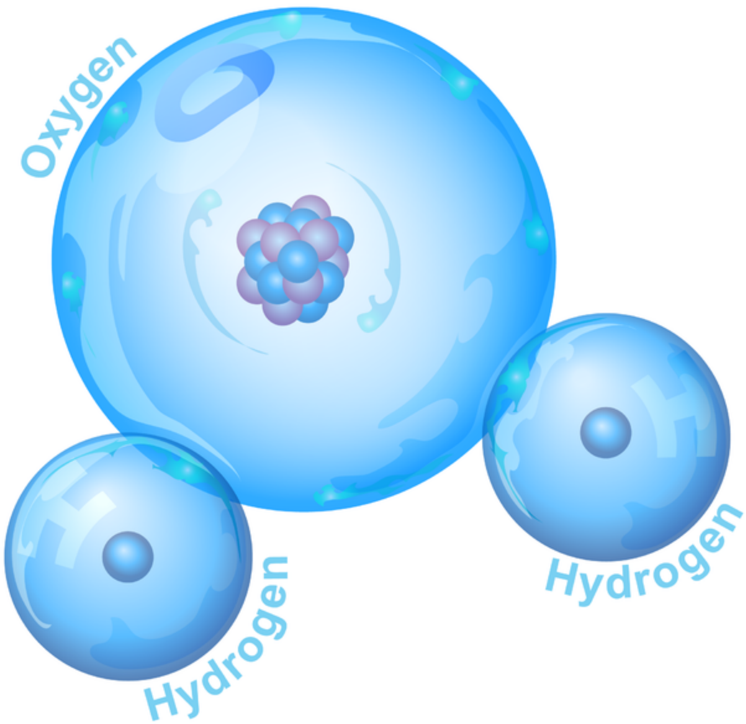


FIGURE 2.3
Model of a water molecule, showing the arrangement of hydrogen and oxygen atoms. The protons (8 in oxygen, 1 in hydrogen) and neutrons (8 in oxygen) are depicted in the nucleus.

Compounds that contain mainly the elements carbon and hydrogen are called **organic compounds**. This is because they are found mainly in living organisms. Most organic compounds are held together by covalent bonds. An example of an organic compound is glucose ($C_6H_{12}O_6$), which is shown in **Figure** 2.4. Glucose is a simple sugar that living cells use for energy. All other compounds are called inorganic compounds. Water is an example of an inorganic compound.

A short animation describing chemical compounds can be seen at http://www.youtube.com/watch?v=-HjMoTthEZ0 (3:53).

MEDIA
Click image to the left for more content.

Mixtures vs. Compounds

Like a chemical compound, a **mixture** consists of more than one chemical substance. Unlike a compound, a mixture does not have a fixed chemical composition. The substances in a mixture can be combined in any proportions. A

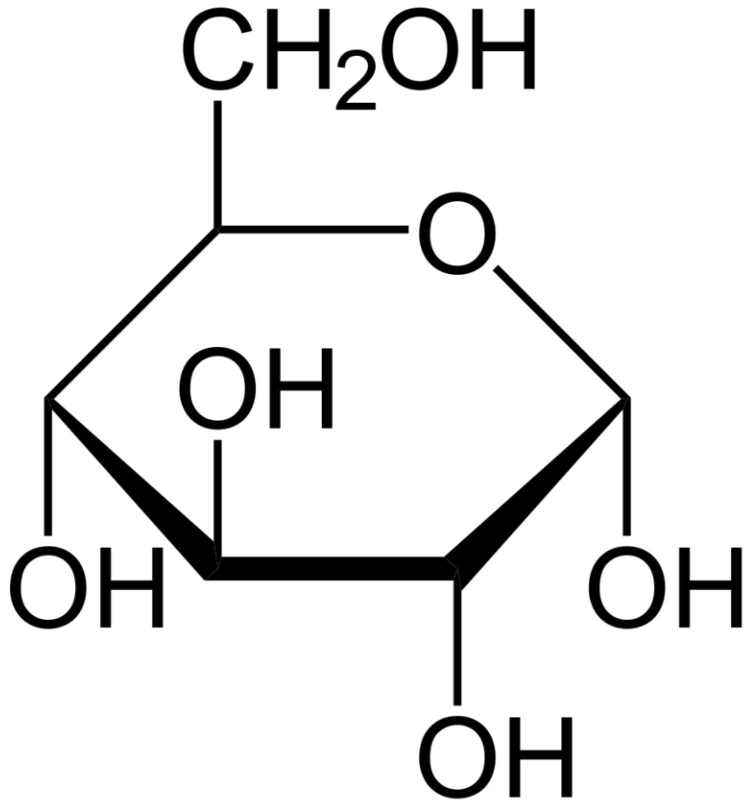


FIGURE 2.4
Glucose Molecule. This model represents a molecule of glucose, an organic compound composed of carbon, hydrogen, and oxygen. The chemical formula for glucose is $C_6H_{12}O_6$. This means that each molecule of glucose contains six carbon atoms, twelve hydrogen atoms, and six oxygen atoms. NOTE: Each unlabeled point where lines intersect represents another carbon atom. Some of these carbons and the oxygen atom are bonded to another hydrogen atom, not shown here.

mixture also does not involve a chemical reaction. Therefore, the substances in a mixture are not changed into unique new substances, and they can be separated from each other without a chemical reaction.

The following examples illustrate these differences between mixtures and compounds. Both examples involve the same two elements: the metal iron (Fe) and the nonmetal sulfur (S).

- When iron filings and sulfur powder are mixed together in any ratio, they form a mixture. No chemical reaction occurs, and both elements retain their individual properties. A magnet can be used to mechanically separate the two elements by attracting the iron filings out of the mixture and leaving the sulfur behind.
- When iron and sulfur are mixed together in a certain ratio and heated, a chemical reaction occurs. This results in the formation of a unique new compound, called iron sulfide (FeS). A magnet cannot be used to mechanically separate the iron from the iron sulfide because metallic iron does not exist in the compound. Instead, another chemical reaction is required to separate the iron and sulfur.

Vocabulary

- **atom**: The smallest particle of an element that still characterizes the element.
- **chemical compound**: Unique substance with a fixed composition that forms when atoms of two or more elements react.
- **chemical reaction**: A process that changes some chemical substances into other chemical substances.
- **chemical substance**: A material that has a definite chemical composition; may be an element or a chemical compound.
- **element**: Pure substance made up of just one type of atom.
- **ion**: An atom that has gained or lost at least one electron.

- **matter**: All the substances of which things are made.
- **mixture**: Combination of chemical substances that does not have a fixed composition and does not result from a chemical reaction.
- **organic compound**: Compound found in living organisms; contains mainly carbon.
- **periodic table**: A tabular display of the chemical elements; organized on the basis of their atomic numbers, electron configurations, and chemical properties.

Summary

- Matter consists of elements and compounds.
- A compound forms when elements combine in fixed proportions and undergo a chemical reaction.
- A mixture forms when substances combine in any proportions without a chemical reaction.

Practice

Use this resource to answer the questions that follow.

- **Elements and Atoms** at http://www.khanacademy.org/science/chemistry/v/elements-and-atoms.

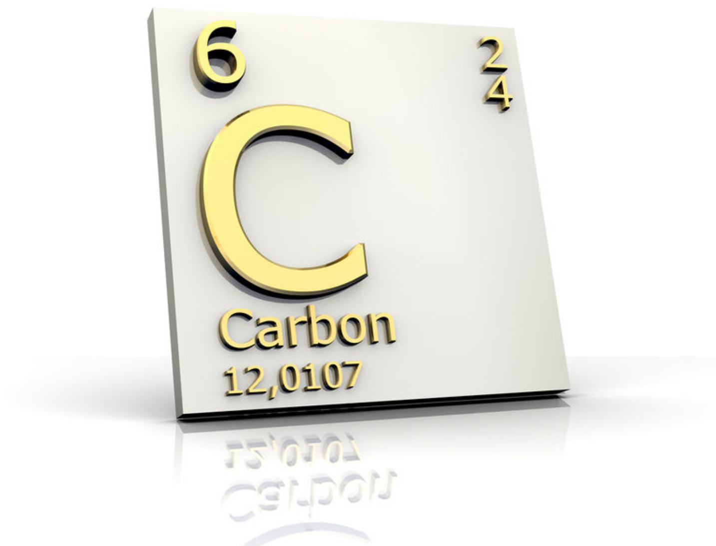
1. What is an *element*?
2. How do elements relate to atoms*?*
3. Most of all living organisms is made out of what element?
4. What are the fundamental particles of an atom? What defines an element?
5. How many protons does carbon have?
6. What is the role of the electrons?

Review

1. Define element, and give an example of an element.
2. State how a compound differs from an element, and give an example of a compound.
3. Compare and contrast mixtures and compounds.
4. Describe the difference between an ionic bond and a covalent bond.

2.2 The Significance of Carbon - Advanced

- Explain why carbon is essential to life on Earth.



Carbon. Element number six. Right in the middle of the first row of the Periodic Table. ***So what?***

Carbon is the most important element to life. Without this element, life as we know it would not exist. As you will see, carbon is the central element in compounds necessary for life-organic compounds. These compounds include carbohydrates, lipids, proteins and nucleic acids.

The Significance of Carbon

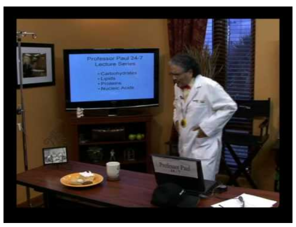
Why is carbon so important to organisms? The answer lies with carbon's unique properties. Carbon has an exceptional ability to bind with a wide variety of other elements. Carbon makes four electrons available to form covalent chemical bonds, allowing carbon atoms to form multiple stable bonds with other small atoms, including hydrogen, oxygen, and nitrogen. Carbon atoms can also form stable bonds with other carbon atoms. In fact, a carbon atom may form single, double, or even triple bonds with other carbon atoms. This allows carbon atoms to form a tremendous variety of very large and complex molecules.

Organic Compounds

Carbon has the ability to form very long chains of interconnecting C-C bonds. This property allows carbon to form the backbone of **organic compounds**, carbon-containing compounds, which are the basis of all known organic life. Nearly 10 million carbon-containing organic compounds are known. Types of carbon compounds in organisms include carbohydrates, lipids, proteins, and nucleic acids. The elements found in each type are listed in the table below. Elements other than carbon and hydrogen usually occur within organic compounds in smaller groups of elements called **functional groups**. When organic compounds react with other compounds, generally just the functional groups are involved. Therefore, functional groups generally determine the nature and functions of organic compounds.

When combined with oxygen and hydrogen, carbon can form many groups of important biological compounds including **carbohydrates** (sugars), lignans (important in plants), chitins (the main component of the cell walls of fungi, the exoskeletons of arthropods), alcohols, **lipids** and fats (triglycerides), and carotenoids (plant pigment). With nitrogen it forms alkaloids, and with the addition of sulfur in addition to the nitrogen, it forms **amino acids** which bind together to form **proteins**, antibiotics, and rubber products. With the addition of phosphorus to these other elements, carbon forms **nucleotides** which bond into **nucleic acids** (DNA and RNA), and **adenosine triphosphate (ATP)**, which is known as the *energy currency* of the cell. The properties of all these organic molecules is related to the composition of the elements that compose the molecule. Certain carbohydrates, proteins and nucleic acids are known as **macromolecules,** as they are very large polymers made of individual monomers.

The Miracle of Life: Carbohydrates, Proteins, Lipids Nucleic Acids video can be viewed at http://www.youtube.com/watch?v=nMevuu0Hxuc (3:28).



MEDIA

Click image to the left for more content.

A Comparison

TABLE 2.1: Organic Compounds

Type of Compound	Elements It Contains	Examples	Functions
Carbohydrates	carbon, hydrogen, oxygen	Glucose, Starch, Glycogen	provides energy to cells, stores energy, forms body structures
Lipids	carbon, hydrogen, oxygen	Cholesterol, Triglycerides (fats), Phospholipids	stores energy, forms cell membranes, carries messages
Proteins	carbon, hydrogen, oxygen, nitrogen, sulfur	Enzymes, Antibodies	helps cells keep their shape/structure, makes up muscles, catalyzes chemical reactions, carries messages and materials
Nucleic Acids	carbon, hydrogen, oxygen, nitrogen, phosphorus	Deoxyribonucleic acid (DNA), Ribonucleic acid (RNA), Adenosine Triphosphate (ATP)	contains instructions for proteins, passes instructions from parents to offspring, helps make proteins

The **Table** 2.1 lists the four types of organic compounds, the elements they contain, and examples and functions of each type of compound.

Condensation and Hydrolysis

Condensation reactions are the chemical processes by which large organic compounds are synthesized from their monomeric units. **Hydrolysis reactions** are the reverse process. During condensation reactions, water is produced from the two molecules being bonded together; an H from one monomer is joined to an -OH from another molecule, producing H_2O.

TABLE 2.2: title

Polymer	Monomer	Bond
carbohydrates	monosaccharides	glycosidic
lipids	fatty acid	ester*
proteins	amino acids	peptide
nucleic acids	nucleotides	phosphodiester**

- The ester linkage is between a glycerol molecule and fatty acid chain.

See http://www.biotopics.co.uk/as/condensation_and_hydrolysis.html for additional information.

Vocabulary

- **adenosine triphosphate (ATP)**: Energy-carrying molecule that cells use to power their metabolic processes; energy-currency of the cell.
- **amino acid**: Small molecule that is a building block of proteins; the monomer of a polypeptide.
- **carbohydrate**: Organic compound such as sugar or starch; major source of energy to living cells.
- **condensation reaction**: A chemical reaction in which two molecules combine to form one single molecule, together with the loss of a small molecule, often water.
- **functional group**: Part of organic compound that generally determines the nature and functions of the compound.
- **hydrolysis reaction**: A chemical process in which a molecule of water is split, resulting in the separation of a large molecule into two smaller molecules.
- **lipid**: Organic compound such as fat or oil.
- **macromolecule**: A large molecule composed of individual monomer units.
- **nucleic acid**: Organic compound such as DNA or RNA.
- **nucleotide**: Monomer of nucleic acids, composed of a nitrogen-containing base, a five-carbon sugar, and a phosphate group.
- **organic compound**: Compound found in living organisms; contains mainly carbon.
- **protein**: Organic compound made of amino acids.

Summary

- Carbon's exceptional ability to form bonds with other elements and with itself allows it to form a huge number of large, complex molecules called organic molecules. These molecules make up organisms and carry out life processes.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Organic Molecules: Overview**

1. What is an organic compound?
2. Describe the element carbon.
3. What is the chemical composition of aspirin? Is it a natural or synthetic compound? Explain your answer.
4. Describe organic reactions.

Also see the following for additional related information.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Elements of Life**

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Organic Chemistry**

Review

1. Why is carbon essential to all known life on Earth?
2. What is an organic compound? Give an example.
3. List the four main classes of organic compounds. What are examples of each?
4. What is condensation of hydrolysis?
5. What is a phosphodiester bond?

2.3 Carbohydrates - Advanced

- Describe the structure and function of carbohydrates.

Sugar. Does this look like biological energy?

As a child, you may have been told that sugar is bad for you. Well, that's not exactly true. Essentially, carbohydrates are made of sugar, from a single sugar molecule to thousands of sugar molecules all attached together. Why? One reason is to store energy. But that does not mean you should eat it by the spoonful.

Carbohydrates

Carbohydrates are organic compounds that contain only carbon (C), hydrogen (H), and oxygen (O). They are the most common of the four major types of organic compounds. There are thousands of different carbohydrates, but they all consist of one or more smaller units called monosaccharides.

Monosaccharides and Disaccharides

The general formula for a **monosaccharide** is:

$(CH_2O)_n$,

where n can be any number greater than two. For example, if n is 6, then the formula can be written:

$C_6H_{12}O_6$.

This is the formula for the monosaccharide glucose. Another monosaccharide, fructose, has the same chemical formula as glucose, but the atoms are arranged differently. Molecules with the same chemical formula but with atoms in a different arrangement are called **isomers**. Compare the glucose and fructose molecules in **Figure** 2.5.

Can you identify their differences? The only differences are the positions of some of the atoms. These differences affect the properties of the two monosaccharides.

Monosaccharides can be classified by the number of carbon atoms they contain: diose (2), triose (3), tetrose (4), pentose (5), hexose (6), heptose (7), and so on.

In addition to glucose, other common monosaccharides include fructose ("fruit sugar"), galactose, xylose ("wood sugar") and ribose (in RNA) and deoxyribose (in DNA).

If two monosaccharides bond together, they form a carbohydrate called a **disaccharide**. Two monosaccharides will bond together through a dehydration reaction, in which a water molecule is lost. A dehydration reaction is a **condensation reaction**, a chemical reaction in which two molecules combine to form one single molecule, losing a small molecule in the process. In the dehydration reaction, this small molecule is water.

An example of a disaccharide is sucrose (table sugar), which consists of the monosaccharides glucose and fructose (**Figure** 2.5). Other common disaccharides include lactose ("milk sugar") and maltose. Monosaccharides and disaccharides are also called *simple sugars*. They provide the major source of energy to living cells.

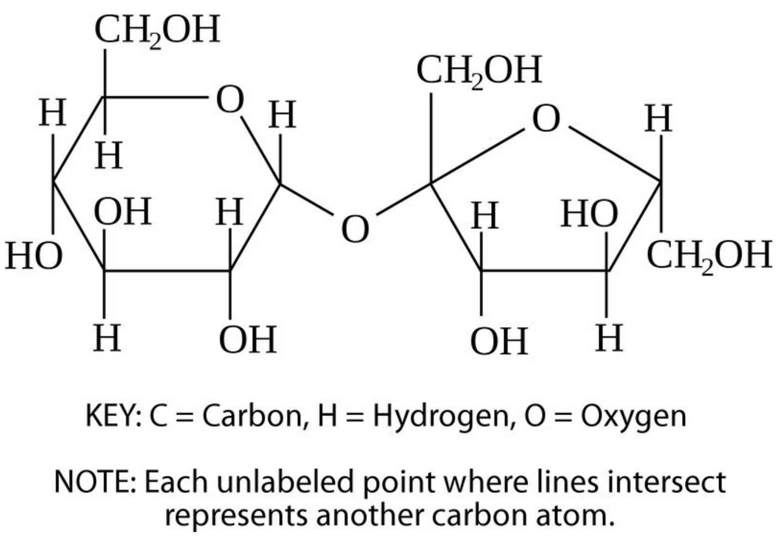


FIGURE 2.5

Sucrose Molecule. This sucrose molecule is a disaccharide. It is made up of two monosaccharides: glucose on the left and fructose on the right. Sucrose forms through a condensation reaction: glucose ($C_6H_{12}O_6$) + fructose ($C_6H_{12}O_6$) sucrose ($C_{12}H_{22}O_{11}$).

Oligosaccharides

An **oligosaccharide** is a saccharide polymer containing a small number (typically two to ten) of monosaccharides. Oligosaccharides can have many functions; for example, they are commonly found on the plasma membrane of animal cells where they can play a role in cell–cell recognition. In general, they are found attached to compatible amino acid side-chains in proteins or to lipids.

Oligosaccharides are often found as a component of **glycoproteins** or **glycolipids.** They are often used as chemical markers on the outside of cells, often for cell recognition. An example is ABO blood type specificity. A and B blood types have two different oligosaccharide glycolipids embedded in the cell membranes of the red blood cells, AB-type blood has both, while O blood type has neither.

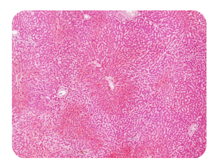
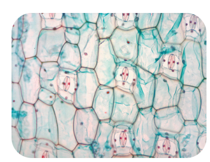
Polysaccharides

Polysaccharides are long carbohydrate molecules of repeated monomer units joined together by **glycosidic bonds**. A polysaccharide may contain anywhere from a few monosaccharides to several thousand monosaccharides. Polysaccharides are also called **complex carbohydrates**. Polysaccharides have a general formula of $C_x(H2O)_y$, where x is usually a large number between 200 and 2500. Considering that the repeating units in the polymer backbone are often six-carbon monosaccharides, the general formula can also be represented as $(C_6H_{10}O_5)_n$, where $40 \leq n \leq 3000$.

Starches are one of the more common polysaccharides. Starch is made up of a mixture of amylose (15–20%) and amylopectin (80–85%). Amylose consists of a linear chain of several hundred glucose molecules and amylopectin is a branched molecule made of several thousand glucose units. Starches can be digested by **hydrolysis reactions**, catalyzed by enzymes called **amylases**, which can break the glycosidic bonds. Humans and other animals have amylases, so they can digest starches. Potato, rice, wheat, and maize are major sources of starch in the human diet. The formations of starches are the ways that plants store glucose. **Glycogen** is sometimes referred to as *animal starch.* Glycogen is used for long-term energy storage in animal cells. Glycogen is made primarily by the liver and the muscles.

The main functions of polysaccharides are to store energy and form structural tissues. Examples of several other polysaccharides and their roles are listed in the **Table** 2.3. These complex carbohydrates play important roles in living organisms.

TABLE 2.3: Complex Carbohydrates

Complex Carbohydrate	Function	Organism
Starch	Stores energy	Plants 
Amylose	Stores energy	Plants
Glycogen	Stores energy	Animals 
Cellulose	Forms cell walls	Plants 
Chitin	Forms an exoskeleton	Some animals 

KQED: Biofuels: From Sugar to Energy

For years there's been buzz – both positive and negative – about generating ethanol fuel from corn. But thanks to recent developments, the Bay Area of California is rapidly becoming a world center for the next generation of green fuel alternatives. The Joint BioEnergy Institute is developing methods to isolate biofeuls from the sugars in cellulose. See *Biofuels: Beyond Ethanol* at http://www.kqed.org/quest/television/biofuels-beyond-ethanol for further information.

MEDIA

Click image to the left for more content.

Vocabulary

- **amylase**: An enzyme that catalyses the breakdown of starch into sugars; present in human saliva.
- **carbohydrate**: Organic compound such as sugar or starch; major source of energy to living cells.
- **complex carbohydrate**: Carbohydrates with three or more monosaccharides bonded together.
- **condensation reaction**: A chemical reaction in which two molecules combine to form one single molecule, together with the loss of a small molecule, often water.
- **disaccharide**: A carbohydrate composed of two monosaccharides.
- **glycogen**: A carbohydrate used for long-term energy storage in animal cells; human muscle and liver cells store energy in this form.
- **glycolipid**: A lipid with a carbohydrate attached; provides energy and serves as markers for cellular recognition.
- **glycoprotein**: A protein that contain oligosaccharide chains (glycans) covalently attached to polypeptide side-chains; often important integral membrane proteins, where they play a role in cell–cell interactions.
- **glycosidic bond**: A covalent bond that joins a carbohydrate molecule to another group, which may or may not be another carbohydrate.
- **hydrolysis reaction**: A chemical process in which a molecule of water is split, resulting in the separation of a large molecule into two smaller molecules.
- **isomers**: Molecules with the same chemical formula but with differently arranged atoms.
- **monosaccharide**: A simple sugar such as glucose; the building block of carbohydrates.
- **oligosaccharide**: A saccharide polymer containing a small number (typically two to ten) of monosaccharides.
- **polysaccharide**: A chain of monosaccharides; a complex carbohydrate such as starch or glycogen.
- **starch**: A carbohydrate used for long-term energy storage in plant cells.

Summary

- Carbohydrates are organic molecules that consist of carbon, hydrogen, and oxygen. They are made up of repeating units called saccharides. They provide cells with energy, store energy, and form structural tissues.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Structure and Function of Polysaccharides**

1. Describe a polysaccharide. How many monomers may make a polysaccharide?
2. How do polysaccharides form?
3. What determines the function of a polysaccharide?
4. Describe 3 properties of cellulose.
5. What is chitin?
6. What is the main function of starch?
7. What is the main structural difference between starch and glycogen?
8. Compare the structures of glycogen and starch to cellulose and chitin.

Review

1. What are carbohydrates?
2. State the function of monosaccharides, such as glucose and fructose.
3. Compare and contrast simple sugars and complex carbohydrates.
4. What are glycoproteins and glycolipids?
5. Give examples of polysaccharides.

2.4 Lipids - Advanced

- Describe the structure and function of lipids.

Oil. Does it mix with water? No. Biologically, why is this important?

Oil is a lipid. The property of chemically not being able to mix with water gives lipids some very important biological functions. A particular type of lipid - the phospholipid - is the main component of the outer membrane of all cells. Why?

Lipids

Lipids are organic compounds that contain mainly carbon, hydrogen, and oxygen. They include substances such as fats and oils, as well as waxes, sterols, some vitamins (A, D, E and K) and phospholipids. Lipid molecules consist of fatty acids, with or without additional molecules. **Fatty acids** are organic compounds that have the general formula $CH_3(CH_2)_nCOOH$, where n usually ranges from 2 to 28 and is always an even number.

A distinguishing feature of lipids is that they are insoluble in water. The main biological functions of lipids include energy storage, as the major structural component of cell membranes, and as important signaling molecules.

Saturated and Unsaturated Fatty Acids

Fatty acids can be saturated or unsaturated. The term saturated refers to the placement of hydrogen atoms around the carbon atoms. In a **saturated fatty acid**, all the carbon atoms (other than the carbon in the -COOH group) are bonded to as many hydrogen atoms as possible (usually two hydrogens). Saturated fatty acids do not contain any other groups except the -COOH. This is why they form straight chains, as shown in **Figure** 2.6. Because of this structure, saturated fatty acids can be packed together very tightly. This allows organisms to store chemical energy very densely. The fatty tissues of animals contain mainly saturated fatty acids.

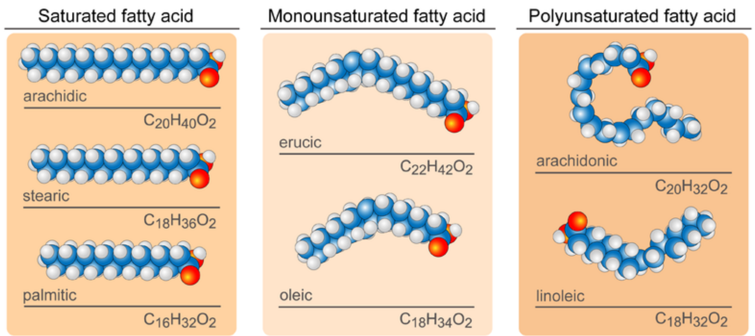


FIGURE 2.6
Saturated and Unsaturated Fatty Acids. Saturated fatty acids include arachidic, stearic, and palmitic fatty acids. Unsaturated fatty acids include all the other fatty acids in the figure. Notice how all the unsaturated fatty acids have bent chains, whereas the saturated fatty acids have straight chains.

In an **unsaturated fatty acid**, some carbon atoms are not bonded to the maximum number of hydrogen atoms. This is because they are bonded to one or more additional groups, including double and triple bonds between carbons. Wherever these other groups bind with carbon, they cause the chain to bend - they do not form straight chains (**Figure** 2.6). This gives unsaturated fatty acids different properties than saturated fatty acids. For example, unsaturated fatty acids are liquids at room temperature whereas saturated fatty acids are solids. Unsaturated fatty acids are found mainly in plants, especially in fatty tissues such as nuts and seeds.

Unsaturated fatty acids occur naturally in the bent shapes shown in **Figure** 2.6. However, unsaturated fatty acids can be artificially manufactured to have straight chains like saturated fatty acids. Called **trans fatty acids**, these synthetic lipids were commonly added to foods until it was found that they increased the risk for certain health problems. Many food manufacturers no longer use trans fatty acids for this reason.

FIGURE 2.7
These plant products all contain unsaturated fatty acids.

Types of Lipids

Lipids may consist of fatty acids alone or in combination with other compounds. Several types of lipids consist of fatty acids combined with a molecule of alcohol:

- **Triglycerides** are the main form of stored energy in animals. This type of lipid is commonly called fat. Triglycerides are composed of a glycerol and three fatty acid chains. An example is shown in **Figure** 2.8.

In humans, triglycerides are a mechanism for storing unused calories, and their high concentration in blood correlates with the consumption of excess starches and other carbohydrate-rich foods.

- **Phospholipids** are a major component of the membranes surrounding the cells of all organisms, as they have the ability to form bilayers. The structure of the phospholipid molecule consists of two hydrophobic tails (a diglyceride made of two fatty acid chains) and a hydrophilic head (a phosphate group, $PO_4{}^{3-}$).
- **Steroids** (or sterols) have several functions. Sterols are a subgroup of steroids. The sterol **cholesterol** is an important part of cell membranes and plays other vital roles in the body. Cholesterol is a precursor to fat-soluble vitamins and steroid hormones. Steroid hormones include the male and female sex hormones. Sterols also have roles as **second messengers** in signalling pathways.

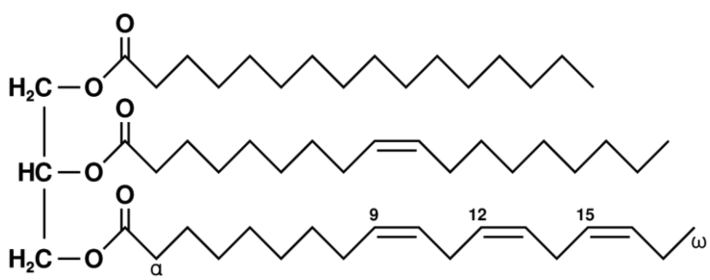


FIGURE 2.8

Triglyceride Molecule. The left part of this triglyceride molecule represents glycerol. Each of the three long chains on the right represents a different fatty acid. From top to bottom, the fatty acids are palmitic acid, oleic acid, and alpha-linolenic acid. The chemical formula for this triglyceride is $C_{55}H_{98}O_6$. KEY: H=hydrogen, C=carbon, O=oxygen

Lipids and Diet

Humans need lipids for many vital functions such as storing energy and forming cell membranes. Lipids can also supply cells with energy. In fact, a gram of lipids supplies more than twice as much energy as a gram of carbohydrates or proteins. Lipids are necessary in the diet for most of these functions. Although the human body can manufacture most of the lipids it needs, there are others, called **essential fatty acids**, that must be consumed in food. Essential fatty acids include omega-3 and omega-6 fatty acids. Both of these fatty acids are needed for important biological processes, not just for energy.

Although some lipids in the diet are essential, excess dietary lipids can be harmful. Because lipids are very high in energy, eating too many may lead to unhealthy weight gain. A high-fat diet may also increase lipid levels in the blood. This, in turn, can increase the risk for health problems such as cardiovascular disease. The dietary lipids of most concern are saturated fatty acids, trans fats, and cholesterol. For example, cholesterol is the lipid mainly responsible for narrowing arteries and causing the disease atherosclerosis.

Vocabulary

- **cholesterol**: A steroid alcohol that is present in animal cells and body fluids, regulates membrane fluidity, and functions as a precursor molecule in various metabolic pathways.
- **essential fatty acids**: Fatty acids that humans and other animals must ingest.
- **fatty acids**: A component of triglycerides and phospholipids; a carboxylic acid (-COOH) with a long hydrocarbon tail, which is either saturated or unsaturated.
- **lipid**: Organic compound such as fat or oil.
- **phospholipid**: A major component of the cell membrane; consists of two hydrophobic tails and a hydrophilic phosphate head group.

- **saturated fatty acid**: Fatty acid (lipid) with carbon atoms bonded to the maximum number of hydrogen atoms; contains only single bonds between carbon atoms.
- **second messenger**: A molecule that relays a signal from a receptor on the cell surface to target molecules inside the cell.
- **steroid**: A type of lipid; examples include cholesterol and the sex hormones.
- **trans fatty acid**: Unsaturated fatty acid artificially manufactured to have straight fatty acid chains, like saturated fatty acids.
- **triglycerides**: The main form of stored energy in animals; commonly called fat; composed of a glycerol and three fatty acid chains.
- **unsaturated fatty acid**: Fatty acid (lipid) with double or triple bonds between carbon atoms; does not contain the maximum number of hydrogen atoms.

Summary

- Lipids are organic compounds that consist of carbon, hydrogen, and oxygen. They are made up of fatty acids and other compounds. They provide cells with energy, store energy, and help form cell membranes.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Structure and Function of Fats**

1. Are fats considered a macromolecule? Why or why not?
2. Describe the structure of triglyceride molecules. How do triglycerides form?
3. What are the roles of triglycerides and phospholipids?
4. Which are non-polar molecules, triglycerides or phospholipids?
5. What determines a fat's function?

Review

1. What are lipids? Give examples of lipids?
2. Why do molecules of saturated and unsaturated fatty acids have different shapes?
3. Describe the structure and role of phospholipids.
4. What type of organic compound is represented by the formula $CH_3(CH_2)_4COOH$? How do you know?
5. What are essential fatty acids?

2.5 Proteins - Advanced

- Describe the structure and function of proteins.

You may have been told proteins are good for you. Do these look good to you?

Proteins as food. To you, these may not look appetizing (or they might), but they do provide a nice supply of amino acids, the building blocks of proteins. Proteins have many important roles, from transporting, signaling, receiving, and catalyzing to storing, defending, and allowing for movement. Where do you get the amino acids needed so your cells can make their own proteins? If you cannot make the amino acids yourself - and some of them you cannot make - then you must eat them.

Proteins

Proteins are organic compounds that contain carbon, hydrogen, oxygen, nitrogen, and, in some cases, sulfur. Proteins are made of smaller units called **amino acids**. There are 20 different common amino acids needed to make proteins. All amino acids have the same basic structure, which is shown in **Figure** 2.9. Only the side chain (labeled R in the figure) differs from one amino acid to another. These side chains can vary in size from just one hydrogen atom in glycine to a large heterocyclic group in tryptophan. The variable side chain gives each amino acid unique properties. The side chains can also characterize the amino acid as (1) nonpolar or hydrophobic, (2) neutral (uncharged) but polar, (3) acidic, with a net negative charge, and (4) basic, with a net positive charge at neutral pH.

Proteins can differ from one another in the number and sequence (order) of amino acids. It is because of the side chains of the amino acids that proteins with different amino acid sequences have different shapes and different chemical properties. Small proteins can contain just a few hundred amino acids. Yeast proteins average 466 amino acids. The largest known proteins are the titins, found in muscle, which are composed from almost 27,000 amino acids.

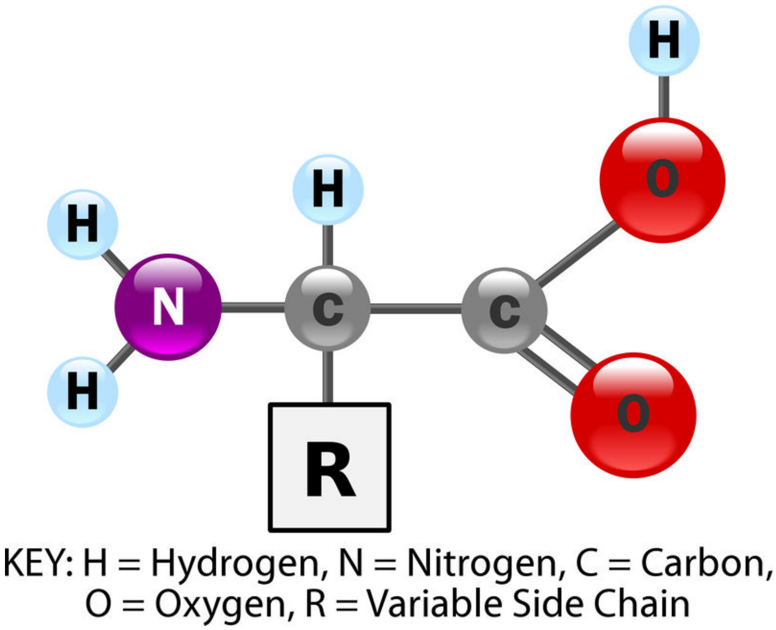


FIGURE 2.9

General Structure of Amino Acids. This model shows the general structure of all amino acids. Only the side chain, R, varies from one amino acid to another. For example, in the amino acid glycine, the side chain is simply hydrogen (H). In glutamic acid, in contrast, the side chain is CH_2CH_2COOH. Variable side chains give amino acids acids different chemical properties. The order of amino acids, together with the properties of the amino acids, determines the shape of the protein, and the shape of the protein determines the function of the protein. KEY: H = hydrogen, N = nitrogen, C = carbon, O = oxygen, R = variable side chain

Protein Structure

Amino acids can bond together through **peptide bonds** to form short chains called peptides or longer chains called **polypeptides** (**Figure** 2.10). A peptide bond is a covalent bond formed from a condensation reaction between two molecules, causing the release of a molecule of water. This bond usually forms between two amino acids, hence forming a peptide or polypeptide. Peptide bonds between amino acids are formed during the process of **translation.**

Polypeptides may have as few as 40 amino acids or as many as several thousand. A protein consists of one or more polypeptide chains. The sequence of amino acids in a protein's polypeptide chain(s) determines the overall structure and chemical properties of the protein.

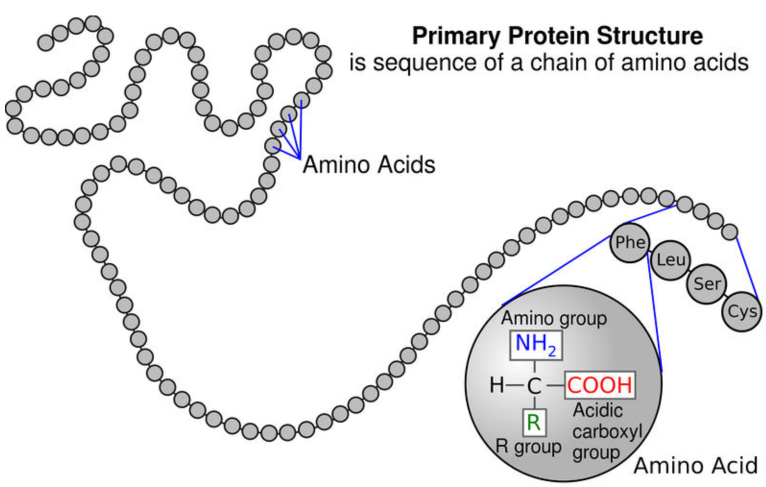


FIGURE 2.10

Polypeptide. This polypeptide is a chain made up of many linked amino acids.

The amino acid sequence is the primary structure of a protein. As explained in **Figure** 2.11, a protein may have up to four levels of structure, from primary to quaternary. The complex structure of a protein allows it to carry out its biological functions.

Secondary structure refers to local sub-structures generated from the primary structure, usually involving alpha helix and beta pleated sheet structures. These secondary structures form through hydrogen bonding between amino acids.

Tertiary structure refers to the three-dimensional structure of a single polypeptide. The alpha-helices and beta-sheets are folded into a compact globule structure. Stability is maintained through hydrogen bonds, disulfide bonds and other interactions.

Quaternary structure is a larger assembly of several polypeptide chains, now referred to as subunits of the protein. The quaternary structure is stabilized by the same interactions as the tertiary structure. Complexes of two or more polypeptides are called multimers. Specifically, a dimer contains two subunits, a trimer contains three subunits, and a tetramer contains four subunits.

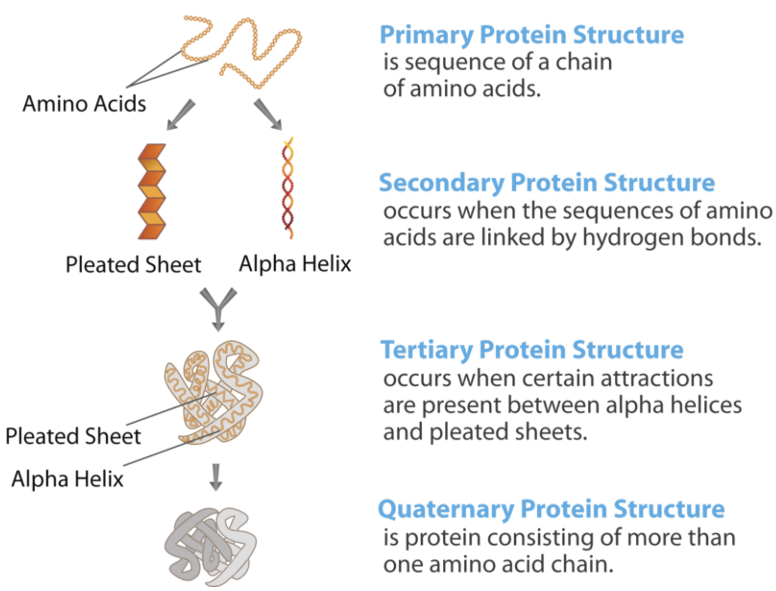


FIGURE 2.11

Protein Structure. Primary protein structure is the sequence of amino acids in a single polypeptide. Secondary protein structure refers to internal shapes, such as alpha helices and beta pleated sheets, that a single polypeptide takes on due to bonds between atoms in different parts of the polypeptide. Tertiary protein structure is the overall three-dimensional shape of a protein consisting of one polypeptide. Quaternary protein structure is the shape of a protein consisting of two or more polypeptides. For a brief animation of protein structure, see www.stolaf.edu/people/giannini/flashanimat/proteins/protein%20structure.swf.

The atomic mass of proteins is measured in **kilodaltons** (kDa). One dalton (Da) is approximately equal to the mass of one proton or one neutron, so a carbon atom has a mass of approximately 12 Da. The molecular weights of amino acids range from 75 Da for glycine to 204 for tryptophan. Human proteins may have molecular weights ranging from a low of about 3.7 kDA to titian, the largest known human protein with 34,350 amino acids and a molecular weight of approximately 3,816.2 kDa.

Functions of Proteins

Proteins are an essential part of all organisms. They play many roles in living things. Certain proteins provide a scaffolding that maintains the shape of cells (structural proteins). Proteins also make up the majority of muscle tissues. Many proteins are **enzymes** that speed up chemical reactions in cells. Other proteins are **antibodies** that protect you from pathogens. Antibodies bond to foreign substances in the body and target them for destruction. Still other proteins help carry messages or materials in and out of cells (transport proteins) or around the body. For example, the blood protein **hemoglobin** (see **Figure** 2.12) bonds with oxygen and carries it from the lungs to cells throughout the body.

A short video describing protein function can be viewed at http://www.youtube.com/watch?v=T500B5yTy58 (4:02).

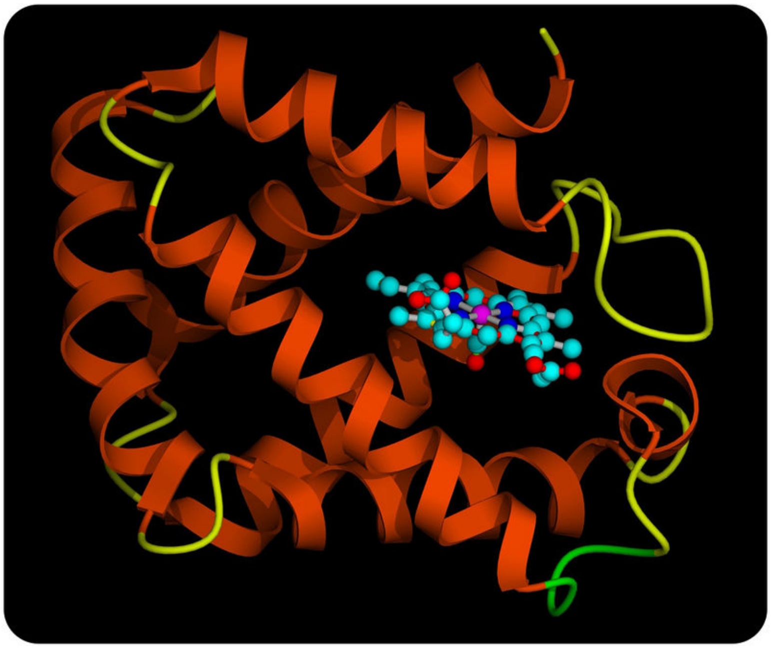
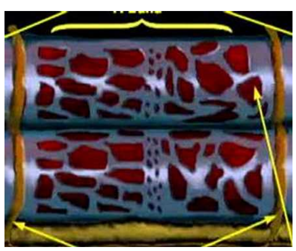


FIGURE 2.12
Hemoglobin Molecule. This model represents the protein hemoglobin. The red parts of the molecule contain iron. The iron binds with oxygen molecules.



MEDIA
Click image to the left for more content.

One of the most important traits of proteins, allowing them to carry out these functions, is their ability to bond with other molecules. They can bond with other molecules very specifically and tightly. This ability, in turn, is due to the complex and highly specific structure of protein molecules. The **structure-function relationship** of proteins is an important principle of biology. A slight difference in the structure of a protein can lead to a difference in the function of that protein, and this can have devastating effects on the cell or organism.

Proteins and Diet

Proteins in the diet are necessary for life. Dietary proteins are broken down into their component amino acids when food is digested. Cells can then use the components to build new proteins. Humans are able to synthesize all but nine of the twenty common amino acids. These nine amino acids, called **essential amino acids**, must be consumed in foods. Like dietary carbohydrates and lipids, dietary proteins can also be broken down to provide cells with energy. The amino acids regarded as essential for humans are phenylalanine, valine, threonine, tryptophan, isoleucine, methionine, leucine, lysine, and histidine. Additionally, cysteine, tyrosine and arginine are required by infants and growing children.

In addition, certain amino acids (arginine, cysteine, glycine, glutamine, histidine, proline, serine and tyrosine) are considered conditionally essential, meaning they are not normally required in the diet, but must be supplied to specific populations that do not synthesize them in adequate amounts. An example would be with the disease

phenylketonuria (PKU). Individuals with PKU must keep their intake of phenylalanine extremely low to prevent mental retardation and other metabolic complications. However, they cannot synthesize tyrosine from phenylalanine, so tyrosine becomes essential in the diet of PKU patients. PKU can be easily detected with a simple blood test. All states in the US require a PKU screening test for all newborns as part of the newborn screening panel. These individuals are placed on a special diet as soon as the disease is detected, a diet that is extremely low in phenylalanine, particularly when the child is growing. The diet must be strictly followed. Those who continue the diet into adulthood have better physical and mental health. Maintaining the diet for life has become the standard recommended by most experts.

Vocabulary

- **amino acid**: Small molecule that is a building block of proteins; the monomer of a polypeptide.
- **antibody**: A large, Y-shaped protein produced by B cells; recognizes and binds to antigens in a humoral immune response; also known as immunoglobulins (Ig).
- **enzyme**: Chemical, usually a protein, that speeds up chemical reactions in organisms; a biological catalyst.
- **essential amino acid**: An amino acid that cannot be synthesized by the organism, and therefore must be supplied in the diet.
- **hemoglobin**: The iron-containing oxygen-transport protein found in red blood cells; allows oxygen to be transported in the blood.
- **kilodalton**: 1,000 daltons; a unit that is used for indicating mass on an atomic or molecular scale; a dalton is defined as one twelfth of the mass carbon-12 atom.
- **peptide bond**: A covalent chemical bond formed between two molecules; usually occurs between amino acids; forms through the release of a molecule of water.
- **phenylketonuria (PKU)**: An autosomal recessive genetic disorder characterized the inability to metabolize the amino acid phenylalanine.
- **polypeptide**: A chain of amino acids that alone or with other such chains makes up a protein.
- **protein**: Organic compound made of amino acids.
- **structure-function relationship**: Principle that states the function of a biological item (molecule, protein, cell) is determined by its structure.

Summary

- Proteins are organic compounds that consist of carbon, hydrogen, oxygen, nitrogen, and, in some cases, sulfur. They are made up of repeating units called amino acids. They provide cells with energy, form tissues, speed up chemical reactions throughout the body, and perform many other cellular functions.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Structure and Function of Proteins**

1. How do amino acids link together?
2. What is a polypeptide?
3. What does "secondary structure" refer to? Describe examples of secondary structure.
4. What causes the tertiary structure to form?
5. Describe the hemoglobin protein.
6. What is the main difference between active sites and binding sites?
7. What is the main role of fibrous proteins?
8. Describe collagen.

Additional information can be found at:

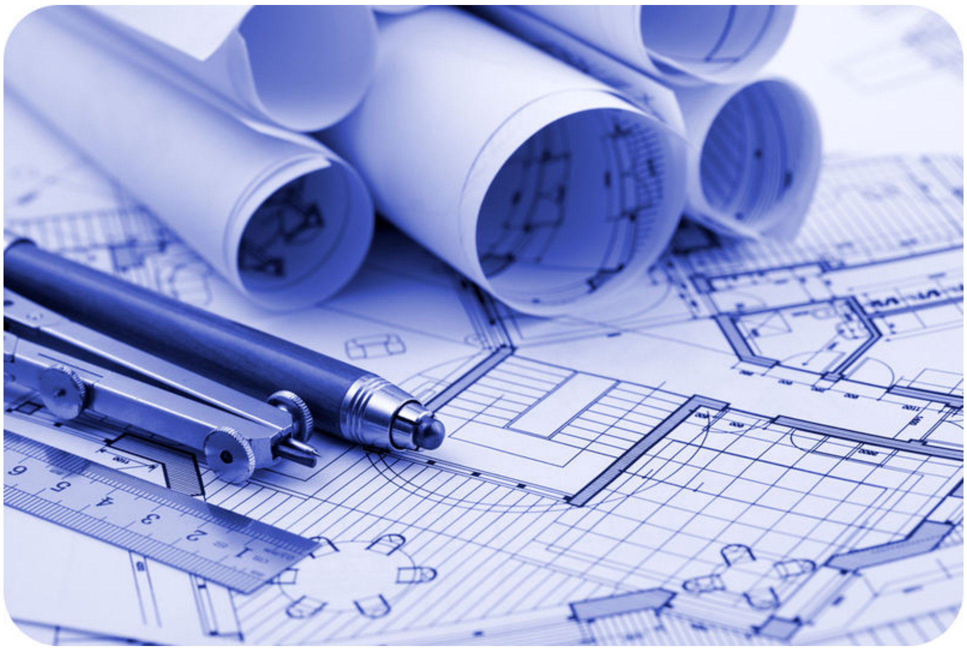
- **Biomolecules - The Proteins** at http://www.wisc-online.com/Objects/ViewObject.aspx?ID=AP13304.
- **What is a Protein?** at http://learn.genetics.utah.edu/content/begin/dna/.

Review

1. What is a protein?
2. What determines the primary structure of a protein?
3. Describe the structural levels of proteins.
4. State three functions of proteins, and explain how the functions depend on the ability of proteins to bind other molecules to them.

2.6 Nucleic Acids - Advanced

- Describe the structure and function of nucleic acids.



You may have heard that "it's in your DNA." What does that mean?

Nucleic acids. Essentially the "instructions" or "blueprints" of life. Deoxyribonucleic acid, or DNA, is the unique blueprints to make the proteins that give you your traits. Half of these blueprints come from your mother, and half from your father. And they come in different combinations every time. In fact, every couple - every man and woman that has every lived - together has over 64,000,000,000,000 combinations of their chromosomes, which is where the DNA is found. Therefore, every person that has ever lived - except for identical twins - has his or her own unique set of blueprints - or instructions - or DNA.

Nucleic Acids

Nucleic acids are organic compounds that contain carbon, hydrogen, oxygen, nitrogen, and phosphorus. They are made of smaller units called **nucleotides**. Nucleic acids are named for the nucleus of the cell, where some of them are found. Nucleic acids are found not only in all living cells but also in viruses. Types of nucleic acids include **deoxyribonucleic acid (DNA)** and **ribonucleic acid (RNA)**.

Structure of Nucleic Acids

A nucleic acid consists of one chain (in RNA) or two chains (in DNA) of nucleotides held together by chemical bonds. Each individual nucleotide unit consists of three parts:

- a base (containing nitrogen)
- a sugar (ribose in RNA, deoxyribose in DNA)

- a phosphate group (containing phosphorus)

The sugar of one nucleotide binds to the phosphate group of the next nucleotide. Alternating sugars and phosphate groups form the backbone of a nucleotide chain, as shown in **Figure** 2.13. The bases, which are bound to the sugars, protrude from the backbone of the chain. In DNA, pairs of bases-one from each of two nucleotides-form the middle section of the molecule.

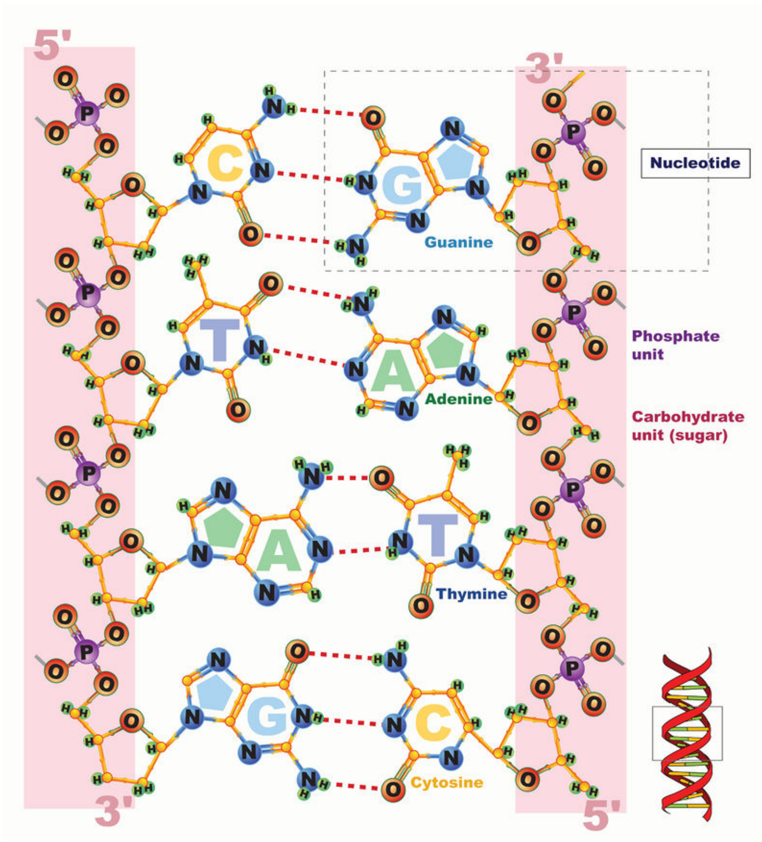
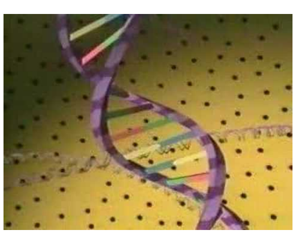


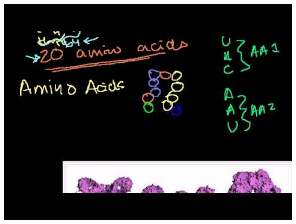
FIGURE 2.13
Part of a Nucleic Acid. This small section of a nucleic acid shows how phosphate groups and sugars alternate to form the backbone of a nucleotide chain. The bases that jut out to the side from the backbone are adenine, thymine, cytosine, and guanine. Hydrogen bonds between complementary bases, such as between adenine and thymine, hold the two chains of nucleotides together.

An animation of DNA structure can be viewed at http://www.youtube.com/watch?v=qy8dk5iS1f0 (1:19).



MEDIA
Click image to the left for more content.

An overview of DNA can be seen at http://www.youtube.com/watch?v=_-vZ_g7K6P0 (28:05).



MEDIA

Click image to the left for more content.

RNA consists of a single chain of nucleotides, and DNA consists of two chains of nucleotides. Bonds form between the bases on the two chains of DNA and hold the chains together (**Figure** 2.13). There are four different types of bases in a nucleic acid molecule: cytosine (C), adenine (A), guanine (G), and either thymine (T) (in DNA) or uracil (U) (in RNA). Each type of base bonds with just one other type of base. Cytosine and guanine always bond together, and adenine and thymine (or uracil) always bond with one another. The pairs of bases that bond together are called **complementary bases**.

The binding of complementary bases allows DNA molecules to take their well-known shape, called a **double helix**. **Figure** 2.14 shows how two chains of nucleotides form a DNA double helix. A simplified double helix is illustrated in **Figure** 2.15. It shows more clearly how the two chains are intertwined. The double helix shape forms naturally and is very strong. Being intertwined, the two chains are difficult to break apart. This is important given the fundamental role of DNA in all living organisms.

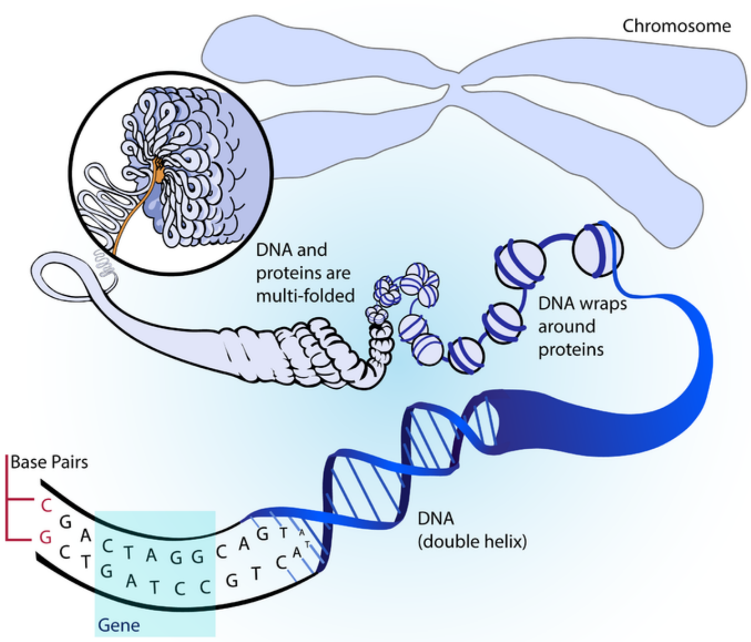


FIGURE 2.14

DNA Molecule. Hydrogen bonds between complementary bases help form the double helix of a DNA molecule. The letters A, T, G, and C stand for the bases adenine, thymine, guanine, and cytosine. The sequence of these four bases in DNA is a code that carries instructions for making proteins. Shown is a representation of how the double helix folds into a chromosome. In this double-stranded nucleic acid, complementary bases (A and T, C and G) form hydrogen bonds that hold the two nucleotide chains together in the shape of a double helix. Notice that A always bonds with T and C always bonds with G. The hydrogen bonds help maintain the double helix shape of the molecule.

A brief overview of DNA, stressing the base-pairing rules, can be seen in the following animation: http://www.youtube.com/watch?v=cwfO6SzGaEg (1:28).

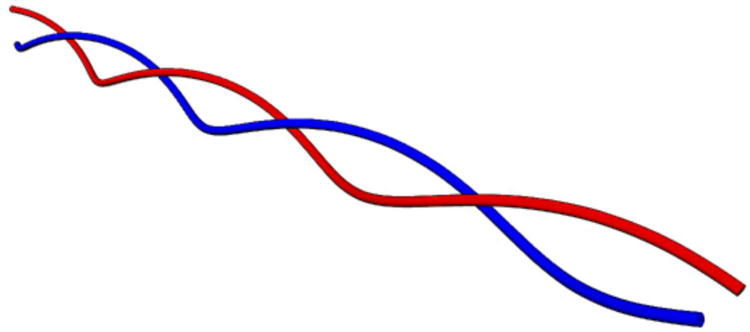
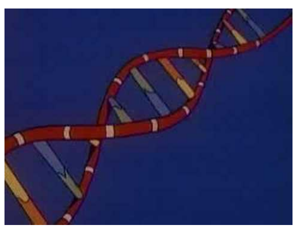


FIGURE 2.15
Simple Model of DNA. In this simple model of DNA, each line represents a nucleotide chain. The double helix shape forms when the two chains wrap around the same axis.



MEDIA
Click image to the left for more content.

Role of Nucleic Acids

The order of bases in nucleic acids is highly significant. The bases are like the letters of a four-letter alphabet. These "letters" can be combined to form "words." Groups of three bases form words of the **genetic code**. Each code word, called a **codon,** stands for a different amino acid. A series of many codons spells out the sequence of amino acids in a polypeptide or protein (**Figure** 2.16). In short, nucleic acids contain the information needed for cells to make proteins. This information is passed from a body cell to its daughter cells when the cell divides. It is also passed from parents to their offspring when organisms reproduce.

How RNA codes for Proteins

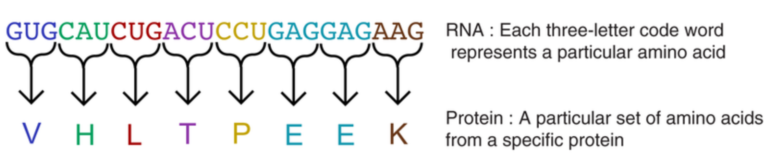


FIGURE 2.16
The letters G, U, C, and A stand for the bases in RNA, specifically mRNA or messenger RNA. Each group of three bases makes up a codon, and each codon represents one amino acid (represented here by a single letter, such as V (valine), H (histidine), or L (leucine)). A string of codons specifies the sequence of amino acids in a protein.

DNA and RNA have different functions relating to the genetic code and proteins. Like a set of blueprints, DNA contains the genetic instructions for the correct sequence of amino acids in proteins. RNA uses the information in

DNA to assemble the amino acids and make the proteins. More about the genetic code and the role of nucleic acids will be discussed in *Molecular Biology - Advanced*.

Adenosine Triphosphate

Adenosine Triphosphate (ATP), or Adenosine-5'-triphosphate, is another important nucleic acid. ATP is described as the "energy currency" of the cell or the "molecular unit of currency." One molecule of ATP contains three phosphate groups, and it is produced by ATP synthase from inorganic phosphate and adenosine diphosphate (ADP) or adenosine monophosphate (AMP). The structure of ATP consists of the purine base adenine, attached to the 1' carbon atom of the pentose sugar ribose. Three phosphate groups are attached at the 5' carbon atom of the pentose sugar. It is the removal of these phosphate groups that convert ATP to ADP (adenosine diphosphate) and to AMP (adenosine monophosphate). ATP is produced during cellular respiration, and will be further discussed in the *Cellular Respiration - Advanced* concepts.

ATP is used as a substrate in signal transduction pathways by kinases that phosphorylate proteins and lipids, as well as by adenylate cyclase, which uses ATP to produce the second messenger molecule cyclic AMP (cAMP). The ratio between ATP and AMP determines the amount of available energy. This regulates the metabolic pathways that produce and consume ATP. Apart from its roles in energy metabolism and signaling, ATP is also incorporated into DNA and RNA by polymerases during both DNA replication and transcription. When ATP is used in DNA synthesis, the ribose sugar is first converted to deoxyribose by ribonucleotide reductase.

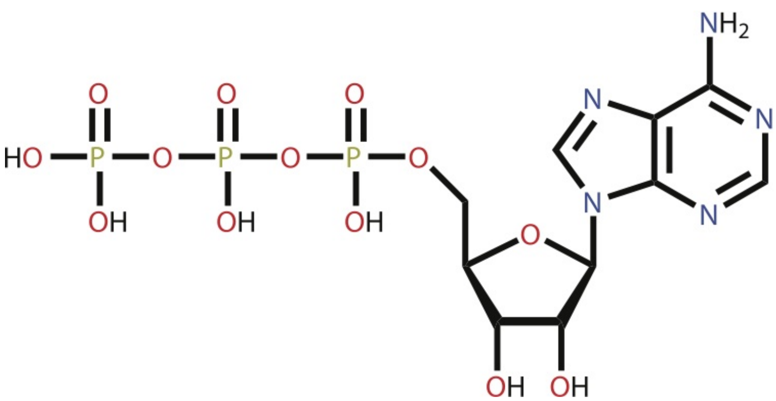


FIGURE 2.17
ATP. The ATP molecule clearly shows the three phosphate groups.

See *DNA and proteins are key molecules of the cell nucleus* at http://www.dnaftb.org/15/animation.html for a description of early work (starting in 1869) on DNA and proteins.

Vocabulary

- **Adenosine Triphosphate** (**ATP**): Energy-carrying molecule that cells use to power their metabolic processes; energy-currency of the cell.
- **codon**: A sequence of three nucleotides within mRNA; encodes for a specific amino acid or termination (stop) sequence.
- **complementary bases**: A pair of nucleotide bases that bond together—either adenine and thymine (or uracil) or cytosine and guanine; complementary base pair.
- **deoxyribonucleic acid** (**DNA**): Double-stranded nucleic acid that composes genes and chromosomes; the hereditary material.
- **double helix**: The double spiral shape of the DNA molecule; resembles a spiral staircase.
- **genetic code**: The universal code of three-base codons; encodes the genetic instructions for the amino acid sequence of proteins.
- **nucleic acid**: organic compound such as DNA or RNA

- **nucleotide**: Monomer of nucleic acids, composed of a nitrogen-containing base, a five-carbon sugar, and a phosphate group.
- **ribonucleic acid** (**RNA**): Single-stranded nucleic acid; involved in protein synthesis.

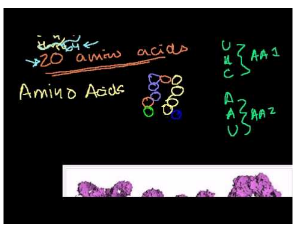
Summary

- Nucleic acids are organic compounds that consist of carbon, hydrogen, oxygen, nitrogen, and phosphorus.
- DNA, RNA and ATP are important nucleic acids.
- DNA and RNA are made up of repeating units called nucleotides. They contain genetic instructions for proteins, help synthesize proteins, and pass genetic instructions on to daughter cells and offspring.

Practice

Use this resource to answer the questions that follow.

- http://www.youtube.com/watch?v=_-vZ_g7K6P0: **DNA: An Introduction to DNA.**



MEDIA
Click image to the left for more content.

1. What is DNA? Describe its shape.
2. What makes the "sides" and the "bridges" of the double helix?
3. What are the 2 base pairs?
4. How many base pairs are in 1 cell?
5. Briefly describe the process of transcription.
6. How many chromosomes are in a human cell?

Additional information can be viewed at

- **What is DNA?** at http://learn.genetics.utah.edu/content/begin/dna/.

Review

1. What is a nucleic acid?
2. Identify the three parts of a nucleotide.
3. What is the structure of DNA?
4. Bases in nucleic acids are represented by the letters A, G, C, and T (or U). How are the bases in nucleic acids like the letters of an alphabet.
5. Describe the role and structure of ATP.

2.7 Water - Advanced

- Describe the distribution of Earth's water, and outline the water cycle.

Dihydrogen oxide or dihydrogen monoxide. Does this chemical sound dangerous?

Another name for this compound is. . . water. Water can create some absolutely beautiful sights. Iguassu Falls is the largest series of waterfalls on the planet, located in Brazil, Argentina, and Paraguay. And water is necessary for life. Water, like carbon, has a special role in biology because of its importance to organisms. Water is essential to all known forms of life. Water, H_2O, such a simple molecule, yet it is this simplicity that gives water its unique properties and explains why water is so vital for life.

The Wonder of Water video can be viewed at http://vimeo.com/7508571.

Water, Water Everywhere

"Water is the driving force of all nature," Leonardo da Vinci.

Water is a common chemical substance on Earth. The term water generally refers to its liquid state. Water is a liquid over a wide range of standard temperatures and pressures. However, water can also occur as a solid (ice) or gas (water vapor).

Where Is All the Water?

Of all the water on Earth, about two percent is stored underground in spaces between rocks. A fraction of a percent exists in the air as water vapor, clouds, or precipitation. Another fraction of a percent occurs in the bodies of plants and animals. So where is most of Earth's water? It's on the surface of the planet. In fact, water covers about 70 percent of Earth's surface. Of water on Earth's surface, 97 percent is salt water, mainly in the ocean. Only 3 percent is **fresh water**. Most of the fresh water is frozen in glaciers and polar ice caps. The remaining fresh water occurs in rivers, lakes, and other fresh water features.

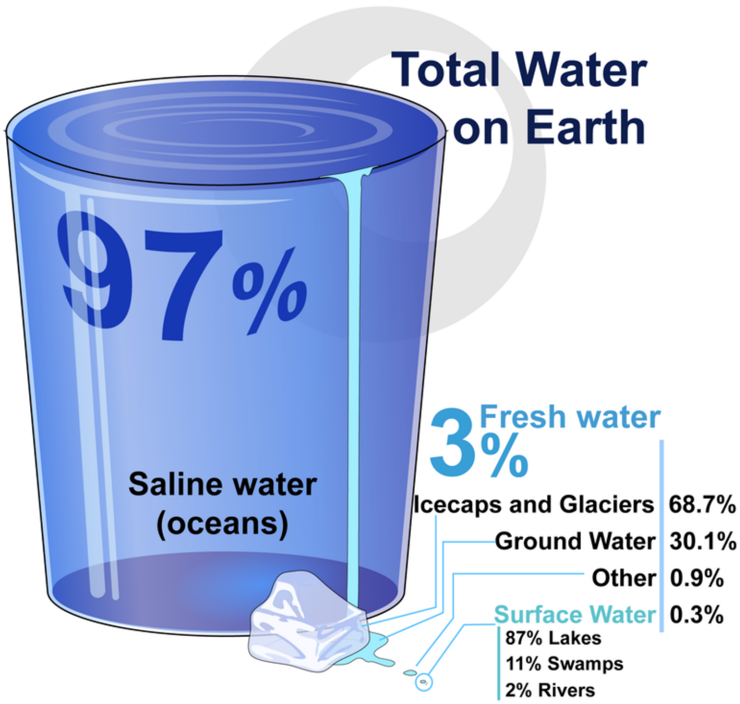


FIGURE 2.18
Most of the water on Earth consists of saltwater in the oceans. What percent of Earth's water is fresh water? Where is most of the fresh water found?

Although clean fresh water is essential to human life, in many parts of the world it is in short supply. The amount of fresh water is not the issue. There is plenty of fresh water to go around, because water constantly recycles on Earth. However, fresh water is not necessarily located where it is needed, and clean fresh water is not always available.

How Water Recycles

Like other matter on Earth, water is continuously recycled. Individual water molecules are always going through the **water cycle**, in which molecules of water cycle through both the living and non-living parts of the biosphere (discussed in the *The Water Cycle - Advanced* concept). In fact, water molecules on Earth have been moving through the water cycle for billions of years. In this cycle, water evaporates from Earth's surface (or escapes from the surface in other ways), forms clouds, and falls back to the surface as precipitation. This cycle keeps repeating. Several processes change water from one state to another during the water cycle. They include:

- **Evaporation**—Liquid water on Earth's surface changes into water vapor in the atmosphere.
- **Sublimation**—Snow or ice on Earth's surface changes directly into water vapor in the atmosphere.
- **Transpiration**—Plants give off liquid water, most of which evaporates into the atmosphere.
- **Condensation**—Water vapor in the atmosphere changes to liquid water droplets, forming clouds or fog.
- **Precipitation**—Water droplets in clouds are pulled to Earth's surface by gravity, forming rain, snow, or other type of falling moisture.

Vocabulary

- **condensation**: The process by which water vapor in the atmosphere changes to liquid water droplets, forming clouds or fog.

- **evaporation**: Liquid water on Earth's surface changes into water vapor in the atmosphere.
- **fresh water**: Naturally occurring water on the Earth's surface in ice sheets, ice caps, glaciers, bogs, ponds, lakes, rivers and streams, and underground as groundwater in aquifers and underground streams; characterized by having low concentrations of dissolved salts and other total dissolved solids.
- **precipitation**: Forms when water droplets in clouds become large enough to fall, forming rain, snow, or other type of falling moisture.
- **sublimation**: The transformation of snow and ice directly into water vapor; occurs as the snow and ice are heated by the sun.
- **transpiration**: A process by which plants lose water; occurs when stomata in leaves open to take in carbon dioxide for photosynthesis and lose water to the atmosphere in the process.
- **water cycle**: The continuous movement of water on, above and below the surface of the Earth; also called the hydrologic cycle.

Summary

- Most of Earth's water is salt water located on the planet's surface.
- Water is constantly recycled through the water cycle, cycling through both the living and non-living parts of the biosphere.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Non-Majors Biology → Search: **Properties of Water**

1. What are all the physical properties of water that make is important to living things? Describe two properties.
2. Why is the specific heat of water important?
3. Why does ice float?

Review

1. Where is most of Earth's water? What percent of that is salt water?
2. Where is most of the fresh water on Earth?
3. What are the two concerns of fresh water?
4. What is the water cycle?
5. Draw a circle diagram to represent basic components of the water cycle. Identify the states of water and the processes in which water changes state throughout the cycle.

2.8 Properties of Water - Advanced

- Identify the chemical structure of water, and explain how it relates to water's unique properties.

What may be the most important molecule for life?

Some may argue DNA. Some may argue certain proteins. But many would argue water. And what makes water so important? Its properties. The nature of the three atoms and how they interact with each other. This allows water to be a polar molecule, which allows it to interact with many other molecules necessary for life. Most of the substances in a cell are floating around in a water-based cytoplasmic environment.

Chemical Structure and Properties of Water

You are probably already familiar with many of water's properties. For example, you no doubt know that water is tasteless, odorless, and transparent. In small quantities, it is also colorless. However, when a large amount of water is observed, as in a lake or the ocean, it is actually light blue in color. The blue hue of water is an intrinsic property and is caused by selective absorption and scattering of white light. These and other properties of water depend on its chemical structure.

The transparency of water is important for organisms that live in water. Because water is transparent, sunlight can pass through it. Sunlight is needed by water plants and other water organisms for photosynthesis.

Chemical Structure of Water

Each molecule of water consists of one atom of oxygen and two atoms of hydrogen, so it has the chemical formula H_2O. The arrangement of atoms in a water molecule, shown in **Figure** 2.19, explains many of water's chemical properties. In each water molecule, the nucleus of the oxygen atom (with 8 positively charged protons) attracts electrons much more strongly than do the hydrogen nuclei (with only one positively charged proton). This results in a negative electrical charge near the oxygen atom (due to the "pull" of the negatively charged electrons toward the oxygen nucleus) and a positive electrical charge near the hydrogen atoms. A difference in electrical charge between different parts of a molecule is called **polarity**. A **polar molecule** is a molecule in which part of the molecule is positively charged and part of the molecule is negatively charged.

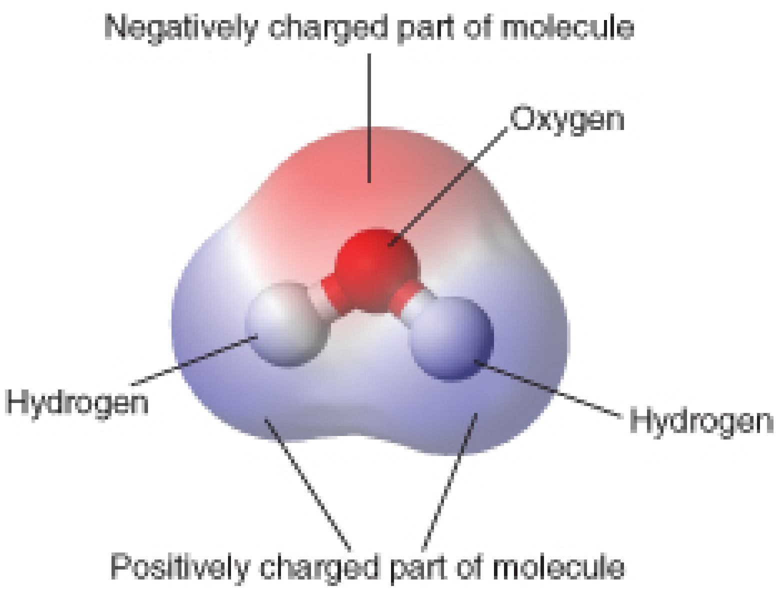


FIGURE 2.19
This model shows the arrangement of oxygen and hydrogen atoms in a water molecule. A water molecule has a bent or angular (non-linear) shape, with an angle of about 105°. The nucleus of the oxygen atom attracts electrons more strongly than do the hydrogen nuclei. As a result, the middle part of the molecule near oxygen has a negative charge, and the other parts of the molecule have a positive charge. In essence, the electrons are "pulled" toward the nucleus of the oxygen atom and away from the hydrogen atom nuclei. Water is a polar molecule, with an unequal distribution of charge throughout the molecule.

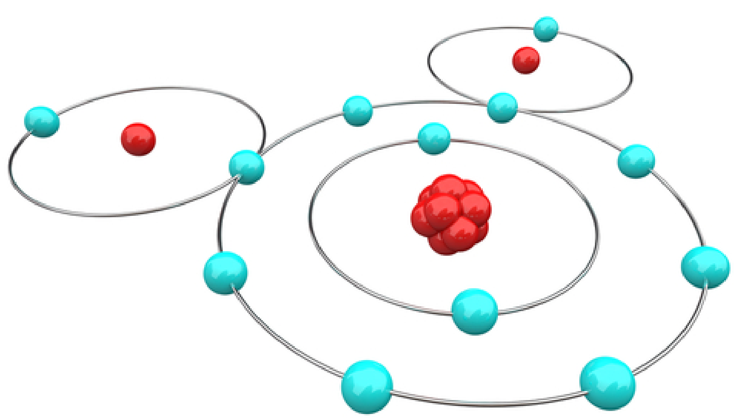


FIGURE 2.20
This model is an atomic diagram of water, showing the two hydrogen atoms and oxygen atom in the center. The protons (red) are in the center (nucleus) of each atom, and the electrons (light blue) circle each nucleus.

Hydrogen Bonding

Opposite electrical charges attract one another. Therefore, the positive part of one water molecule is attracted to the negative parts of other water molecules. Because of this attraction, bonds form between hydrogen and oxygen atoms

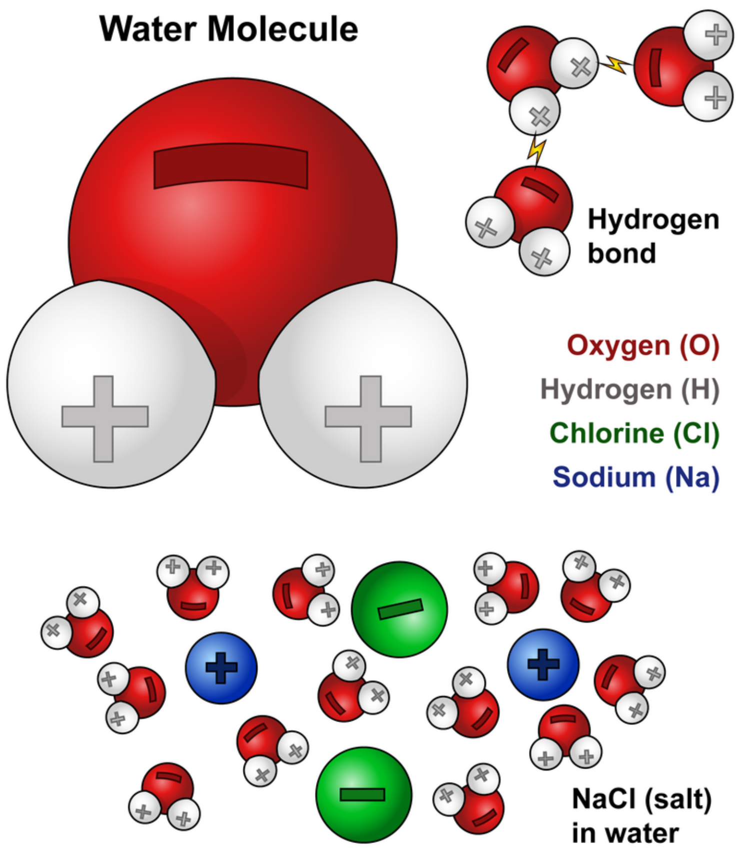


FIGURE 2.21
This diagram shows the positive and negative parts of a water molecule. It also depicts how a charge, such as on an ion (Na or Cl, for example) can interact with a water molecule.

of adjacent water molecules, as demonstrated in **Figure** below. This type of bond always involves a hydrogen atom, so it is called a **hydrogen bond**. Hydrogen bonds are bonds between molecules, and they are not as strong as bonds within molecules. Nonetheless, they help hold water molecules together.

Hydrogen bonds can also form within a single large organic molecule. For example, hydrogen bonds that form between different parts of a protein molecule bend the molecule into a distinctive shape, which is important for the protein's functions. Hydrogen bonds also hold together the two nucleotide chains of a DNA molecule.

Sticky, Wet Water

Water has some unusual properties due to its hydrogen bonds. One property is **cohesion**, the tendency for water molecules to stick together. The cohesive forces between water molecules are responsible for the phenomenon known as **surface tension**. The molecules at the surface do not have other like molecules on all sides of them and consequently they cohere more strongly to those directly associated with them on the surface. For example, if you drop a tiny amount of water onto a very smooth surface, the water molecules will stick together and form a droplet, rather than spread out over the surface. The same thing happens when water slowly drips from a leaky faucet. The water doesn't fall from the faucet as individual water molecules but as droplets of water. The tendency of water to stick together in droplets is also illustrated by the dew drops in **Figure** 2.23.

Another important physical property of water, is **adhesion**. In terms of water, adhesion is the bonding of a water molecule to another substance, such as the sides of a leaf's veins. This process happens because hydrogen bonds are special in that they break and reform with great frequency. This constant rearranging of hydrogen bonds allows a percentage of all the molecules in a given sample to bond to another substance. This grip-like characteristic that

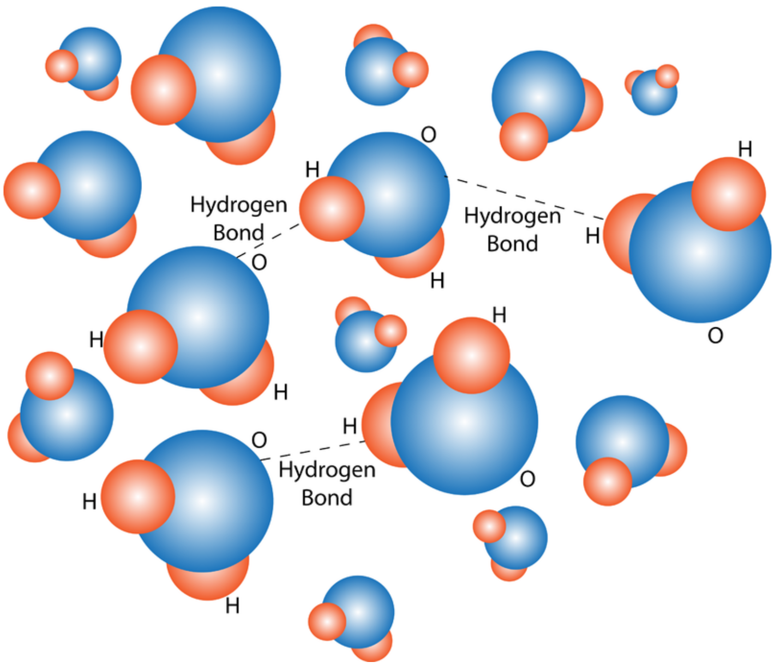


FIGURE 2.22
Hydrogen bonds form between positively and negatively charged parts of water molecules. The bonds hold the water molecules together. How do you think this might affect water's properties?

FIGURE 2.23
Droplets of dew cling to a spider web, demonstrating cohesion, the tendency of water molecules to stick together because of hydrogen bonds.

water molecules form causes **capillary action**, the ability of a liquid to flow against gravity in a narrow space. An example of capillary action is when you place a straw into a glass of water. The water seems to climb up the straw before you even place your mouth on the straw. The water has created hydrogen bonds with the surface of the straw, causing the water to adhere to the sides of the straw. As the hydrogen bonds keep interchanging with the straw's surface, the water molecules interchange positions and some begin to ascend the straw.

Adhesion and capillary action are necessary to the survival of most organisms. It is the mechanism that is responsible for water transport in plants through roots and stems, and in animals through small blood vessels.

Hydrogen bonds also explain why water's **boiling point** (100°C) is higher than the boiling points of similar substances without hydrogen bonds. Because of water's relatively high boiling point, most water exists in a liquid state on Earth. Liquid water is needed by all living organisms. Therefore, the availability of liquid water enables life to survive over much of the planet.

Furthermore, water has a high **specific heat** because it takes a lot of energy to raise or lower the temperature of water. As a result, water plays a very important role in temperature regulation. Since cells are made up of water, this property helps to maintain **homeostasis**.

Density of Ice and Water

The **melting point** of water is 0°C. Below this temperature, water is a solid (ice). Unlike most chemical substances, water in a solid state has a lower density than water in a liquid state. This is because water expands when it freezes. Again, hydrogen bonding is the reason. Hydrogen bonds cause water molecules to line up less efficiently in ice than in liquid water. As a result, water molecules are spaced farther apart in ice, giving ice a lower density than liquid water. A substance with lower density floats on a substance with higher density. This explains why ice floats on liquid water, whereas many other solids sink to the bottom of liquid water.

In a large body of water, such as a lake or the ocean, the water with the greatest density always sinks to the bottom. Water is most dense at about 4°C. As a result, the water at the bottom of a lake or the ocean usually has temperature of about 4°C. In climates with cold winters, this layer of 4°C water insulates the bottom of a lake from freezing temperatures. Lake organisms such as fish can survive the winter by staying in this cold, but unfrozen, water at the bottom of the lake.

Vocabulary

- **adhesion**: The force of attraction between unlike molecules, or the attraction between the surfaces of contacting bodies.
- **boiling point**: The temperature at which a liquid changes state into a gas.
- **capillary action**: The ability of a liquid to flow against gravity in a narrow space.
- **cohesion**: The tendency for water molecules to stick together.
- **homeostasis**: The process of maintaining a stable environment inside a cell or an entire organism.
- **hydrogen bond**: A weak bond between two molecules resulting from an electrostatic attraction between a proton in one molecule and an electronegative atom in the other; always involves a hydrogen atom.
- **melting point**: The temperature at which a solid changes state into a liquid.
- **polarity**: A difference in electrical charge between different parts of a molecule.
- **polar molecule**: A molecule with an unequal distribution of charge throughout the molecule.
- **specific heat**: The amount of heat per unit mass required to raise the temperature by one degree Celsius.
- **surface tension**: The energy required to increase the surface area of a liquid due to intermolecular forces.

Summary

- Water molecules are polar, so they form hydrogen bonds. This gives water unique properties, such as a relatively high boiling point, high specific heat, cohesion, adhesion and density.

Practice

Use this resource to answer the questions that follow.

- **Water** at http://johnkyrk.com/H2O.html.

1. How do hydrogen and oxygen bind to form water?
2. Why is water a polar molecule?

3. What are Van der Waals forces?
4. Describe the bond between water molecules.
5. What happens to water molecules as the temperature increases?
6. What is hydronium?

Review

1. Describe the structure of a water molecule.
2. What is polarity, and why is water polar?
3. Explain how hydrogen bonds cause molecules of liquid water to stick together.
4. What is capillary action and give an example.
5. What property of water helps to maintain homeostasis and how?

2.9 Solutions - Advanced

- Define solution, and describe water's role as a solvent.
- State how water is used to define acids and bases, and identify the pH ranges of acids and bases.

Acids and bases. Why are these important in biology?

It comes back to a number of biological and biochemical processes. For example, some enzymes work best at specific pH levels of acids. Other biochemical reactions need a relatively neutral environment to function properly. Take your stomach, a very acidic environment. The enzyme pepsin that works best in that acidic environment could not work in your mouth. What would your food taste like if your mouth was also a very acidic environment? Other biochemical reactions need a relatively neutral environment to function properly.

Solutions

Water is one of the most common ingredients in solutions. A **solution** is a homogeneous mixture composed of two or more substances. In a solution, one substance is dissolved in another substance, forming a mixture that has the same proportion of substances throughout. The dissolved substance in a solution is called the **solute**. The substance in which it is dissolved is called the **solvent**. An example of a solution in which water is the solvent is salt water. In this solution, a solid—sodium chloride—is the solute. In addition to a solid dissolved in a liquid, solutions can also form with solutes and solvents in other states of matter. Examples are given in the **Table** 2.4.

TABLE 2.4: **Solutions and Three States of Matter**

	Gas	**Liquid**	**Solid**
Gas	Oxygen and other gases in nitrogen (air)		

TABLE 2.4: (continued)

	Gas	Liquid	Solid
Liquid	Carbon dioxide in water (carbonated water)	Ethanol (an alcohol) in water	Sodium chloride in water (salt water)
Solid	Hydrogen gas in metals	Mercury in silver and other metals (dental fillings)	Iron in carbon (steel)

The ability of a solute to dissolve in a particular solvent is called **solubility**. Many chemical substances are soluble in water. In fact, so many substances are soluble in water that water is called the universal solvent. Water is a strongly polar solvent, and polar solvents are better at dissolving polar solutes. Many organic compounds and other important biochemicals are polar, so they dissolve well in water. On the other hand, strongly polar solvents like water cannot dissolve strongly nonpolar solutes like oil. Did you ever try to mix oil and water? Even after being well shaken, the two substances quickly separate into distinct layers.

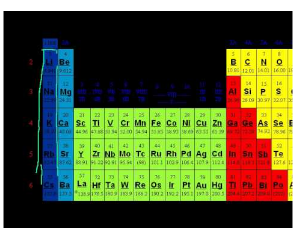
Acids and Bases

Water is the solvent in solutions called acids and bases. To understand acids and bases, it is important to know more about pure water, in which nothing is dissolved. In pure water (such as distilled water), a tiny fraction of water molecules naturally breaks down, or dissociates, to form ions. An **ion** is an electrically charged atom or molecule. The dissociation of pure water into ions is represented by the chemical equation:

$2\ H_2O \rightarrow H_3O^+ + OH^-$.

The products of this reaction are a hydronium ion (H_3O^+) and a hydroxide ion (OH^-). The hydroxide ion is negatively charged. It forms when a water molecule donates, or gives up, a positively charged hydrogen ion. The hydronium ion, modeled in **Figure** 2.24, is positively charged. It forms when a water molecule accepts a positively charged hydrogen ion (H^+).

An introduction to acid and bases, **Acid Base Introduction**, can be seen at http://www.youtube.com/watch?v=vShCnTY1-T0.



MEDIA

Click image to the left for more content.

Acidity and pH

Acidity refers to the hydronium ion concentration of a solution. It is measured by **pH**. In pure water, the hydronium ion concentration is very low. Only about one in ten million water molecules naturally dissociates to form a hydronium ion in pure water. This gives water a pH of 7. The hydronium ions in pure water are also balanced by hydroxide ions, so pure water is neutral (neither an acid nor a base).

Because pure water is neutral, any other solution with the same hydronium ion concentration and pH is also considered to be neutral. If a solution has a higher concentration of hydronium ions and lower pH than pure water, it is called an **acid**. If a solution has a lower concentration of hydronium ions and higher pH than pure water, it is called a **base**. Several acids and bases and their pH values are identified on the pH scale, which ranges from 0 to 14, in **Figure** 2.25.

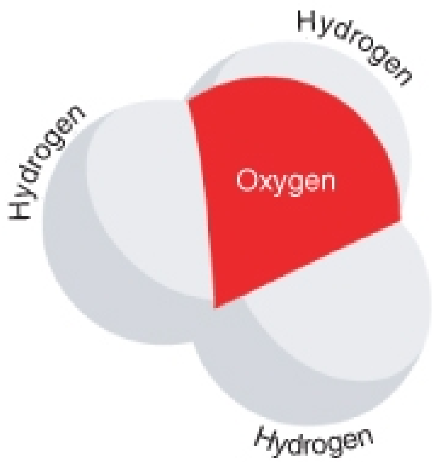


FIGURE 2.24
A hydronium ion has the chemical formula H_3O^+. The plus sign ($^+$) indicates that the ion is positively charged. How does this molecule differ from a water molecule?

The pH scale is a negative logarithmic scale. Because the scale is negative, as the ion concentration increases, the pH value decreases. In other words, the more acidic the solution, the lower the pH value. Because the scale is logarithmic, each one-point change in pH reflects a ten-fold change in the hydronium ion concentration and acidity. For example, a solution with a pH of 6 is ten times as acidic as pure water with a pH of 7.

Acids

An acid can be defined as a hydrogen ion donor. The hydrogen ions bond with water molecules, leading to a higher concentration of hydronium ions than in pure water. For example, when hydrochloric acid (HCl) dissolves in pure water, it donates hydrogen ions (H^+) to water molecules, forming hydronium ions (H_3O^+) and chloride ions (Cl^-). This is represented by the chemical equation:

$HCl + H_2O$ rar;; $Cl^- + H_3O^+$.

Strong acids can be harmful to organisms and damaging to materials. Acids have a sour taste and may sting or burn the skin. Testing solutions with litmus paper is an easy way to identify acids. Acids turn blue litmus paper red.

Bases

A base can be defined as a hydrogen ion acceptor. It accepts hydrogen ions from hydronium ions, leading to a lower concentration of hydronium ions than in pure water. For example, when the base ammonia (NH_3) dissolves in pure water, it accepts hydrogen ions (H^+) from hydronium ions (H_3O^+) to form ammonium ions (NH_4^+) and hydroxide ions (OH^-). This is represented by the chemical equation:

$NH_3 + H_2O \rightarrow NH_4^+ + OH^-$.

Like strong acids, strong bases can be harmful to organisms and damaging to materials. Bases have a bitter taste and feel slimy to the touch. They can also burn the skin. Bases, like acids, can be identified with litmus paper. Bases

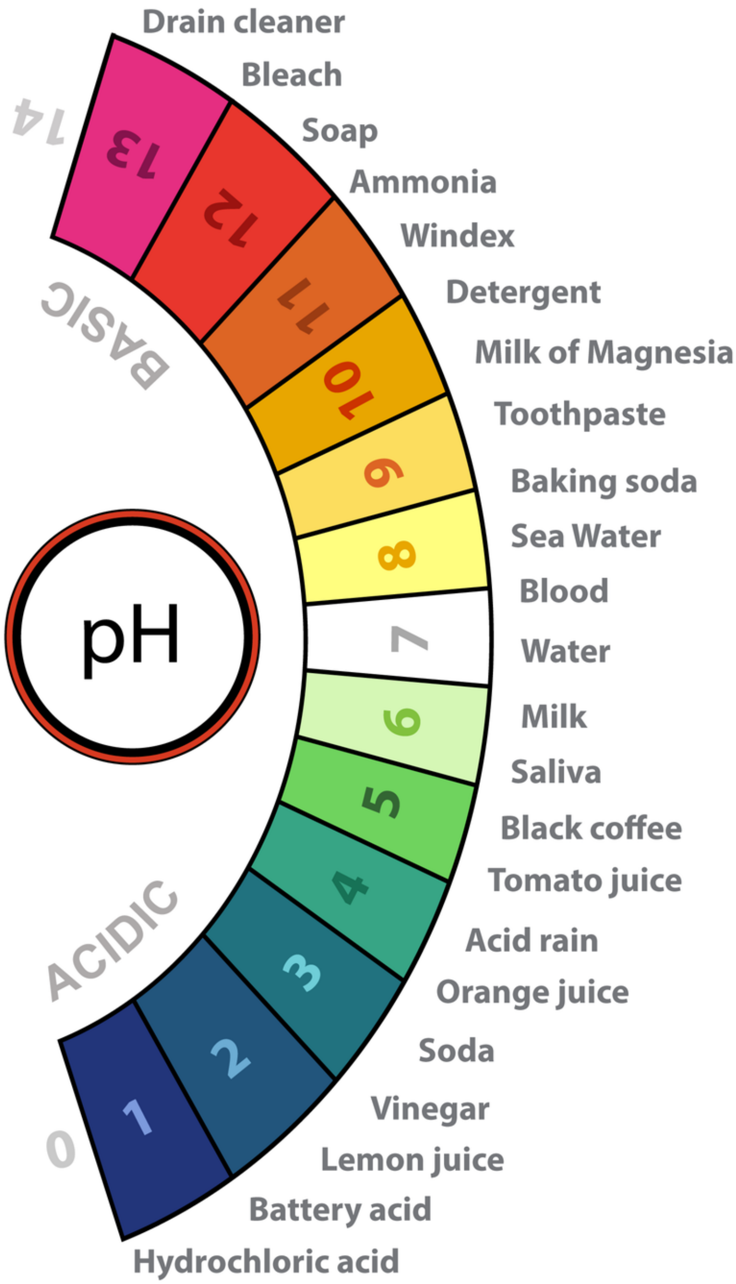


FIGURE 2.25
Acidity and the pH Scale. Water has a pH of 7, so this is the point of neutrality on the pH scale. Acids have a pH less than 7, and bases have a pH greater than 7. Approximate pHs of examples are depicted.

turn red litmus paper blue.

Neutralization

What do you think would happen if you mixed an acid and a base? If you think the acid and base would "cancel each other out," you are right. When an acid and base react, they form a neutral solution of water and a salt (a molecule composed of a positive and negative ion). This type of reaction is called a **neutralization reaction**. For example, when the base sodium hydroxide (NaOH) and hydrochloric acid (HCl) react, they form a neutral solution of water and the salt sodium chloride (NaCl). This reaction is represented by the chemical equation:

$NaOH + HCl \rightarrow NaCl + H_2O$.

In this reaction, hydroxide ions (OH^-) from the base combine with hydrogen ions (H^+) from the acid to form water. The other ions in the solution (Na^+) and (Cl^-) combine to form sodium chloride.

Acids and Bases in Organisms

Enzymes are needed to speed up biochemical reactions. Most enzymes require a specific range of pH in order to do their job. For example, the enzyme **pepsin**, which helps break down proteins in the human stomach, requires a very acidic environment in order to function. Strong acid is secreted into the stomach, allowing pepsin to work. Once the contents of the stomach enter the small intestine, where most digestion occurs, the acid must be neutralized. This is because enzymes that work in the small intestine need a basic environment. An organ near the small intestine, called the pancreas, secretes bicarbonate ions ($HCO_3{}^-$) into the small intestine to neutralize the stomach acid.

Bicarbonate ions play an important role in neutralizing acids throughout the body. Bicarbonate ions are especially important for protecting tissues of the central nervous system from changes in pH. The central nervous system includes the brain, which is the body's control center. If pH deviates too far from normal, the central nervous system cannot function properly. This can have a drastic effect on the rest of the body.

Vocabulary

- **acid**: A solution with a pH lower than 7.
- **acidity**: A measure of the ability of a solution to neutralize a base; refers to the hydronium ion concentration of a solution.
- **base**: A solution with a pH higher than 7.
- **neutralization reaction**: A chemical reaction where a base and an acid react to form a salt.
- **pepsin**: The main digestive enzyme in the stomach; degrades food proteins into peptides.
- **pH**: The negative logarithm of the hydrogen ion concentration; the scale that is used to measure acidity.
- **solubility**: The ability of a solute to dissolve in a particular solvent.
- **solute**: The substance that is dissolved in a solvent.
- **solution**: Mixture that has the same composition throughout; mixture of a solute in a solvent.
- **solvent**: A substance that dissolves another substance to form a solution.

Summary

- A solution is a homogeneous mixture in which a solute dissolves in a solvent. Water is a very common solvent, especially in organisms.
- The ion concentration of neutral, pure water gives water a pH of 7 and sets the standard for defining acids and bases. Acids have a pH lower than 7, and bases have a pH higher than 7.

Practice

Use this resource to answer the questions that follow.

- **Water** at http://johnkyrk.com/H2O.html.

1. What is hydronium? What is the charge of a hydroxyl ion?
2. What does HCl do to the hydrogen:hydroxyl ratio?
3. What is a strong acid?
4. What is the definition of pH?
5. Describe the pH scale.
6. At what pHs do most cellular processes function?

7. Give an example of a strong acid and strong base.

Review

1. What is pH?
2. Define solution, and give an example of a solution.
3. What is the pH of a neutral solution? Why?
4. What type of reaction is represented by this chemical equation: $KOH + HCl \rightarrow KCl + H_2O$? Defend your answer.
5. What is pepsin and give an example of how the body neutralizes its environment?

2.10 Water and Life - Advanced

- Explain why water is essential for life processes.
- Explain biochemical reactions involving water.

Condensation. Just in clouds?

Condensation occurs in your cells constantly. It occurs in the form of a chemical reaction. These condensation reactions involve the formation of a water molecule from two other molecules. Water forms when two molecules, such as amino acids or monosaccharides, are joined together. The amino acids join together to form peptides (or polypeptides or proteins) and the monosaccharides join together to form disaccharides or polysaccharides.

Water and Life

Humans are composed of about 60-70 percent water (not counting water in body fat). This water is crucial for normal functioning of the body. Water's ability to dissolve most biologically significant compounds—from inorganic salts to large organic molecules—makes it a vital solvent inside organisms and cells.

Water is an essential part of most metabolic processes within organisms. **Metabolism** is the sum total of all body reactions, including those that build up molecules (**anabolic reactions**) and those that break down molecules (**catabolic reactions**). In anabolic reactions, water is generally removed from small molecules in order to make larger molecules. In catabolic reactions, water is used to break bonds in larger molecules in order to make smaller molecules.

Water is central to two related, fundamental metabolic reactions in organisms: **photosynthesis** and **cellular respiration**. All organisms depend directly or indirectly on these two reactions. In photosynthesis, cells use the energy in sunlight to change water and carbon dioxide into glucose ($C_6H_{12}O_6$) and oxygen (O_2). This is an anabolic reaction, represented by the chemical equation:

$6\ CO_2 + 6\ H_2O + \text{energy} \rightarrow C_6H_{12}O_6 + 6\ O_2$.

In cellular respiration, cells break down glucose in the presence of oxygen and release energy, water, and carbon dioxide. This is a catabolic reaction, represented by the chemical equation:

$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$ + energy

Two other types of reactions that occur in organisms and involve water are dehydration and hydration reactions. A **dehydration reaction** occurs when molecules combine to form a single, larger molecule and also a molecule of water. (If some other small molecule is formed instead of water, the reaction is called by the more general term, **condensation reaction**.) It is a type of anabolic reaction. An example of a dehydration reaction is the formation of peptide bonds between amino acids in a polypeptide chain. When two amino acids bond together, a molecule of water is lost. This is shown in **Figure** 2.26.

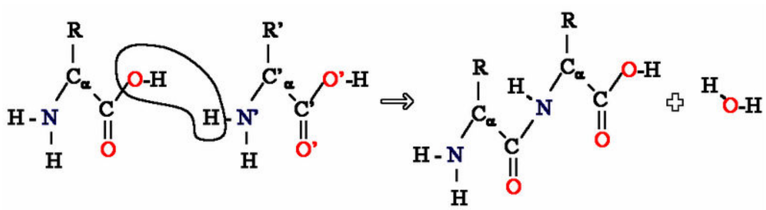


FIGURE 2.26
In this dehydration reaction, two amino acids form a peptide bond. A water molecule also forms.

A **hydration reaction** is the opposite of a dehydration reaction. A hydration reaction adds water to an organic molecule and breaks the large molecule into smaller molecules. Hydration reactions occur in an acidic water solution. An example of hydration reaction is the breaking of peptide bonds in polypeptides. A hydroxide ion (OH^-) and a hydrogen ion (H^+) (both from a water molecule) bond to the carbon atoms that formed the peptide bond. This breaks the peptide bond and results in two amino acids.

Water is essential for all of these important chemical reactions in organisms. As a result, virtually all life processes depend on water. Clearly, without water, life as we know it could not exist.

Vocabulary

- **anabolic reaction**: Endothermic reaction that occurs in organisms; chemical reaction that builds new molecules and/or stores energy.
- **catabolic reaction**: Chemical reaction that breaks down more complex organic molecules into simpler substances; usually releases energy.
- **cellular respiration**: Metabolic process which transfers chemical energy from glucose (a deliverable fuel molecule) to ATP (a usable energy-rich molecule); most efficient in the presence of oxygen (aerobic).
- **condensation reaction**: A chemical reaction in which two molecules combine to form one single molecule, together with the loss of a small molecule, often water.
- **dehydration reaction**: A condensation reaction that involves the loss of water from the reacting molecule (product).
- **hydration reaction**: A chemical reaction in which a water molecule is added to a molecule, breaking the reactant into two separate products.
- **metabolism**: The sum of all the chemical reactions in a cell and/or organism.
- **photosynthesis**: The process by which carbon dioxide and water are converted to glucose and oxygen, using sunlight for energy.

Summary

- Water is essential for most life processes, including photosynthesis, cellular respiration, and other important chemical reactions that occur in organisms.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Water and Life: Summary**

1. How is water able to dissolve polar molecules or ions?
2. Describe the importance of hydrogen bonding.

Review

1. What percent of humans are composed of water?
2. Summarize how metabolism in organisms depends on water.
3. What is a condensation reaction?
4. Distinguish between anabolic and catabolic reactions.
5. Distinguish between between hydration and dehydration reactions.

Summary

The cell is the basic unit of life. A cell is made of molecules, which are made of elements. All life-which means all bacteria and archaea, all protists, fungi, plants and animals-is built around the element carbon, and four categories of organic compounds: carbohydrates, lipids, proteins, and nucleic acids. These molecules come together to form a cell, which is the basis of life. One particular type of protein, enzymes, are biological catalysts, allowing biochemical reactions to proceed at the rate necessary to maintain life. One other molecule, water, is also essential to life, though water is not an organic compound.

2.11 References

1. CK-12 Foundation - Christopher Auyeung. . CC-BY-NC-SA 3.0
2. CK-12 Foundation - Christopher Auyeung. . CC-BY-NC-SA 3.0
3. Mariana Ruiz Villarreal (LadyofHats) for the CK-12 Foundation. . CC-BY-NC-SA 3.0
4. User:NEUROtiker/Wikimedia Commons. . Public Domain
5. User:Booyabazooka/Wikimedia Commons. . Public Domain
6. Mariana Ruiz Villarreal (LadyofHats) for the CK-12 Foundation. . CC-BY-NC-SA 3.0
7. Seed image copyright Luis Carlos Jimenez del rio, 2010; olives image copyright H. Brauer a, 2010; nuts image copyright Madlen, 2010; composite created by CK-12 Foundation - Hana Zavadska. . Used under licenses from Shutterstock.com
8. Wolfgang Schaefer (Wikimedia: WS62). . Public Domain
9. User:YassineMrabet/Wikimedia Commons. . Public Domain
10. Courtesy of the National Human Genome Research Institute. . Public Domain
11. CK-12 Foundation - Hana Zavadska, based on image from the National Human Genome Research Institue. . CC-BY-NC-SA 3.0
12. Image copyright ynse, 2010. . Used under license from Shutterstock.com
13. Marianna Ruiz Villarreal (LadyofHats) for the CK-12 Foundation. . CC-BY-NC-SA 3.0
14. Marianna Ruiz Villarreal (LadyofHats) for the CK-12 Foundation. . CC-BY-NC-SA 3.0
15. User:Honeymane/Wikimedia Commons and User:LucasVB/Wikimedia Commons. . Public Domain
16. Madeleine Price Ball (Wikimedia: Madprime), modified by CK-12 Foundation. . Public Domain
17. Image copyright Leonid Andronov, 2012. . Used under license from Shutterstock.com
18. Mariana Ruiz Villarreal (LadyofHats) for the CK-12 Foundation. . CC-BY-NC-SA 3.0
19. Ben Mills (Wikimedia: Benjah-bmm27), modified by CK-12 Foundation. . Public Domain
20. Image copyright iQoncept, 2012. . Used under license from Shutterstock.com
21. Mariana Ruiz Villarreal (LadyofHats) for the CK-12 Foundation. Water Molecule. CC-BY-NC-SA 3.0
22. CK-12 Foundation - Jodi So. Hydrogen Bonding in Water Molecule. CC-BY-NC-SA 3.0
23. Courtesy of the US Fish and Wildlife Service. . Public Domain
24. User:Bensacoount/Wikipedia. . Public Domain
25. CK-12 Foundation - Hana Zavadska and Marianna Ruiz Villarreal (LadyofHats). . CC-BY-NC-SA 3.0
26. User:LukeSurl/Wikipedia and User:DMacks/Wikipedia. . Public Domain