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# CK-12 Life Science
## Middle School

# CK-12 Life Science For Middle School

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Printed: March 17, 2015

# Contents

# CHAPTER 1 MS Studying Life

## Chapter Outline



Look at the plastic waste that has washed up on this beach. There's plastic everywhere in the ocean, and it's harmful to ocean life. It may take hundreds of years for plastic waste to break down in the environment. What if there was a quicker way to break down plastic? Bacteria decompose other kinds of waste, such as dead leaves. Can any bacteria decompose plastic? That's what two high school students, named Miranda Wang and Jeanny Yao, wondered. They decided to do a science project to find out.

# 1.1 Scientific Ways of Thinking

## Lesson Objectives

- Define science.
- State what it means to think like a scientist.
- Distinguish between scientific laws and scientific theories.

## Lesson Vocabulary

- science
- scientific law
- scientific theory

## Introduction

Like Miranda Wang and Jeanny Yao, you've probably done science projects. But did you ever really think about what science is or what it means to be a scientist? In this lesson you'll consider these questions.

## What Is Science?

Most people think of science as a collection of facts or a body of knowledge. For example, you may have memorized the processes of the water cycle. As shown in **Figure** 1.1, the processes include evaporation and precipitation.

Such knowledge of the natural world is only part of what science is. Science is as much about doing as knowing. **Science** is a way of learning about the natural world that depends on evidence, reasoning, and repeated testing. Scientists explain the world based on their observations. If they develop new ideas about the way the world works, they set up ways to test these new ideas. Scientific knowledge keeps changing because scientists are always "doing science."

## Thinking Like a Scientist

When Miranda and Jeanny wondered whether bacteria might decompose plastic, they were thinking like a scientist. What does it mean to "think like a scientist?"

- A scientist is observant. Miranda and Jeanny observed all the plastic trash when they visited a landfill. They also saw a lot of plastic trash along a local river.

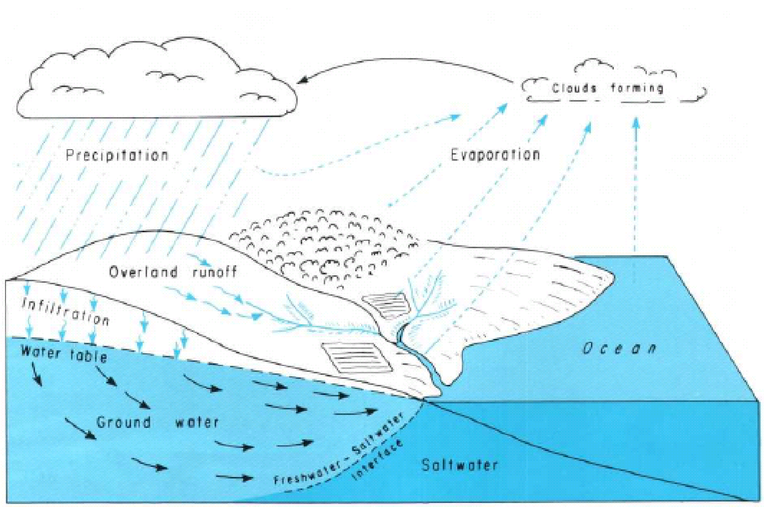


FIGURE 1.1
The water cycle

- A scientist wonders and asks questions. Miranda and Jeanny wondered if any bacteria could help break down plastic. They asked: "Can some bacteria consume chemicals in plastic for food?"
- A scientist tries to find answers using evidence and logic. Often, a scientist does experiments to gather more evidence and test ideas. Miranda and Jeanny did a lot of online research to find out what other scientists had already learned. Then they did their own experiments. They gathered and tested bacteria. For example, they grew bacteria on gel like the red gel in **Figure** 1.2. You can learn the details of their research and their amazing results by watching this video:

https://www.ted.com/talks/two_young_scientists_break_down_plastics_with_bacteria/transcript

- A scientist is skeptical. Claims must be backed by adequate evidence. Miranda and Jeanny repeated their experiments so they were confident in their results. Only then did they draw conclusions.
- A scientist has an open mind. Scientific knowledge is always evolving as new evidence comes in. Miranda and Jeanny made an important contribution with the evidence they gathered. They discovered two species of bacteria that could consume a harmful chemical in plastic.

## Scientific Theories and Scientific Laws

Some knowledge in science gains the status of a theory. Scientists use the term "theory" differently than it is used in everyday language. You might say, "I think my dad is late because he got stuck in traffic, but it's just a theory." In other words, it's just one of many possible explanations for why he's late. In science, a theory is much more than that. A **scientific theory** is a broad explanation that is widely accepted because it is supported by a great deal of evidence. Scientific theories are tested and confirmed repeatedly. Because theories are broad explanations, they generally help explain many different observations. An example in life science is the theory of evolution by natural selection. It explains how living things change through time as they adapt to their environment. This theory is supported by a huge amount of evidence. The evidence ranges from DNA to fossils like the ones in **Figure** 1.3.

Another sort of scientific knowledge is called a law. A **scientific law** is a description of what always occurs under certain conditions in nature. In other words, it describes many observations but doesn't explain them. Examples of scientific laws in life science include Mendel's laws of inheritance. These laws describe how traits are passed from parents to their offspring.

FIGURE 1.2
Bacteria can be grown on different types of gel to see what they can consume.

FIGURE 1.3
This amazing fossil reptile is named Dimetrodon. It lived almost 300 million years ago. It was a dinosaur ancestor. What do you think scientists might be able to learn about it from its fossilized bones?

## Lesson Summary

- Science is a way of learning about the natural world that depends on evidence, reasoning, and repeated testing.
- A scientist is observant and questioning. She tests ideas with evidence. A scientist is also skeptical and open minded.
- A scientific theory, such as the theory of evolution, is a broad explanation that is widely accepted because it is supported by a great deal of evidence. A scientific law, such as Mendel's laws of inheritance, is a description of what always occurs under certain conditions in nature.

## Lesson Review Questions

### Recall

1. Define science.
2. Identify traits of a good scientist.

### Apply Concepts

3. Sometimes luck plays a role in science. What role did luck play in Miranda's and Jeanny's research?

### Think Critically

4. Compare and contrast scientific theories and scientific laws. Give an example of each in life science.
5. Do you think that being a scientist requires creativity? Why or why not?

## Points to Consider

Most scientists specialize in just one area of science. An example is life science.

1. What do you think life scientists study?
2. What do you think might be some specializations within life science?

# 1.2 What Is Life Science?

## Lesson Objectives

- Describe the scope of life science.
- Identify the focus of specific fields within life science.
- Outline basic theories that underlie all the fields of life science.
- Distinguish between basic and applied life science.

## Lesson Vocabulary

- applied science
- basic science
- life science
- organism

## Introduction

**Life science** is the study of life and living things. Living things are also called **organisms**. Life science is often referred to as biology. Life scientists work in many different settings, from classrooms to labs to natural habitats. Dr. Katherine Smith, who is pictured in **Figure** 1.4 is a life scientist who works for NOAA (National Oceanic and Atmospheric Administration). She studies freshwater shrimp and fish in their natural habitats.

FIGURE 1.4
Dr. Katherine Smith (NOAA life scientist) and friend (freshwater shrimp)

## Fields in Life Science

Life is complex, and there are millions of species alive today. Many millions more lived in the past and then went extinct. Organisms include microscopic, single-celled organisms. They also include complex, multicellular animals such as you. Clearly, life science is a huge science. That's why a life scientist usually specializes in just one field within life science. Dr. Smith, for example, specializes in ecology. You can see the focus of ecology and several other life science fields in **Table** 1.1. Click on the links provided if you want to learn about careers in these fields.

**TABLE 1.1:** Specific fields within life science

| Field | Focus of Study | Learn about a Career in this Field |
|---|---|---|
| Ecology | interactions of organisms with each other and their environment | http://www.agriculture.purdue.edu/ usda/careers/ecologist.html |
| Botany | plants | http://www.botany.org/bsa/careers/ |
| Zoology | animals | http://www.bls.gov/ooh/life-physical-and-social-science/ zoologists-and-wildlife-biologists.htm |
| Microbiology | microorganisms such as bacteria | http://www.asm.org/index.php/scientists-in-k-12-outreach/ careers-in-microbiology |
| Entomology | insects | http://www.entsoc.org/resources/education |
| Cell biology | cells of living things | http://education-portal.com/articles/Careers_in_Cellular_Biology_ Job_Options_and_Requirements.html |
| Physiology | tissues and organs and how they function | http://www.the-aps.org/mm/careers |
| Genetics | genes, traits, and inheritance | http://www.agriculture.purdue.edu/usda/careers/geneticist.html |
| Epidemiology | causes of diseases and how they spread | http://explorehealthcareers.org/en/Career/45/Epidemiology |
| Paleontology | fossils and evolution | http://www.priweb.org/ed/lol/careers.html |

## Life Science Theories

Each field of life science has its own specific body of knowledge and relevant theories. However, two theories are basic to all of the life sciences. They form the foundation of every life science field. They are the cell theory and the theory of evolution by natural selection. Both theories have been tested repeatedly. Both are supported by a great deal of evidence.

### Cell Theory

According to the cell theory, all organisms are made up of one or more cells. Cells are the sites where all life processes take place. Cells come only from pre-existing cells. New cells forms when existing cells divide.

Most cells are too small to see without a microscope. If you were to look at a drop of your blood under a microscope, **Figure** 1.5 shows two types of cells you might see. You can learn more about cells and the cell theory in the chapter Cells and Their Structures.

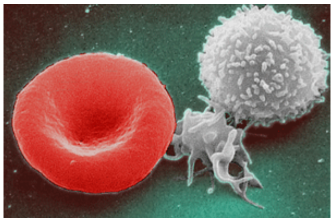

FIGURE 1.5
Human red and white blood cells

### Theory of Evolution by Natural Selection

The theory of evolution by natural selection explains how populations of organisms can change over time. As environments change, so must the traits of organisms if they are to survive in the new conditions. Evolution by natural selection explains how this happens. It also explains why there are so many different species of organisms on Earth today. You can see examples of the incredible diversity of living animals in **Figure** 1.6. You can read more about the theory of evolution in the chapter Evolution.

FIGURE 1.6
Evolution explains how there came to be so many different species of organisms on Earth

## Basic and Applied Life Science

Most scientific theories were developed by scientists doing basic scientific research. Like other sciences, life science may be either basic or applied science.

### Basic Science

The aim of **basic science** is to discover new knowledge. It leads to a better understanding of the natural world. It doesn't necessarily have any practical use. An example of basic research in life science is studying how yeast cells grow and divide. Yeasts are single-celled organisms that are easy to study. By studying yeast cells, life scientists discovered the series of events called the cell cycle. The cell cycle works not only in yeasts but in all other organisms with similar cells. Therefore, this basic research made a major contribution to our understanding of living things. Watch the following animation to learn more about the basic yeast research and the cell cycle. You can also see yeast cells dividing.

http://www.dnalc.org/view/16784-Animation-38-Development-balances-cell-growth-and-death-.html

### Applied Science

Knowledge gained by this basic research on yeast cells has been applied to practical problems. Scientists have developed drugs to treat cancer based on knowledge of the cell cycle. Cancer is a disease in which cells divide out of control. The new drugs interfere with the cell cycle of cancer cells, so the cells stop dividing. This is an example of applied science. The aim of **applied science** is to find solutions to practical problems. Applied science generally rests on knowledge gained by basic science.

## Lesson Summary

- Life science is the study of life and living organisms. Life science is also called biology.
- Life is complex and living things are incredibly diverse. Therefore, life science is divided into many fields, such as ecology, botany, and zoology.
- Two theories underlie all of the fields of life science: the cell theory and the theory of evolution by natural selection.
- Life science may be basic or applied science. The aim of basic science is to gain new knowledge and a better understanding of the natural world. The aim of applied science is to find solutions to practical problems.

## Lesson Review Questions

### Recall

1. What is life science?
2. Define organism.
3. List three different fields in life science. What is the focus of study in each of these fields?

### Apply Concepts

4. Many scientists may work together on the same research problem. Explain which fields of life science you think might be involved in studying the effects of an oil spill in the ocean.

### Think Critically

5. Explain why the cell theory is basic to all of the fields of life science.
6. How does the theory of evolution by natural selection explain the tremendous diversity of living things on Earth?
7. Relate basic and applied scientific research.

## Points to Consider

The cell theory and the theory of evolution by natural selection are basic to all of the fields of life science.

- Do you think that the same basic methods are used in all of the fields of life science?
- How do you think life scientists increase their knowledge of living things?

# 1.3 The Scientific Method

## Lesson Objectives

- Outline the steps of the scientific method.
- State the meaning of scientific hypothesis.
- Define experiment.
- Identify independent and dependent variables and controls.

## Lesson Vocabulary

- control
- dependent variable
- experiment
- hypothesis
- independent variable
- observation
- replication
- scientific method

## Introduction

Look at the athletes in **Figure** 1.7. Some athletes, like the one on the left, seem destined to be weight lifters. They respond to exercise by building big muscles. Other athletes, like the one on the right, are better suited for long-distance running. They can develop awesome levels of endurance. What determines how the human body responds to training? Could it be "genetic?" Might our athletic potential be controlled by our genes? How would a life scientist try to answer this question?


FIGURE 1.7

Both of these athletes excel but in different athletic events

## Steps in a Scientific Investigation

A life scientist would carry out a scientific investigation to try to answer this question. A scientific investigation follows a general plan called the scientific method. The **scientific method** is a series of logical steps for testing a possible answer to a question. The steps are shown in the flow chart in **Figure** 1.8.

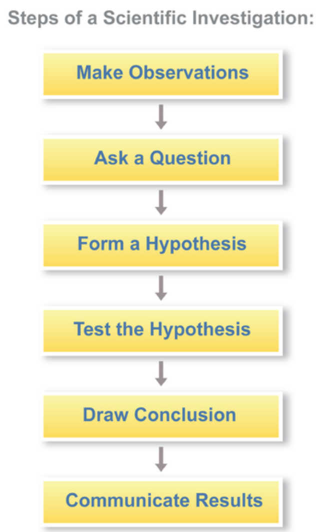


FIGURE 1.8
Scientific method flow chart

## The Scientific Method: A Closer Look

The steps of the scientific method are described in greater detail below. Note that these steps are meant as a guide, not a rigid sequence. Steps may be followed in a somewhat different order, for example, or steps may be repeated or skipped.

1. Make observations. **Observations** refer to anything detected with one or more senses. The senses include sight, hearing, touch, smell, and taste.
2. Ask a question raised by the observations.
3. Form a hypothesis. A **hypothesis** is a potential, testable answer to a scientific question. Testable means that if the hypothesis is false, it's possible to find evidence showing that it's false. This step usually requires some research. You have to find out what other investigators have already learned about the observations. For example, has anyone already tried to answer the question? What other hypotheses have been proposed?
4. Test the hypothesis. Make predictions based on the hypothesis and then determine if they are correct. This may involve carrying out an experiment. An **experiment** is a controlled scientific test that often takes place in a lab. It investigates the effects of one factor, called the **independent variable**, on another factor, called the **dependent variable**. Experimental **controls** are other factors that might affect the dependent variable. Controls are kept constant so they will not affect the results of the experiment.
5. Analyze the results of the test and draw a conclusion. Do the results agree with the predictions? If so, they provide support for the hypothesis. If not, they disprove the hypothesis.
6. Communicate results. One way is by presenting a poster at a scientific conference, like the scientists in **Figure** 1.9. Other ways include reading papers at conferences or publishing them in scientific journals. When results

are communicated, scientists should describe their hypothesis and how it was tested in addition to the results of the test. This allows other scientists to repeat the investigation to see whether they get the same results. This is called **replication**. Replication is important because it adds weight to the findings. The results are more likely to be reliable if they can be repeated.


FIGURE 1.9

Posters are a quick, visual way for scientists to communicate the results of their research to other scientists. Professional science posters serve the same purpose as science fair posters.

## Applying the Scientific Method

You can apply the scientific method to the question that was raised above about athletic ability. Assume you are a life scientist. You observe variation in athletic abilities. Some athletes tend to build more muscle mass. Others tend to develop greater endurance. You ask, "Is there a gene that might explain these differences?" You research the problem on the Internet. You learn about a gene named ACE that might affect how people respond to athletic training.

Based on all of your research, you develop a hypothesis. You hypothesize that people with different versions (D or I) of the ACE gene will respond differently to the same athletic training program. People with D genes will increase their muscle mass but not their endurance. People with I genes will increase their endurance but not their muscle mass.

How can you test your hypothesis? You can see how actual life science researchers did it by watching this video: http://www.youtube.com/watch?v=AsNytYms5OY .


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## Lesson Summary

- Scientific investigations generally follow a process called the scientific method. Steps of the scientific method include making observations, asking a question, forming a hypothesis, testing the hypothesis, drawing a conclusion, and communicating the results.
- A hypothesis is a potential, testable answer to a scientific question. It must be possible to find evidence showing that the hypothesis is false if it really is false.
- An experiment is a controlled scientific test that often takes place in a lab. It investigates the effects of an independent variable on a dependent variable.
- Experimental controls are other factors that might affect the dependent variable. They are kept constant so they will not affect the results of the experiment.

## Lesson Review Questions

### Recall

1. Outline the steps of the scientific method.
2. Define scientific hypothesis.
3. What is a scientific experiment? Define independent and dependent variables and controls.

### Apply Concepts

4. How did the ACE gene researchers in the video above test the hypothesis that people with D genes and people with I genes respond differently to the same athletic training program? Identify independent and dependent variables in their study. What factors were controlled?

### Think Critically

5. Summarize the results of the ACE gene study. How would you communicate the results?
6. What is replication in science? Why is it important?

## Points to Consider

Whether they do basic or applied research, many life scientists use microscopes as one of their most important tools.

1. What is a microscope?
2. Why do you think microscopes are so important in life science?

# 1.4 The Microscope

## Lesson Objectives

- Define microscope.
- Explain why the microscope is so important in life science.
- Outline how the microscope was invented.
- Compare and contrast modern light microscopes and electron microscopes.

## Lesson Vocabulary

- electron microscope
- light microscope
- microscope

## Introduction

It's hard to overstate the importance of the microscope to life science. A **microscope** is an instrument that makes magnified images of very small objects so they are visible to the human eye.

## Importance of the Microscope in Life Science

Many life science discoveries would not have been possible without the microscope. For example:

- Cells are the tiny building blocks of living things. They couldn't be discovered until the microscope was invented. The discovery of cells led to the cell theory. This is one of the most important theories in life science.
- Bacteria are among the most numerous living things on the planet. They also cause many diseases. However, no one knew bacteria even existed until they could be seen with a microscope.

The invention of the microscope allowed scientists to see cells, bacteria, and many other structures that are too small to be seen with the unaided eye. It gave them a direct view into the unseen world of the extremely tiny. You can get a glimpse of that world in **Figure** 1.10.

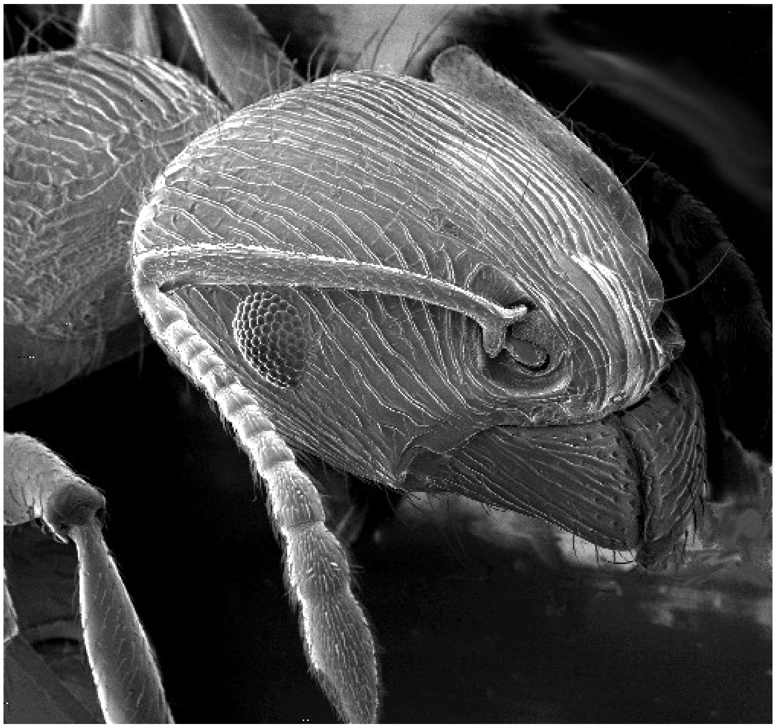

FIGURE 1.10
The head of ant as seen with an electron microscope

## Invention of the Microscope

The microscope was invented more than four centuries ago. In the late 1500s, two Dutch eyeglass makers, Zacharias Jansen and his father Hans, built the first microscope. They put several magnifying lenses in a tube. They discovered that using more than one lens magnified objects more than a single lens. Their simple microscope could make small objects appear nine times bigger than they really were.

### Hooke Discovers Cells

In the mid-1600s, the English scientist Robert Hooke was one of the first scientists to observe living things with a microscope. He published the first book of microscopic studies, called *Micrographia*. It includes wonderful drawings of microscopic organisms and other objects. One of Hooke's most important discoveries came when he viewed thin slices of cork under a microscope. Cork is made from the bark of a tree. When Hooke viewed it under a microscope, he saw many tiny compartments that he called cells. He made the drawing in **Figure** 1.11 to show what he observed. Hooke was the first person to observe the cells from a once-living organism.

### Van Leeuwenhoek Sees Animalcules

In the late 1600s, Anton van Leeuwenhoek, a Dutch lens maker and scientist, started making much stronger microscopes. His microscopes could magnify objects as much as 270 times their actual size. Van Leeuwenhoek made many scientific discoveries using his microscopes. He was the first to see and describe bacteria. He observed them in a sample of plaque that he had scraped off his own teeth. He also saw yeast cells, human sperm cells, and the microscopic life teeming in a drop of pond water. He even saw blood cells circulating in tiny blood vessels called capillaries. The drawings in **Figure** 1.12 show some of tiny organisms and living cells that van Leeuwenhoek viewed with his microscopes. He called them "animalcules."

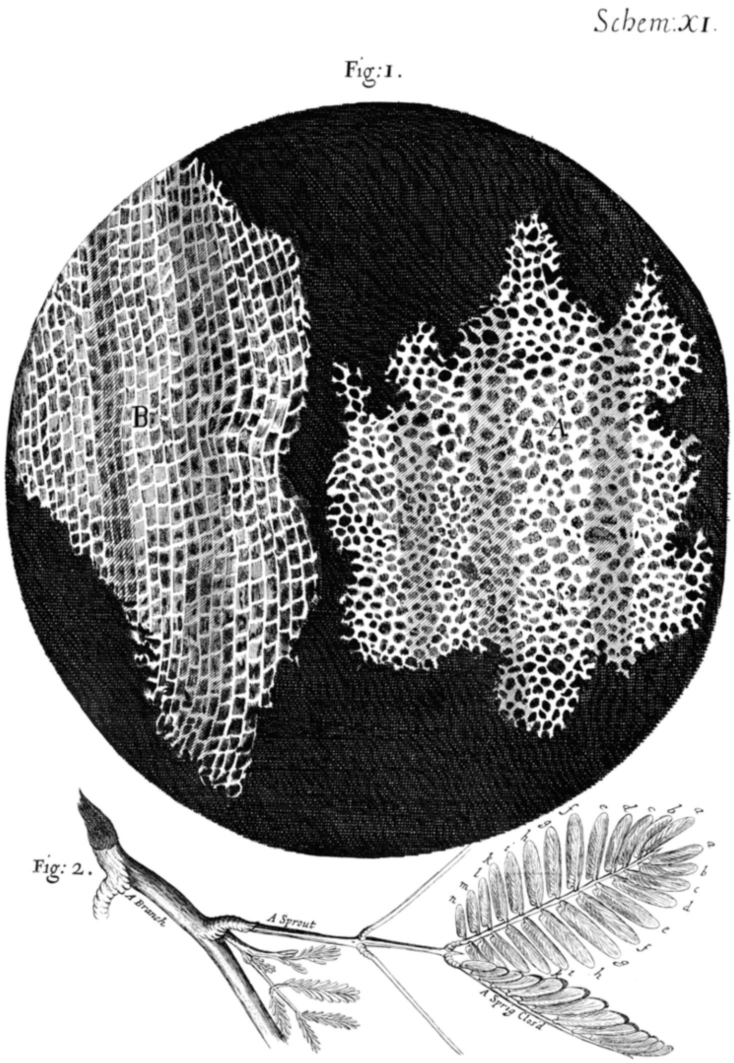


FIGURE 1.11
Cells in cork

## Modern Microscopes

These early microscopes used lenses to refract light and create magnified images. This type of microscope is called a **light microscope**. Light microscopes continued to improve and are still used today. The microscope you might use in science class is a light microscope. The most powerful light microscopes now available can make objects look up to 2000 times their actual size. You can learn how to use a light microscope by watching this short video: http://www.youtube.com/watch?v=jP9HtcAvGDk .

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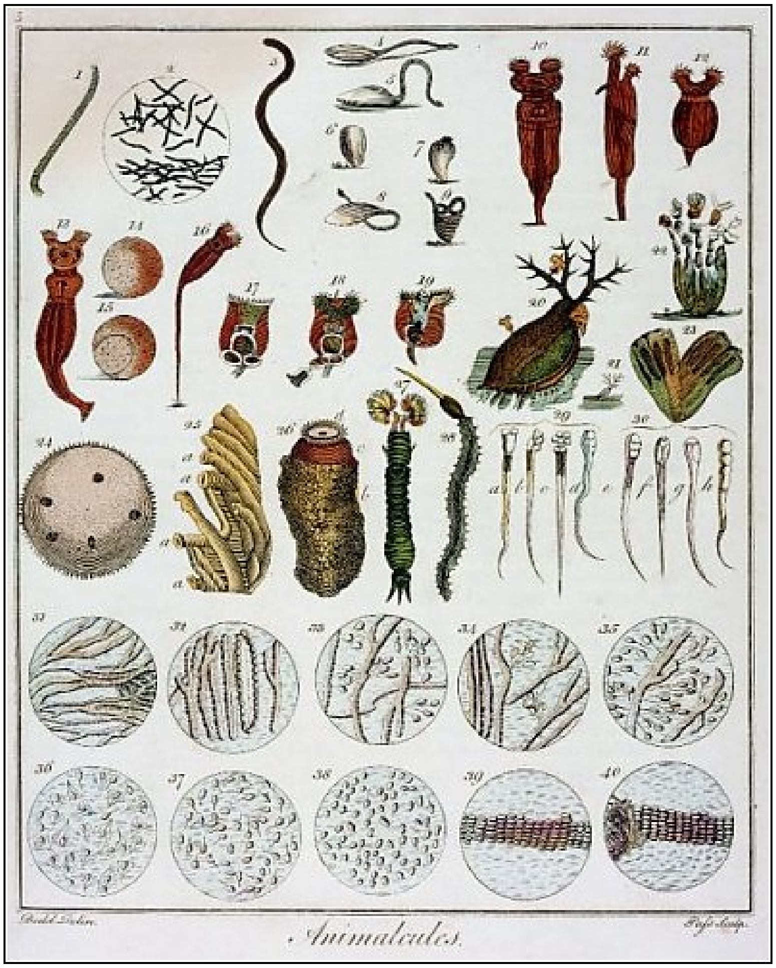


FIGURE 1.12
Van Leeuwenhoek's drawings of "animalcules" as they appeared under his microscope

To see what you might observe with a light microscope, watch the following video. It shows some amazing creatures in a drop of stagnant water from an old boat. What do you think the creatures might be? Do they look like any of van Leeuwenhoek's "animalcules" in **Figure** 1.12?

http://www.youtube.com/watch?v=7JIDkgE4HLk

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URL: http://www.ck12.org/flx/render/embeddedobject/149603

For an object to be visible with a light microscope, it can't be smaller than the wavelength of visible light (about 550 nanometers). To view smaller objects, a different type of microscope, such as an electron microscope, must be used. **Electron microscopes** pass beams of electrons through or across an object. They can make a very clear image that is up to 2 million times bigger than the actual object. An electron microscope was used to make the image of the ant head in **Figure** 1.10.

## Lesson Summary

- A microscope is an instrument that makes magnified images of very small objects so they are visible to the human eye. Many important life science discoveries would not have been possible without the microscope.
- Hans and Zacharias Jansen made the first light microscope in the late 1500s. In the mid-1600s, Robert Hooke was the first scientist to study living things with a microscope. He was also the first to identify and describe cells. In the late 1600s, van Leeuwenhoek improved the microscope. He used it to observe many living cells and organisms. He was the first to observe bacteria.
- Light microscopes continued to improve and are still used today. However, to see extremely small objects, a different type of microscope, such as an electron microscope, must be used.

## Lesson Review Questions

### Recall

1. What is a microscope?
2. Outline the contributions of Hooke and van Leeuwenhoek to the microscope and to life science.

### Apply Concepts

3. Assume you want to view a structure that is 400 nanometers wide. Explain which type of microscope you would use, a light microscope or an electron microscope.

### Think Critically

4. Explain why the microscope is such an important tool in life science.

## Points to Consider

Microscopes are usually used in a lab setting. Science labs can be dangerous places unless you follow safety rules.

1. Can you think of a danger you might be exposed to in a science lab?
2. What might be a common-sense lab safety rule?

# 1.5 Safety in Life Science Research

## Lesson Objectives

- Identify common safety symbols and lab safety rules.
- Explain how to stay safe while doing field research.
- State what to do in case of an accident during scientific research.

## Lesson Vocabulary

- fieldwork

## Introduction

Some life scientists mainly do lab research. Other life scientists, like the botanist in **Figure** 1.13, work in natural settings. This is called **fieldwork**. Whether in the lab or the field, research in life science can be dangerous. It's important to be aware of the risks and how to stay safe.

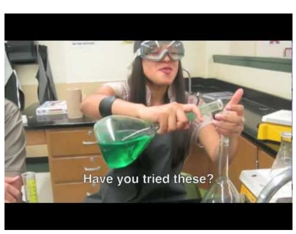
FIGURE 1.13
This field botanist is collecting water samples near the wild pitcher plants she is studying. These insect-eating plants are rare, and there are many unanswered questions about them. Why might her research be risky?

## Safety in the Lab

A science lab has many potential dangers. That's why lab procedures and equipment are often labeled with safety symbols, like the ones in **Figure** 1.14. These symbols warn of specific hazards, such as flames or broken glass. Learn the symbols so you can recognize the dangers. Then learn how to avoid them.


FIGURE 1.14
Common safety symbols

The best way to avoid lab dangers is to follow the lab safety rules listed below. Following the rules can help prevent accidents. Watch this funny student video to see just how important some of these rules are: http://www.youtube.com/watch?v=NjJz85bQqdM .

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### Lab Safety Rules

- Wear long sleeves and shoes that completely cover your feet.
- If your hair is long, tie it back or cover it with a hair net.
- Protect your eyes, skin, and clothing by wearing safety goggles, an apron, and gloves.
- Use hot mitts to handle hot objects.
- Never work alone in the lab.
- Never engage in horseplay in the lab.

- Never eat or drink in the lab.
- Never do experiments without your teacher's approval.
- Always add acid to water, never the other way around. Add the acid slowly to avoid splashing.
- Take care to avoid knocking over Bunsen burners. Keep them away from flammable materials such as paper.
- Use your hand to fan vapors toward your nose rather than smelling substances directly.
- Never point the open end of a test tube toward anyone—including you!
- Clean up any spills immediately.
- Dispose of lab wastes according to your teacher's instructions.
- Wash glassware and counters when you finish your work.
- Wash your hands with soap and water before leaving the lab.

## Safety in the Field

Many of the lab safety rules are common-sense precautions. Common-sense should also prevail in the field. Be aware, however, that field research may have its own unique dangers. Therefore, other safety rules may apply when you work in the field. The rules will depend on the particular field setting and its specific risks.

Consider the field botanist in **Figure** 1.13. There may be microorganisms in the water that could make her sick. She might come into contact with plants that cause an allergic reaction. The water or shore might be strewn with dangerous objects such as broken glass that could cause serious injury. To stay safe in the field, she needs to be aware of these risks and take steps to avoid them. If you work in the field or take a science fieldtrip, you should do the same—and always follow your teacher's instructions.

## In Case of Accident

Even when you follow the rules, accidents can happen. Immediately alert your teacher if an accident occurs. Report all accidents, whether or not you think they are serious.

## Lesson Summary

- Lab safety symbols warn of specific hazards, such as flames or broken glass. Knowing the symbols allows you to recognize and avoid the dangers.
- Following basic safety rules, such as wearing safety gear, helps prevent accidents in the lab and in the field.
- All accidents should be reported immediately.

## Lesson Review Questions

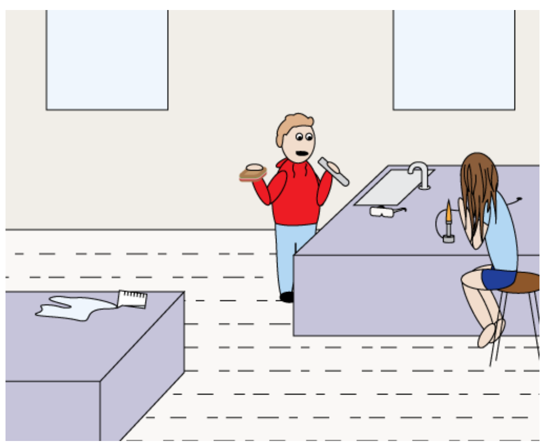
### Recall

1. Look at the safety symbol in the picture below. What hazard does it represent?


2. Identify three safety rules that help prevent accidents in the lab.

### Apply Concepts

3. Examine this sketch of students working in a lab. Identify at least three lab safety rules they are breaking.



### Think Critically

4. Assume you are a field researcher studying ants. What risks might you face? How could you reduce or avoid these risks?

## Points to Consider

In this chapter, you learned that life science is the study of life and living things.

1. What separates life from nonlife?
2. What characteristics define living organisms?

# 1.6 References


1. Heath, Ralph C.. The water cycle . Public Domain
2. USHHS. Bacteria on a gel . Public Domain
3. Eden, Janine, and Jim. This fossil is from a reptile named Dimetrodon that lived 300 million years ago. . CC-BY 2.0
4. U.S. Department of Commerce (National Oceanic and Atmospheric Administration). http://commons.wikimedia.org/wiki/File:Scientific_name,_Atya_lanipes_(Spanish_common_name,_Gata),_a_crustacean_(fresh_water_shrimp)_in_Toro_Negro_State_Forest,_in_Ponce,_Puerto_Rico.jpg . Public Domain
5. National Cancer Institute-Frederick. http://commons.wikimedia.org/wiki/File:Red_White_Blood_cells.png . Public Domain
6. Butterfly: Flickr:whologwhy; Owl: Marie Hale; Monkey: Julie Langford; Tiger: Keith Roper; Frog: Anthony Masi; Snail: Brooke Anderson; Spider: John Fowler; Seal: Northwest Power and Conservation Council; Raccoon: Neil McIntosh; Fish: Taras Kalapun. Evolution explains the millions of varieties of organisms on Earth . CC BY 2.0
7. U.S. Navy photo by Mass Communication Specialist 1st Class Justin K. Thomas, Jos van Zetten from Amsterdam, the Netherlands. Both of these athletes excel but in different athletic events . Public Domain, CC-BY 2.0
8. Hana Zavadska. Scientific method flow chart . CC BY-NC 3.0
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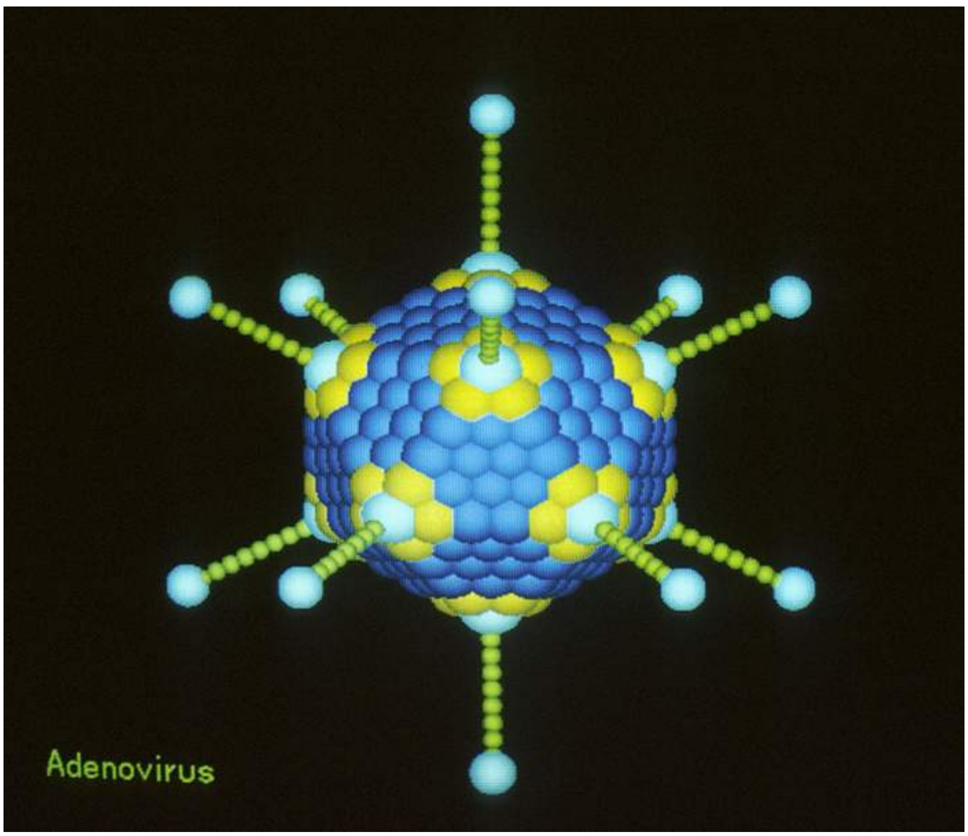
10. US Government. Image obtained using an electron microscope . Public Domain
11. Robert Hooke, Micrographia,1665. Cells in cork under a microscope . Public Domain
12. Anton van Leeuwenhoek. Anton van Leeuwenhoek's drawings of "animalcules" as they appeared under his microscope . Public Domain
13. US Fish and Wildlife Service Southeast Region. Being aware of potential dangers is important in both fieldwork and laboratory research . Public Domain
14. Laura Guerin. Common safety symbols that can be found in the lab . CC BY-NC 3.0

# CHAPTER 2 MS What is a Living Organism?

## Chapter Outline






This colorful image represents a virus that commonly causes respiratory infections in people. Living organisms called bacteria are also common causes of human infections. Are viruses living organisms as well?

Actually, this is one of the great unanswered questions of life science. Some scientists think viruses should be considered living organisms. Other scientists disagree. In this chapter, you'll learn the basic characteristics of living things and the characteristics of viruses. At the end of the chapter, you can decide for yourself whether you think viruses are living organisms.

# 2.1 Characteristics of Living Organisms

## Lesson Objectives

- Identify characteristics of living organisms.
- Describe cells.
- Explain why living things need energy.
- Give an example of a stimulus and response.
- Compare sexual and asexual reproduction.
- Define homeostasis.

## Lesson Vocabulary

- cell
- energy
- homeostasis
- reproduction
- response
- stimulus (stimuli, plural)

## Introduction

Look at the photos in **Figure** 2.1. How are they similar? All of them show living organisms. Observe how different the organisms are from each other. Clearly, living things are very diverse. Yet all of the organisms in the pictures share the same basic characteristics of life. Can you guess what these characteristics are?

## Defining Life

Five characteristics are used to define life. All living things share these characteristics. All living things:

1. are made of one or more cells.
2. need energy to stay alive.
3. respond to stimuli in their environment.
4. grow and reproduce.
5. maintain a stable internal environment.

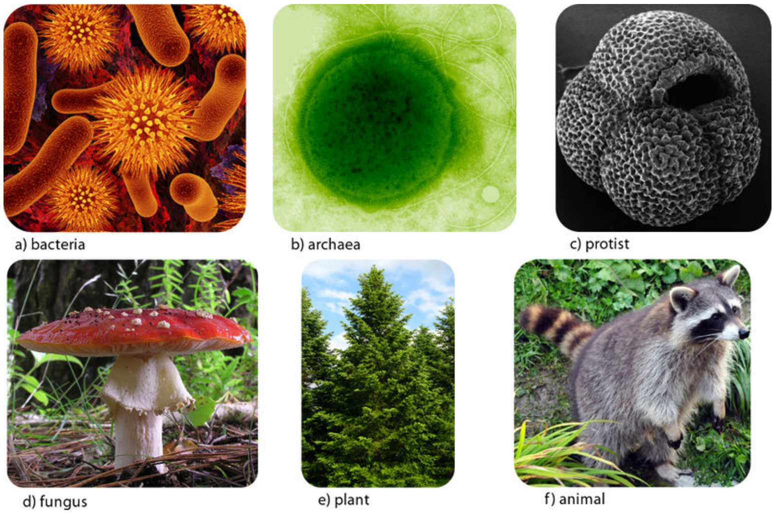



FIGURE 2.1
These pictures represent the diversity of living organisms. Organisms in the top row (a–c) are microscopic.

## Living Things Are Made of Cells

**Cells** are the basic building blocks of life. They are like tiny factories where virtually all life processes take place. Some living things, like the bacteria in **Figure** 2.1, consist of just one cell. They are called single-celled organisms. You can see other single-celled organisms in Figure 2.2. Some living things are composed of a few to many trillions of cells. They are called multicellular organisms. Your body is composed of trillions of cells.

Regardless of the type of organism, all living cells share certain basic structures. For example, all cells are enclosed by a membrane. The cell membrane separates the cell from its environment. It also controls what enters or leaves the cell.

## Living Things Need Energy

Everything you do takes energy. **Energy** is the ability to change or move matter. Whether it's reading these words or running a sprint, it requires energy. In fact, it takes energy just to stay alive. Where do you get energy? You probably know the answer. You get energy from food. **Figure** {{ref|MS-LS-SE-02-03-Food|below}] shows some healthy foods that can provide you with energy.

Just like you, other living things need a source of energy. But they may use a different source. Organisms may be grouped on the basis of the source of energy they use. In which group do you belong?

- Producers such as the tree in **Figure** 2.1 use sunlight for energy to produce their own "food." The process is called photosynthesis, and the "food" is sugar. Plants and other organisms use this food for energy.
- Consumers such as the raccoon in **Figure** 2.1 eat plants—or other consumers that eat plants—as a source of energy.
- Some consumers such as the mushroom in **Figure** 2.1 get their energy from dead organic matter. For example, they might consume dead leaves on a forest floor.

FIGURE 2.2
The green scum in this canal consists of billions of single-celled green algae. Algae are plant-like microorganisms that produce food by photosynthesis.

## Living Things Respond to their Environment

When a living thing responds to its environment, it is responding to a stimulus. A **stimulus** ( **stimuli, plural**) is something in the environment that causes a reaction in an organism. The reaction a stimulus produces is called a **response**.

Imagine how you would respond to the following stimuli:

- You're about to cross a street when the walk light turns red.
- You hear a smoke alarm go off in the kitchen.
- You step on an upturned tack with a bare foot.
- You smell the aroma of your favorite food.
- You taste something really sour.

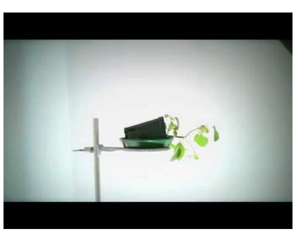
It doesn't take much imagination to realize that responding appropriately to such stimuli might help keep you safe. It might even help you survive.

Like you, all other living things sense and respond to stimuli in their environment. In general, their responses help them survive or reproduce. Watch this amazing time-lapse video to see how a plant responds to the stimuli of light

FIGURE 2.3
Fruits, vegetables, and nuts are healthy sources of food energy.

and gravity as it grows. Why do you think it is important for a plant to respond appropriately to these stimuli for proper growth?

http://www.youtube.com/watch?v=RzD4skFeJ7Y



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## Living Things Grow and Reproduce

Like plants, all living things have the capacity for growth. The ducklings in **Figure** 2.4 have a lot of growing to do to catch up in size to their mother. Multicellular organisms like ducks grow by increasing the size and number of their cells. Single-celled organisms just grow in size.

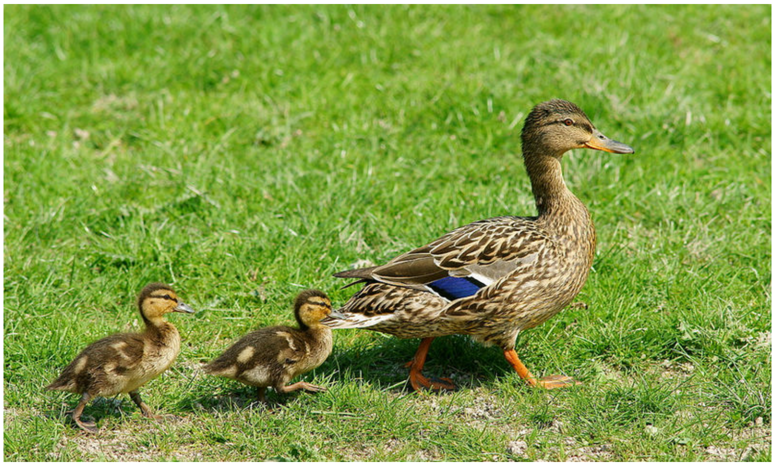


FIGURE 2.4
These ducklings will grow to become as big as their mother by the time they are about a year old.

As the ducklings grow, they will develop and mature into adults. By adulthood, they will be able to reproduce. **Reproduction** is the production of offspring. The ability to reproduce is another characteristic of living things.

Many organisms reproduce sexually. In sexual reproduction, parents of different sexes mate to produce offspring. The offspring have some combination of the traits of the two parents. Ducks are examples of sexually reproducing organisms. Other organisms reproduce asexually. In asexual reproduction, a single parent can produce offspring alone. For example, a bacterial cell reproduces by dividing into two daughter cells. The daughter cells are identical to each other and to the parent cell.

## Living Things Maintain a Stable Internal Environment

The tennis player in **Figure** 2.5 has really worked up a sweat. Do you know why we sweat? Sweating helps to keep us cool. When sweat evaporates from the skin, it uses up some of the body's heat energy. Sweating is one of the ways that the body maintains a stable internal environment. It helps keep the body's internal temperature constant. When the body's internal environment is stable, the condition is called **homeostasis**.

All living organisms have ways of maintaining homeostasis. They have mechanisms for controlling such factors as their internal temperature, water balance, and acidity. Homeostasis is necessary for normal life processes that take place inside cells. If an organism can't maintain homeostasis, normal life processes are disrupted. Disease or even death may result.

## Lesson Summary

- All living things are made of cells, use energy, respond to stimuli, grow and reproduce, and maintain homeostasis.

FIGURE 2.5
Sweating is one way the body maintains homeostasis.

- All living things consist of one or more cells. Cells are the basic units of structure and function of living organisms.
- Energy is the ability to change or move matter. All life processes require energy, so all living things need energy.
- All living things can sense and respond to stimuli in their environment. Stimuli might include temperature, light, or gravity.
- All living things grow and reproduce. Multicellular organisms grow by increasing in cell size and number. Single-celled organisms increase in cell size. All organisms can normally reproduce, or produce offspring. Reproduction can be sexual or asexual.
- All living things have ways of maintaining a stable internal environment. This stable condition is called homeostasis.

## Lesson Review Questions

### Recall

1. List five characteristics of living things.
2. Describe cells.
3. What is energy? How do organisms use energy?

### Apply Concepts

4. Describe a response to an environmental stimulus that might save your life.

### Think Critically

5. Discuss the role of reproduction in life.
6. Explain why having a fever when you are sick disrupts your body's homeostasis.

## Points to Consider

In this lesson, you read that all living things consist of one or more cells.

- What are cells made of?
- Is there any matter that is smaller than a cell?

# 2.2 Chemistry of Living Things

- Describe the makeup of matter.
- Outline the four main classes of biochemical compounds.
- Explain the role of biochemical reactions in living things.

## Lesson Vocabulary

- atom
- biochemical compound
- biochemical reaction
- carbohydrates
- cellulose
- chemical bond
- chemical reaction
- compound
- element
- enzyme
- lipids
- matter
- metabolism
- molecule
- nucleic acids
- proteins

## Introduction

Did you ever wonder what you're made of? The short answer is matter. Matter is anything that has mass and takes up space. All living things consist of matter.

## What's the Matter?

All known matter can be divided into a little more than 100 different substances called elements.

### Elements and Compounds

An element is pure substance that cannot be broken down into other substances. Each element has a particular set of properties that, taken together, distinguish it from all other elements. **Table** 2.2 lists the major elements in the human body. As you can see, you consist mainly of the elements oxygen, carbon, and hydrogen.

**TABLE 2.1:** Elements that make up you

| Element | Percent of Body Mass |
|---|---|
| Oxygen | 65 |
| Carbon | 18 |
| Hydrogen | 10 |
| Nitrogen | 3 |
| Calcium | 1.5 |
| Phosphorus | 1.0 |
| Potassium | 0.35 |
| Sulfur | 0.25 |

In your body, most elements are combined with other elements to form chemical compounds. A **compound** is a unique type of matter in which two or more elements are combined chemically in a certain ratio. For example, much of the oxygen and hydrogen in your body are combined in the chemical compound water, or H2O.

### Atoms and Molecules

The smallest particle of an element that still has the properties of that element is an atom. Atoms are extremely tiny. They can be observed only with an electron microscope. They are commonly represented by models, like the one **Figure** 2.6. An atom has a central nucleus that is positive in charge. The nucleus is surrounded by negatively charged particles called electrons.

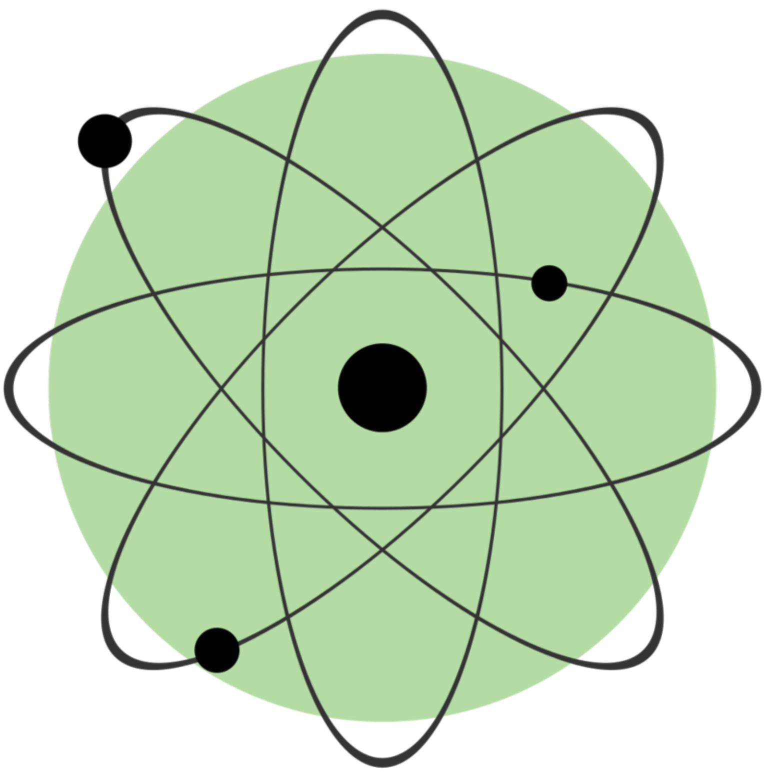


FIGURE 2.6
Model of an atom

The smallest particle of a compound that still has the properties of that compound is a **molecule**. A molecule consists of two or more atoms. For example, a molecule of water consists of two atoms of hydrogen and one atom of oxygen.

That's why the chemical formula for water is $H_2O$. You can see a simple model of a water molecule in **Figure** 2.7.

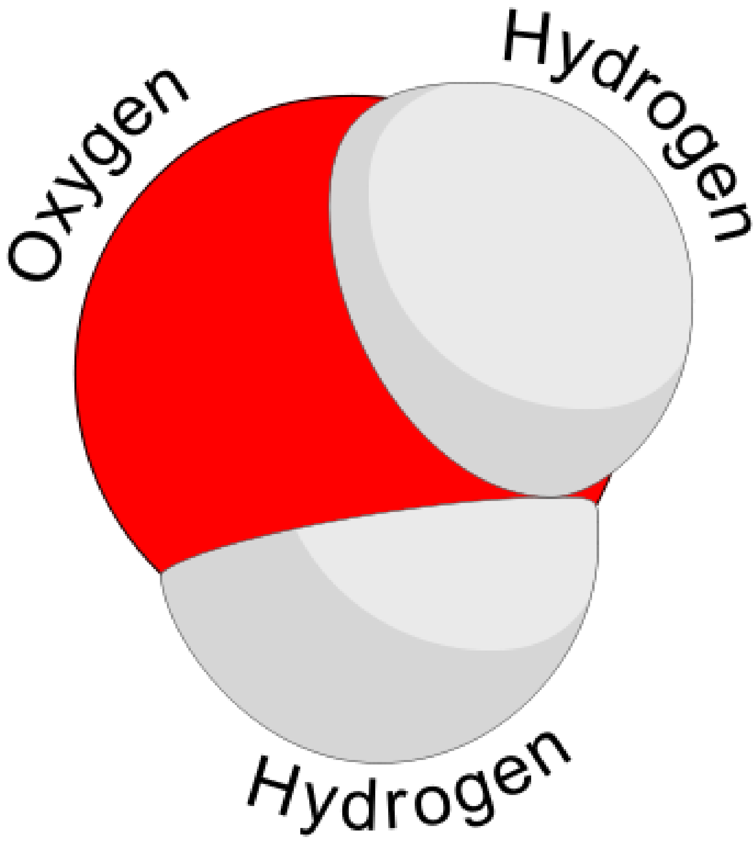



FIGURE 2.7
Model of a water molecule

## Biochemical Compounds

Besides water, most of the compounds in living things are biochemical compounds. A **biochemical compound** is a carbon-based compound that is found in living organisms. Carbon is an element that has a tremendous ability to form large compounds. Each atom of carbon can form four chemical bonds with other atoms. A **chemical bond** is the sharing of electrons between atoms. Bonds hold the atoms together in chemical compounds. A carbon atom can form bonds with other carbon atoms or with atoms of other elements.

### Classes of Biochemical Compounds

Biochemical compounds make up the cells and tissues of living things. They are also involved in all life processes. Given their diversity of functions, it's not surprising that there are millions of different biochemical compounds. Even so, all biochemical compounds can be grouped into just four main classes: carbohydrates, proteins, lipids, and nucleic acids. The classes are summarized in **Table** 2.2.

TABLE 2.2: Classes of Biochemical Compounds

| Class | Elements | Examples | Functions |
|---|---|---|---|

**TABLE 2.2:** (continued)

| Class | Elements | Examples | Functions |
|---|---|---|---|
| Carbohydrates | carbon<br>hydrogen<br>oxygen | sugars<br>starch<br>glycogen<br>cellulose | provide energy to cells<br>stores energy in plants<br>stores energy in animals<br>makes up the cell walls of plants |
| Proteins | carbon<br>hydrogen<br>oxygen<br>nitrogen<br>sulfur | enzymes<br>hormones | speed up biochemical reactions<br>regulate life processes |
| Lipids | carbon<br>hydrogen<br>oxygen | fats<br>oils<br>phospholipids | store energy in animals<br>store energy in plants<br>make up cell membranes |
| Nucleic acids | carbon<br>hydrogen<br>oxygen<br>nitrogen<br>phosphorus | DNA<br>RNA | stores genetic information in cells<br>helps cells make proteins |

### Characteristics of Biochemical Compounds

You can see from **Table** 2.2 that all biochemical compounds contain hydrogen and oxygen as well as carbon. They may also contain nitrogen, phosphorus, and/or sulfur. Almost all biochemical compounds are polymers. Polymers are large molecules that consist of many smaller, repeating molecules, called monomers.

Most biochemical molecules are macromolecules. The prefix macro- means "large," and many biochemical molecules are very large indeed. They may contain thousands of monomer molecules. The largest known biochemical molecule contains more than 34,000 monomers!

### Carbohydrates

**Carbohydrates** are biochemical compounds that include sugar, starch, glycogen, and cellulose. Sugars are simple carbohydrates with relatively small molecules. Glucose is one of the smallest sugar molecules. Its chemical formula is $C_6H_{12}O_6$. This means that a molecule of glucose contains 6 atoms of carbon, 12 atoms of hydrogen, and 6 atoms of oxygen. Plants and some other organisms make glucose in the process of photosynthesis. Living things that cannot make glucose can obtain it by consuming plants or organisms that consume plants.

Starches are complex carbohydrates. They are polymers of glucose. Starches contain hundreds of glucose monomers. Plants make starches to store extra glucose. Consumers can get starches by eating plants. Common sources of starches in the human diet are pictured **Figure** 2.8. Our digestive system breaks down starches to sugar, which our cells use for energy. Like other animals, we store any extra glucose as the complex carbohydrate called glycogen. Glycogen is also a polymer of glucose.

**Cellulose** is another complex carbohydrate found in plants that is a polymer of glucose. Cellulose molecules bundle together to form long, tough fibers. Cellulose is the most abundant biochemical compound. It makes up the cell walls of plants and gives support to stems and tree trunks.

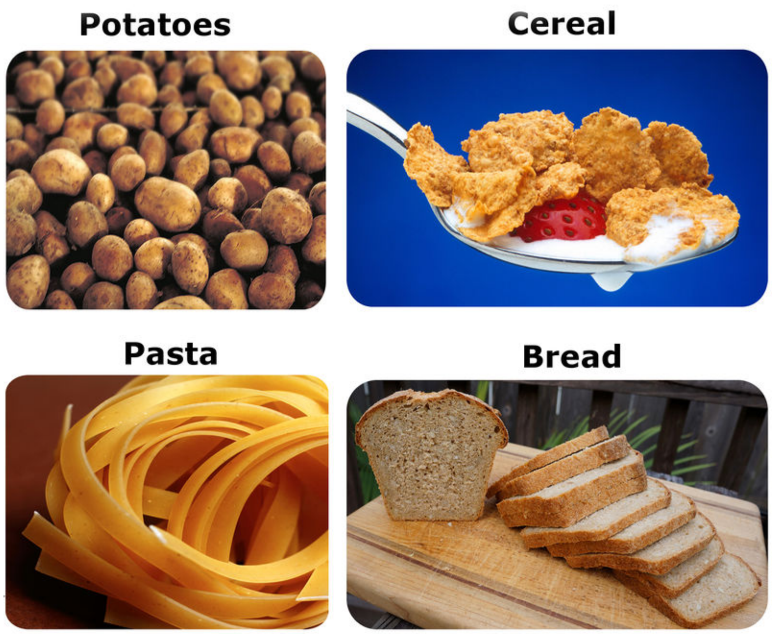
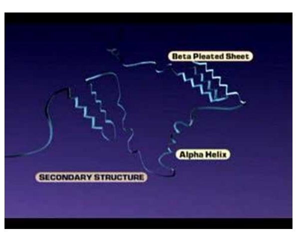



FIGURE 2.8
Starchy foods

## Proteins

**Proteins** are biochemical compounds that consist of one or more chains of small molecules called amino acids. Amino acids are the monomers of proteins. There are only about 20 different amino acids. The sequence of amino acids in chains and the number of chains in a protein determine the protein's shape. Shapes may be very complex. You can learn more about the shapes of proteins at this link:

http://www.youtube.com/watch?v=lijQ3a8yUYQ

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The shape of a protein determines its function. Proteins have many different functions. For example, proteins:

- make up muscle tissues.
- speed up chemical reactions in cells.
- regulate life processes.
- help defend against infections.
- transport materials around the body in the blood.

Hemoglobin is an example of a transport protein in the blood. You can see how it works in **Figure** 2.9. The heme parts of a hemoglobin molecule bind with oxygen. Each red blood cell has hundreds of hemoglobin molecules. This is how oxygen is carried in the blood to cells throughout the body.

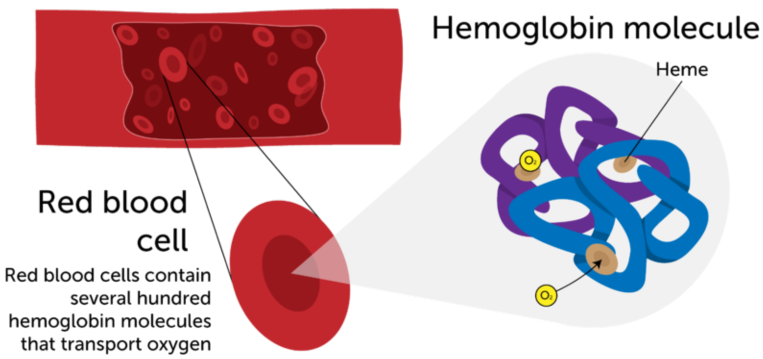



FIGURE 2.9
How hemoglobin transports oxygen in the blood

## Lipids

Lipids are biochemical compounds that living things use to store energy and make cell membranes. Types of lipids include fats, oils, and phospholipids.

- Fats are solid lipids that animals use to store energy. Examples of fats include butter and the fat in meat.
- Oils are liquid lipids that plants use to store energy. Examples of oils include olive oil and corn oil.
- Phospholipids contain the element phosphorus. They make up the cell membranes of living things.

Lipids are made of long chains consisting almost solely of carbon and hydrogen. These long chains are called fatty acids. Fatty acids may be saturated or unsaturated. **Figure** 2.10 shows an example of each type of fatty acid.

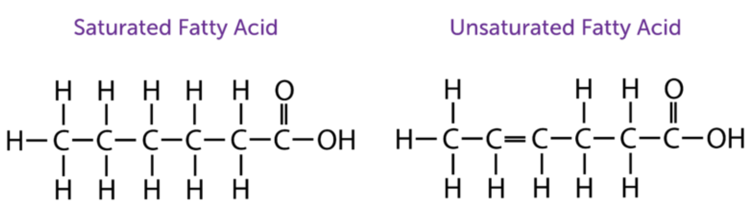



FIGURE 2.10
Saturated and unsaturated fatty acids

- In saturated fatty acids, carbon atoms are bonded to as many hydrogen atoms as possible. In other words, the carbon atoms are saturated with hydrogen. Saturated fatty acids are found in fats.
- In unsaturated fatty acids, some carbon atoms are not bonded to as many hydrogen atoms as possible. Instead, they share double bonds with other carbon atoms. Unsaturated fatty acids are found in oils.

## Nucleic Acids

Nucleic acids are biochemical compounds that include RNA (ribonucleic acid) and DNA (deoxyribonucleic acid). Nucleic acids consist of chains of small molecules called nucleotides. Nucleotides are the monomers of nucleic acids. A nucleotide is shown in **Figure** 2.11.

Each nucleotide consists of:

1. a phosphate group, which contains phosphorus and oxygen.
2. a sugar, which is deoxyribose in DNA and ribose in RNA.

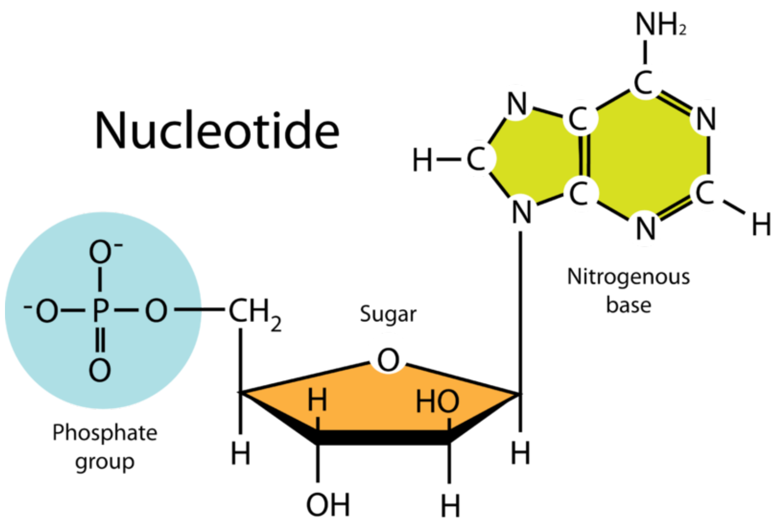



FIGURE 2.11
A nucleotide

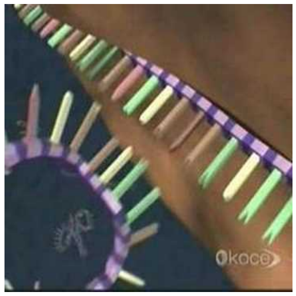
3. one of four nitrogen-containing bases. (A base is a compound that is not neither acidic nor neutral.) In DNA, the bases are adenine, thymine, guanine, and cytosine. RNA has the base uracil instead of thymine, but the other three bases are the same.

RNA consists of just one chain of nucleotides. DNA consists of two chains. Nitrogen bases on the two chains of DNA form bonds with each other. The bonded bases are called base pairs. Bonds form only between adenine and thymine, and between guanine and cytosine. They hold together the two chains of DNA and give it its characteristic double helix, or spiral, shape. You can see the shape of the DNA molecule in **Figure** 2.12. Sugars and phosphate groups form the "backbone" of each chain of DNA. Determining the structure of DNA was a huge scientific breakthrough. You can read the interesting story of its discovery and why it was so important at this link:

http://nobelprize.org/educational/medicine/dna_double_helix/readmore.html

DNA stores genetic information in the cells of all living things. It contains the genetic code. This is the code that instructs cells how to make proteins. The instructions are encoded in the sequence of nitrogen bases in DNA's nucleotide chains. RNA copies and interprets the genetic code in DNA. RNA is also involved in the synthesis of proteins based on the code. You can watch these events unfolding at this link:

http://www.youtube.com/watch?v=NJxobgkPEAo



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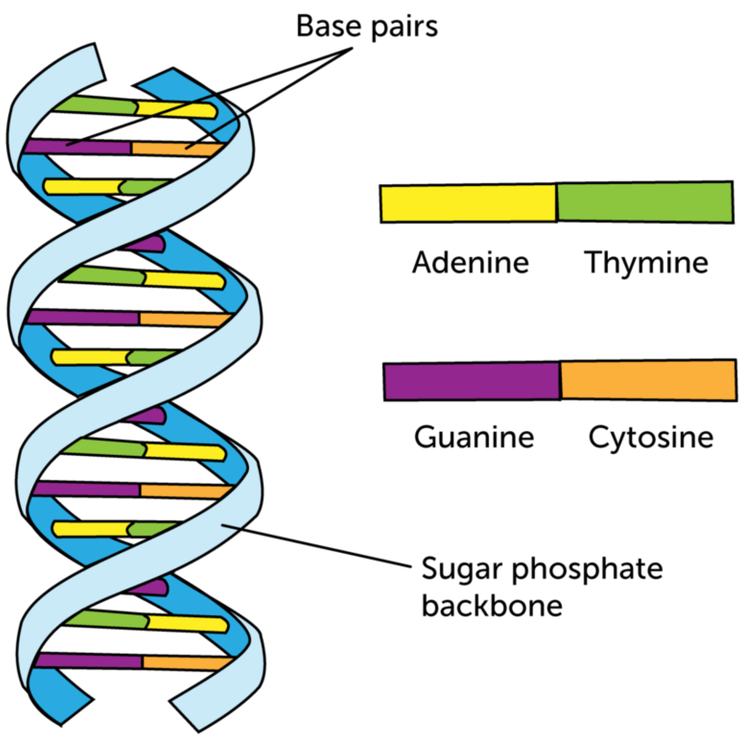



FIGURE 2.12
DNA molecule

## Biochemical Reactions

The student athlete in **Figure** 2.13 is practically flying down the track! Running takes a lot of energy. But you don't have to run a race to use energy. All living things need energy all the time just to stay alive. The energy is produced in chemical reactions. A **chemical reaction** is a process in which some substances, called reactants, change chemically into different substances, called products. Reactants and products may be elements or compounds.

Chemical reactions that take place inside living things are called **biochemical reactions**. Living things depend on biochemical reactions for more than just energy. Every function and structure of a living organism depends on thousands of biochemical reactions taking place in each cell.

### Metabolism

The sum of all of an organism's biochemical reactions is called **metabolism**. Biochemical reactions of metabolism can be divided into two general categories: catabolic reactions and anabolic reactions. You can watch an animation showing how the two categories of reactions are related at this link:

http://classes.midlandstech.edu/carterp/courses/bio225/chap05/lecture1.htm

- Anabolic reactions involve forming bonds. Smaller molecules combine to form larger ones. These reactions require energy. For example, it takes energy to build starches from sugars.
- Catabolic reactions involve breaking bonds. Larger molecules break down to form smaller ones. These reactions release energy. For example, energy is released when starches break down to sugars.


FIGURE 2.13
This student athlete is using energy to run a race.

### Enzymes

Each of the trillions of cells in your body is continuously performing thousands of anabolic and catabolic reactions. That's an amazing number of biochemical reactions—far more than the number of chemical reactions that might take place in a science lab or chemical plant. So many biochemical reactions can take place simultaneously in our cells because biochemical reactions occur very quickly. That's because of enzymes.

Enzymes are proteins that increase the rate of biochemical reactions. Enzymes aren't changed or used up in the reactions, so they can be used to speed up the same reaction over and over again. Enzymes are highly specific for certain chemical reactions, so they are very effective. A reaction that would take years to occur without its enzyme might occur in a split second with the enzyme.

### Photosynthesis and Cellular Respiration

Some of the most important biochemical reactions are the reactions involved in photosynthesis and cellular respiration.

- Photosynthesis is the process in which producers capture light energy from the sun and use it to make glucose. This involves anabolic reactions.
- Cellular respiration is the process in which energy is released from glucose and stored in smaller amounts in other molecules that cells can use for energy. This involves catabolic reactions.

Photosynthesis and cellular respiration together provide energy to almost all living cells. **Figure** 2.14 shows how photosynthesis and cellular respiration are related. You can read more about both processes in the chapter *Cell Functions*.

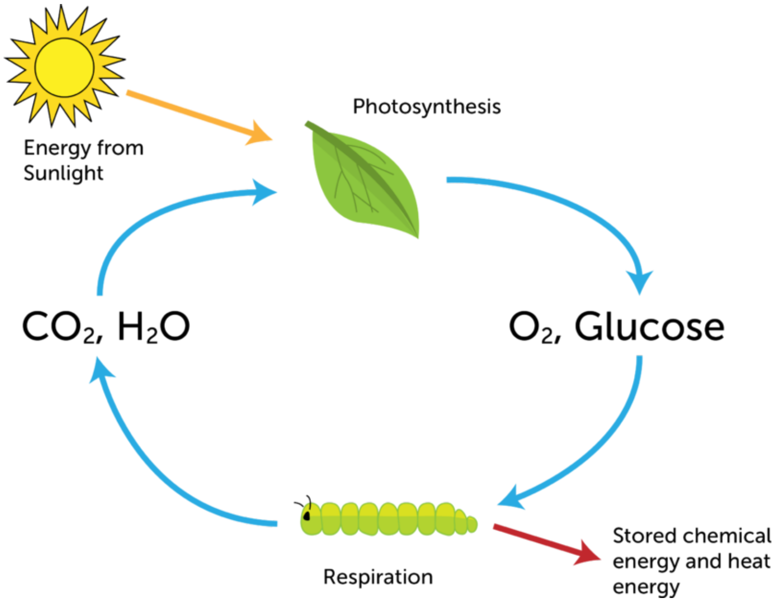



FIGURE 2.14
The products of photosynthesis are oxygen ($O_2$) and glucose. These two substances are also the reactants of cellular respiration. The products of cellular respiration are carbon dioxide ($CO_2$) and water ($H_2O$). These two substances are also the reactants of photosynthesis.

## Lesson Summary

- All living things are made of matter. Matter can consist of pure substances called elements or of combinations of elements called chemical compounds. Atoms are the smallest particles of elements. Molecules are the smallest particles of compounds.
- Biochemical compounds are carbon-based compounds that make up living organisms. There are four main classes of biochemical compounds: carbohydrates, proteins, lipids, and nucleic acids. The classes have different structures and functions.
- Life depends on biochemical reactions constantly taking place inside cells. Metabolism is the sum of all the biochemical reactions in an organism. It includes anabolic reactions that build up molecules and catabolic reactions that break down molecules. Enzymes speed up biochemical reactions.

## Lesson Review Questions

### Recall

1. What are elements and compounds? What are their smallest particles?
2. Identify the four main classes of biochemical compounds. Give an example and list a function of each class.
3. Define metabolism.

### Apply Concepts

4. Lipids consist of fatty acids. Most nutrition experts agree that we should limit the amount of saturated fatty acids that we eat. They think that unsaturated fatty acids are healthier. To follow this advice, which foods should you limit? Which foods are healthier choices?

### Think Critically

5. Explain the relationship between nucleic acids and proteins.
6. Compare and contrast anabolic and catalytic reactions. Give an example of each type of reaction.

## Points to Consider

All living things share many of the same biochemical compounds and biochemical reactions. Yet living things are extremely diverse.

- How do scientists make sense of the diversity of living things?
- How do modern scientists classify organisms? What types of traits do they use?

# 2.3 Classification of Living Things

## Lesson Objectives

- Define taxonomy.
- Outline Linnaeus' contributions to taxonomy.
- Describe the three-domain system of classification.
- Decide how viruses should be classified.

## Lesson Vocabulary

- binomial nomenclature
- class
- domain
- family
- genus (genera, plural)
- kingdom
- Linnaeus
- order
- phylum (phyla, plural)
- species (singular and plural)
- taxon (taxa, plural)
- taxonomy
- virus

## Introduction

When you see an organism that you have never seen before, you probably group it with other, similar organisms without even thinking about it. You would probably classify it on the basis of obvious physical characteristics. For example, if an organism is green and has leaves, no doubt you would classify it as a plant.

How would you classify the organisms in **Figure** 2.15? They look quite similar, but scientists place them in very different categories. The organism on the left is a type of fungus. The organism on the right is an animal called a sponge. In many ways, a sponge is no more like a fungus than you are.

## Taxonomy

Like you, scientists also group together similar organisms. The science of classifying living things is called taxonomy. Scientists classify living things in order to organize and make sense of the incredible diversity of life. Modern

FIGURE 2.15
A fungus (left) and sponge (right) are placed in two different kingdoms of living things.

scientists base their classifications mainly on molecular similarities. They group together organisms that have similar proteins and DNA. Molecular similarities show that organisms are related. In other words, they are descendants of a common ancestor in the past.

## Contributions of Linnaeus

Carl **Linnaeus** (1707-1778) is called the "father of taxonomy." You may already be familiar with the classification system Linnaeus introduced.

### Linnaean Classification System

You can see the main categories, or **taxa (taxon, singular)**, of the Linnaean system in **Figure** 2.16. As an example, the figure applies the Linnaean system to classify our own species, Homo sapiens. Although the Linnaean system has been revised, it forms the basis of modern classification systems.

The broadest category in the Linnaean system is the **kingdom**. **Figure** 2.16 shows the Animal Kingdom because *Homo sapiens* belongs to that kingdom. Other kingdoms include the Plant Kingdom, Fungus Kingdom, and Protist Kingdom.

Kingdoms are divided, in turn, into **phyla (phylum, singular)**. Each phylum is divided into **classes**, each class into **orders**, each order into **families**, and each family into **genera (genus, singular)**. Each genus is divided into one or more species. The **species** is the narrowest category in the Linnaean system. A species is defined as a group of organisms that can breed and produce fertile offspring together.

### Binomial Nomenclature

Linnaeus is also famous for his method of naming species, which is still used today. The method is called **binomial nomenclature**. Every species is given a unique two-word name. Usually written in Latin, it includes the genus name followed by the species name. Both names are always written in italics, and the genus name is always capitalized. For example, the human species is named *Homo sapiens*. The species of the family dog is named *Canis familiaris*.

Coming up with a scientific naming method may not seem like a big deal, but it really is. Prior to Linnaeus, there was no consistent way to name species. Names given to organisms by scientists were long and cumbersome. Often, different scientists came up with different names for the same species. Common names also differed, generally from one place to another. A single, short scientific name for each species avoided a lot of mistakes and confusion.

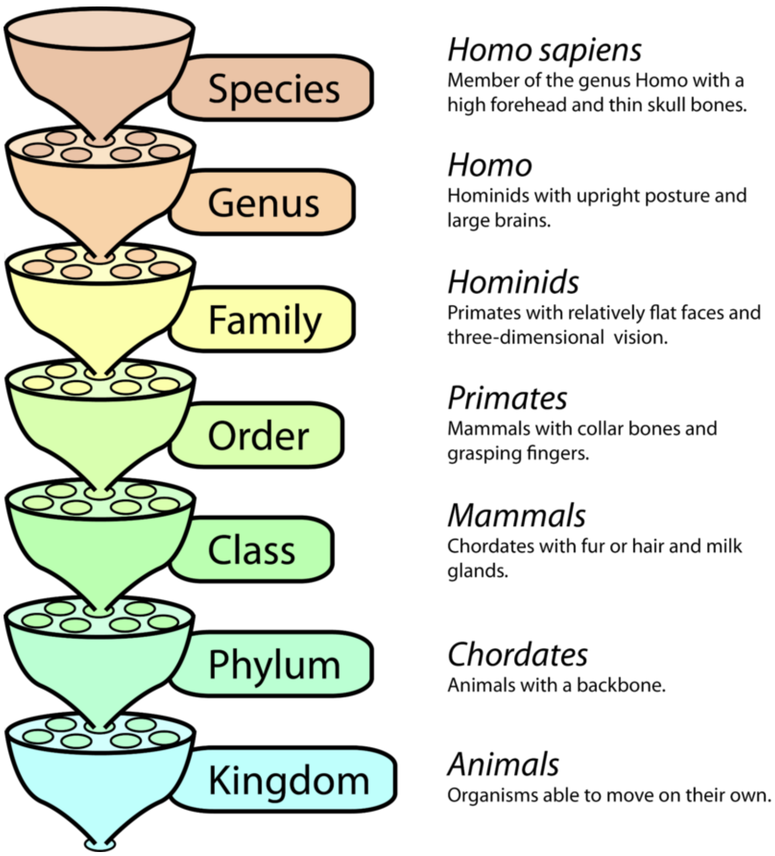



FIGURE 2.16

## Domains

When Linnaeus was naming and classifying organisms in the 1700s, almost nothing was known of microorganisms. With the development of powerful microscopes, scientists discovered many single-celled organisms that didn't fit into any of Linnaeus' kingdoms. As a result, a new taxon, called the **domain**, was added to the classification system. The domain is even broader than the kingdom, as you can see in **Figure** 2.17.

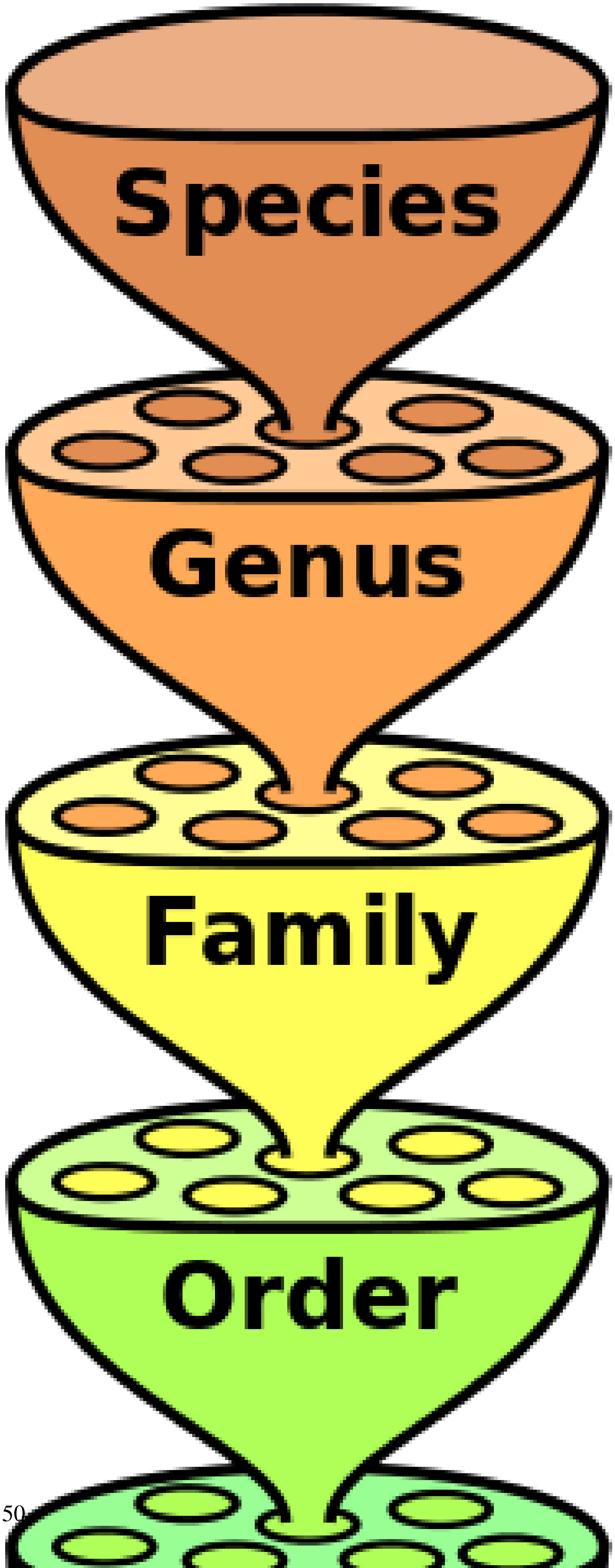
Most scientists think that all living things can be classified in three domains: Archaea, Bacteria, and Eukarya. These domains are compared in Table 2.3. The Archaea Domain includes only the Archaea Kingdom, and the Bacteria Domain includes only the Bacteria Kingdom. The Eukarya Domain includes the Animal, Plant, Fungus, and Protist Kingdoms.

**TABLE 2.3:** Comparison of the three domains of life

| Trait | Archaea | Bacteria | Eukarya |
|---|---|---|---|
| Multicellularity | No | No | Yes except for many protists |
| Cell Wall | Yes<br>Without peptidoglycan | Yes<br>With peptidoglycan | Yes for plants, fungi, and some protists<br>No for animals and other protists |
| Cell Nucleus (DNA inside a membrane) | No | No | Yes |

**TABLE 2.3:** (continued)

| Trait | Archaea | Bacteria | Eukarya |
|---|---|---|---|
| Cell Organelles (other structures inside membranes) | No | No | Yes |


Species
Genus
Family
Order

The Archaea and Bacteria Domains contain only single-celled organisms. Both Archaea and Bacteria have cells walls, but their cell walls are made of different materials. The cells of Archaea and Bacteria lack a nucleus. A nucleus is membrane-enclosed structure for holding a cell's DNA.

Some Eukarya are also single-celled, but many are multicellular. Some have a cell wall; others do not. However, the cells of all Eukarya have a nucleus and other organelles.

Archaea and Bacteria may seem more similar to each other than either is to Eukarya. However, scientists think that Archaea may actually be more closely related to Eukarya than Bacteria are. This view is based on similarities in their DNA.

## How Should Viruses Be Classified?

This question was posed at the beginning of the chapter. Should viruses be placed in one of the three domains of life? Are viruses living things? Before considering these questions, you need to know the characteristics of viruses.

- A **virus** is nothing more than some DNA or RNA surrounded by a coat of proteins.
- A virus is not a cell.
- A virus cannot use energy, respond to stimuli, grow, or maintain homeostasis.
- A virus cannot reproduce on its own. However, a virus can reproduce by infecting the cell of a living host. Inside the host cell, the virus uses the cell's structures, materials, and energy to make copies of itself.
- Because they have genetic material and can reproduce, viruses can evolve. Their DNA or RNA can change through time. The ability to evolve is a very lifelike attribute.

Many scientists think that viruses should not be classified as living things because they lack most of the defining traits of living things. Other scientists aren't so sure. They think that the ability of viruses to evolve and interact with living cells earns them special consideration. Perhaps a new category of life should be created for viruses. What do you think?

## Lesson Summary

- Scientists classify living things to make sense of biodiversity and who how living things are related. The science of classifying living things is called taxonomy.
- Linnaeus introduced the classification system that forms the basis of modern classification. Taxa in the Linnaean system include the kingdom, phylum, class, order, family, genus, and species. Linnaeus also developed binomial nomenclature for naming species.
- More recently, scientists have added the domain to the Linnaean system of classification. The domain is a broader taxon than the kingdom. There are three widely recognized domains: Archaea, Bacteria, and Eukarya.
- Viruses lack many traits of living things so the majority of scientists do not classify them as living organisms.

## Lesson Review Questions

### Recall

1. What is taxonomy, and why is it important?
2. List the taxa in Linnaeus' system of classification, from the broadest taxon to the narrowest taxon.
3. Describe binomial nomenclature.

### Apply Concepts

4. Apply the Linnaean classification system to the human species.

### Think Critically

5. What is a domain? Explain why scientists added the domain to the Linnaean classification system.
6. Identify and compare the three domains of life.
7. How do you think viruses should be classified? Support your answer.

## Points to Consider

Cells are the basic units of living things. Some cells have a nucleus.

- Besides a nucleus, what are some other structures that cells may contain?
- How do plant and animal cells differ?

# 2.4 References


1. (a) Tischenko Irina, (b) Angels Tapias, (c) Hannes Grobe/AWI, (d) Tony Wills, (e) Crusier, (f) Michael Gabler. Diversity of living organisms . (a) Used under license from Shutterstock.com, (b) CC BY 3.0, (c) CC BY 3.0, (d) CC BY 3.0, (e) CC BY 3.0, (f) CC BY 3.0
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15. Left: Thomas R Machnitzki, Right: NOAA. A fungus and a sponge . Left: CC BY 3.0, Right: Public Domain
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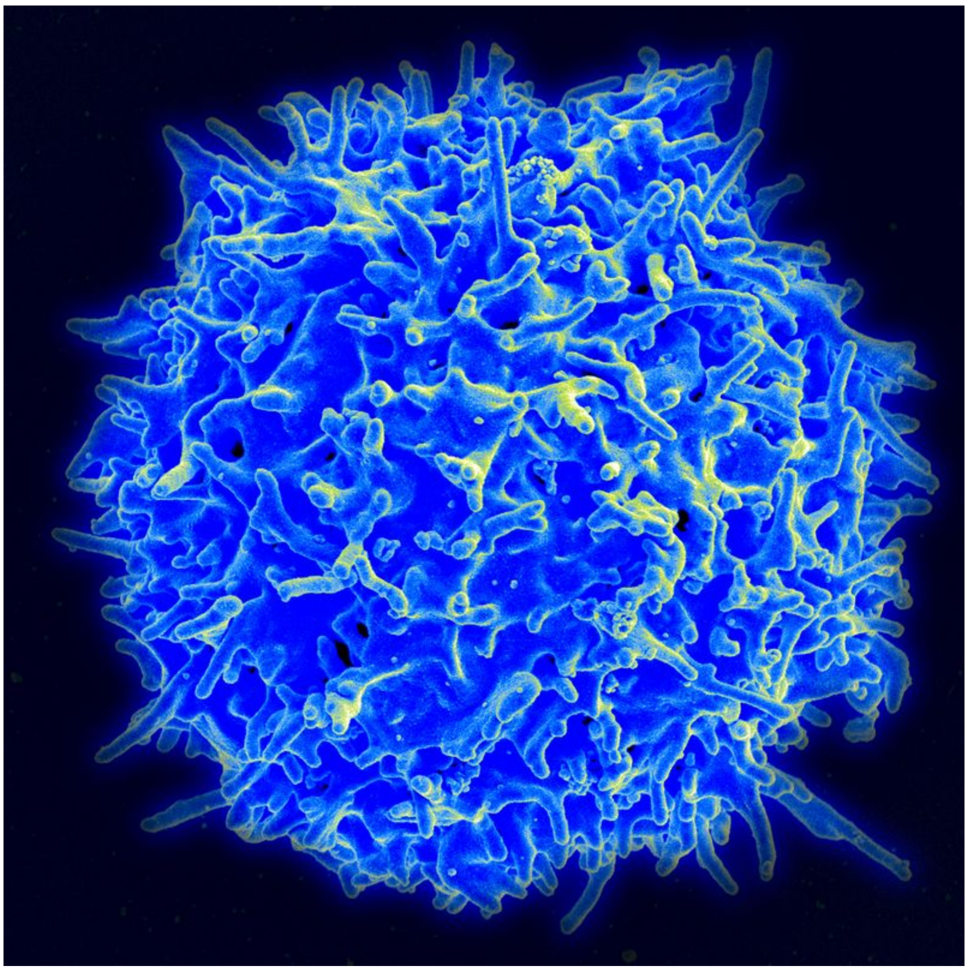
17. Pengo. Domain in a biological classification system . Public Domain

# CHAPTER 3 MS Cells and Their Structures

## Chapter Outline





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This image shows a human cell as it looks under an electron microscope. The image makes the cell look thousands of times bigger than it really is. Clearly, cells are very small in size. However, their small size belies their importance to life. Like all other living things, you are made of cells. In fact, your body contains trillions of cells. Without cells, life as we know it would not exist. You'll learn more about these amazing building blocks of life when you read this chapter.

# 3.1 Life's Building Blocks

## Lesson Objectives

- Review the discovery of cells and the cell theory.
- Identify the basic parts of all cells.
- Compare and contrast prokaryotic and eukaryotic cells.
- Relate cell shape and cell function.
- Outline the levels of organization in living things.
- Explain why cells must be very small.

## Lesson Vocabulary

- cell membrane
- cell theory
- cytoplasm
- eukaryote
- eukaryotic cell
- nucleus
- organ
- organelle
- organ system
- prokaryote
- prokaryotic cell
- ribosome
- tissue

## Introduction

Cells are the building blocks of life. This is clear from the photo in **Figure** 3.1. It shows stacks upon stacks of cells in an onion plant. Cells are also the basic functional units of living things. They are the smallest units that can carry out the biochemical reactions of life. No matter how different organisms may be from one another, they all consist of cells. Moreover, all cells have the same basic parts and processes. Knowing about cells and how they function is necessary to understanding life itself.

## Discovery of Cells and the Cell Theory

Cells were first discovered in the mid-1600s. The cell theory came about some 200 years later. You can see a re-enactment of some of the discoveries that led to the cell theory in this video: http://www.youtube.com/watch?v=d

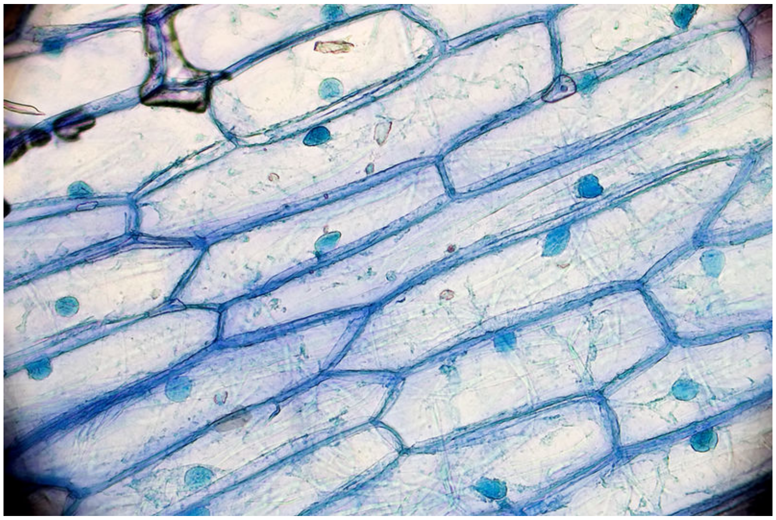

FIGURE 3.1

scY_2QQbKU .


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## Early Observations of Cells

British scientist Robert Hooke first discovered cells in 1665. He was one of the earliest scientists to study living things under a microscope. He saw that cork was divided into many tiny compartments, like little rooms. (Do the cells in **Figure** 3.1 look like little rooms to you too?) Hooke called these little rooms cells. Cork comes from trees, so what Hooke observed was dead plant cells.

In the late 1600s, Dutch scientist Anton van Leeuwenhoek made more powerful microscopes. He used them to observe cells of other organisms. For example, he saw human blood cells and bacterial cells. Over the next century, microscopes were improved and more cells were observed.

## Development of the Cell Theory

By the early 1800s, scientists had seen cells in many different types of organisms. Every organism that was examined was found to consist of cells. From all these observations, German scientists Theodor Schwann and Matthias Schleiden drew two major conclusions about cells. They concluded that:

- cells are alive.
- all living things are made of cells.

Around 1850, a German doctor named Rudolf Virchow was observing living cells under a microscope. As he was watching, one of the cells happened to divide. **Figure** 3.2 shows a cell dividing, like the cell observed by Virchow.

This was an "aha" moment for Virchow. He realized that living cells produce new cells by dividing. This was evidence that cells arise from other cells.

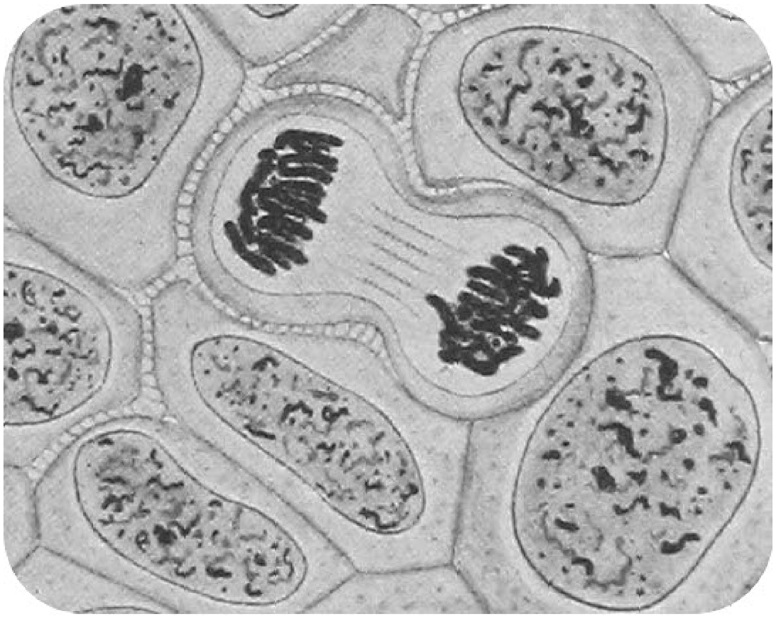

FIGURE 3.2
The cell in the middle of this clump of cells is dividing. It will produce two identical daughter cells.

The work of Schwann, Schleiden, and Virchow led to the cell theory. This is one of the most important theories in life science. The **cell theory** can be summed up as follows:

- All organisms consist of one or more cells.
- Cells are alive and the site of all life processes.
- All cells come from pre-existing cells.

## Structures Found in All Cells

All cells have certain parts in common. These parts include the cell membrane, cytoplasm, DNA, and ribosomes.

- The **cell membrane** is a thin coat of phospholipids that surrounds the cell. It's like the "skin" of the cell. It forms a physical boundary between the contents of the cell and the environment outside the cell. It also controls what enters and leaves the cell. The cell membrane is sometimes called the plasma membrane.
- **Cytoplasm** is the material inside the cell membrane. It includes a watery substance called cytosol. Besides water, cytosol contains enzymes and other substances. Cytoplasm also includes other cell structures suspended in the cytosol.
- DNA is a nucleic acid found in cells. It contains genetic instructions that cells need to make proteins.
- **Ribosomes** are structures in the cytoplasm where proteins are made. They consist of RNA and proteins.

These four components are found in all cells. They are found in the cells of organisms as different as bacteria and people. How did all known organisms come to have such similar cells? The answer is evolution. The similarities show that all life on Earth evolved from a common ancestor.

## Prokaryotic and Eukaryotic Cells

Besides the four parts listed above, many cells also have a nucleus. The **nucleus** of a cell is a structure enclosed by a membrane that contains most of the cell's DNA. Cells are classified in two major groups based on whether or not they have a nucleus. The two groups are prokaryotic cells and eukaryotic cells.

### Prokaryotic Cells

**Prokaryotic cells** are cells that lack a nucleus. The DNA in prokaryotic cells is in the cytoplasm, rather than enclosed within a nuclear membrane. All the organisms in the Bacteria and Archaea Domains have prokaryotic cells. No other organisms have this type of cell. Organisms with prokaryotic cells are called **prokaryotes**. They are all single-celled organisms. They were the first type of organisms to evolve. They are still the most numerous organisms today.

You can see a model of a prokaryotic cell in **Figure** 3.3. The cell in the figure is a bacterium. Notice how it contains a cell membrane, cytoplasm, ribosomes, and several other structures. However, the cell lacks a nucleus. The cell's DNA is circular. It coils up in a mass called a nucleoid that floats in the cytoplasm.

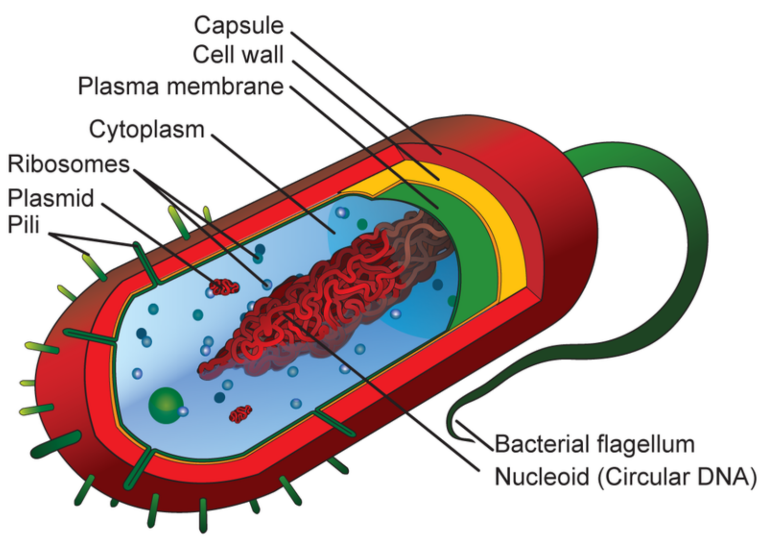


FIGURE 3.3
Prokaryotic Cell. This diagram shows the structure of a typical prokaryotic cell, a bacterium. Like other prokaryotic cells, this bacterial cell lacks a nucleus but has other cell parts, including a plasma membrane, cytoplasm, ribosomes, and DNA. Identify each of these parts in the diagram.

### Eukaryotic Cells

**Eukaryotic cells** are cells that contain a nucleus. They are larger than prokaryotic cells. They are also more complex. Living things with eukaryotic cells are called **eukaryotes**. All of them belong to the Eukarya Domain. This domain includes protists, fungi, plants, and animals. Many protists consist of a single cell. However, most eukaryotes have more than one cell. You can see a model of a eukaryotic cell in **Figure** 3.4. The cell in the figure is an animal cell.

The nucleus is an example of an **organelle**. An organelle is any structure inside a cell that is enclosed by a membrane. Eukaryotic cells may contain many different organelles. Each does a special job. For example, the mitochondrion is an organelle that provides energy to the cell. You can see a mitochondrion and several other organelles in the animal cell in **Figure** 3.4. Organelles allow eukaryotic cells to carry out more functions than prokaryotic cells can.

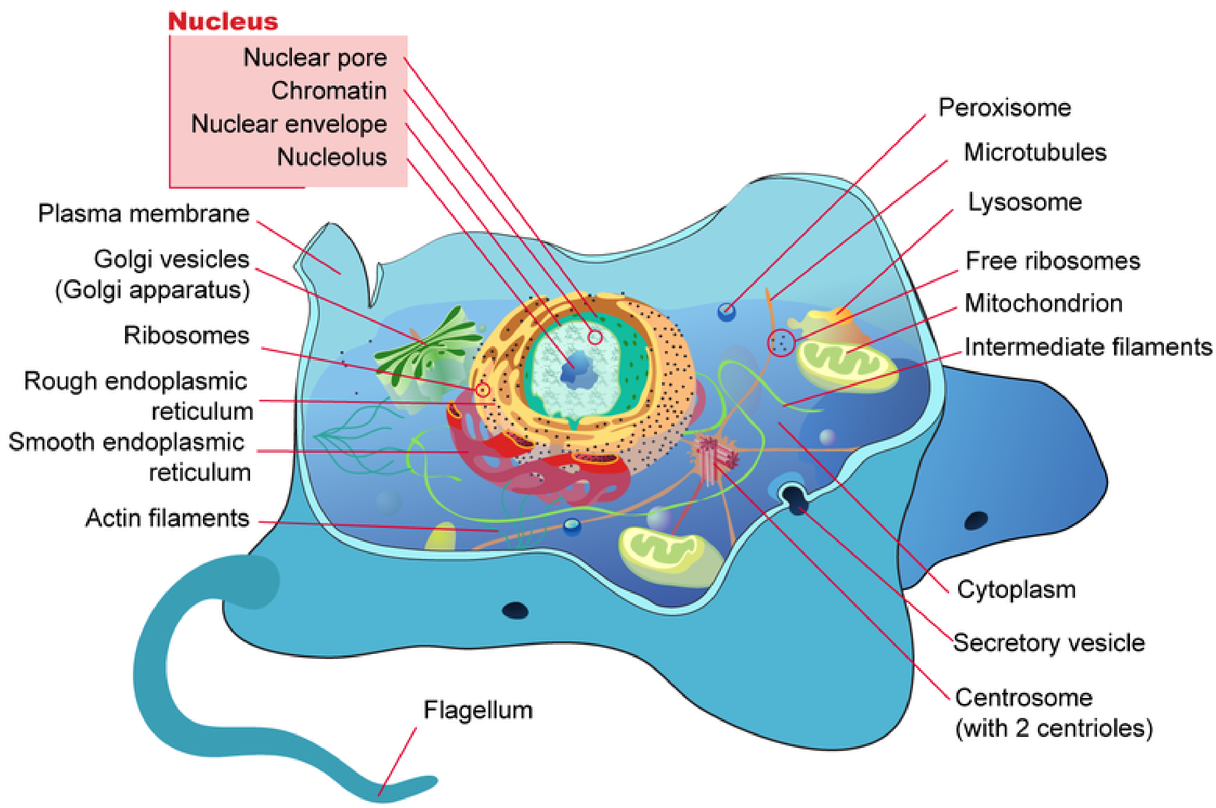


FIGURE 3.4
Model of a eukaryotic cell: animal cell

## Specialized Cells

All living cells have certain things in common. Besides having the basic parts described above, all cells can perform the same basic functions. For example, all cells can use energy, respond to their environment, and reproduce. However, cells may also have special functions. Multicellular organisms such as you have many different types of specialized cells. Each specialized cell has a particular job. Cells with special functions generally have a shape that suits them for that job.

**Figure** 3.5 shows four examples of specialized cells. Each type of cell in the figure has a different function. It also has a shape that helps it perform that function.

- The function of a nerve cell is to carry messages to other cells. It has many long “arms” that extend outward from the cell. The "arms" let the cell pass messages to many other cells at once.
- The function of a red blood cell is to carry oxygen to other cells. A red blood cell is small and smooth. This helps it slip through small blood vessels. A red blood cell is also shaped like a fattened disc. This gives it a lot of surface area for transferring oxygen.
- The function of a sperm cell is to swim through fluid to an egg cell. A sperm cell has a long tail that helps it swim.

- The function of a pollen cell is to pollinate flowers. The pollen cells in the figure have tiny spikes that help them stick to insects such as bees. The bees then carry the pollen cells to other flowers for pollination.

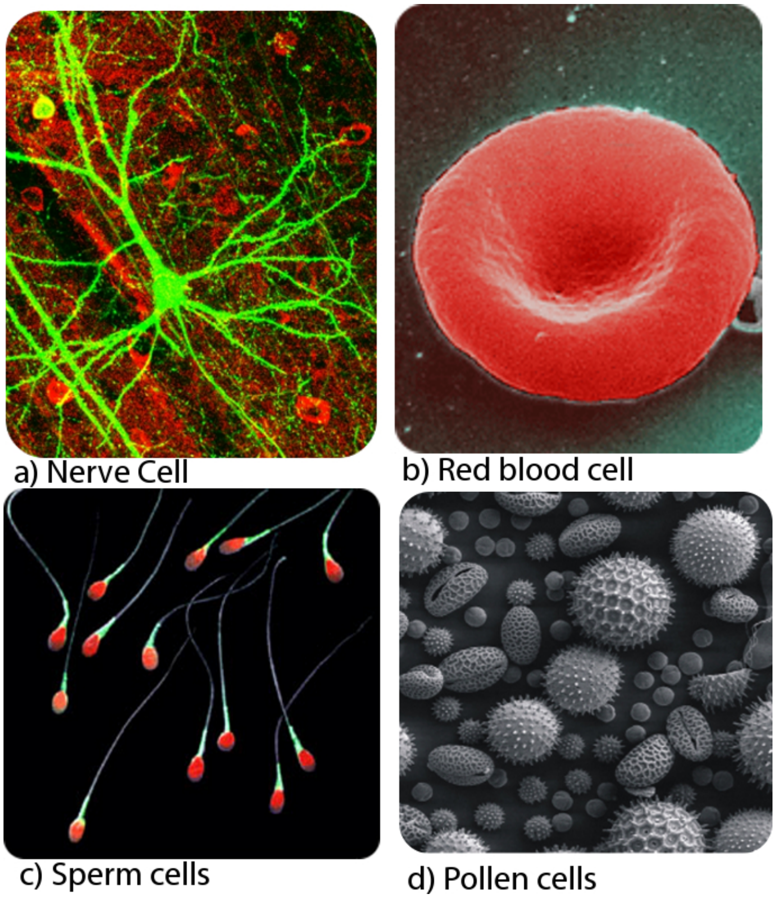


FIGURE 3.5
Examples of specialized cells include (a) nerve cells, (b) red blood cells, (c) sperm cells, and (d) pollen cells

## Levels of Organization

Cells and organelles are made of biochemical molecules. These include nucleic acids and proteins. Molecules, in turn, are made of atoms. **Figure** 3.6 shows these different levels of organization in living things.

As you can see in **Figure** 3.6, living things also have levels of organization higher than the cell. These higher levels are found only in multicellular organisms with specialized cells.

- Specialized cells may be organized into tissues. A **tissue** is a group of cells of the same kind that performs the same function. For example, muscle cells are organized into muscle tissue. The function of muscle tissue is to contract in order to move the body or its parts.
- Tissues may be organized into organs. An **organ** is a structure composed of two or more types of tissue that work together to do a specific task. For example, the heart is an organ. It consists of muscle, nerve, and other types of tissues. Its task is to pump blood.
- Organs may be organized into organ systems. An **organ system** is a group of organs that work together to do the same job. For example, the heart is part of the cardiovascular system. This system also includes blood vessels and blood. The job of the cardiovascular system is to transport substances in blood to and from cells throughout the body.

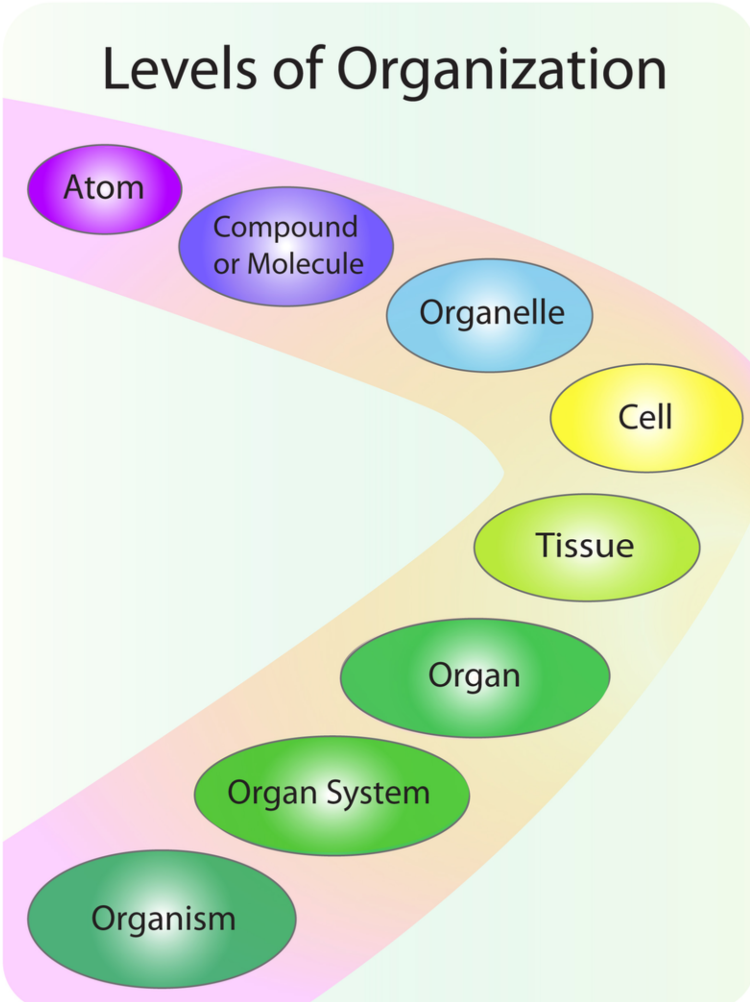


FIGURE 3.6
Levels of organization in living things

- Organ systems are organized into the organism. The different organ systems work together to carry out all the life functions of the individual. For example, cardiovascular and respiratory systems work together to provide the individual with oxygen and rid it of carbon dioxide.

## Why Cells Are So Small

Cells with different functions often vary in shape. They may also vary in size. However, all cells are very small. Even the largest organisms have microscopic cells. Cells are so small that their diameter is measured in micrometers. A micrometer is just one-millionth of a meter. Use the sliding scale at the following link to see how small cells and cell parts are compared with other objects.

http://learn.genetics.utah.edu/content/cells/scale/

Why are cells so small? The answer has to do with the surface area and volume of cells.

- To carry out life processes, a cell must be able to pass substances into and out of the cell. For example, it must be able to pass nutrients into the cell and waste products out of the cell. Anything that enters or leaves a cell has to go through the cell membrane on the surface of the cell.

- A bigger cell needs more nutrients and creates more wastes. As the size of a cell increases, its volume increases more quickly that its surface area. If the volume of a cell becomes too great, it won't have enough surface area to transfer all of its nutrients and wastes.

## Lesson Summary

- The cell theory states that all organisms consist of one or more cells; cells are alive and the site of all life processes; and all cells come from pre-existing cells.
- All cells have a cell membrane, cytoplasm, DNA, and ribosomes.
- Cells are either prokaryotic cells, which lack a nucleus, or eukaryotic cells, which have a nucleus.
- Cells may be specialized for different functions. They generally have a shape that suits their function.
- In multicellular organisms, specialized cells may be organized into tissues. Tissues may be organized into organs, and organs may be organized into organ systems. Organ systems work together to carry out all the functions of the whole organism.

## Lesson Review Questions

### Recall

1. Identify discoveries that led to the cell theory.
2. What are the four basic parts found in all cells?

### Apply Concepts

3. Apply the levels of organization of an organism to a human being. List the levels of organization in order from the atom to the organism, and give an example at each level.

### Think Critically

4. Compare and contrast prokaryotic and eukaryotic cells.
5. Use examples to show how cell shape relates to cell function.
6. Explain what limits the size of cells.

## Points to Consider

All eukaryotic cells have a nucleus and other organelles. Each organelle has a special job to do.

1. What do you think some of the special jobs of organelles might be?
2. Do you think that plant and animal cells might have different organelles?

# 3.2 Cell Structures

## Lesson Objectives

- Describe the structure and functions of the cell membrane.
- Identify the parts and roles of the cytoplasm and cytoskeleton.
- List organelles in eukaryotic cells and their special jobs.
- Describe structures found in plant cells but not animal cells.

## Lesson Vocabulary

- ATP (adenosine triphosphate)
- cell wall
- central vacuole
- centriole
- cytoskeleton
- endoplasmic reticulum (ER)
- Golgi apparatus
- lysosome
- mitochondrion (mitochondria, plural)
- vacuole
- vesicle

## Introduction

In some ways, a cell resembles a plastic bag full of Jell-O. Its basic structure is a cell membrane filled with cytoplasm. The cytoplasm of a eukaryotic cell is like Jell-O containing mixed fruit. It also contains a nucleus and other organelles.

**Figure** 3.7 shows the structures inside a typical eukaryotic cell. The model cell in the figure represents an animal cell. Refer to the model as you read about the structures below. You can also explore the structures in the interactive animal cell at this link:

## Cell Membrane

The cell membrane is like the bag holding the Jell-O. It encloses the cytoplasm of the cell. It forms a barrier between the cytoplasm and the environment outside the cell. The function of the cell membrane is to protect and support the cell. It also controls what enters or leaves the cell. It allows only certain substances to pass through. It keeps other substances inside or outside the cell.

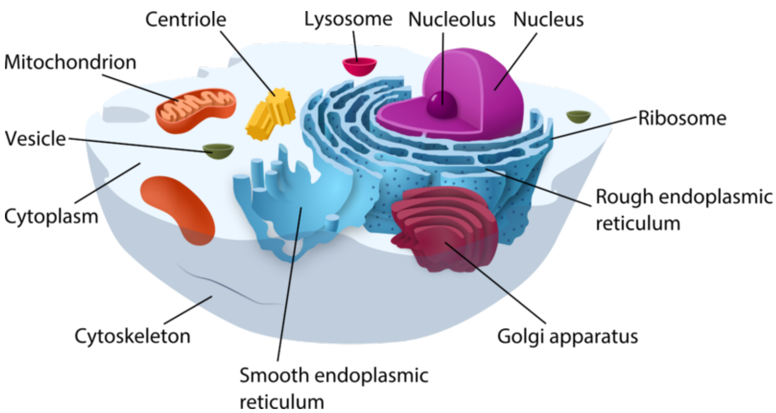


FIGURE 3.7
Model of an animal cell

### Structure of the Cell Membrane

The structure of the cell membrane explains how it can control what enters and leaves the cell. The membrane is composed mainly of two layers of phospholipids. **Figure** 3.8 shows how the phospholipids are arranged in the cell membrane. Each phospholipid molecule has a head and two tails. The heads are "water loving" (hydrophilic), and the tails are "water fearing" (hydrophobic). The water-loving heads are on the outer surfaces of the cell membrane. They point toward the watery cytoplasm within the cell or the watery fluid that surrounds the cell. The water-fearing tails are in the middle of the cell membrane.

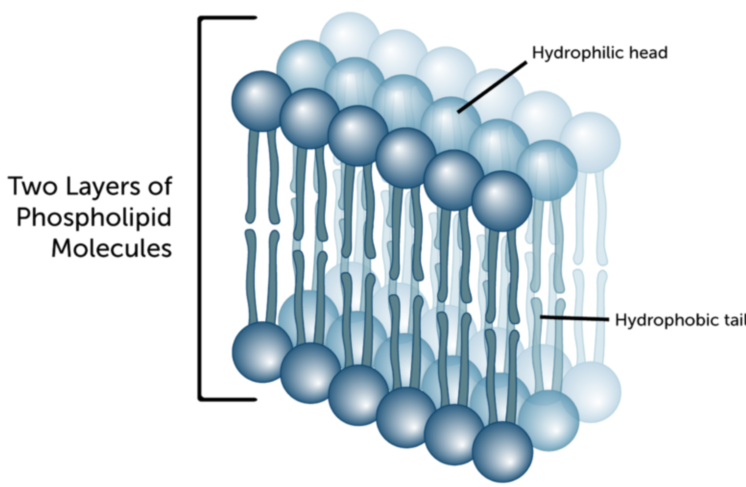


FIGURE 3.8
Arrangement of phospholipids in a cell membrane

### How the Cell Membrane Works

Hydrophobic molecules "like" to be near other hydrophobic molecules. They "fear" being near hydrophilic molecules. The opposite is true of hydrophilic molecules. They "like" to be near other hydrophilic molecules. They "fear" being near hydrophobic molecules. These "likes" and "fears" explain why some molecules can pass through the cell membrane while others cannot.

- Hydrophobic molecules can pass through the cell membrane. That's because they like the hydrophobic interior of the membrane and fear the hydrophilic exterior of the membrane.

- Hydrophilic molecules can't pass through the cell membrane. That's because they like the hydrophilic exterior of the membrane and fear the hydrophobic interior of the membrane.

You can see how this works in the video at this link: http://www.youtube.com/watch?v=p6NNEetG0Cw .


MEDIA

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URL: http://www.ck12.org/flx/render/embeddedobject/149613

## Cytoplasm and Cytoskeleton

Cytoplasm is everything inside the cell membrane (except the nucleus if there is one). It includes the watery, gel-like cytosol. It also includes other structures. The water in the cytoplasm makes up about two-thirds of the cell's weight. It gives the cell many of its properties.

### Roles of Cytoplasm

Why does a cell have cytoplasm? Cytoplasm has several important functions. These include:

- suspending cell organelles.
- pushing against the cell membrane to help the cell keep its shape.
- providing a site for many of the biochemical reactions of the cell.

### Cytoskeleton

Crisscrossing the cytoplasm is a structure called the **cytoskeleton**. It consists of thread-like filaments and tubules. The cytoskeleton is like a cellular "skeleton." It helps the cell keep its shape. It also holds cell organelles in place within the cytoplasm.

**Figure** 3.9 shows several cells. In the figure, the filaments of their cytoskeletons are colored green. The tubules are colored red. The blue dots are the cell nuclei.

## Organelles

Eukaryotic cells contain a nucleus and several other types of organelles. These structures carry out many vital cell functions.

### Nucleus

The nucleus is the largest organelle in a eukaryotic cell. It contains most of the cell's DNA. DNA, in turn, contains the genetic code. This code "tells" the cell which proteins to make and when to make them. You can see a diagram of a cell nucleus in Figure 3.10. Besides DNA, the nucleus contains a structure called a nucleolus. Its function is to

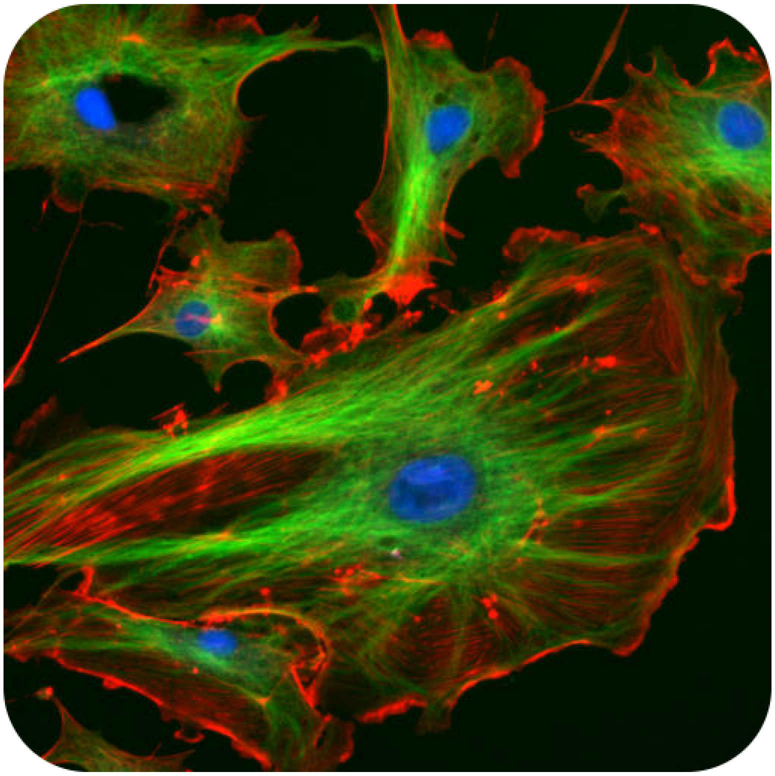

FIGURE 3.9
Cytoskeleton and nuclei of cells

form ribosomes. The membrane enclosing the nucleus is called the nuclear envelope. The envelope has tiny holes, or pores, in it. The pores allow substances to move into and out of the nucleus.

### Mitochondrion

The **mitochondrion (mitochondria, plural)** is an organelle that makes energy available to the cell. It's like the power plant of a cell. It uses energy in glucose to make smaller molecules called **ATP (adenosine triphosphate)**. ATP packages energy in smaller amounts that cells can use.

Think about buying a bottle of water from a vending machine. The machine takes only quarters, and you have only dollar bills. The dollar bills won't work in the vending machine. Glucose is like a dollar bill. It contains too much energy for cells to use. ATP is like a quarter. It contains just the right amount of energy for use by cells.

### Ribosomes

A ribosome is a small organelle where proteins are made. It's like a factory in the cell. It gathers amino acids and joins them together into proteins. Unlike other organelles, the ribosome is not surrounded by a membrane. As a result, some scientists do not classify it as an organelle. Ribosomes may be found floating in the cytoplasm. Some ribosomes are located on the surface of another organelle, the endoplasmic reticulum.

### Endoplasmic Reticulum

The **endoplasmic reticulum (ER)** is an organelle that helps make and transport proteins and lipids. It's made of folded membranes. Bits of membrane can pinch off to form tiny sacs called vesicles. The vesicles carry proteins or lipids away from the ER.

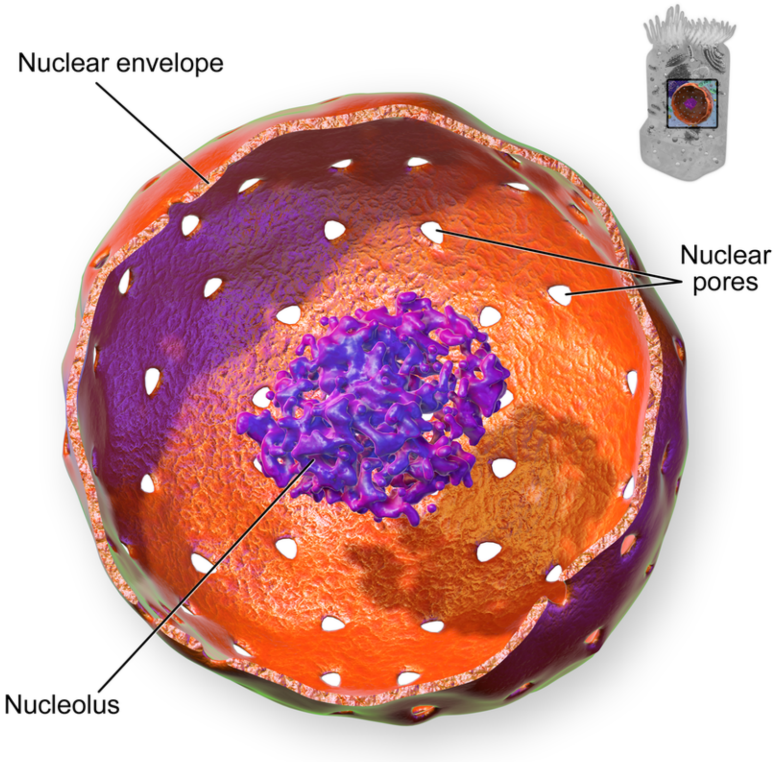


FIGURE 3.10
Nucleus of a eukaryotic cell

There are two types of endoplasmic reticulum. They are called rough endoplasmic reticulum (RER) and smooth endoplasmic reticulum (SER). Both types are shown in **Figure** 3.11.

NOTE: Crop to include only part ’a’ of the original image.]

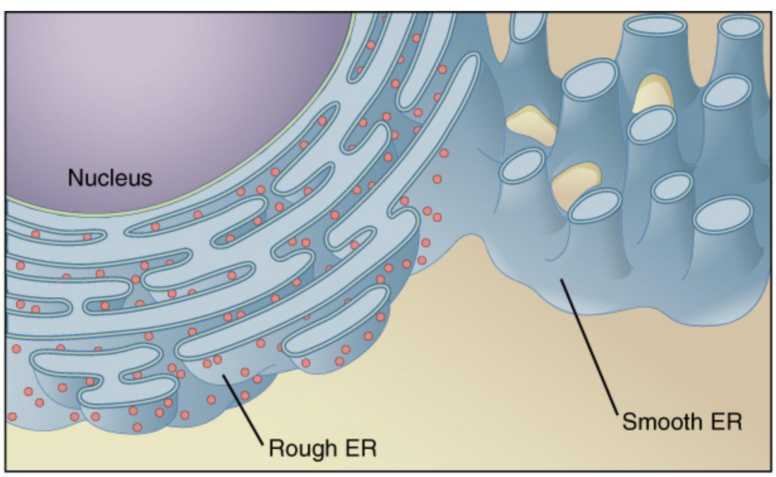


FIGURE 3.11
RER and SER are located outside the cell nucleus. The red dots on the RER are ribosomes.

### Golgi Apparatus

The **Golgi apparatus** is a large organelle that sends proteins and lipids where they need to go. It’s like a post office. It receives molecules from the endoplasmic reticulum. It packages and labels the molecules. Then it sends them where they are needed. Some molecules are sent to different parts of the cell. Others are sent to the cell membrane for transport out of the cell. Small bits of membrane pinch off the Golgi apparatus to enclose and transport the proteins and lipids. You can see a Golgi apparatus at work in this animation:

http://www.johnkyrk.com/golgiAlone.html

### Vesicles and Vacuoles

Both **vesicles** and **vacuoles** are sac-like organelles. They store and transport materials in the cell. They are like movable storage containers.

- Some vacuoles are used to isolate materials that are harmful to the cell. Other vacuoles are used to store needed substances such as water.
- Vesicles are much smaller than vacuoles and have a variety of functions. Some vesicles pinch off from the membranes of the endoplasmic reticulum and Golgi apparatus. These vesicles store and transport proteins and lipids. Other vesicles are used as chambers for biochemical reactions.

### Lysosomes

A **lysosome** is an organelle that recycles unneeded molecules. It uses enzymes to break down the molecules into their components. Then the components can be reused to make new molecules. Lysosomes are like recycling centers.

### Centrioles

**Centrioles** are organelles that are found only in animal cells. They are located near the nucleus. They help organize the DNA in the nucleus before cell division takes place. They ensure that the DNA divides correctly when the cell divides.

## Special Structures in Plant Cells

All but one of the structures described above are found in plant cells as well as animal cells. The only exception is centrioles, which are not found in plant cells. Plant cells have three additional structures that are not found in animals cells. These include a cell wall, large central vacuole, and organelles called plastids. You can see these structures in the model of a plant cell in **Figure** 3.12. You can also see them in the interactive plant cell at this link:

http://www.cellsalive.com/cells/cell_model.htm

### Cell Wall

The **cell wall** is a rigid layer that surrounds the cell membrane of a plant cell. It's made mainly of the complex carbohydrate called cellulose. The cell wall supports and protects the cell. The cell wall isn't solid like a brick wall. It has tiny holes in it called pores. The pores let water, nutrients, and other substances move into and out of the cell.

### Central Vacuole

Most plant cells have a large **central vacuole**. It can make up as much as 90 percent of a plant cell's total volume. The central vacuole is like a large storage container. It may store substances such as water, enzymes, and salts. It

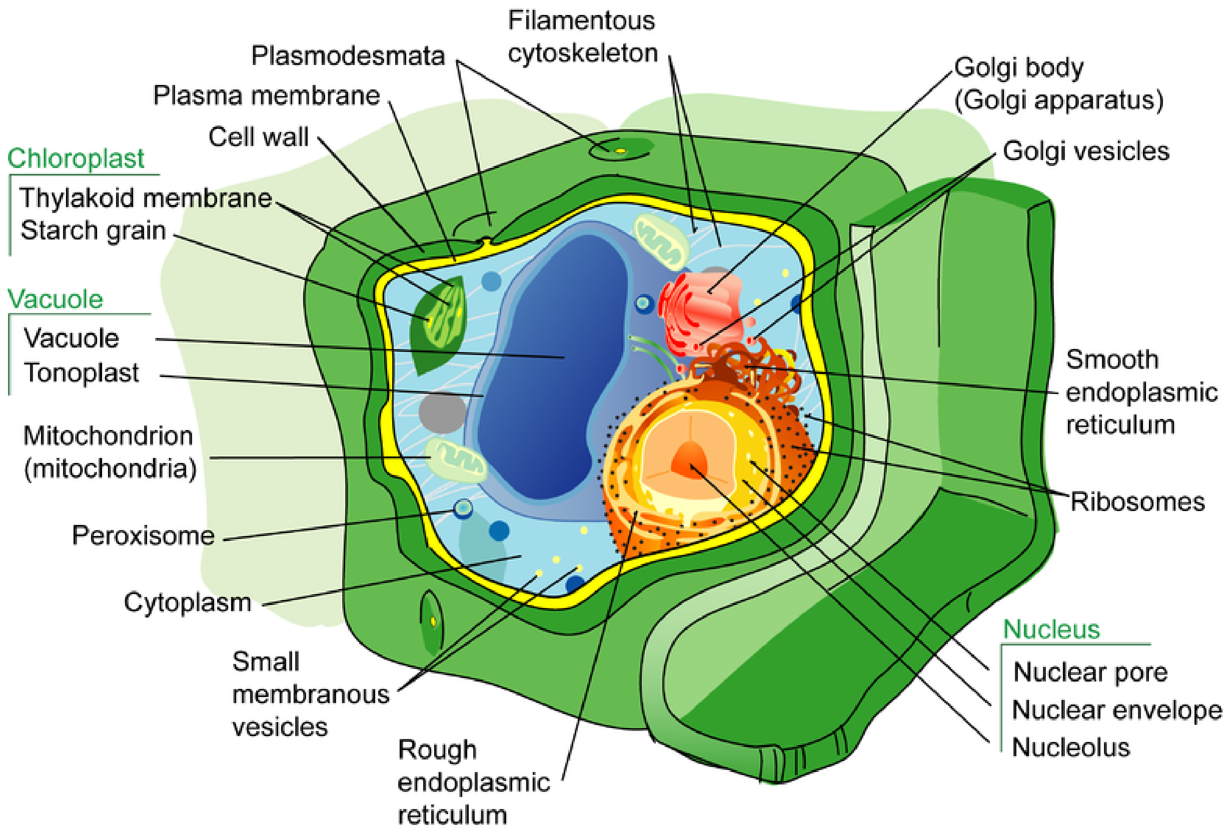


FIGURE 3.12
Model of a plant cell

may have other roles as well. For example, the central vacuole helps stems and leaves hold their shape. It may also contain pigments that give flowers their colors.

### Plastids

Plastids are organelles in plant cells that may have various jobs. The main types of plastids are chloroplasts, chromoplasts, and leucoplasts.

- Chloroplasts are plastids that contain chlorophyll. Chlorophyll is a green pigment. It gives plants their green color. Photosynthesis takes place in chloroplasts. They capture sunlight and use its energy to make glucose.
- Chromoplasts are plastids that contain other pigments. These other pigments give flowers and fruits their colors.
- Leucoplasts are plastids that make or store other molecules. For example, some leucoplasts make amino acids. Other leucoplasts store starch or oil.

## Lesson Summary

- The cell membrane consists of two layers of phospholipids. It encloses the cytoplasm and controls what enters and leaves the cell.
- The cytoplasm consists of watery cytosol and cell structures. It has several functions. The cytoskeleton is the "skeleton" of the cell. It helps the cell keep its shape.
- Eukaryotic cells contain a nucleus and other organelles. They include the mitochondrion, endoplasmic reticulum, Golgi apparatus, vesicles, vacuoles, lysosomes, and—in animal cells—centrioles. Each type of organelle has a special function.
- Plant cells have several structures not found in animal cells. They include a cell wall, large central vacuole, and plastids such as chloroplasts.

## Lesson Review Questions

### Recall

1. Describe the composition of the cytoplasm and list its functions.
2. What is the cytoskeleton? What does it do?
3. Identify three organelles in eukaryotic cells and state their roles.

### Apply Concepts

4. Why is the nucleus like the control center of a cell?

### Think Critically

5. Explain how the structure of the cell membrane controls what enters and leaves the cell.
6. Compare and contrast plant and animal cells.

## Points to Consider

Molecules that enter or leave a cell must pass through the cell membrane. Some of these molecules may be hydrophilic. Other may be too large to squeeze between the phospholipid molecules of the membrane.

1. How might hydrophilic molecules pass through the cell membrane?
2. How might very large molecules pass through the cell membrane?

# 3.3 References


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3. Mariana Ruiz Villarreal (User:LadyofHats/Wikimedia Commons). Diagram of a typical Prokaryotic cell . Public Domain
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7. User:Kelvinsong/Wikimeida Commons. Model of an animal cell . Public Domain
8. Christopher Auyeung. Phospholipids in a membrane . CC BY-NC 3.0
9. Courtesy of the National Institute of Health (NIH). Cytoskeleton and nuclei of cells . Public Domain
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11. OpenStax College. Drawing of the endoplasmic reticulum . CC-BY 3.0
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# CHAPTER 4 MS Cell Functions

## Chapter Outline



This window screen has a fly on it. In a way, the window screen is like a cell membrane. It lets some things pass through while keeping other things out. Air molecules and raindrops can pass through the screen, but larger objects like the fly cannot. In the first lesson of this chapter, you'll learn about different ways that substances can pass through the cell membrane. You'll find out how the cell membrane lets some substances pass through while keeping other substances out.

# 4.1 Transport

## Lesson Objectives

- Describe the structure of the cell membrane.
- Identify ways that passive transport occurs.
- Define and give examples of active transport.

## Lesson Vocabulary

- active transport
- concentration
- diffusion
- facilitated diffusion
- osmosis
- passive transport
- simple diffusion
- transport
- transport protein
- vesicle transport

## Introduction

The cell is the site of all of the basic biochemical processes that keep organisms alive. To do its work, the cell needs substances such as oxygen, water, and glucose. The cell also must get rid of substances, including wastes such as carbon dioxide. In addition, harmful substances must be kept out of the cell. Controlling what enters or leaves a cell is an important role of the cell membrane.

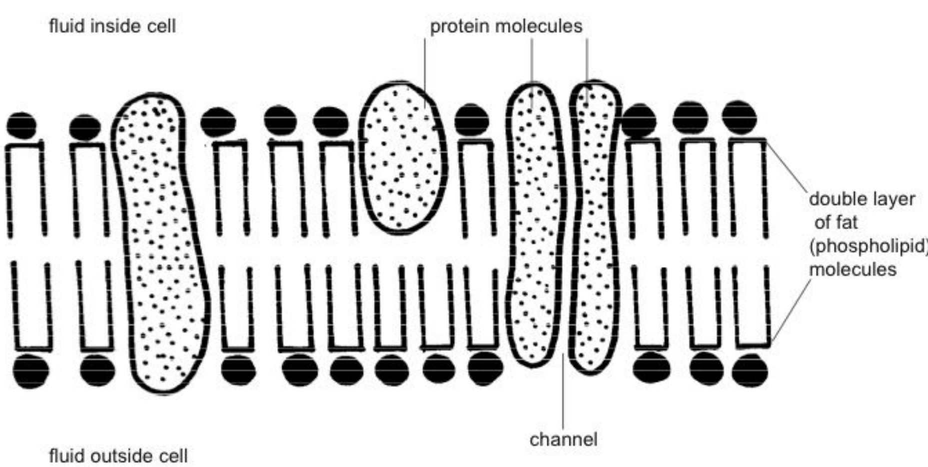
## The Cell Membrane

You've probably blown soap bubbles like the child in **Figure** 4.1. In some ways, the thin film of soap molecules that forms a bubble resembles the cell membrane. Like the soap film, the cell membrane consists of a thin skin of molecules.

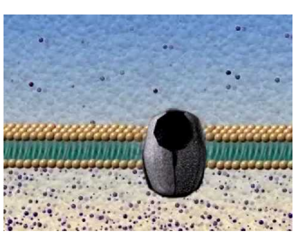
You can see a model of the cell membrane in **Figure** below. The molecules that make up the cell membrane are mainly phospholipids. There are two layers of phospholipids. They are arranged so the lipid tails are on the inside of the membrane. They make the interior of the membrane hydrophobic, or "water fearing". The lipid heads point toward the outside of the membrane. The make the outer surfaces of the membrane hydrophilic, or "water

FIGURE 4.1
Blowing soap bubbles

loving". Different types of proteins are embedded in the lipid layers. The proteins are needed to help transport many substances across the membrane.




The passage of a substance through a cell membrane is called **transport**. There are two basic ways that transport can occur: passive transport and active transport. For a good video introduction to passive and active transport, click on this link: http://www.youtube.com/watch?v=kfy92hdaAH0 .



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## Passive Transport

**Passive transport** occurs when a substance passes through the cell membrane without needing any energy to pass through. This happens when a substance moves from an area where it is more concentrated to an area where it is less concentrated. **Concentration** is the number of particles of a substance in a given volume. Let's say you dissolve a teaspoon of salt in a cup of water. Then you dissolve two teaspoons of salt in another cup of water. The second solution will have a higher concentration of salt.

Why does passive transport require no energy? A substance naturally moves from an area of higher to lower concentration. This is known as moving down the concentration gradient. The process is called **diffusion**. It's a little like a ball rolling down a hill. The ball naturally rolls from a higher to lower position without any added energy. You can see diffusion if you place a few drops of food coloring in a pan of water. Even without shaking or stirring, the food coloring gradually spreads throughout the water in the pan. Some substances can also diffuse through a cell membrane. This can occur in two ways: simple diffusion or facilitated diffusion.

### Simple Diffusion

**Simple diffusion** occurs when a substance diffuses through a cell membrane without any help from other molecules. The substance simply passes through tiny spaces in the membrane. It moves from the side of the membrane where it is more concentrated to the side where it is less concentrated. You can see how this happens in **Figure** 4.2.

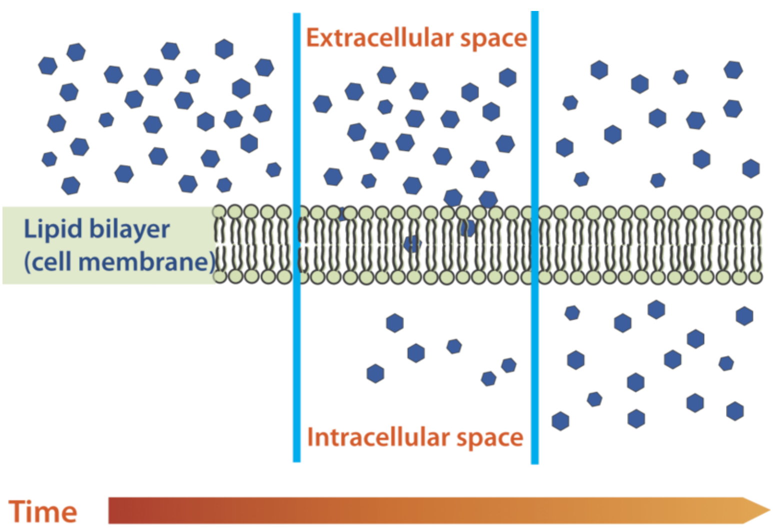



FIGURE 4.2
Simple diffusion of molecules (blue) from outside to inside a cell membrane

Substances that cross cell membranes by simple diffusion must squeeze between the lipid molecules in the membrane. As a result, the diffusing molecules must be very small. Oxygen ($O_2$) and carbon dioxide ($CO_2$) are examples of molecules that can cross cell membranes this way.

- When you breathe in, oxygen is more concentrated in the air in your lungs than it is in your blood. So oxygen diffuses from your lungs to your blood.
- The reverse happens with carbon dioxide. Carbon dioxide is more concentrated in your blood than it is in the air in your lungs. So carbon dioxide diffuses out of your blood to your lungs.

### Facilitated Diffusion

Hydrophilic molecules and very large molecules can't pass through the cell membrane by simple diffusion. They need help to pass through the membrane. The help is provided by proteins called **transport proteins**. This process is known as **facilitated diffusion**.

There are two types of transport proteins: channel proteins and carrier proteins. They work in different ways. You can see how they work in **Figure** 4.3.

- A channel protein forms a tiny hole called a pore in the cell membrane. This allows water or hydrophilic molecules to bypass the hydrophobic interior of the membrane.
- A carrier protein binds with a diffusing molecule. This causes the carrier protein to change shape. As it does, it carries the molecule across the membrane. This allows large molecules to pass through the cell membrane.

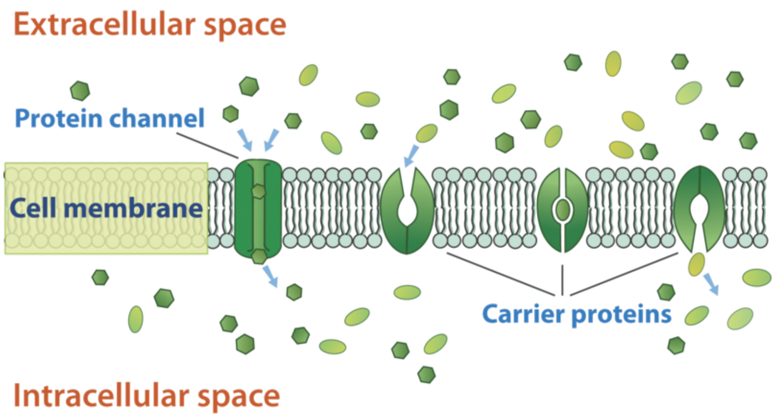



FIGURE 4.3
Transport proteins

### Osmosis

**Osmosis** is the special case of the diffusion of water. It's an important means of transport in cells because the fluid inside and outside cells is mostly water. Water can pass through the cell membrane by simple diffusion, but it can happen more quickly with the help of channel proteins. Water moves in or out of a cell by osmosis until its concentration is the same on both sides of the cell membrane.

## Active Transport

**Active transport** occurs when a substance passes through the cell membrane with the help of extra energy. This happens when a substance moves from an area where it is less concentrated to an area where it is more concentrated. This is the opposite of diffusion. The substance moves up, instead of down, the concentration gradient. Like rolling a ball uphill, this requires an input of energy. The energy comes from the molecule named ATP (adenosine triphosphate). The energy allows special transport proteins called pumps to move substances to areas of higher concentration. An example is the sodium-potassium pump.

### Sodium-Potassium Pump

Sodium and potassium are two of the most important elements in living things. They are present mainly as positively charged ions dissolved in water. The sodium-potassium pump moves sodium ions ($Na^+$) out of the cell and potassium ions ($K^+$) into the cell. In both cases, the ions are moving from an area of lower to higher concentration. Energy in ATP is needed for this "uphill" process. **Figure** 4.4 shows how this pump works. Trace these steps from left to right in the figure:

1. Three sodium ions inside the cell bind with a carrier protein in the cell membrane.
2. The carrier protein receives a phosphate from ATP. This forms ADP (adenosine diphosphate) and releases energy.
3. The energy causes the carrier protein to change shape. As it does, it pumps the three sodium ions out of the cell.
4. Two potassium ions outside the cell next bind with the carrier protein. Then the process reverses, and the two potassium ions are pumped into the cell.

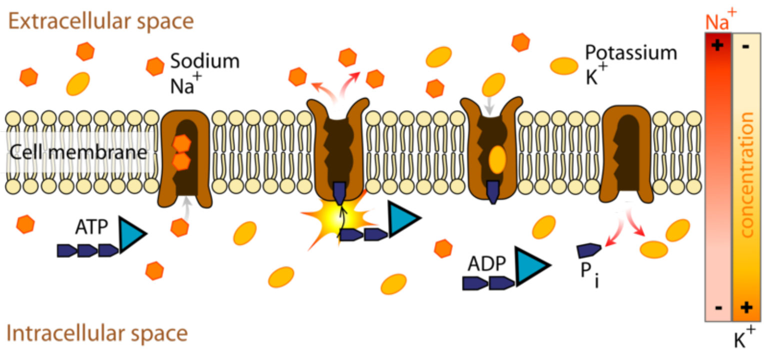


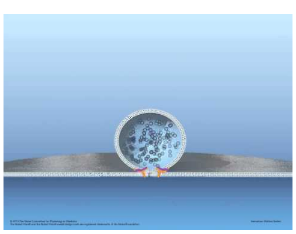

FIGURE 4.4

Sodium-potassium pump

## Vesicle Transport

Some substances are too big to be pumped across the cell membrane. They may enter or leave the cell by **vesicle transport**. This takes energy, so it's another form of active transport. You can see how vesicle transport occurs in **Figure** 4.5.

- Vesicle transport out of the cell is called exocytosis. A vesicle containing the substance moves through the cytoplasm to the cell membrane. Then the vesicle fuses with the cell membrane and releases the substance outside the cell. You can watch this happening in this very short animation: http://www.youtube.com/watch?v=V2FrQB6rX34 .



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- Vesicle transport into the cell is called endocytosis. The cell membrane engulfs the substance. Then a vesicle pinches off from the membrane and carries the substance into the cell.

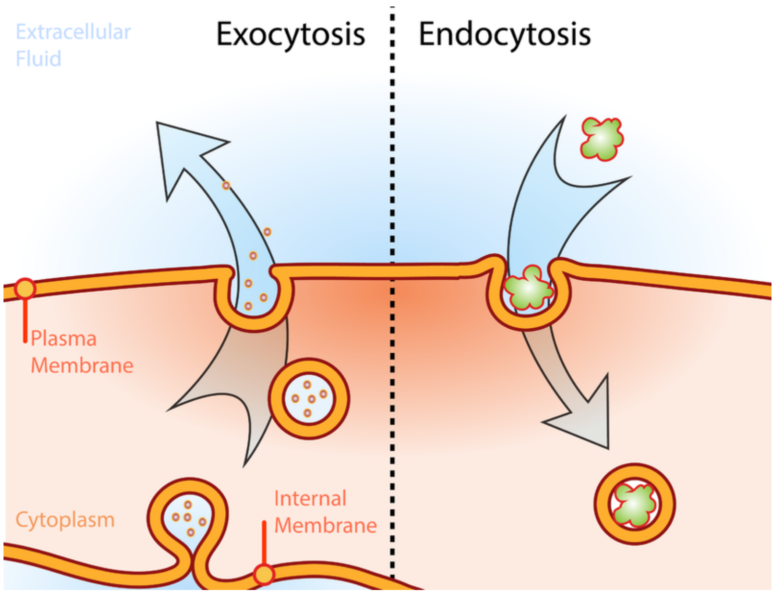



FIGURE 4.5
Vesicle transport

## Lesson Summary

- The cell membrane consists of two layers of phospholipids. Transport proteins are embedded in the layers. The movement of substances across the cell membrane may be by passive or active transport.
- Passive transport requires no energy because it moves substances by diffusion, from an area of higher to lower concentration. This happen by simple diffusion or by facilitated diffusion, which requires the help of transport proteins.
- Active transport requires energy because it moves substances from an area of lower to higher concentration. An example is the sodium-potassium pump. Another form of active transport is vesicle transport, which is needed for very large molecules.

## Lesson Review Questions

### Recall

1. Describe the cell membrane.
2. Define diffusion.
3. What is simple diffusion? Give an example.
4. What is osmosis?

### Apply Concepts

5. Assume that the concentration of a substance is lower outside than inside a cell. In which direction—into or out of the cell—can passive transport of the substance occur? Explain your answer.

### Think Critically

6. Compare and contrast passive and active transport.
7. Explain how channel proteins and carrier proteins facilitate diffusion across a cell membrane.

## Points to Consider

Glucose is a substance that passes across cell membranes by facilitated diffusion. All cells need glucose for energy.

1. Where does glucose come from?
2. What process produces glucose?

# 4.2 Photosynthesis

## Lesson Objectives

- Define photosynthesis, and identify photosynthetic organisms.
- Describe the chloroplast and its role in photosynthesis.
- Outline what happens during the two stages of photosynthesis.

## Lesson Vocabulary

- autotroph
- Calvin cycle
- chlorophyll
- chloroplast
- glucose
- heterotroph
- light reactions
- photosynthesis
- stroma
- thylakoid

## Introduction

All living things need energy. You can often see energy at work in living things. Look at the hummingbird and jellyfish in **Figure** 4.6. Both of them are obviously using energy. Living things constantly use energy in less obvious ways as well. Inside every cell, all living things need energy to carry out life processes. Life runs on chemical energy. Where does this chemical energy come from?

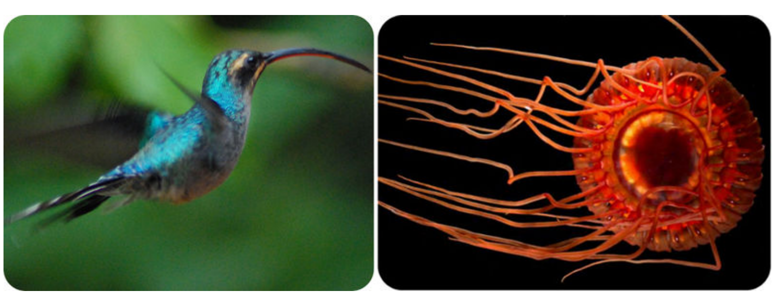


FIGURE 4.6

Some ways living things use energy are to move and to produce light. On the left, a hummingbird's wings are a blur of motion. On the right, a jellyfish glows with its own light.

## Making Glucose

Chemical energy that organisms need comes from food. The nearly universal food for life is the sugar glucose. **Glucose** is a simple carbohydrate with the chemical formula $C_6H_{12}O_6$. The glucose molecule stores chemical energy in a concentrated, stable form. In your body, glucose is the form of energy that is carried in your blood and taken up by each of your trillions of cells.

### What Is Photosynthesis?

What is the source of glucose for living things? It is made by plants and certain other organisms. The process in which glucose is made using energy in light is **photosynthesis**. This process requires carbon dioxide and water. It produces oxygen in addition to glucose.

Photosynthesis consists of many chemical reactions. Overall, the reactions of photosynthesis can be summed up by this chemical equation:

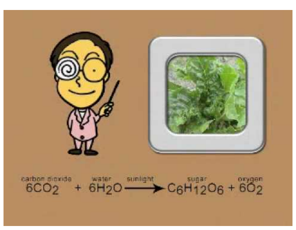
$$6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

In words, this means that six molecules of carbon dioxide ($CO_2$) combine with six molecules of water ($H_2O$) in the presence of light energy. This produces one molecule of glucose ($C_6H_{12}O_6$) and six molecules of oxygen ($O_2$).

Use this interactive animation to learn more about photosynthesis:

http://www.pbs.org/wgbh/nova/nature/photosynthesis.html

Click on this link for a song about photosynthesis to reinforce the basic ideas: http://www.youtube.com/watch?v=C1_uez5WX1o .

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### Autotrophs vs. Heterotrophs

Types of organisms that make glucose by photosynthesis are pictured in **Figure** 4.7. They include plants, plant-like protists such as algae, and some kinds of bacteria. Living things that make glucose are called **autotrophs** ("self feeders"). All other living things obtain glucose by eating autotrophs (or organisms that eat autotrophs). These living things are called **heterotrophs** ("other feeders").

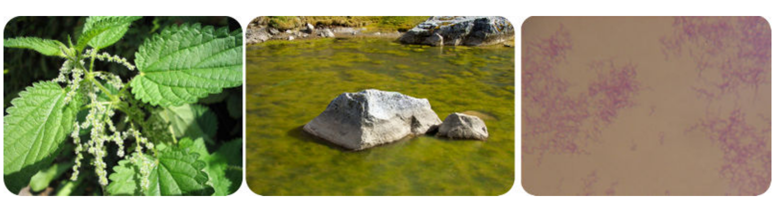


FIGURE 4.7

Photosynthetic organisms include plants, algae, and some bacteria.

## Site of Photosynthesis: The Chloroplast

In plants and algae, photosynthesis takes place in chloroplasts. (Photosynthetic bacteria have other structures for this purpose.) A **chloroplast** is a type of plastid, or plant organelle. It contains the green pigment known as **chlorophyll**. The presence of chloroplasts in plant cells is one of the major ways they differ from animal cells. You can see chloroplasts in plant cells **Figure** 4.8.

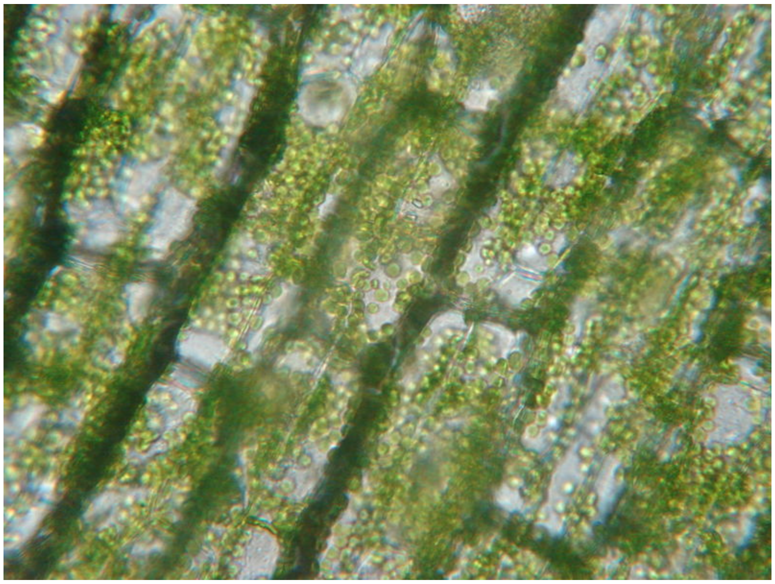


FIGURE 4.8

The small green, circular structures in the plant cells pictured here are chloroplasts.

### Chloroplast Structure

The structure of a chloroplast is shown in **Figure** 4.9. The chloroplast is surrounded by two membranes. Inside the chloroplast are stacks of flattened sacs of membrane, called **thylakoids**. The thylakoids contain chlorophyll. Surrounding the thylakoids is a space called the **stroma**. The stroma is filled with watery ("aqueous") fluid.

### How the Chloroplast Gets Raw Materials

In plants, most chloroplasts are found in the leaves. Therefore, all the raw materials needed for photosynthesis must be present in the leaves. These materials include light, water, and carbon dioxide. The shape of the leaves gives them a lot of surface area to absorb light for photosynthesis. Roots take up water from the soil. Stems carry the water from the roots to the leaves. Carbon dioxide enters the leaves through tiny openings called stomata. (The oxygen released during photosynthesis also exits the leaves through the stomata.)

## Stages of Photosynthesis

Photosynthesis occurs in two stages, called the light reactions and the Calvin cycle. **Figure** 4.10 sums up what happens in these two stages. Both stages are described below.

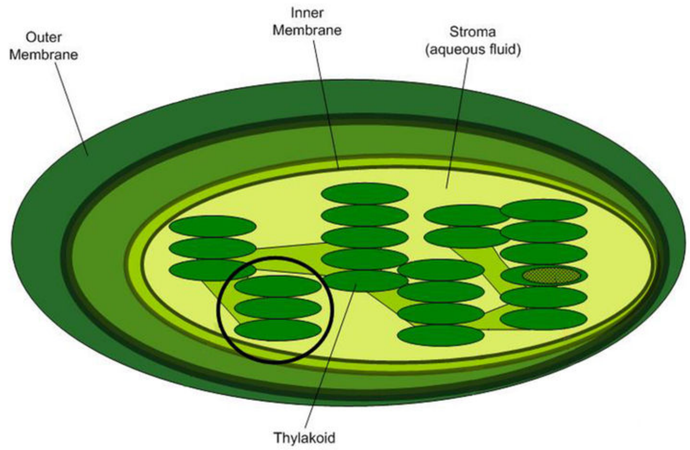



FIGURE 4.9
Chloroplast

### Light Reactions

The **light reactions** occur in the first stage of photosynthesis. This stage takes place in the thylakoid membranes of the chloroplast. In the light reactions, energy from sunlight is absorbed by chlorophyll. This energy is temporarily transferred to two molecules: ATP and NADPH. These molecules are used to store the energy for the second stage of photosynthesis. The light reactions use water and produce oxygen.

### Calvin Cycle

The **Calvin cycle** occurs in the second stage of photosynthesis. This stage takes place in the stroma of the chloroplast. In the Calvin cycle, carbon dioxide is used to produce glucose (sugar) using the energy stored in ATP and NADPH. The energy is released from these molecules when ATP loses phosphate ($P_i$) to become ADP and NADPH loses hydrogen (H) to become $NADP^+$.

## Lesson Summary

- Most living things use glucose for energy. The process in which glucose is made using light energy is photosynthesis. Water and carbon dioxide are needed for this process, and oxygen is produced as a byproduct. Photosynthetic organisms include plants, algae, and some bacteria.
- In plants and algae, photosynthesis takes place in organelles called chloroplasts. Chloroplasts contain stacks of membranes called thylakoids, which contain chlorophyll. Thylakoids are surrounded by a fluid-filled space called stroma.
- Photosynthesis takes place in two stages: the light reactions and the Calvin cycle. The light reactions take place in the thylakoids. They capture light energy. The Calvin cycle takes place in the stroma. It uses the energy to produce glucose from carbon dioxide.

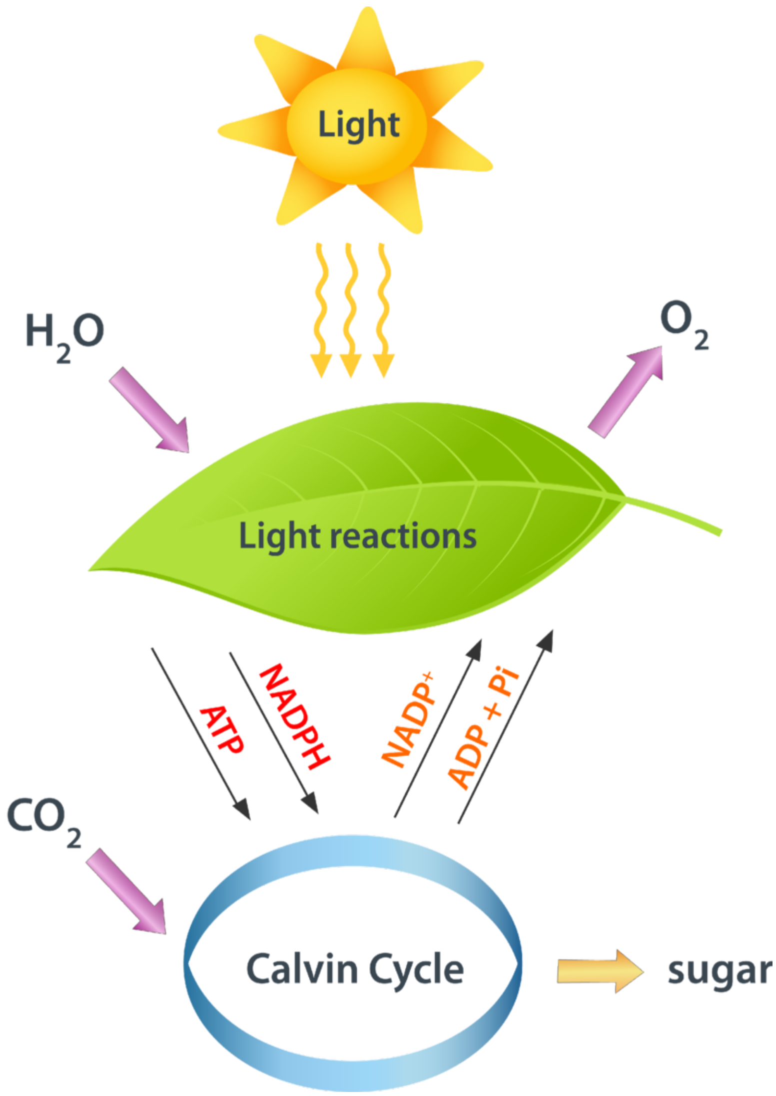



FIGURE 4.10
The light reactions and Calvin cycle of photosynthesis

## Lesson Review Questions

### Recall

1. What is glucose? Why is it important?
2. Write the overall chemical equation for photosynthesis. What does the equation mean in words?
3. Describe the structure and function of a chloroplast.
4. Identify what happens during the light reactions and the Calvin cycle.

### Apply Concepts

5. A plant in a pot of soil is placed in bright sunlight for 12 hours a day. The plant is located near an open window with good air circulation. If the plant is left alone for a month, will it produce glucose? Why or why not?

### Think Critically

6. Compare and contrast autotrophs and heterotrophs. Give examples of each type of living thing.
7. Explain how the raw materials needed for photosynthesis get to the site of photosynthesis in plants.

## Points to Consider

The flow of energy through living things begins with photosynthesis. This process stores energy from sunlight in the chemical bonds of glucose. All cells take up glucose for energy.

1. How do you think cells get energy from glucose?
2. How do they use that energy?

# 4.3 Cellular Respiration

## Lesson Objectives

- Summarize what happens during cellular respiration and where it takes place.
- Outline the three stages of cellular respiration and how much ATP is made in each stage.
- Explain how cellular respiration and photosynthesis are related.
- Describe two types of fermentation.
- Identify advantages of aerobic and anaerobic respiration.

## Lesson Vocabulary

- aerobic
- anaerobic
- cellular respiration
- electron transport
- fermentation
- glycolysis
- Krebs cycle

## Introduction

If you're like astronaut Chris Hadfield in **Figure** 4.11, you grab a piece of fruit when you need a boost of energy. Most fruits are good sources of glucose. Glucose is the simple sugar that living things use to store and transport energy. Glucose is taken up by all of your cells. However, cells don't use the energy in glucose directly. They first need to release the energy and store it in ATP, or adenosine triphosphate. The much smaller amount of energy stored in ATP is just right for fueling cell processes. How do your cells change glucose to ATP? It happens during cellular respiration.

## Using Glucose to Make ATP

**Cellular respiration** is the process in which cells break down glucose, release the stored energy, and use the energy to make ATP. For each glucose molecule that undergoes this process, up to 38 molecules of ATP are produced. Each ATP molecules forms when a phosphate is added to ADP, or adenosine diphosphate. This requires energy, which is stored in the ATP molecule. When cells need energy, a phosphate can be removed from ATP. This releases the energy and forms ADP again.

FIGURE 4.11
Astronaut Chris Hadfield eats a banana aboard the International Space Station.

### What Happens During Cellular Respiration?

Cellular respiration involves many biochemical reactions. However, the overall process can be summed up in a single chemical equation:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy (stored in ATP)}$$

Cellular respiration uses oxygen in addition to glucose. It releases carbon dioxide and water as waste products. Cellular respiration actually "burns" glucose for energy. However, it doesn't produce light or intense heat like burning a candle or log. Instead, it releases the energy slowly, in many small steps. The energy is used to form dozens of molecules of ATP.

### Where Does Cellular Respiration Take Place?

Cellular respiration takes place in the cells of all organisms. It occurs in autotrophs such as plants as well as heterotrophs such as animals. Cellular respiration begins in the cytoplasm of cells. It is completed in mitochondria. The mitochondrion is a membrane-enclosed organelle in the cytoplasm. It's sometimes called the "powerhouse" of the cell because of its role in cellular respiration. **Figure** 4.12 shows the parts of the mitochondrion involved in cellular respiration.

## Stages of Cellular Respiration

Cellular respiration occurs in three stages. The flow chart in Figure don't purge me shows the order in which the stages occur and how much ATP forms in each stage. The names of the stages are glycolysis, the Krebs cycle, and electron transport. Each stage is described below.

### Stage 1: Glycolysis

**Glycolysis** is the first stage of cellular respiration. It takes place in the cytoplasm of the cell. The world glycolysis means "glucose splitting". That's exactly what happens in this stage. Enzymes split a molecule of glucose into

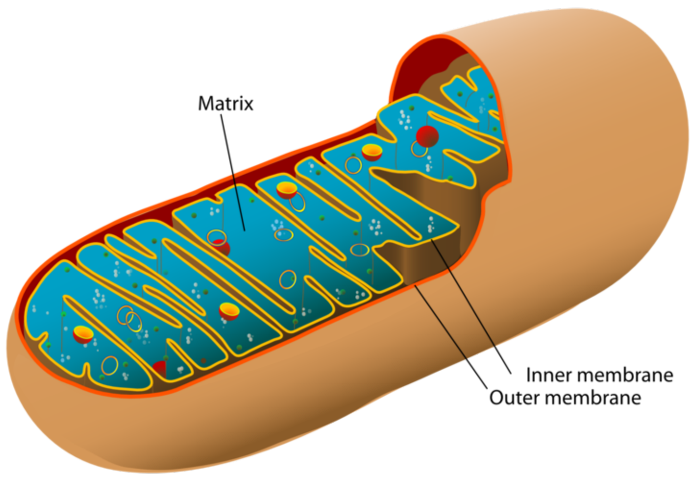



FIGURE 4.12
Cut-away view of a mitochondrion

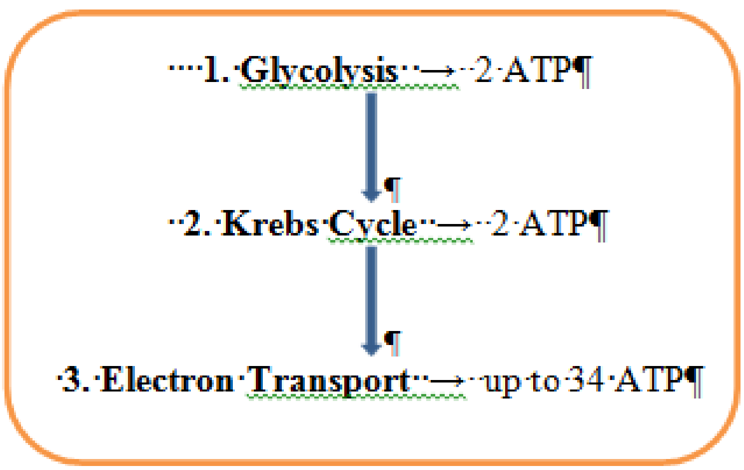



FIGURE 4.13

two smaller molecules called pyruvate. This results in a net gain of two molecules of ATP. Other energy-storing molecules are also produced. (Their energy will be used in stage 3 to make more ATP.) Glycolysis does not require oxygen. Anything that doesn't need oxygen is described as **anaerobic**.

### Stage 2: The Krebs Cycle

The pyruvate molecules from glycolysis next enter the matrix of a mitochondrion. That's where the second stage of cellular respiration takes place. This stage is called the **Krebs cycle**. During this stage, two more molecules of ATP are produced. Other energy-storing molecules are also produced (to be used to make more ATP in stage 3). The Krebs cycle requires oxygen. Anything that needs oxygen is described as **aerobic**. The oxygen combines with the carbon from the pyruvate molecules. This forms carbon dioxide, a waste product.

### Stage 3: Electron Transport

The third and final stage of cellular respiration is called **electron transport**. Remember the other energy-storing molecules from glycolysis and the Krebs cycle? Their energy is used in this stage to make many more molecules of ATP. In fact, during this stage, as many as 34 molecules of ATP are produced. Electron transport requires oxygen, so this stage is also aerobic. The oxygen combines with hydrogen from the energy-storing molecules. This forms water, another waste product.

## Cellular Respiration and Photosynthesis

Cellular respiration and photosynthesis are like two sides of the same coin. This is clear from the diagram in **Figure** 4.14. The products of photosynthesis are needed for cellular respiration. The products of cellular respiration are needed for photosynthesis. Together, the two processes store and release energy in virtually all living things.

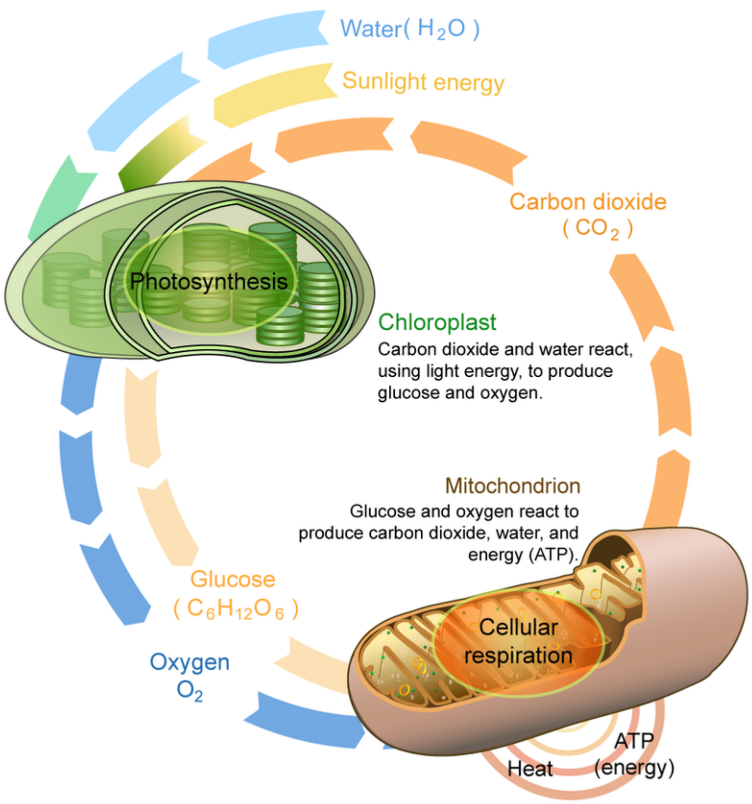



FIGURE 4.14
How photosynthesis and cellular respiration are related

## Fermentation

Some organisms can produce ATP from glucose anaerobically. One way this happens is called **fermentation**. Fermentation includes the glycolysis step of cellular respiration. However, it doesn't include the other, aerobic steps. There are two types of fermentation: lactic acid fermentation and alcoholic fermentation.

### Lactic Acid Fermentation

In lactic acid fermentation, glycolysis is followed by a step that produces lactic acid. This step forms additional molecules of ATP. Lactic acid fermentation occurs in some bacteria, including the bacteria in yogurt. The lactic acid gives unsweetened yogurt its sour taste.

Your own muscle cells can also undertake lactic acid fermentation. This occurs when the cells are working very hard. They use fermentation because they can't get oxygen fast enough for aerobic respiration to supply them with all the energy they need. The muscle cells of the hurdlers in **Figure** 4.15 are using lactic acid fermentation by the time the athletes reach finish line.

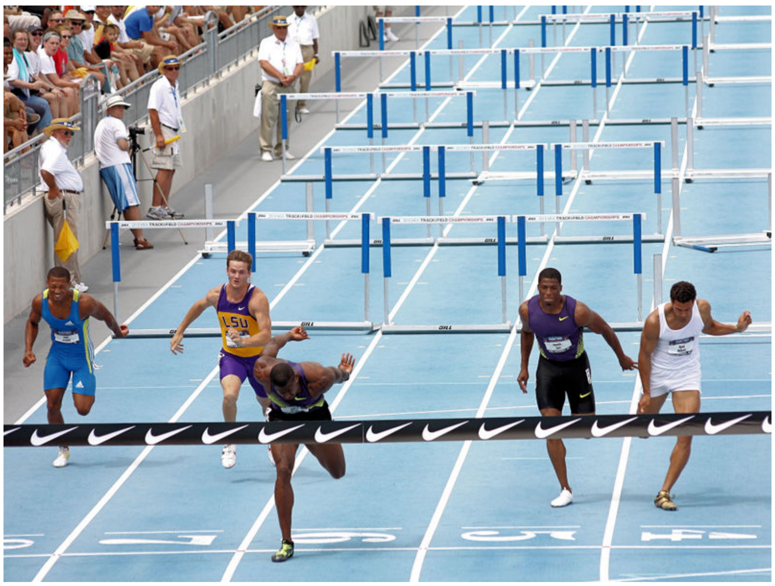



FIGURE 4.15
The muscles of these hurdlers are working too hard for aerobic respiration to keep them supplied with energy.

### Alcoholic Fermentation

In alcoholic fermentation, glycolysis is followed by a step that produces alcohol and carbon dioxide. This step also forms additional molecules of ATP. It occurs in yeast, such as the yeast in bread. Carbon dioxide from alcoholic fermentation creates gas bubbles in bread dough. The bubbles leave little holes in the bread after it bakes. You can see them in the bread in **Figure** 4.16. The holes make the bread light and fluffy.

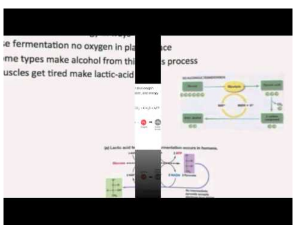
## Aerobic vs. Anaerobic Respiration

Both aerobic and anaerobic respiration have certain advantages.

- Aerobic respiration releases far more energy than anaerobic respiration does. It results in the formation of many more molecules of ATP.
- Anaerobic respiration is much quicker than aerobic respiration. It also allows organisms to live in places where there is little or no oxygen, such as deep under water or soil.

For an entertaining review of aerobic and anaerobic respiration, watch this creative music video: http://www.youtube.com/watch?v=FHWbjnzfi_U .

FIGURE 4.16
Bread has little holes in it from carbon dioxide produced by yeast.



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## Lesson Summary

- Cellular respiration is the process in which cells break down glucose, release the stored energy, and use it to make ATP. The process begins in the cytoplasm and is completed in a mitochondrion.
- Cellular respiration occurs in three stages: glycolysis, the Krebs cycle, and electron transport. Glycolysis is an anaerobic process. The other two stages are aerobic processes.
- The products of cellular respiration are needed for photosynthesis, and vice versa. Together, the two processes store and release energy in virtually all living things.
- Some organisms can produce ATP from glucose anaerobically. One way is by fermentation. There are two types of fermentation: lactic acid fermentation and alcoholic fermentation.
- Both aerobic and anaerobic respiration have certain advantages.

## Lesson Review Questions

### Recall

1. Define cellular respiration, and state where it takes place.
2. Identify the three stages of cellular respiration. How many molecules of ATP are produced in each stage?

3. What is fermentation?

### Apply Concepts

4. Many bacteria live in the human intestines. Like all other cells, these bacteria must obtain ATP from glucose. Do you think intestinal bacteria use aerobic or anaerobic respiration for this purpose? Explain your answer.

### Think Critically

5. Explain how cellular respiration and photosynthesis are related.
6. Compare and contrast aerobic and anaerobic respiration.

## Points to Consider

Obtaining energy from glucose is one of the basic functions of cells. Another basic function of living cells is dividing.

1. How does a cell divide?
2. Do all cells divide the same way?

# 4.4 References


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# Chapter 5 MS Cell Division, Reproduction, and Protein Synthesis

## Chapter Outline



This baby boy is just a few days old, but his body already consists of billions of cells. By the time he's as big as his father, his body will contain trillions of cells. Like all other organisms, the baby actually started out in life as a single cell. How do we develop from a single cell into an organism with trillions of cells? The answer is cell division.

# 5.1 Cell Division

## Lesson Objectives

- Outline the process of DNA replication.
- Compare and contrast cell division in prokaryotic and eukaryotic cells.
- Describe the four phases of mitosis in eukaryotic cells.
- Identify the stages of the cell cycle in prokaryotic and eukaryotic cells.

## Lesson Vocabulary

- anaphase
- binary fission
- cell cycle
- cell division
- chromosome
- cytokinesis
- DNA (deoxyribonucleic acid)
- DNA replication
- interphase
- metaphase
- mitosis
- prophase
- telophase

## Introduction

Cell division is the process in which a cell divides to form two new cells. The original cell is called the parent cell. The two new cells are called daughter cells. All cells contain DNA. DNA is the nucleic acid that stores genetic information. Before a cell divides its DNA must be copied. That way, each daughter cell gets a complete copy of the parent cell's genetic material.

## Copying DNA

DNA stands for deoxyribonucleic acid. It is a very large molecule. It consists of two strands of smaller molecules called nucleotides. Before learning how DNA is copied, it's a good idea to review its structure.

### DNA Structure

As you can see in **Figure** 5.1, each nucleotide includes a sugar, a phosphate, and a nitrogen base. The sugar in DNA is called deoxyribose. There are four different nitrogen bases in DNA: adenine (A), thymine (T), cytosine (C), and guanine (G). Chemical bonds between the bases hold the two strands of DNA together. Adenine always bonds with thymine, and cytosine always bonds with guanine. These pairs of bases are called complementary base pairs.

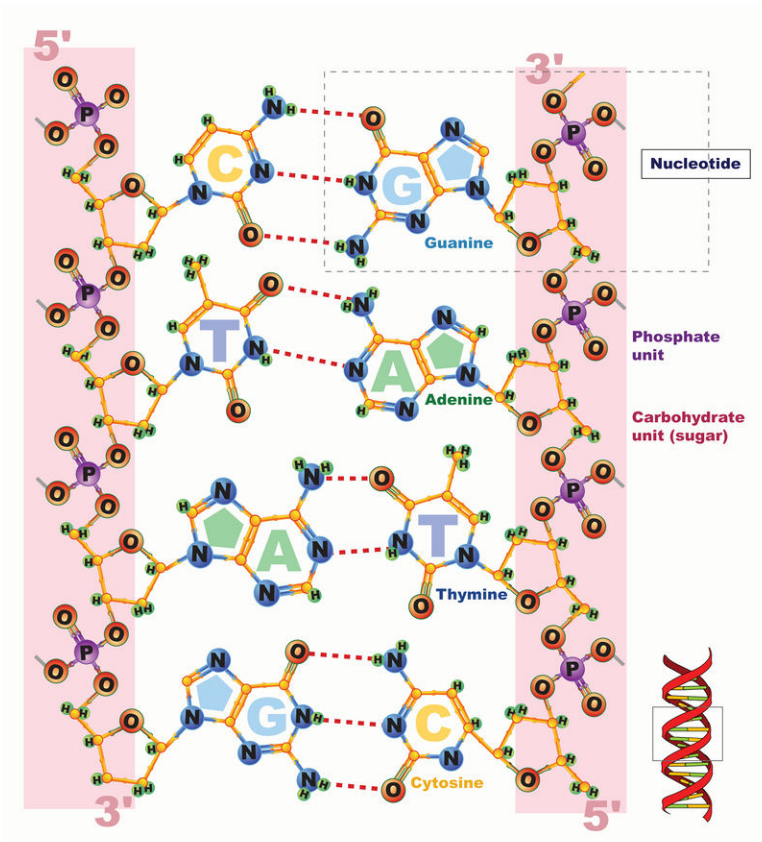



FIGURE 5.1
Structure of DNA

### Chromosomes

As a cell prepares to divide, its DNA first forms one or more structures called chromosomes. A **chromosome** consists of DNA and protein molecules coiled into a definite shape. Chromosomes are circular in prokaryotes and rodlike in eukaryotes. You can see an example of a human chromosome in **Figure** below. The rest of the time, DNA looks like a tangled mass of strings. In this form, it would be very difficult to copy and divide.

### DNA Replication

The process in which DNA is copied is called **DNA replication**. You can see how it happens in **Figure** 5.3. An enzyme breaks the bonds between the two DNA strands. Another enzyme pairs new, complementary nucleotides with those in the original chains. Two daughter DNA molecules form. Each contains one new chain and one original chain.

FIGURE 5.2
Human chromosome

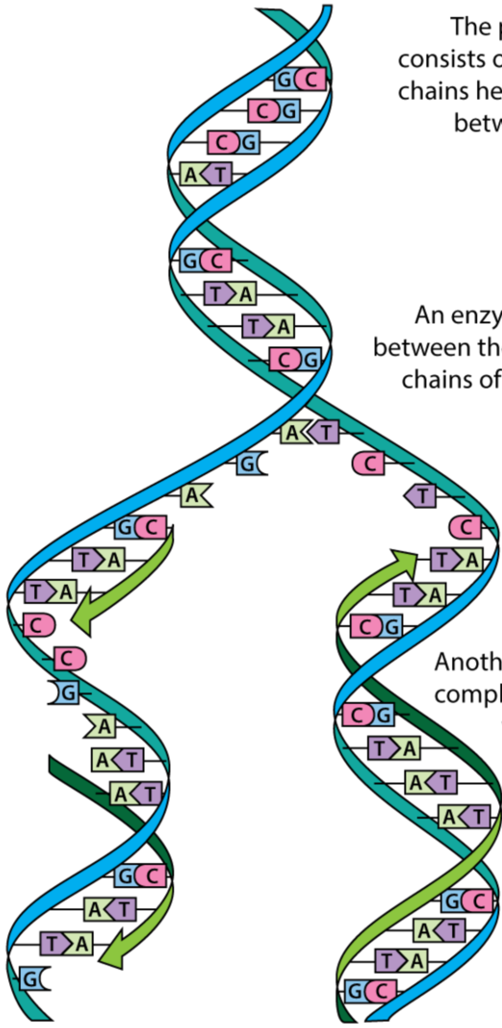



FIGURE 5.3
DNA replication

## Cell Division in Prokaryotic and Eukaryotic Cells

How cell division proceeds depends on whether a cell has a nucleus. Prokaryotic cells lack a nucleus. Their DNA is in the cytoplasm. It forms just one circular chromosome. Eukaryotic cells have a nucleus holding their DNA. Their DNA forms multiple rodlike chromosomes, like the one in Figure 5.2. Eukaryotic cells also have other organelles. For these reasons, cell division is more complex in eukaryotic cells.

### Prokaryotic Cell Division

You can see how a prokaryotic cell divides in **Figure** 5.4. This type of cell division is called binary fission. The cell simply splits into two equal halves. Binary fission occurs in bacteria and other prokaryotes. It takes place in three continuous steps:

1. The cell's chromosome is copied to form two identical chromosomes. This is DNA replication.
2. The copies of the chromosome separate from each other. They move to opposite poles, or ends, of the cell. This is called chromosome segregation.

3. The cell wall grows toward the center of the cell. The cytoplasm splits apart, and the cell pinches in two. This is called **cytokinesis**.

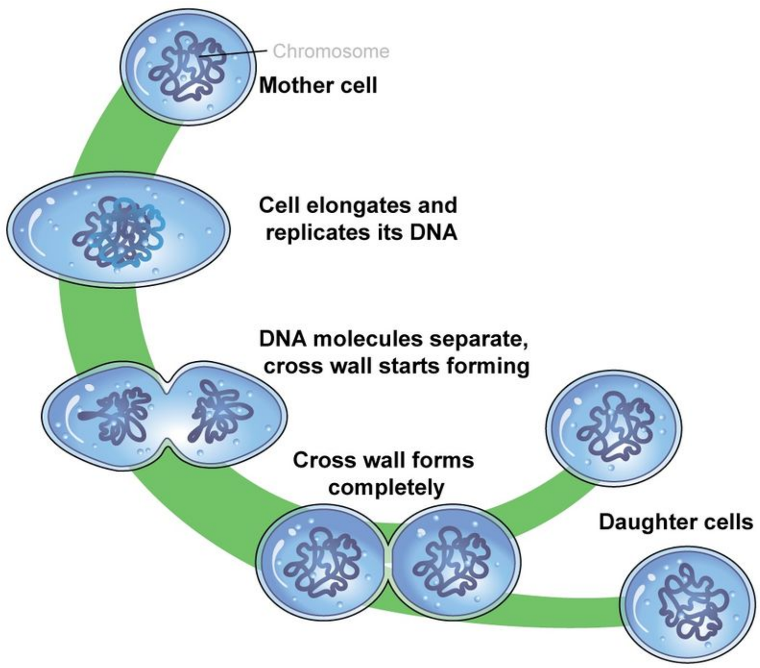



FIGURE 5.4
Binary fission in a prokaryotic cell

### Eukaryotic Cell Division

Before a eukaryotic cell divides, the nucleus and other organelles must be copied. Only then will each daughter cell have all the needed structures.

1. The first step in eukaryotic cell division, as it is in prokaryotic cell division, is DNA replication. As you can see in **Figure** 5.5, each chromosome then consists of two identical copies. The two copies are called sister chromatids. They are attached to each other at a point called the centromere.

2. The second step in eukaryotic cell division is division of the cell's nucleus. This includes division of the chromosomes. This step is called mitosis. It is a complex process that occurs in four phases. The phases of mitosis are described below.

3. The third step is the division of the rest of the cell. This is called cytokinesis, as it is in a prokaryotic cell. During this step, the cytoplasm divides, and two daughter cells form.

These three steps are shown in **Figure** 5.6.

## Mitosis

**Mitosis**, or division of the nucleus, occurs only in eukaryotic cells. By the time mitosis occurs, the cell's DNA has already replicated. Mitosis occurs in four phases, called prophase, metaphase, anaphase, and telophase. You can see what happens in each phase in **Figure** below. The phases are described below. You can also learn more about the phases of mitosis by watching this video: https://www.youtube.com/watch?v=gwcwSZIfKlM .

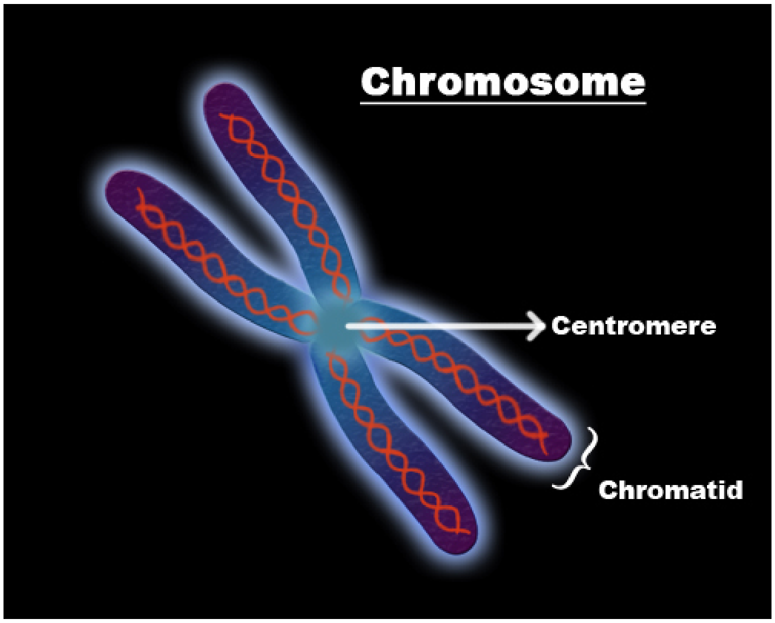



FIGURE 5.5

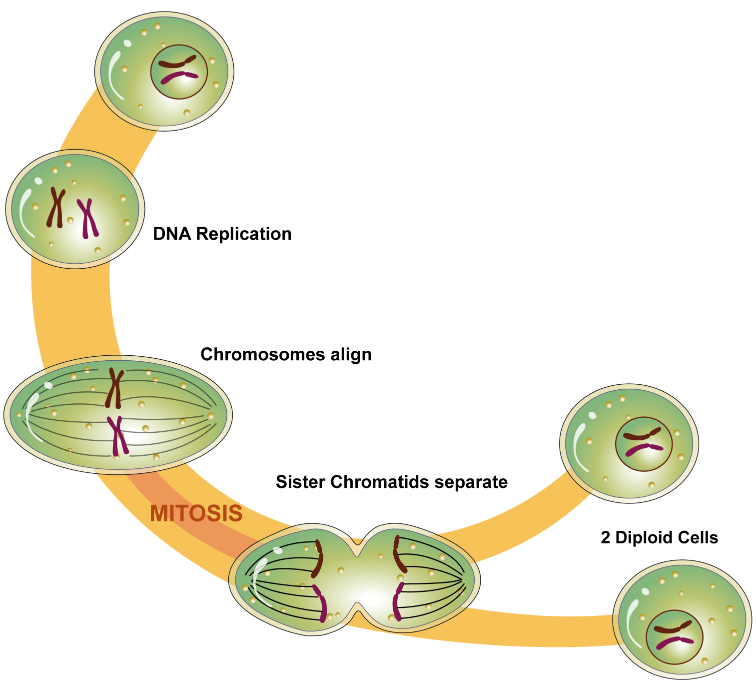
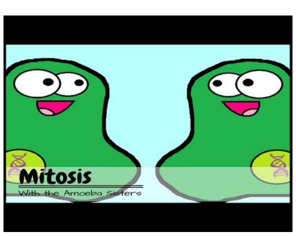



FIGURE 5.6

Cell division in a eukaryotic cell

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Phases of mitosis

1. **Prophase**: Chromosomes form, and the nuclear membrane breaks down. In animal cells, the centrioles near the nucleus move to opposite poles of the cell. Fibers called spindles form between the centrioles.
2. **Metaphase**: Spindle fibers attach to the centromeres of the sister chromatids. The sister chromatids line up at the center of the cell.
3. **Anaphase**: Spindle fibers shorten, pulling the sister chromatids toward the opposite poles of the cell. This gives each pole a complete set of chromosomes.
4. **Telophase**: The chromosomes uncoil, and the spindle fibers break down. New nuclear membranes form.

## The Cell Cycle

Cell division is just one of the stages that a cell goes through during its lifetime. All of the stages that a cell goes through make up the **cell cycle**.

### Prokaryotic Cell Cycle

The cell cycle of a prokaryotic cell is simple. The cell grows in size, its DNA replicates, and the cell divides.

### Eukaryotic Cell Cycle

In eukaryotes, the cell cycle is more complicated. The diagram in **Figure** 5.7 shows the stages that a eukaryotic cell goes through in its lifetime. There are two main stages: interphase and mitotic phase. They are described below. You can watch a eukaryotic cell going through the phases of the cell cycle at this link: http://www.cellsalive.com/cell_cycle.htm

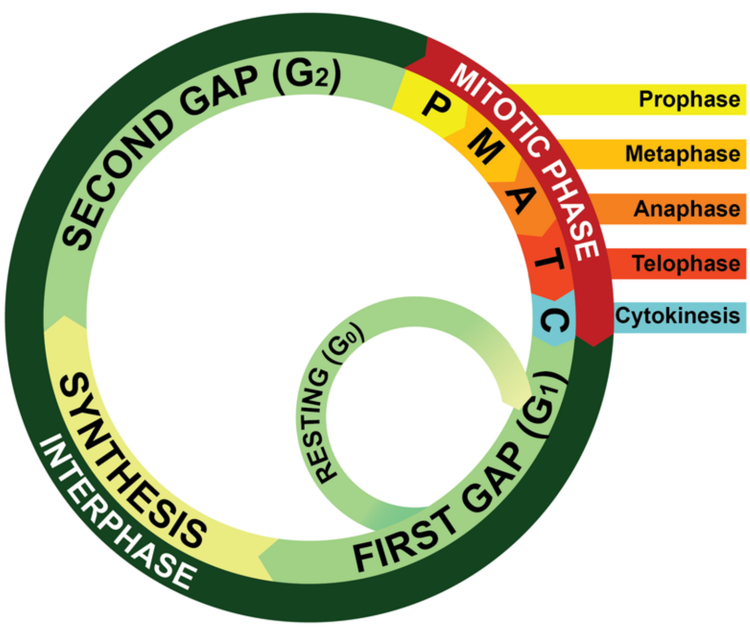



FIGURE 5.7
Eukaryotic cell cycle

**Interphase** is longer than mitotic phase. Interphase, in turn, is divided into three phases:

1. Growth phase 1 (G1): The cell grows rapidly. It also carries out basic cell functions. It makes proteins needed for DNA replication and copies some of its organelles. A cell usually spends most of its lifetime in this phase.
2. Synthesis phase (S): The cell copies its DNA. This is DNA replication.
3. Growth phase 2 (G2): The cell gets ready to divide. It makes more proteins and copies the rest of its organelles.

Mitotic phase is when the cell divides. It includes mitosis (M) and cytokinesis (C).

## Lesson Summary

- DNA is the nucleic acid that stores genetic information. It must be copied before a cell divides. DNA replication is the process in which DNA is copied.
- Cell division is the process in which a parent cell divides to form two daughter cells. It occurs by binary fusion in most prokaryotic cells. It is more complex in eukaryotic cells.
- Mitosis is the process by which the nucleus of a eukaryotic cell divides. It happens in four phases: prophase, metaphase, anaphase, and telophase.
- Cell division is just one stage of the cell cycle. The cell cycle includes all of the stages in the life of a cell. The cell cycle is more complex in eukaryotic than prokaryotic cells.

## Lesson Review Questions

### Recall

1. What is DNA replication? When and why does it occur?
2. What are chromosomes? When do chromosomes form?
3. Identify the steps of cell division in a prokaryotic cell.
4. List the phases of mitosis and what happens during each phase.

### Apply Concepts

5. A single-celled organism belongs to the Eukarya Domain. Apply lesson concepts to describe how the organism's cells divide.

### Think Critically

6. Explain why cell division is more complicated in eukaryotic than prokaryotic cells.
7. Compare and contrast the cell cycles of prokaryotic and eukaryotic cells.

## Points to Consider

Cell division is how organisms grow and replace worn out or damaged cells. It's also how they produce offspring. Producing offspring is known as reproduction.

- How do you think prokaryotes reproduce?
- How do you think multicellular eukaryotes reproduce?

# 5.2 Reproduction

## Lesson Objectives

- Identify three methods of asexual reproduction.
- Give an overview of sexual reproduction.
- Explain how meiosis produces haploid gametes.
- State advantages of asexual and sexual reproduction.

## Lesson Vocabulary

- asexual reproduction
- diploid
- egg
- fertilization
- gamete
- haploid
- homologous chromosomes
- meiosis
- sexual reproduction
- sperm
- zygote

## Introduction

Reproduction is how organisms produce offspring. The ability to reproduce is a characteristic of all living things. In some species, all the offspring are genetically identical to the parent. In other species, each offspring is genetically unique. Look at the kittens in **Figure** 5.8. They are brothers and sisters, but they are all different from each other. Why does this happen in some species but not others? It's because there are two types of reproduction. Reproduction can be sexual or asexual.

## Asexual Reproduction

Asexual reproduction is simpler than sexual reproduction. It involves just one parent. The offspring are genetically identical to each other and to the parent. All prokaryotes and some eukaryotes reproduce this way. There are several different methods of asexual reproduction. They include binary fission, fragmentation, and budding.

FIGURE 5.8
These kittens have the same parents, but each kitten is unique.

### Binary Fission

Binary fission occurs when a parent cell simply splits into two daughter cells. This method is described in detail in the lesson "Cell Division." Bacteria reproduce this way. You can see a bacterial cell reproducing by binary fission in **Figure** 5.9.

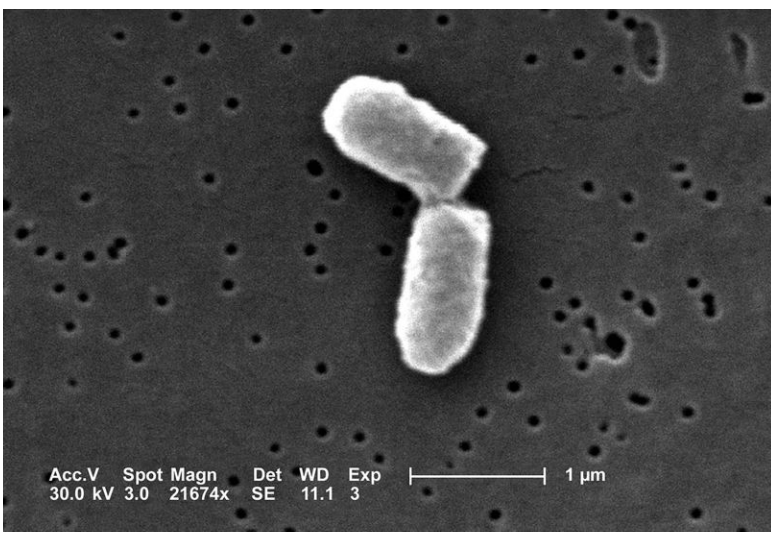



FIGURE 5.9
Binary fission in a bacterium

## Fragmentation

Fragmentation occurs when a piece breaks off from a parent organism. Then the piece develops into a new organism. Sea stars, like the one in **Figure** 5.10, can reproduce this way. In fact, a new sea star can form from a single "arm."

FIGURE 5.10
A sea star can reproduce by asexually by fragmentation. It can also reproduce sexually.

### Budding

Budding occurs when a parent cell forms a bubble-like bud. The bud stays attached to the parent while it grows and develops. It breaks away from the parent only after it is fully formed. Yeasts can reproduce this way. You can see two yeast cells budding in **Figure** 5.11.

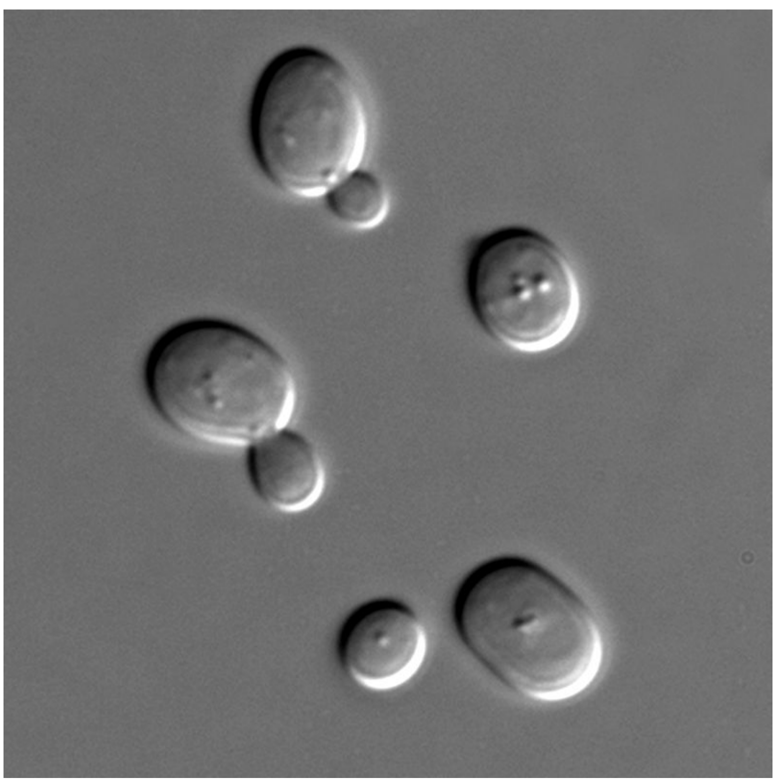


FIGURE 5.11
Budding in yeast cells

## Sexual Reproduction

**Sexual reproduction** is more complicated. It involves two parents. Special cells called **gametes** are produced by the parents. A gamete produced by a female parent is generally called an **egg**. A gamete produced by a male parent is usually called a **sperm**. An offspring forms when two gametes unite. The union of the two gametes is called **fertilization**. You can see a human sperm and egg uniting in **Figure** 5.12. The initial cell that forms when two gametes unite is called a **zygote**.

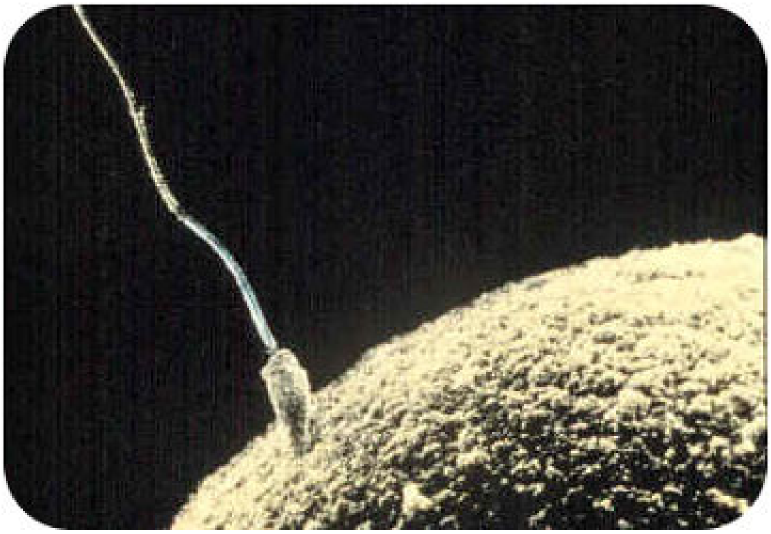


FIGURE 5.12
Fertilization: human sperm and egg

### Chromosome Numbers

In species with sexual reproduction, each cell of the body has two copies of each chromosome. For example, human beings have 23 different chromosomes. Each body cell contains two of each chromosome, for a total of 46 chromosomes. You can see the 23 pairs of human chromosomes in **Figure** 5.13. The number of different types of chromosomes is called the haploid number. In humans, the haploid number is 23. The number of chromosomes in normal body cells is called the diploid number. The diploid number is twice the haploid number. In humans, the diploid number is two times 23, or 46.

### Homologous Chromosomes

The two members of a given pair of chromosomes are called **homologous chromosomes**. We get one of each homologous pair, or 23 chromosomes, from our father. We get the other one of each pair, or 23 chromosomes, from our mother. A gamete must have the haploid number of chromosomes. That way, when two gametes unite, the zygote will have the diploid number. How are haploid cells produced? The answer is meiosis.

## Meiosis

**Meiosis** is a special type of cell division. It produces haploid daughter cells. It occurs when an organism makes gametes. Meiosis is basically mitosis times two. The original diploid cell divides twice. The first time is called

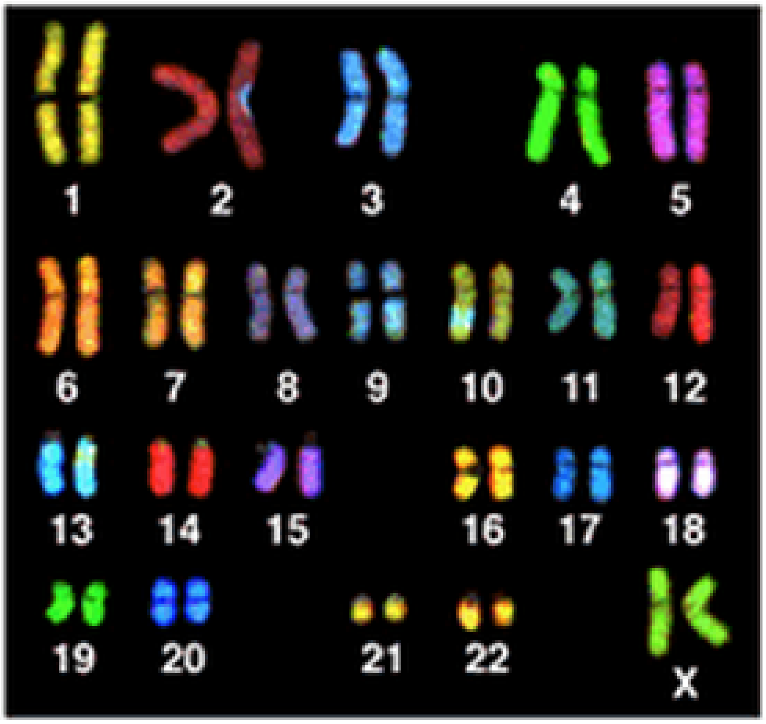
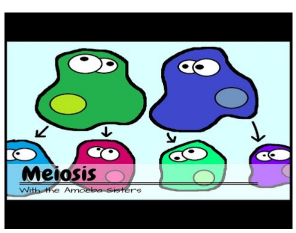



FIGURE 5.13
Humans have 23 pairs of chromosomes in each body cell

meiosis I. The second time is called meiosis II. However, the DNA replicates only once. It replicates before meiosis I but not before meiosis II. This results in four haploid daughter cells.

Meiosis I and meiosis II occurs in the same four phases as mitosis. The phases are prophase, metaphase, anaphase, and telophase. However, meiosis I has an important difference. In meiosis I, homologous chromosomes pair up and then separate. As a result, each daughter cell has only one chromosome from each homologous pair.

**Figure** 5.14 is a simple model of meiosis. It shows both meiosis I and II. You can read more about the stages below. You can also learn more about them by watching this video: http://www.youtube.com/watch?v=toWK0fIyFlY .

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### Meiosis I

After DNA replicates during interphase, the nucleus of the cell undergoes the four phases of meiosis I:

1. Prophase I: Chromosomes form, and the nuclear membrane breaks down. Centrioles move to opposite poles of the cell. Spindle fibers form between the centrioles. *Here's what's special about meiosis*: Homologous chromosomes pair up! You can see this in **Figure** below.
2. Metaphase I: Spindle fibers attach to the centromeres of the paired homologous chromosomes. The paired chromosomes line up at the center of the cell.

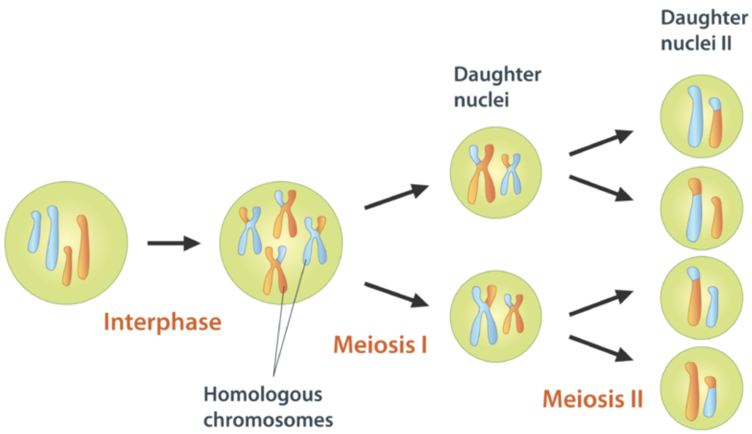



FIGURE 5.14
Meiosis occurs in two stages: meiosis I and meiosis II

3. Anaphase I: Spindle fibers shorten, pulling apart the chromosome pairs. The chromosomes are pulled toward opposite poles of the cell. One of each pair goes to one pole. The other of each pair goes to the opposite pole.
4. Telophase I: The chromosomes uncoil, and the spindle fibers break down. New nuclear membranes form.

Phases of meiosis I

Meiosis I is followed by cytokinesis. That's when the cytoplasm of the cell divides. Two haploid daughter cells result. Both of these cells go on to meiosis II.

### Meiosis II

Meiosis II is just like mitosis.

1. Prophase II: Chromosomes form. The nuclear membrane breaks down. Centrioles move to opposite poles. Spindle fibers form.
2. Metaphase II: Spindle fibers attach to the centromeres of sister chromatids. Sister chromatids line up at the center of the cell.
3. Anaphase II: Spindle fibers shorten. They pull the sister chromatids to opposite poles.
4. Telophase II: The chromosomes uncoil. The spindle fibers break down. New nuclear membranes form.

Meiosis II is also followed by cytokinesis. This time, four haploid daughter cells result. That's because both daughter cells from meiosis I have gone through meiosis II. The four daughter cells must continue to develop before they become gametes. For example, in males, the cells must develop tails, among other changes, in order to become sperm.

## Advantages of Sexual and Asexual Reproduction

Both types of reproduction have certain advantages.

### Advantage of Asexual Reproduction

Asexual reproduction can happen very quickly. It doesn't require two parents to meet and mate. Under ideal conditions, 100 bacteria can divide to produce millions of bacteria in just a few hours! Most bacteria don't live under ideal conditions. Even so, rapid reproduction may allow asexual organisms to be very successful. They may crowd out other species that reproduce more slowly.

### Advantage of Sexual Reproduction

Sexual reproduction is typically slower. However, it also has an advantage. Sexual reproduction results in offspring that are all genetically different. This can be a big plus for a species. The variation may help it adapt to changes in the environment.

How does genetic variation arise during sexual reproduction? It happens in three ways: crossing over, independent assortment, and the random union of gametes.

- Crossing over occurs during meiosis I. It happens when homologous chromosomes pair up during prophase I. The paired chromosomes exchange bits of DNA. This recombines their genetic material. You can see where crossing over has occurred in Figures 5.15 and 5.16.
- Independent assortment occurs when chromosomes go to opposite poles of the cell in anaphase I. Which chromosomes end up together at each pole is a matter of chance. You can see this in Figures 5.15 and 5.16 as well.
- In sexual reproduction, two gametes unite to produce an offspring. Which two gametes is a matter of chance. The union of gametes occurs randomly.

Due to these sources of variation, each human couple has the potential to produce more than 64 trillion unique offspring. No wonder we are all different!

## Lesson Summary

- Asexual reproduction involves just one parent. It produces offspring that are genetically identical to the parent. Methods of asexual reproduction include binary fission, fragmentation, and budding.
- Sexual reproduction involves two parents. It produces offspring that are all genetically unique. It requires the production of haploid gametes. The union of gametes is called fertilization. It results in a diploid zygote.
- Haploid gametes are produced through meiosis. This is a special type of cell division. The cell divides twice, called meiosis I and meiosis II. However, the DNA replicates just once. Homologous chromosomes separate. The outcome is four haploid cells.
- Asexual reproduction has the advantage of occurring quickly. Sexual reproduction has the advantage of creating genetic variation. This can help a species adapt to environmental change. The genetic variation arises due to crossing over, independent assortment, and the random union of gametes.

## Lesson Review Questions

### Recall

1. What are three methods of asexual reproduction? For each method, give an example of an organism that can reproduce that way.
2. Briefly describe sexual reproduction.
3. Define haploid and diploid numbers. Which cells are haploid and which are diploid?

### Apply Concepts

4. If you don't have an identical twin, how likely is it that a brother or sister would be just like you?

### Think Critically

5. A single-celled organism belongs to the Eukarya Domain. Apply lesson concepts to describe how the organism divides."
6. Some organisms can reproduce sexually or asexually. Under what conditions might each type of reproduction be an advantage?

## Points to Consider

All of our cells contain DNA. Meiosis ensures that each gamete receives a copy of each chromosome.

- Why do cells need DNA?
- What specific role does DNA play?

# 5.3 Protein Synthesis

## Lesson Objectives

- Identify the structure and functions of RNA.
- Describe the genetic code and how to read it.
- Explain how proteins are made.
- List causes and effects of mutations.

## Lesson Vocabulary

- codon
- genetic code
- mutagen
- mutation
- protein synthesis
- RNA (ribonucleic acid)
- transcription
- translation

### Introduction

Blueprints, like those pictured in **Figure** 5.15, contain the instructions for building a house. Your cells also contain "blueprints." They are encoded in the DNA of your chromosomes.

## DNA, RNA, and Proteins

DNA and RNA are nucleic acids. DNA stores genetic information. RNA helps build proteins. Proteins, in turn, determine the structure and function of all your cells. Proteins consist of chains of amino acids. A protein's structure and function depends on the sequence of its amino acids. Instructions for this sequence are encoded in DNA.

In eukaryotic cells, chromosomes are contained within the nucleus. But proteins are made in the cytoplasm at structures called ribosomes. How do the instructions in DNA reach the ribosomes in the cytoplasm? RNA is needed for this task.

### Comparing RNA with DNA

**RNA** stands for ribonucleic acid. RNA is smaller than DNA. It can squeeze through pores in the membrane that encloses the nucleus. It copies instructions in DNA and carries them to a ribosome in the cytoplasm. Then it helps build the protein.

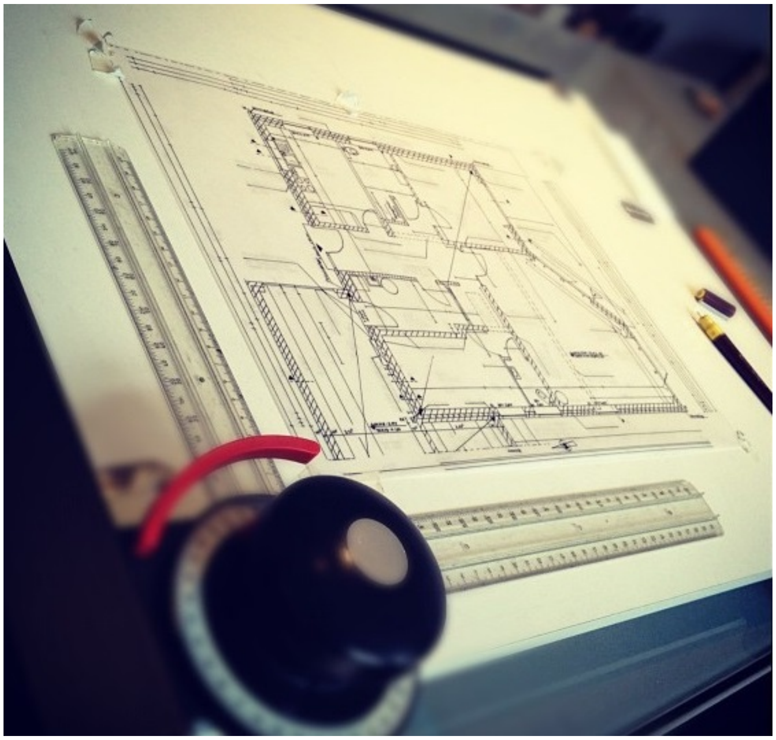


FIGURE 5.15
Blueprints for a house

RNA is not only smaller than DNA. It differs from DNA in other ways as well. It consists of one nucleotide chain rather than two chains as in DNA. It also contains the nitrogen base uracil (U) instead of thymine (T). In addition, it contains the sugar ribose instead of deoxyribose. You can see these differences in **Figure** 5.16.

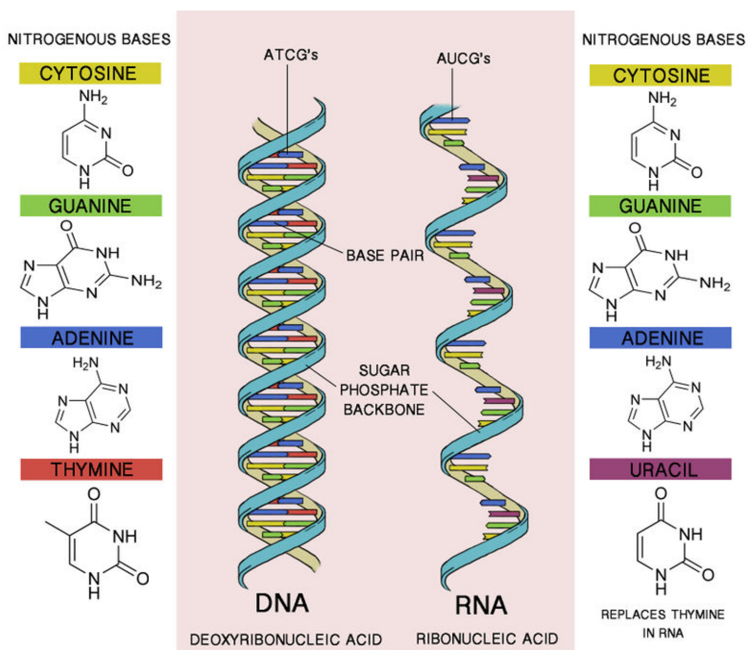



FIGURE 5.16
Comparison of RNA and DNA

### Types of RNA

There are three different types of RNA. All three types are needed to make proteins.

- Messenger RNA (mRNA) copies genetic instructions from DNA in the nucleus. Then it carries the instructions to a ribosome in the cytoplasm.
- Ribosomal RNA (rRNA) helps form a ribosome. This is where the protein is made.
- Transfer RNA (tRNA) brings amino acids to the ribosome. The amino acids are then joined together to make the protein.

## The Genetic Code

How is the information for making proteins encoded in DNA? The answer is the genetic code. The genetic code is based on the sequence of nitrogen bases in DNA. The four bases make up the "letters" of the code. Groups of three bases each make up code "words." These three-letter code words are called codons. Each codon stands for one amino acid or else for a start or stop signal.

There are 20 amino acids that make up proteins. With three bases per codon, there are 64 possible codons. This is more than enough to code for the 20 amino acids plus start and stop signals. You can see how to translate the genetic code in **Figure** 5.17. Start at the center of the chart for the first base of each three-base codon. Then work your way out from the center for the second and third bases.

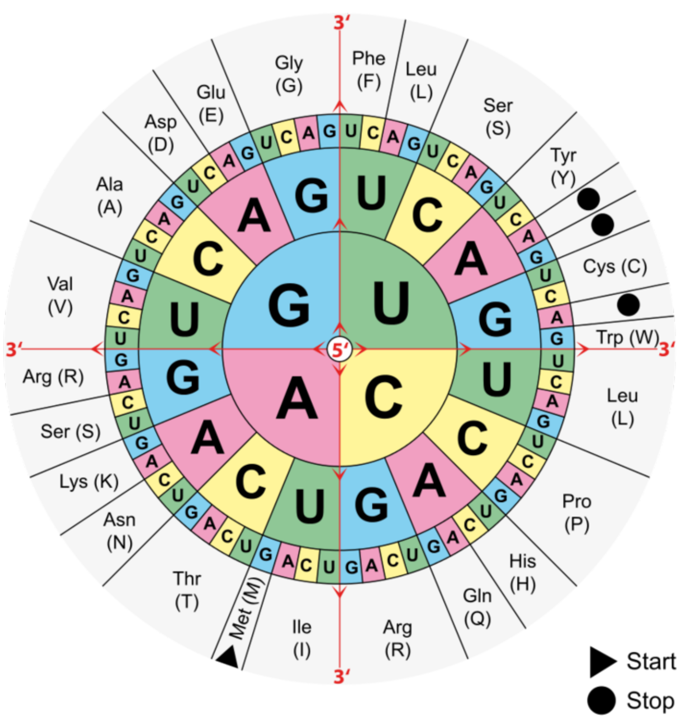



FIGURE 5.17
Translating the genetic code

Find the codon AUG in **Figure** 5.17. It codes for the amino acid methionine. It also codes for the start signal. After an AUG start codon, the next three letters are read as the second codon. The next three letters after that are read as the third codon, and so on. You can see how this works in **Figure** 5.18. The figure shows the bases in a molecule of RNA. The codons are read in sequence until a stop codon is reached. UAG, UGA, and UAA are all stop codons. They don't code for any amino acids.

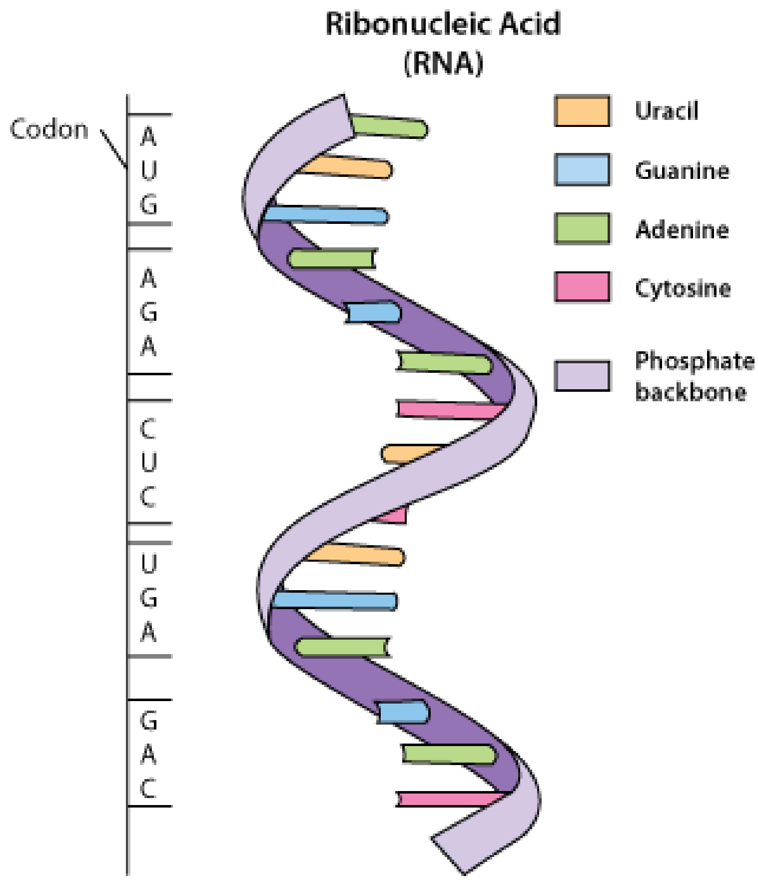



FIGURE 5.18
How the genetic code is read

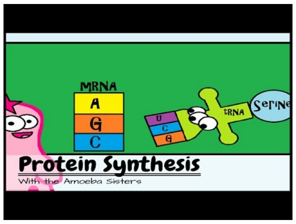
### Characteristics of the Genetic Code

The genetic code has three other important characteristics.

- The genetic code is the same in all living things. This shows that all organisms are related by descent from a common ancestor.
- Each codon codes for just one amino acid (or start or stop). This is necessary so the correct amino acid is always selected.
- Most amino acids are encoded by more than one codon. This is helpful. It reduces the risk of the wrong amino acid being selected if there is a mistake in the code.

## Protein Synthesis

The process in which proteins are made is called protein synthesis. It occurs in two main steps. The steps are transcription and translation. Watch this video for a good introduction to both steps of protein synthesis: http://www.youtube.com/watch?v=h5mJbP23Buo .

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### Transcription: DNA → RNA

Transcription is the first step in protein synthesis. It takes place in the nucleus. During transcription, a strand of DNA is copied to make a strand of mRNA. How does this happen? It occurs by the following steps, as shown in **Figure** 5.19.

1. An enzyme binds to the DNA. It signals the DNA to unwind.
2. After the DNA unwinds, the enzyme can read the bases in one of the DNA strands.
3. Using this strand of DNA as a template, nucleotides are joined together to make a complementary strand of mRNA. The mRNA contains bases that are complementary to the bases in the DNA strand.


FIGURE 5.19

Transcription step of protein synthesis

Translation is the second step in protein synthesis. It is shown in **Figure** 5.20. Translation takes place at a ribosome in the cytoplasm. During translation, the genetic code in mRNA is read to make a protein. Here's how it works:

1. The molecule of mRNA leaves the nucleus and moves to a ribosome.
2. The ribosome consists of rRNA and proteins. It reads the sequence of codons in mRNA.
3. Molecules of tRNA bring amino acids to the ribosome in the correct sequence.
4. At the ribosome, the amino acids are joined together to form a chain of amino acids.
5. The chain of amino acids keeps growing until a stop codon is reached. Then the chain is released from the ribosome.

### Causes of Mutations

Mutations have many possible causes. Some mutations occur when a mistake is made during DNA replication or transcription. Other mutations occur because of environmental factors. Anything in the environment that causes a

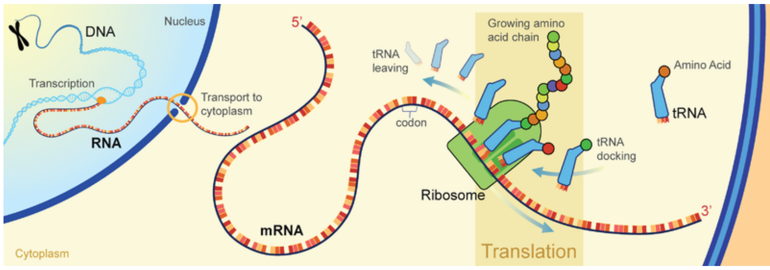


FIGURE 5.20
Translation step of protein synthesis

mutation is known as a **mutagen**. Examples of mutagens are shown in **Figure** 5.21. They include ultraviolet rays in sunlight, chemicals in cigarette smoke, and certain viruses and bacteria.

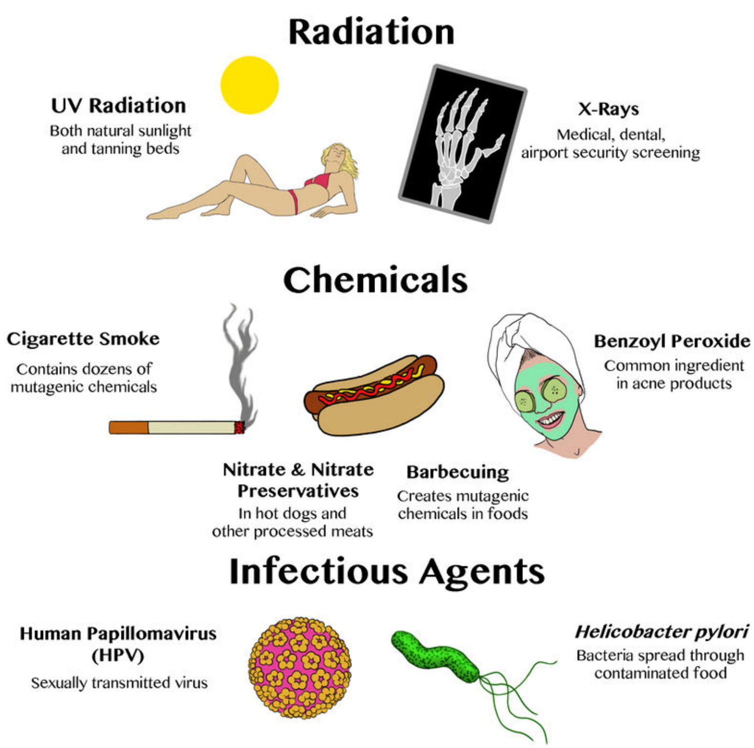


FIGURE 5.21
Examples of mutagens

### Effects of Mutations

Many mutations have no effect on the proteins they encode. These mutations are considered neutral. Occasionally, a mutation may make a protein even better than it was before. Or the protein might help the organism adapt to a new environment. These mutations are considered beneficial. An example is a mutation that helps bacteria resist antibiotics. Bacteria with the mutation increase in numbers, so the mutation becomes more common. Other mutations are harmful. They may even be deadly. Harmful mutations often result in a protein that no longer can do its job. Some harmful mutations cause cancer or other genetic disorders.

Mutations also vary in their effects depending on whether they occur in gametes or in other cells of the body.

- Mutations that occur in gametes can be passed on to offspring. An offspring that inherits a mutation in a

gamete will have the mutation in all of its cells.
- Mutations that occur in body cells cannot be passed on to offspring. They are confined to just one cell and its daughter cells. These mutations may have little effect on an organism.

### Types of Mutations

The effect of a mutation is likely to depend as well on the type of mutation that occurs.

- A mutation that changes all or a large part of a chromosome is called a chromosomal mutation. This type of mutation tends to be very serious. Sometimes chromosomes are missing or extra copies are present. An example is the mutation that causes Down syndrome. In this case, there is an extra copy of one of the chromosomes.
- Deleting or inserting a nitrogen base causes a frameshift mutation. All of the codons following the mutation are misread. This may be disastrous. To see why, consider this English-language analogy. Take the sentence "The big dog ate the red cat." If the second letter of "big" is deleted, then the sentence becomes: "The bgd oga tet her edc at." Deleting a single letter makes the rest of the sentence impossible to read.
- Some mutations change just one or a few bases in DNA. A change in just one base is called a point mutation. **Table** 5.1 compares different types of point mutations and their effects.

**TABLE 5.1:** Types of point mutations

| Type | Description | Example | Effect |
|---|---|---|---|
| Silent | mutated codon codes for the same amino acid | CAA (glutamine) → CAG (glutamine) | none |
| Missense | mutated codon codes for a different amino acid | CAA (glutamine) → CCA (proline) | variable |
| Nonsense | mutated codon is a premature stop codon | CAA (glutamine) → UAA (stop) | serious |

## Lesson Summary

- DNA encodes instructions for proteins. RNA copies the genetic code in DNA and carries it to a ribosome. There, amino acids are joined together in the correct sequence to make a protein.
- The genetic code is based on the sequence of nitrogen bases in DNA. A code "word," or codon, consists of three bases. Each codon codes for one amino acid or for a *Protein synthesis is the process in which proteins are made. In the first step, called transcription, the genetic code in DNA is copied by RNA. In the second step, called translation, the genetic code in RNA is read to make a protein.
- A mutation is a change in the base sequence of DNA or RNA. Environmental causes of mutations are called mutagens. The effects of a mutation depend on the type of mutation and whether it occurs in a gamete or body cell.

## Lesson Review Questions

### Recall

1. What are three types of RNA? What role does each type play in protein synthesis?
2. Describe the genetic code and its characteristics.
3. Give an overview of the transcription step of protein synthesis. Where does it take place?
4. What is a mutation? What are some causes of mutations?

### Apply Concepts

5. Use Figure 5.17 to translate the following sequence of RNA bases into a chain of amino acids: AUGUACCCCACAGACUAA.

### Think Critically

6. Compare and contrast RNA and DNA.
7. Explain what happens during the translation step of protein synthesis.
8. Why is a single base insertion or deletion likely to drastically change how the rest of the genetic code is read?

## Points to Consider

Offspring generally resemble their parents. This is true even when the offspring are not genetically identical to the parents.

- Can you apply your knowledge of reproduction and protein synthesis to explain why offspring and parents have similar traits?

# 5.4 References


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# CHAPTER 6 MS Genetics

## Chapter Outline



Believe it or not, but this pea plant holds the secrets of heredity. A monk named Gregor Mendel studied pea plants like this one in the 1800s. From his research, he discovered how parents pass traits to their offspring. Mendel's discoveries apply to you as well as to peas. In fact, they apply to all living things that reproduce sexually. In this chapter, you'll read about Mendel's experiments. You'll also learn the secrets of heredity he discovered.

# 6.1 Mendel's Discoveries

## Lesson Objectives

- Identify Mendel, and explain why peas were good plants for him to study.
- Outline Mendel's experiments, and state his laws of heredity.
- Summarize Mendel's scientific legacy.

## Lesson Vocabulary

- dominant
- genetics
- law of independent assortment
- law of segregation
- Mendel
- pollination
- recessive

## Introduction

People have long known that offspring are similar to their parents. Whether it's puppies or people, offspring and parents usually share many traits. However, before Gregor Mendel's research, people didn't know how parents pass traits to their offspring.

## A Monk and His Peas

**Mendel** was an Austrian Monk who lived in the 1800s. You can see his picture in **Figure** 6.1.

### Mendel the Scientist

Mendel didn't call himself a scientist. But he had all the traits of good scientist. He was observant and curious, and he asked a lot of questions. He also tried to find answers to his questions by doing experiments. Working alone in his garden in the mid-1800s, he grew thousands of pea plants over many years. He carefully crossed plants with different traits. Then he observed what traits showed up in their offspring. He repeated each experiment many times.

FIGURE 6.1
Gregor Mendel

### Why Study Peas?

Pea plants were a good choice to study for several reasons. One reason is that they are easy to grow. They also grow quickly. In addition, peas have many traits that are easy to observe, and each trait exists in two different forms. **Figure** 6.2 shows the traits that Mendel studied in pea plants. For example, one trait is flower color. Flowers may be either white or violet. Another trait is stem length. Plants may be either tall or short.

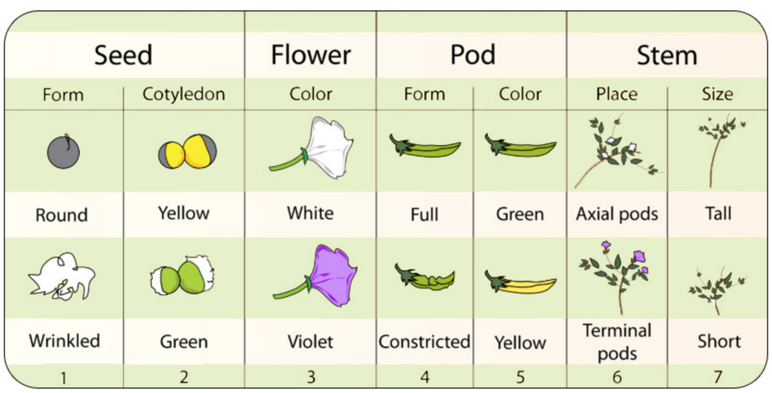


FIGURE 6.2
Traits Mendel studied in peas

Pea plants reproduce sexually. The male gametes are released by tiny grains of pollen. The female gametes lie deep within the flowers. Fertilization occurs when pollen from one flower reaches the female gametes in the same or a different flower. This is called **pollination**. Mendel was able to control which plants pollinated each other. He transferred pollen by hand from flower to flower.

## Mendel's Experiments and Laws of Heredity

At first, Mendel studied one trait at a time. This was his first set of experiments. These experiments led to his first law, the law of segregation. Then Mendel studied two traits at a time. This was his second set of experiments. These experiments led to his second law, the law of independent assortment.

### Mendel's First Set of Experiments

An example of Mendel's first set of experiments is his research on flower color. He transferred pollen from a plant with white flowers to a plant with violet flowers. This is called cross-pollination. Then Mendel observed flower color in their offspring. The offspring formed the first generation (F1). You can see the outcome of this experiment in **Figure** 6.3.

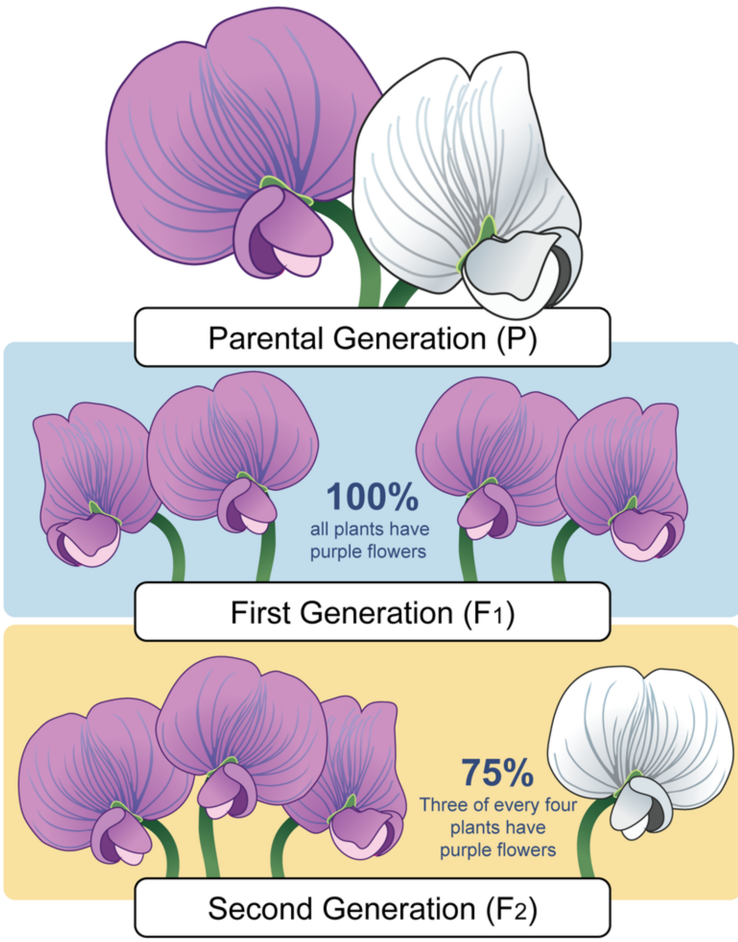


FIGURE 6.3
Mendel's flower color experiment

All of the F1 plants had violet flowers. Mendel wondered, "What happened to the white form of the trait?" "Did it disappear?" If so, the F1 plants should have only violet-flowered offspring. Mendel let the FI plants pollinate themselves. This is called self-pollination. Then he observed flower color in their offspring. These offspring formed the second generation (F2). Surprisingly, the trait of white flowers showed up in the F2 plants. One out of every four F2 plants had white flowers. The other three out of four had violet flowers. In other words, F2 plants with violet flowers and F2 plants with white flowers had a 3:1 ratio.

Mendel repeated this experiment with each of the other traits. For each trait, he got the same results. One form of the trait seemed to disappear in the F1 plants. Then it showed up again in the F2 plants. Moreover, the two forms of the trait always showed up in the F2 plants in the same 3:1 ratio.

### Law of Segregation

Based on these results, Mendel concluded that each trait is controlled by two factors. He also concluded that one of the factors for each trait dominates the other. He described the dominating factor as **dominant**. He used the term **recessive** to describe the other factor. If both factors are present in an individual, only the dominant factor is expressed. This explains why one form of a trait always seems to disappear in the F1 plants. These plants inherit both factors for the trait, but only the dominant factor shows up. The recessive factor is hidden.

When F1 plants reproduce, the two factors separate and go to different gametes. This is Mendel's first law, the **law of segregation**. It explains why both forms of the trait show up again in the F2 plants. One out of four F2 plants inherits two of the recessive factors for the trait. In these plants, the recessive form of the trait is expressed.

### Second Set of Experiments

Mendel wondered whether different traits are inherited together. For example, are seed form and seed color passed together from parents to offspring? Or do the two traits split up in the offspring? To answer these questions, Mendel studied two traits at a time. For example, he crossed plants that had round, yellow seeds with plants that had wrinkled, green seeds. Then he observed how the two traits showed up in their offspring (F1). You can see the results of this cross in **Figure** 6.4. All of the F1 plants had round, yellow seeds. The wrinkled and green forms of the traits seemed to disappear in the F1 plants.

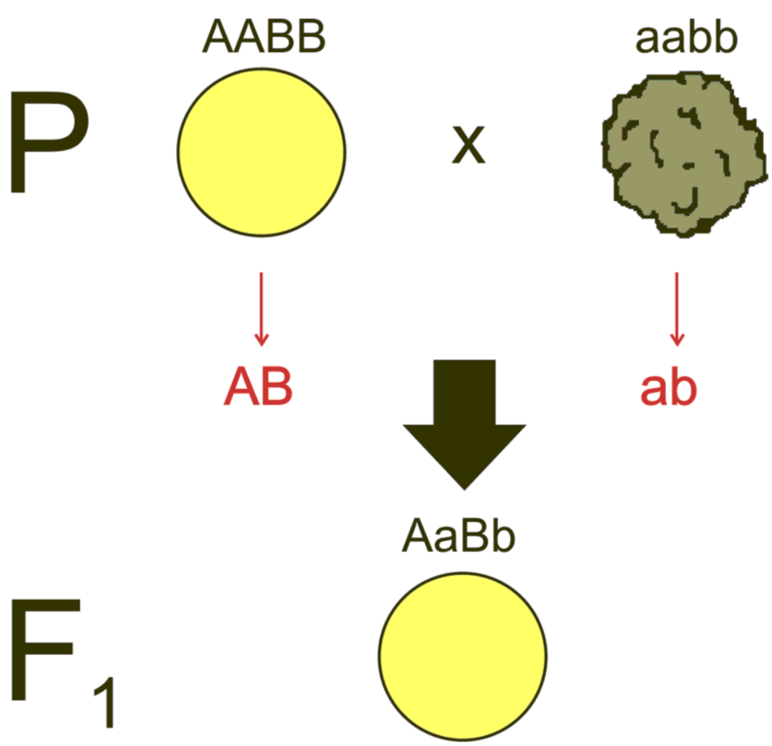


FIGURE 6.4

Seed color: B = yellow (dominant); b = green (recessive)

Then Mendel let the F1 plants self-pollinate. Their offspring, the F2 plants, had all possible combinations of the two traits. You can see this in **Figure** 6.5. For example there were plants that had round, green seeds, as well as plants that had wrinkled, yellow seeds. In this case the ratios were 9:3:3:1. The ratios are shown across the bottom of **Figure** 6.5.

Mendel repeated this experiment with other combinations of two traits. In each case, he got the same results. One form of each trait seemed to disappear in the F1 plants. Then these forms reappeared in the F2 plants in all possible

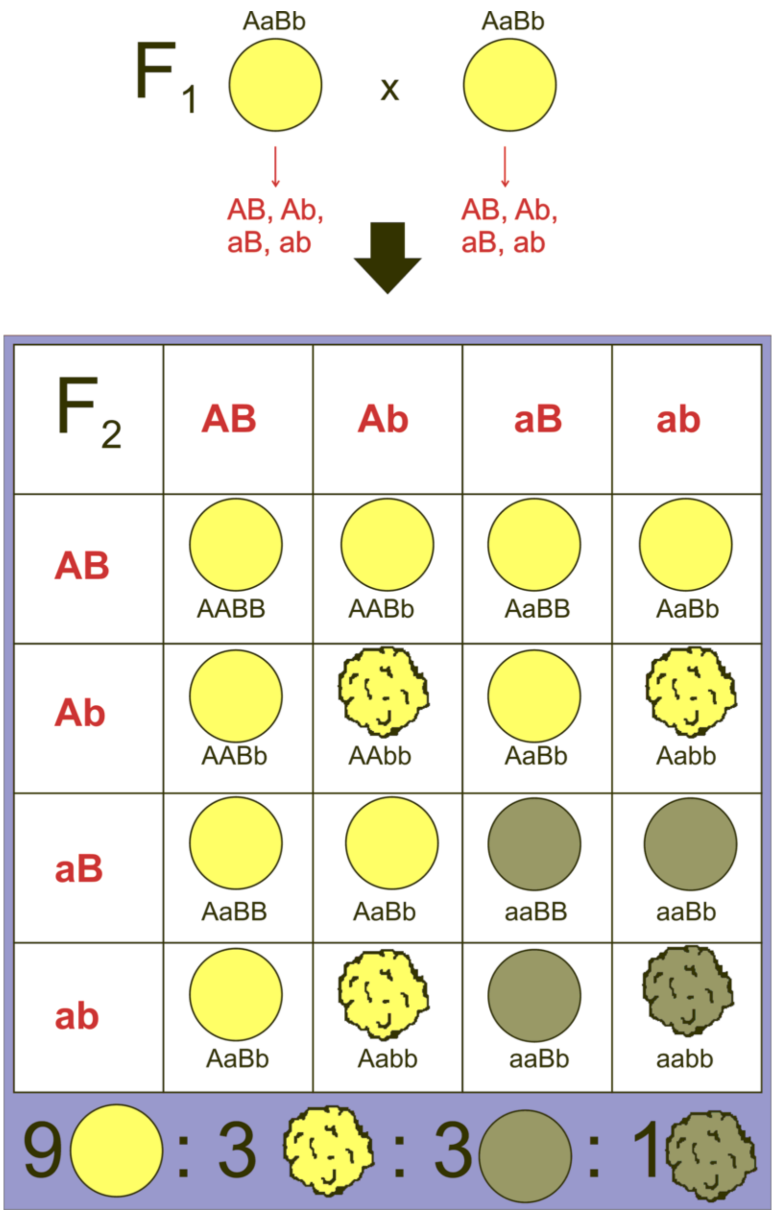


FIGURE 6.5
F2 plants produced when F1 plants self-pollinate

combinations. Moreover, the different combinations of traits always occurred in the same 9:3:3:1 ratio.

### Law of Independent Assortment

The results of Mendel's two-trait experiments led to the **law of independent assortment**. This law states that factors controlling different traits go to gametes independently of each other. This explains why F2 plants have all possible combinations of the two traits.

## Mendel's Legacy

You might think that Mendel's discoveries would have made him an instant science rock star. He'd found the answers to age-old questions about heredity. In fact, Mendel's work was largely ignored until 1900. That's when three other scientists independently arrived at Mendel's laws. Only then did people appreciate what a great contribution to science Mendel had made. Mendel's discoveries form the basis of the modern science of genetics. **Genetics** is the science of heredity. For his discoveries, Mendel is now called the "father of genetics."

Watch this entertaining, upbeat video for an excellent review of Mendel's life and work. It's also a good introduction to the next lesson, "Introduction to Genetics."

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## Lesson Summary

- Gregor Mendel was an Austrian monk who studied heredity in pea plants in the mid-1800s. Peas were a good choice for this purpose for several reasons.
- Mendel first experimented with one trait at a time. This led to his law of segregation. According to this law, the two factors that control a trait separate and go to different gametes.
- Mendel then experimented with two traits at a time. This led to his law of independent assortment. According to this law, the factors that control different traits go to gametes independently of each other.
- Mendel's discoveries were not appreciated until 1900. Now Mendel is called the "father of genetics." Genetics is the science of heredity.

## Lesson Review Questions

### Recall

1. Who was Gregor Mendel?
2. Why were peas a good choice of plants for Mendel to study?
3. State Mendel's laws.

### Apply Concepts

4. Some plants reproduce asexually. What results would Mendel have obtained if he had chosen to study these plants instead of peas?

### Think Critically

5. Why did Mendel need to grow two offspring generations (F1 and F2) to develop his law of segregation?
6. Explain how the results of Mendel's second set of experiments led to his law of independent assortment.

## Points to Consider

Mendel's research revealed that traits are controlled by "factors" that parents pass to their offspring. Today, we know that Mendel's "factors" are genes.

1. What are genes?
2. How do genes control traits?

# 6.2 Introduction to Genetics

## Lesson Objectives

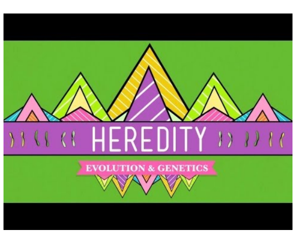
- Define gene and allele.
- Describe the relationship between genotype and phenotype.
- Show how to predict genotype and phenotype ratios in offspring for simple traits.
- Identify ways traits may be more complex than those studied by Mendel.
- Explain how sex-linked traits are inherited.

## Lesson Vocabulary

- allele
- autosome
- genotype
- heterozygote
- homozygote
- phenotype
- Punnett square
- sex chromosome
- sex-linked trait

## Introduction

When Mendel's laws were rediscovered in 1900, scientists were starting to learn about the molecules of heredity. They had already observed chromosomes and seen cells undergoing meiosis. Within a few decades they would learn the structure of DNA and how proteins are made. They would also learn that Mendel's "factors" consist of DNA. We now call these factors genes. For a great review of Mendel's work and an excellent introduction to this lesson, watch this entertaining video: https://www.youtube.com/watch?v=CBezq1fFUEA .

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## Genes and Alleles

Today we know that the traits of organisms are controlled by genes on chromosomes. A gene can be defined as a section of a chromosome that contains the genetic code for a particular protein. The position of a gene on a chromosome is called its locus. Each gene may have different versions. The different versions are called **alleles**. **Figure** 6.6 shows an example in pea plants. It shows the gene for flower color. The gene has two alleles. There is a purple-flower allele and a white-flower allele. Different alleles account for most of the variation in the traits of organisms within a species.

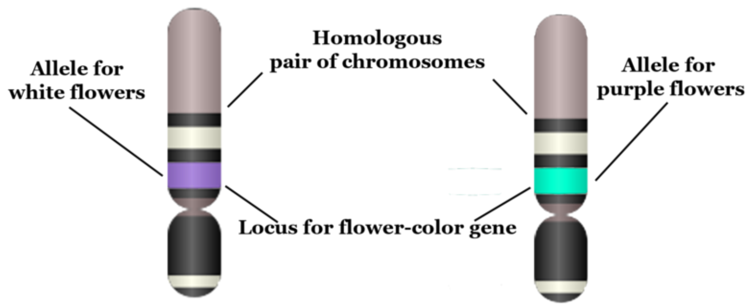



FIGURE 6.6
This diagram shows how genes and alleles are related.

In sexually reproducing species, chromosomes are present in cells in pairs. Chromosomes in the same pair are called homologous chromosomes. They have the same genes at the same loci. These may be the same or different alleles. During meiosis, when gametes are produced, homologous chromosomes separate. They go to different gametes. Thus, the alleles for each gene also go to different gametes.

## Genotype and Phenotype

When gametes unite during fertilization, the resulting zygote inherits two alleles for each gene. One allele comes from each parent.

### Genotype

The two alleles that an individual inherits make up the individual's **genotype**. The two alleles may be the same or different. Look at **Table** 6.1. It shows alleles for the flower-color gene in peas. The alleles are represented by the letters B (purple flowers) and b (white flowers). A plant with two alleles of the same type (BB or bb) is called a **homozygote**. A plant with two different alleles (Bb) is called a **heterozygote**.

TABLE 6.1: Genotypes and phenotypes for alleles B and b, with B dominant to b

| Genotypes | Phenotypes |
|---|---|
| BB (homozygote) | purple flowers |
| Bb (heterozygote) | purple flowers |
| bb (homozygote) | white flowers |

### Phenotype

The expression of an organism's genotype is called its **phenotype**. The phenotype refers to the organism's traits, such as purple or white flowers. Different genotypes may produce the same phenotype. This will be the case if one allele is dominant to the other. Both BB and Bb genotypes in Table 6.1 have purple flowers. That's because the B allele is dominant to the b allele, which is recessive. The terms *dominant* and *recessive* are the terms Mendel used to describe his "factors." Today we use them to describe alleles. In a Bb heterozygote, only the dominant B allele is expressed. The recessive b allele is expressed only in the bb genotype.

## Mendelian Inheritance

Each trait Mendel studied was controlled by one gene with two alleles. In each case, one of the alleles was dominant to the other. This resulted in just two possible phenotypes for each trait. Each trait Mendel studied was also controlled by a gene on a different chromosome. As a result, each trait was inherited independently of the others. With traits like these, it's easy to predict which forms of a trait will show up in the offspring of a given set of parents.

### Predicting Alleles in Gametes

Consider a purple-flowered pea plant with the genotype Bb. Half the gametes produced by this parent will have a B allele. The other half will have a b allele. You can see this in **Figure** 6.7. This is similar to tossing a coin. There is a 50 percent chance of a head and a 50 percent chance of a tail. Like a head or tail, there is a 50 percent chance that any gamete from this parent will have the B allele. There is also a 50 percent chance that any gamete will have the b allele.

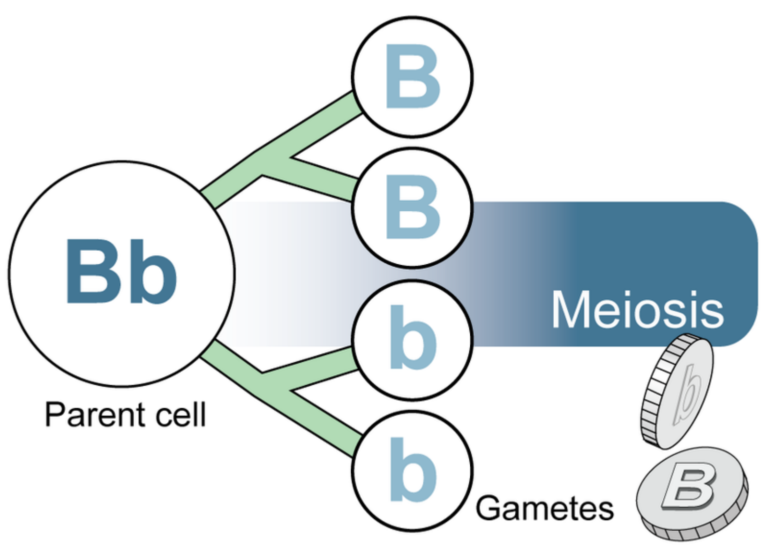



FIGURE 6.7
Gametes from a heterozygote parent (Bb)

### Predicting Genotype Ratios

Now let's see what happens if two parent pea plants have the Bb genotype. What genotypes are possible for their offspring? And what ratio of genotypes would you expect? The easiest way to find the answer to these questions is with a Punnett square.

A **Punnett square** is a chart that makes it easy to find the possible genotypes in offspring of two parents. **Figure** 6.8 shows a Punnett square for the two parent pea plants. The gametes produced by the male parent are at the top of the chart. The gametes produced by the female parent are along the left side of the chart. The different possible combinations of alleles in their offspring can be found by filling in the cells of the chart.

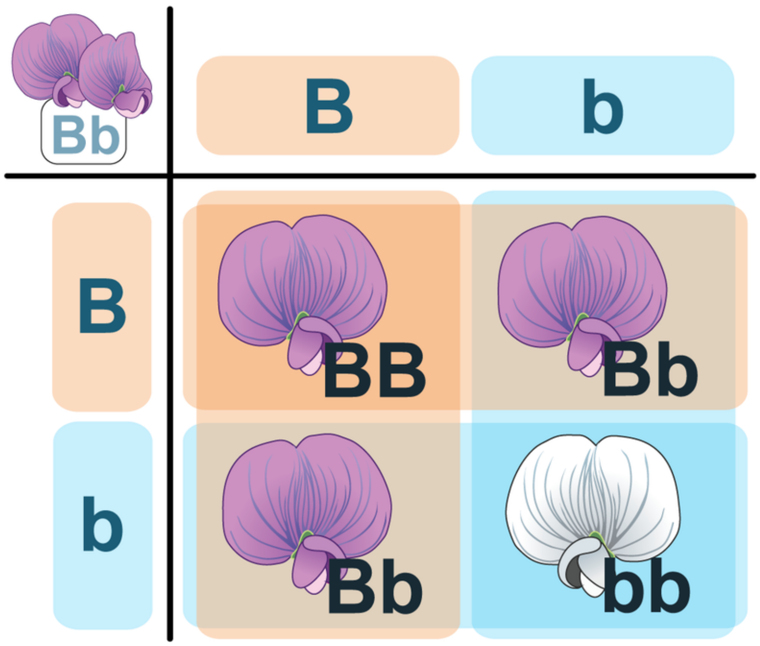



FIGURE 6.8
Punnett square for two Bb parents

If the parents had four offspring, their most likely genotypes would be one BB, two Bb, and one bb. But the genotype ratios of their actual offspring may differ. That's because which gametes happen to unite is a matter of chance, like a coin toss. The Punnett square just shows the possible genotypes and their most likely ratios.

### Predicting Phenotype Ratios

You know that the B allele is dominant to the b allele. Therefore, you can also use the Punnett square in **Figure** 6.8 to predict the most likely offspring phonotypes. If the parents had four offspring, their most likely phenotypes would be three with purple flowers (1 BB + 2 Bb) and one with white flowers (1 bb).

## Non-Mendelian Inheritance

Inheritance is often more complex than it is for traits like those Mendel studied. Several factors can complicate it.

### Codominance and Incomplete Dominance

If a gene has two alleles, one may not be dominant to the other. There are other possibilities. One possibility is called codominance. Another is called incomplete dominance.

- With codominance, both alleles are expressed equally in heterozygotes. The red and white flower in **Figure** 6.9 has codominant alleles for red petals and white petals.

- With incomplete dominance, a dominant allele is not completely dominant. Instead, it is influenced by the recessive allele in heterozygotes. The pink flower in **Figure** 6.9 is an example. It has an incompletely dominant allele for red petals. It also has a recessive allele for white petals. This results in a flower with pink petals.

FIGURE 6.9
Codominance (left) and incomplete dominance (right)

### Multiple Alleles

Many genes have more than two alleles. An example is ABO blood type in people. There are three common alleles for the gene that controls this trait. The allele for type A is codominant with the allele for type B. Both of these alleles are dominant to the allele for type O. The possible genotypes and phenotypes for this trait are shown in **Table** below

TABLE 6.2: ABO genotypes and phenotypes

| Genotype | Phenotype |
|---|---|
| AA | Type A |
| AO | Type A |
| BB | Type B |
| BO | Type B |
| AB | Type AB |
| OO | Type O |

### Polygenic Traits

Some traits are controlled by more than one gene. They are called polygenic traits. Each gene for a polygenic trait may have two or more alleles. The genes may be on the same or different chromosomes. Polygenic traits may have many possible phenotypes. Skin color and adult height are examples of polygenic traits in humans. Think about all the variation in the heights of adults you know. Normal adults may range from less than 5 feet tall to more than 7 feet tall. There are people at every gradation of height in between these extremes.

### Environmental Influences

Genes play an important role in determining an organism's traits. However, for many traits, phenotype is influenced by the environment as well. For example, skin color is controlled by genes but also influenced by exposure to sunlight. You can see the effect of sunlight on skin in **Figure** 6.10.

FIGURE 6.10
Skin color darkens when exposed to the sun.

## Sex Chromosomes and Sex-Linked Traits

Animals and most plants have two special chromosomes. They are called **sex chromosomes**. These are chromosomes that determine the sex of the organism. All of the other chromosomes are called **autosomes**. Genes on sex chromosomes may be inherited differently than genes on autosomes.

### Human Sex Chromosomes

In people, the sex chromosomes are called X and Y chromosomes. Individuals with two X chromosomes are normally females. Individuals with one X and one Y chromosome are normally males. As you can see in **Figure** 6.11, mothers pass an X chromosome to each of their children. Fathers pass an X to their daughters and a Y to their sons.

### Sex-Linked Traits

Traits controlled by genes on the sex chromosomes are called **sex-linked traits**. One gene on the Y chromosome determines male sex. There are very few other genes on the Y chromosome, which is the smallest human chromosome. There are hundreds of genes on the much larger X chromosome. None is related to sex. Traits controlled by genes on the X chromosome are called X-linked traits.

X-linked traits have a different pattern of inheritance than traits controlled by genes on autosomes. With just one X chromosome, males have only one allele for any X-linked trait. Therefore, a recessive X-linked allele is always expressed in males. With two X chromosomes, females have two alleles for any X-linked trait, just as they do for autosomal traits. Therefore, a recessive X-linked allele is expressed in females only when they inherit two copies of it. This explains why X-linked recessive traits show up less often in females than males.

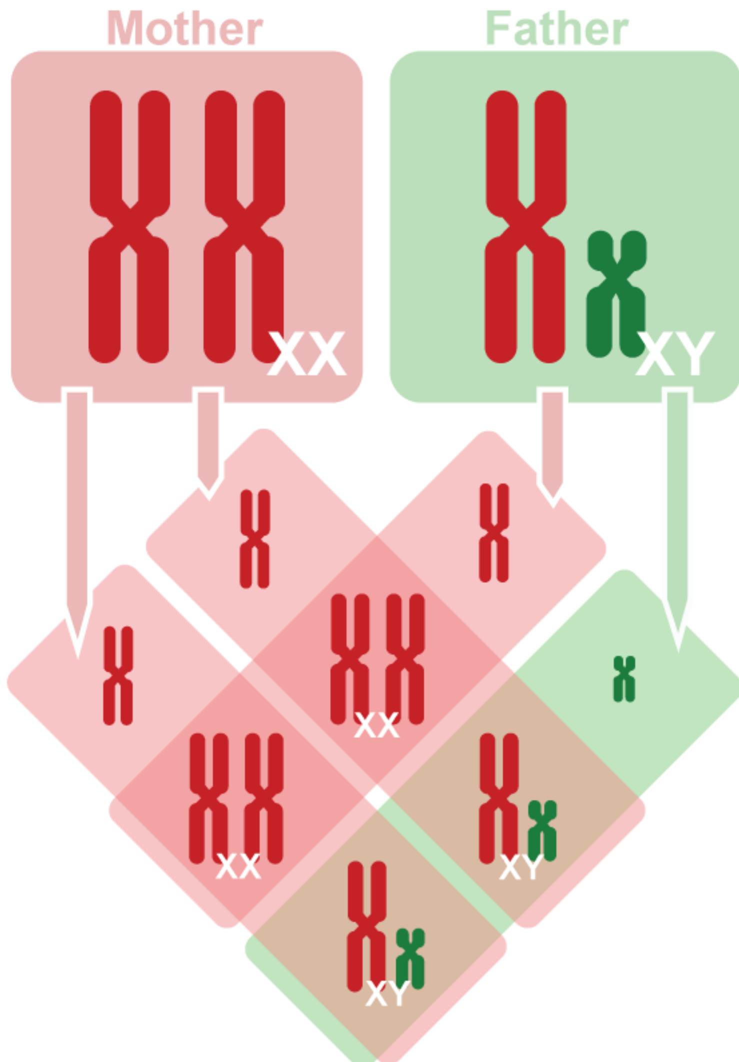



FIGURE 6.11
Inheritance of sex chromosomes

### Inheritance of Color Blindness

An example of a recessive X-linked trait is red-green color blindness. People with this trait can't see red or green colors. This trait is fairly common in males but rare in females. **Figure** 6.12 is a pedigree for this trait. A pedigree is a chart that shows how a trait is inherited in a family. The mother has one allele for color blindness. She doesn't have color blindness because she also has a dominant normal allele for the gene. Instead, she is called a carrier for the trait. She passes the allele to half of her children. One daughter is a carrier, and one son has the color blindness trait. No matter how many children this couple has, none of the daughters will have color blindness, but half of the sons, on average, will have the trait. Can you explain why?

## Lesson Summary

- Traits are controlled by genes on chromosomes. A gene may have different versions called alleles.
- The two alleles for a gene that an individual inherits make up the individual's genotype. The expression of the genotype as a trait is the individual's phenotype.

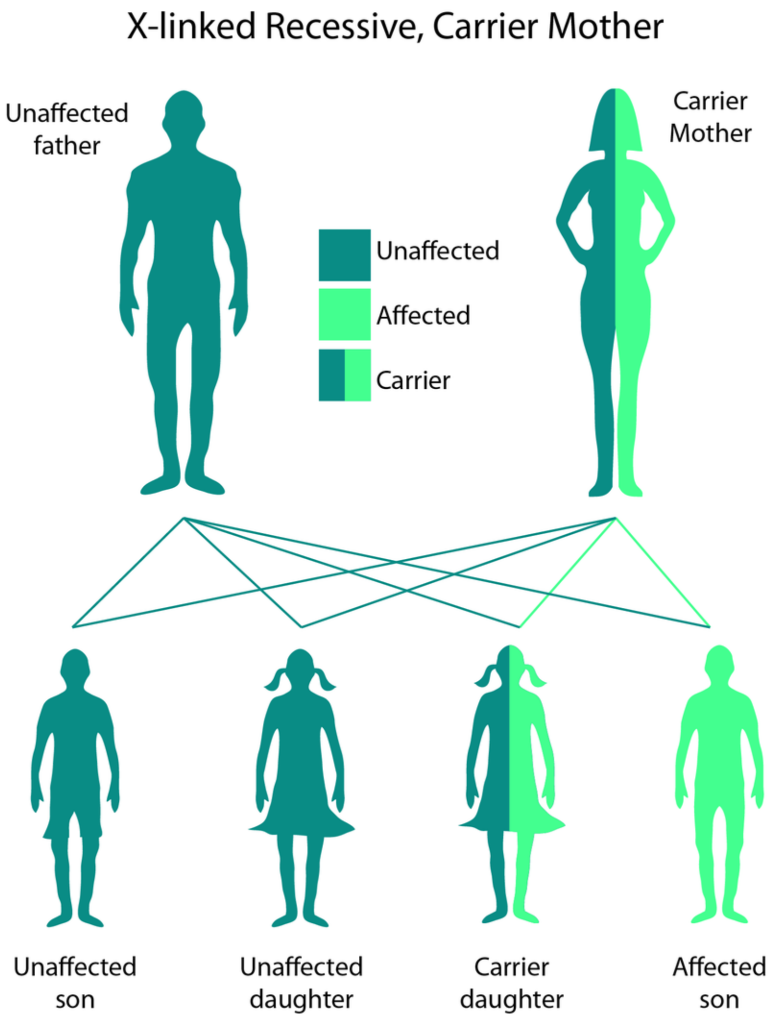



FIGURE 6.12
Pedigree for color blindness

- Mendel studied simple traits controlled by one gene with two alleles and dominance. For traits like these, Punnett squares can be used to predict possible genotypes and phenotypes and their likely ratios in offspring.
- Inheritance is more complex for traits in which there is codominance or incomplete dominance. Traits may also be controlled by multiple alleles or multiple genes. Many traits are influenced by the environment as well.
- Sex chromosomes determine sex in animals and many plants. Other chromosomes are called autosomes. Sex-linked traits are controlled by genes on sex chromosomes. They may be inherited differently than autosomal traits.

## Lesson Review Questions

### Recall

1. Write a short paragraph in which you correctly use the concepts chromosome, gene, allele, locus, and trait.
2. What are codominance and incomplete dominance? Give an example of each.
3. What is the difference between a multiple allele trait and a polygenic trait?

### Apply Concepts

4. Use a Punnett square to determine the possible offspring genotypes of parents with the genotypes Bb and bb. Assume that B is the dominant allele for violet flower color in peas and b is the recessive allele for white flower color. What is the expected ratio of violet-flowered to white-flowered offspring based on your Punnett square?

### Think Critically

5. Compare and contrast genotype and phenotype.
6. Explain why it is the father rather than the mother who determines the sex of their offspring.

## Points to Consider

Genetics began with the rediscovery of Mendel's laws in 1900. There have been many advances in genetics since then.

1. What are some recent advances in genetics?
2. What do we now know about human genes?

# 6.3 Advances in Genetics

## Lesson Objectives

- Explain the significance of the Human Genome Project.
- Describe human genetic disorders.
- Identify methods and uses of biotechnology.

## Lesson Vocabulary

- biotechnology
- gene therapy
- genetically modified organism (GMO)
- genetic disorder
- genome
- Human Genome Project

## Introduction

The science of genetics has come a long way since Mendel's laws were rediscovered in 1900. There have been many advances in genetics. One of the most impressive advances was sequencing the human genome.

## Sequencing the Human Genome

A species' **genome** consists of all of its genetic information. The human genome consists of the complete set of genes in the human organism. It's all the DNA of a human being.

### The Human Genome Project

The **Human Genome Project** was launched in 1990. It was an international effort to sequence all 3 billion bases in human DNA. Another aim of the project was to identify the more than 20,000 human genes and map their locations on chromosomes. The logo of the Human Genome Project in **Figure** 6.13 shows that the project brought together experts in many fields.

The Human Genome Project was completed in 2003. It was one of the greatest feats of modern science. It provides a complete blueprint for a human being. It's like having a very detailed manual for making a human organism.

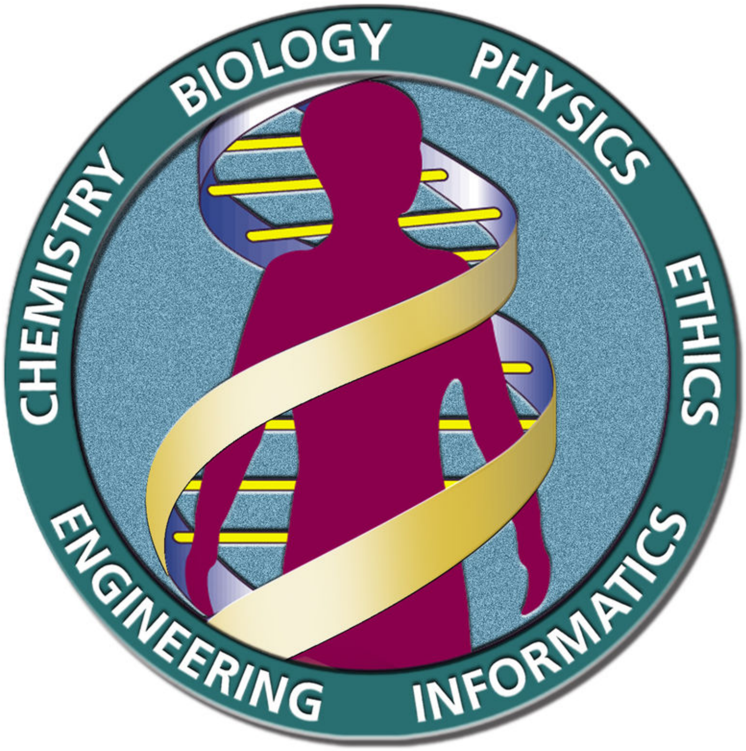
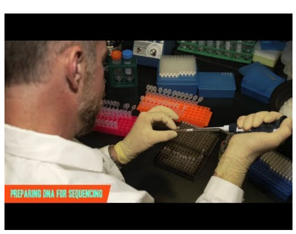



FIGURE 6.13
Human Genome Project logo

### Applications of the Sequence

Knowing the sequence of the human genome is very useful. For example, it helps us understand how humans evolved. Another use is in medicine. It is helping researchers identify and understand genetic disorders. You can learn more about the Human Genome Project and its applications by watching this funny, fast-paced video: http://www.youtube.com/watch?v=F5LzKupeHtw .



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## Human Genetic Disorders

Sequencing the human genome has increased our knowledge of genetic disorders. **Genetic disorders** are diseases caused by mutations. Many genetic disorders are caused by mutations in a single gene. Others are caused by abnormal numbers of chromosomes.

### Disorders Caused by Single Gene Mutations

**Table** 6.3 lists some genetic disorders caused by mutations in just one gene. It include autosomal and X-linked disorders. It also includes dominant and recessive disorders.

**TABLE 6.3:** Examples of human genetic disorders caused by single gene mutations

| Genetic Disorder | Effect of Mutation | Signs of the Disorder | Type of Trait |
|---|---|---|---|
| Marfan syndrome | Defective protein in tissues such as cartilage and bone | Heart and bone defects; unusually long limbs | Autosomal dominant |
| Cystic fibrosis | Defective protein needed to make mucus | Unusually thick mucus that clogs airways in lungs and ducts in other organs | Autosomal recessive |
| Sickle Cell Anemia | Defective hemoglobin protein that is needed to transport oxygen in red blood cells | Sickle-shaped red blood cells that block blood vessels and interrupt blood flow | Autosomal recessive |
| Hemophilia A | Reduced activity of a protein needed for blood to clot | Excessive bleeding that is difficult to control | X-linked recessive |

Relatively few genetic disorders are caused by dominant alleles. A dominant allele is expressed in everybody who inherits even one copy of it. If it causes a serious disorder, affected people may die young and fail to reproduce. They won't pass the allele to the next generation. As a result, the allele may die out of the population. One of the exceptions is Marfan syndrome. It is thought to have affected Abraham Lincoln. He's pictured in **Figure** 6.14. His very long limbs are one reason for the suspicion of Marfan syndrome in this former U.S. president.

Recessive disorders are more common than dominant ones. Why? A recessive allele is not expressed in heterozygotes. These people are called carriers. They don't have the genetic disorder but they carry the recessive allele. They can also pass this allele to their offspring. A recessive allele is more likely than a dominant allele to pass to the next generation rather than die out.

### Chromosomal Disorders

In the process of meiosis, paired chromosomes normally separate from each other. They end up in different gametes. Sometimes, however, errors occur. The paired chromosomes fail to separate. When this happens, some gametes get an extra copy of a chromosome. Other gametes are missing a chromosome. If one of these gametes is fertilized and survives, a chromosomal disorder results. You can see examples of such disorders in **Table** 6.4

**TABLE 6.4:** Disorders caused by abnormal numbers of chromosomes

| Genetic Disorder | Genotype | Phenotypic Effects |
|---|---|---|
| Down syndrome | Extra copy (complete or partial) of chromosome 21 | Developmental delays, distinctive facial appearance, and other abnormalities |
| Turner's syndrome | One X chromosome and no other sex chromosome (XO) | Female with short height and inability to reproduce |
| Klinefelter's syndrome | One Y chromosome and two or more X chromosomes (XXY, XXXY) | Male with abnormal sexual development and reduced level of male sex hormone |

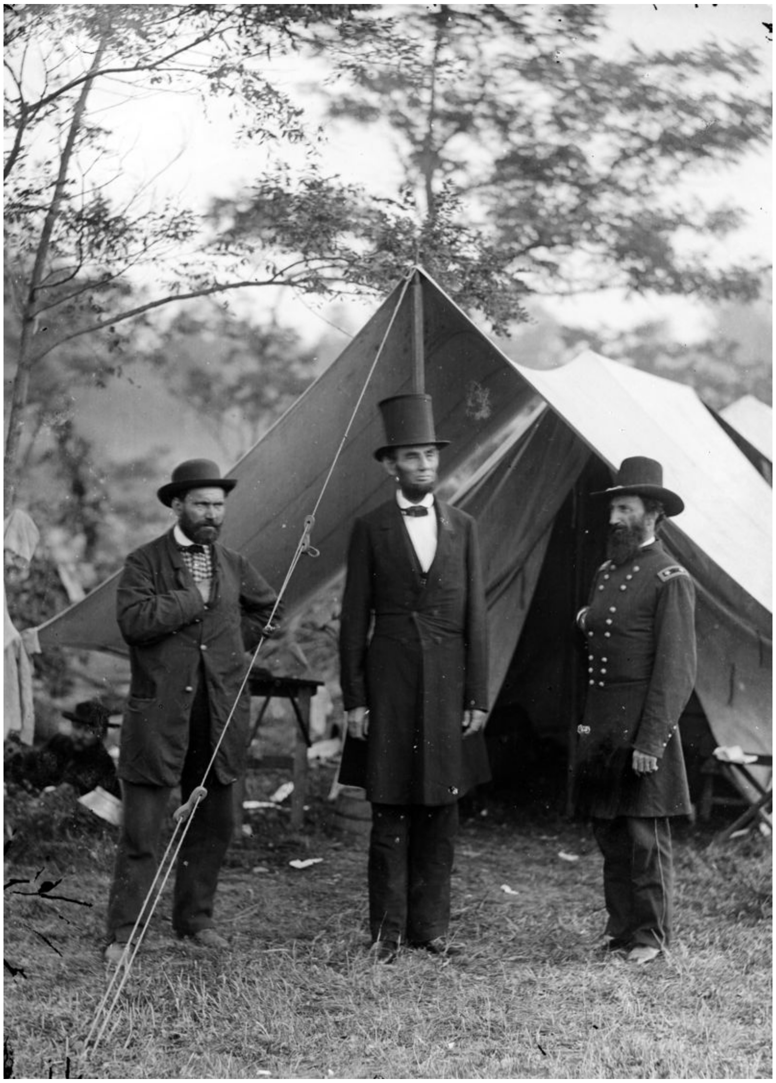

FIGURE 6.14
Abraham Lincoln (center) may have had the genetic disorder Marfan syndrome

Most chromosomal disorders involve the sex chromosomes. Can you guess why? The X and Y chromosomes are very different in size. The X is much larger than the Y. This difference in size creates problems. It increases the chances that the two chromosomes will fail to separate properly during meiosis.

## Biotechnology

Treating genetic disorders is one use of biotechnology. **Biotechnology** is the use of technology to change the genetic makeup of living things for human purposes. It's also called genetic engineering. Besides treating genetic disorders, biotechnology is used to change organisms so they are more useful to people.

### Methods in Biotechnology

Biotechnology uses a variety of methods, but some are commonly used in many applications. A common method is the polymerase chain reaction. Another common method is gene cloning.

- The polymerase chain reaction is a way of making copies of a gene. It uses high temperatures and an enzyme to make new DNA molecules. The process keeps cycling to make many copies of a gene.
- Gene cloning is another way of making copies of a gene. A gene is inserted into the DNA of a bacterial cell. **Figure** 6.15 shows how this is done. Bacteria multiply very rapidly by binary fission. Each time a bacterial cell divides, the inserted gene is copied.

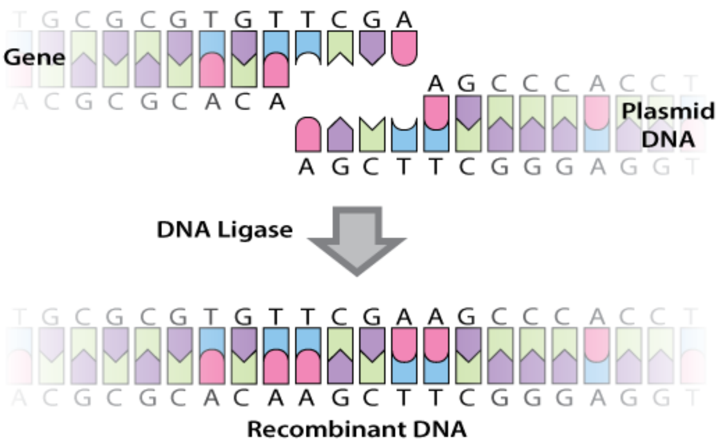


FIGURE 6.15
The enzyme DNA ligase joins together a gene and bacterial (plasmid) DNA. The DNA that results is called recombinant DNA.

## Uses of Biotechnology

Biotechnology has many uses. It is especially useful in medicine and agriculture. Biotechnology is used to

- treat genetic disorders. For example, copies of a normal gene might be inserted into a patient with a defective gene. This is called **gene therapy**. Ideally, it can cure a genetic disorder.
- create **genetically modified organisms (GMOs)**. Many GMOs are food crops such as corn. Genes are inserted into plants to give them desirable traits. This might be the ability to get by with little water. Or it might be the ability to resist insect pests. The modified plants are likely to be healthier and produce more food. They may also need less pesticide.
- produce human proteins. Insulin is one example. This protein is needed to treat diabetes. The human insulin gene is inserted into bacteria. The bacteria reproduce rapidly. They can produce large quantities of the human protein. You can see another example in **Figure** 6.16.

## Concerns about Biotechnology

Biotechnology has many benefits. Its pros are obvious. It helps solve human problems. However, biotechnology also raises many concerns. For example, some people worry about eating foods that contain GMOs. They wonder if GMOs might cause health problems. The person in **Figure** 6.17 favors the labeling of foods that contain GMOs. That way, consumers can know which foods contain them and decide for themselves whether to eat them.

Another concern about biotechnology is how it may affect the environment. Negative effects on the environment have already occurred because of some GMOs. For example, corn has been created that has a gene for a pesticide. The corn plants have accidentally cross-pollinated nearby milkweeds. Monarch butterfly larvae depend on milkweeds for food. When they eat milkweeds with the pesticide gene, they are poisoned. This may threaten the survival of the monarch species as well as other species that eat monarchs. Do the benefits of the genetically modified corn outweigh the risks? What do you think?

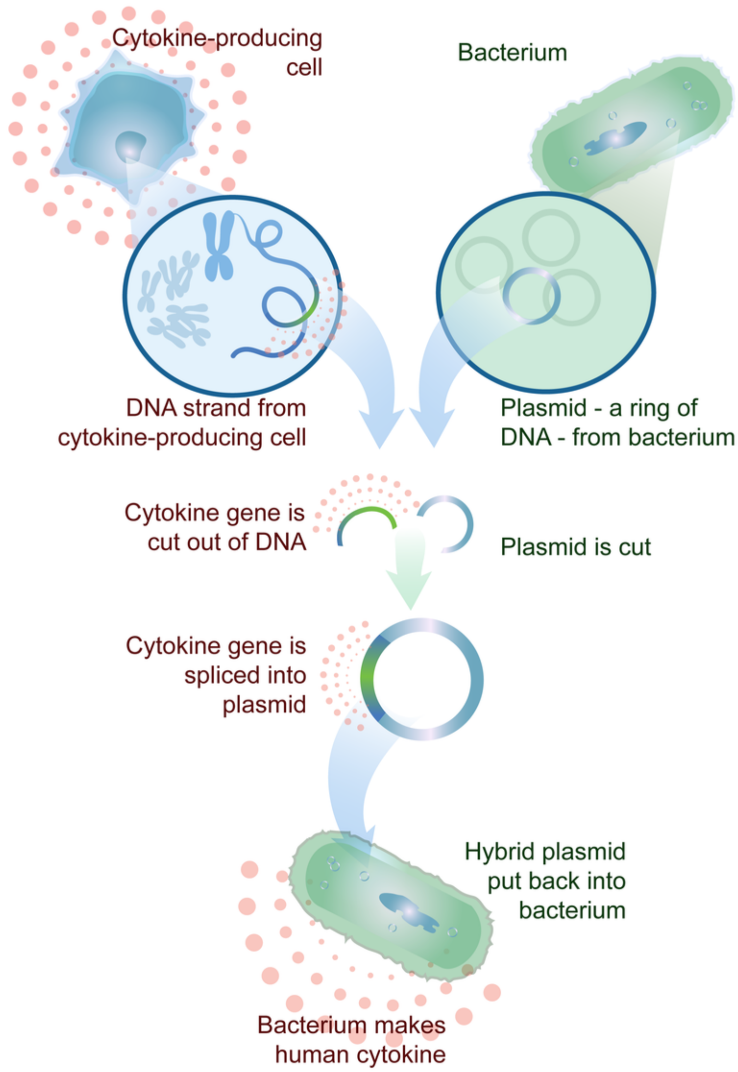


FIGURE 6.16

Bacteria are modified to produce the human protein cytokine. This is a protein that helps fight infections.

## Lesson Summary

- A species' genome consists of all of its genetic information. One of the greatest advances in modern genetics was sequencing the human genome. This was achieved in 2003 by the Human Genome Project.
- Sequencing the human genome has increased our knowledge of genetic disorders. These are diseases caused by mutations. They may be caused by single gene mutations or the failure of chromosomes to separate correctly during meiosis.
- Biotechnology is the use of technology to treat genetic disorders or change organisms so they are more useful to people. Methods include gene cloning. Applications include gene therapy and genetically modified food crops.


FIGURE 6.17
Chances are that some of the foods you eat contain GMOs. However, they may not be labeled that way.

## Lesson Review Questions

### Recall

1. Define genome.
2. What was the Human Genome Project? What had it accomplished by 2003?
3. Identify and describe an autosomal recessive genetic disorder.

### Apply Concepts

4. Pedigrees show that a certain genetic disorder passes from mothers to about half of their sons or from fathers to all of their daughters. Only males are actually affected by the disorder. What type of disorder is it?

### Think Critically

5. Compare and contrast the polymerase chain reaction and gene cloning.
6. Weigh the pros and cons of using biotechnology to produce genetically modified organisms.

## Points to Consider

Biotechnology can be used to artificially change the genetic makeup of organisms in a species.

1. How can the genetic makeup of a species change naturally?
2. What might be the outcome of this type of change?

# 6.4 References


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# CHAPTER 7 MS Evolution

## Chapter Outline

# 7.1 Darwin's Theory of Evolution

## Lesson Objectives

- State Darwin's theory of evolution by natural selection.
- Describe Darwin's voyage on the Beagle.
- Identify other influences on Darwin.
- Explain how Darwin arrived at his theory.

## Lesson Vocabulary

- Darwin
- evolution
- Galápagos Islands
- natural selection
- theory of evolution by natural selection

## Introduction

Charles Darwin is one of the best-known scientists of all time. **Figure** 7.1 shows Darwin as a young man in the 1830s. Why is Darwin so famous? His theory of evolution was a major leap forward in human understanding. It explains and unifies all of life science.

## Darwin's Theory in a Nutshell

Darwin's **theory of evolution by natural selection** contains two major ideas:

- One idea is that evolution happens. **Evolution** is a change in the inherited traits of organisms over time. Living things have changed as descendants diverged from common ancestors in the past.
- The other idea is that evolution occurs by natural selection. **Natural selection** is the process in which living things with beneficial traits produce more offspring. As a result, their traits increase in the population over time.

## Voyage of the

How did Darwin come up with the theory of evolution by natural selection? A major influence was an amazing scientific expedition he took on a ship called the *Beagle*. Darwin was only 22 years old when the ship set sail. The

FIGURE 7.1
Charles Darwin as a young man in the 1830s

trip lasted for almost five years and circled the globe. **Figure** 7.2 shows the route the ship took. It set off from Plymouth, England in 1831. It wouldn't return to Plymouth until 1836. Imagine setting out for such an incredible adventure at age 22, and you'll understand why the trip had such a big influence on Darwin.

Darwin's job on the voyage was to observe and collect specimens whenever the ship went ashore. This included plants, animals, rocks, and fossils. Darwin loved nature, so the job was ideal for him. During the long voyage, he made many observations that helped him form his theory of evolution. Some of his most important observations were made on the Galápagos Islands.

The 16 **Galápagos Islands** lie 966 kilometers (about 600 miles) off the west coast of South America. (You can see their location on the map in Figure 7.2.) Some of the animals Darwin observed on the islands were giant tortoises and birds called finches. Watch this video for an excellent introduction to Darwin, his voyage, and the Galápagos:

http://www.sciencechannel.com/video-topics/earth-science/galapagos-beyond-darwin-charles-darwin.htm

### Giant Tortoises

The Galápagos Islands are still famous for their giant tortoises. These gentle giants are found almost nowhere else in the world. Darwin was amazed by their huge size. He was also struck by the variety of shapes of their shells. You can see two examples in **Figure** 7.3. Each island had tortoises with a different shell shape. The local people even


FIGURE 7.2
Route of the Beagle

could tell which island a tortoise came from based on the shape of its shell.

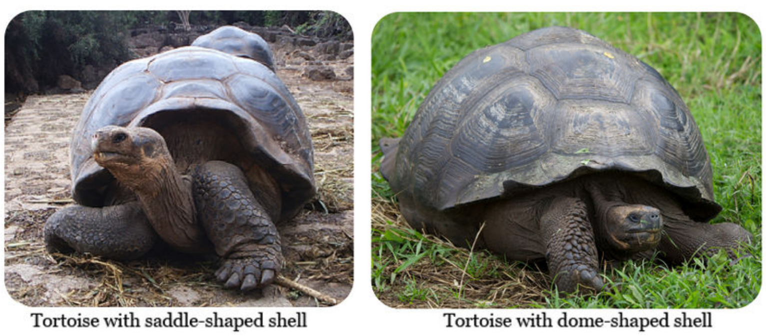



FIGURE 7.3
Giant tortoises on the Galápagos Islands varied in shell shape, depending on which island they inhabited.

Darwin wondered how each island came to have its own type of tortoise. He found out that tortoises with dome-shaped shells lived on islands where the plants they ate were abundant and easy to reach. Tortoises with saddle-shaped shells, in contrast, lived on islands that were drier. On those islands, food was often scarce. The saddle shape of their shells allowed tortoises on those islands to reach up and graze on vegetation high above them. This made sense, but how had it happened?

## Darwin's Finches

Darwin also observed that each of the Galápagos Islands had its own species of finches. The finches on different islands had beaks that differed in size and shape. You can see four examples in **Figure** 7.4.

Darwin investigated further. He found that the different beaks seemed to suit the birds for the food available on their island. For example, finch number 1 in **Figure** 7.4 used its large, strong beak to crack open and eat big, tough seeds. Finch number 4 had a long, pointed beak that was ideal for eating insects. This seemed reasonable, but how had it come about?

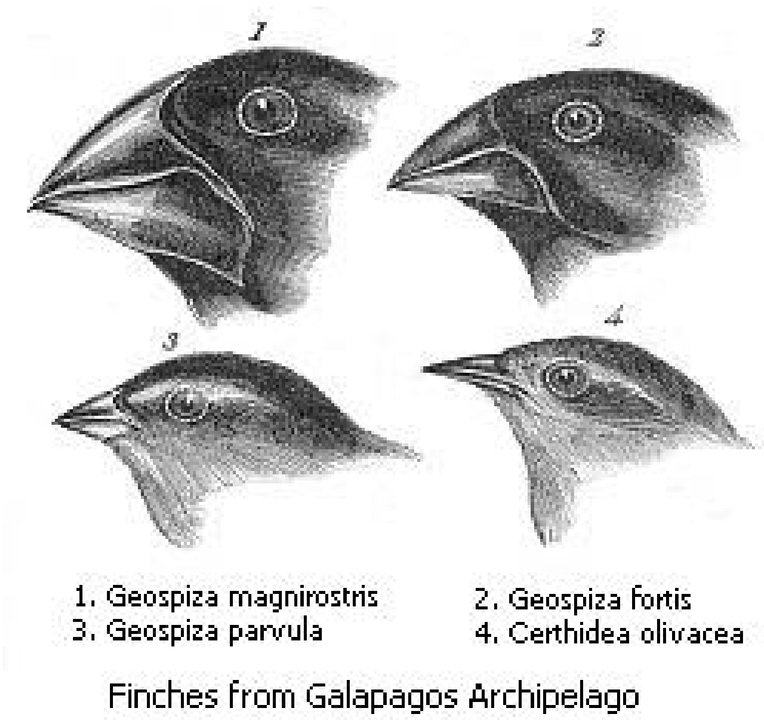



FIGURE 7.4
Variation in beak size and shape in Galápagos finches

## More Influences on Darwin

Besides his observations on the Beagle, other influences helped Darwin develop his theory of evolution by natural selection. These included his knowledge of plant and animal breeding and the ideas of other scientists.

### Plant and Animal Breeding

Darwin knew that people could breed plants and animals to have useful traits. By selecting which individuals were allowed to reproduce, they could change an organism's traits over several generations. Darwin called this type of change in organisms artificial selection. You can see an example in **Figure** 7.5. Keeping and breeding pigeons was a popular hobby in Darwin's day. Both types of pigeons in the bottom row were bred from the common rock pigeon at the top of the figure.

### Other Scientists

There were three other scientists in particular that influenced Darwin. Their names are Lamarck, Lyell, and Malthus. All three were somewhat older than Darwin, and he was familiar with their writings.

- Jean Baptiste Lamarck was a French naturalist. He was one of the first scientists to propose that species change over time. In other words, he proposed that evolution occurs. Lamarck also tried to explain how it happens, but he got that part wrong. Lamarck thought that the traits an organism developed during its life time could be passed on to its offspring. He called this the inheritance of acquired characteristics.
- Charles Lyell was an English geologist. He wrote a famous book called *Principles of Geology*. Darwin took the book with him on the *Beagle*. Lyell argued that geological processes such as erosion change Earth's surface


FIGURE 7.5
Variation in pigeons as a result of artificial selection

very gradually. To account for all the changes that had occurred on the planet, Earth must be a lot older than most people believed.

- Thomas Malthus was an English economist. He wrote a popular essay called "On Population." He argued that human populations have the potential to grow faster than the resources they need. When populations get too big, disease and famine occur. These calamities control population size by killing off the weakest people.

## Putting It All Together

Darwin spent many years thinking about his own observations and the writings of Lamarck, Lyell, and Malthus. What did it all mean? How did it all fit together? The answer, of course, is the theory of evolution by natural selection.

### Evolution of Darwin's Theory

Here's how Darwin thought through his theory:

- Like Lamarck, Darwin assumed that species evolve, or change their traits over time. Fossils Darwin found on his voyage helped convince him that evolution occurs.
- From Lyell, Darwin realized that Earth is very old. This meant that living things had a long time in which to evolve. There was enough time to produce the great diversity of living things that Darwin had observed.
- From Malthus, Darwin saw that populations could grow faster than their resources. This "overproduction of offspring" led to a "struggle for existence," in Darwin's words. In this struggle, only the "fittest" survive.

- From Darwin's knowledge of artificial selection, he knew how traits can change over time. Breeders artificially select the traits that they find beneficial. These traits become more common over many generations.
- In nature, Darwin reasoned, individuals with certain traits might be more likely to survive the "struggle for existence" and have offspring. Their traits would become more common over time. In this case, nature selects the traits that are beneficial. That's why Darwin called this process natural selection. Darwin used the word fitness to refer to the ability to reproduce and pass traits to the next generation

### Darwin's Book

Darwin finally published his theory of evolution by natural selection in 1859. He presented it in his book *On the Origin of Species*. The book is very detailed and includes a lot of evidence for the theory. Darwin's book changed science forever. The theory of evolution by natural selection became the unifying theory of all life science.

## Lesson Summary

- Darwin proposed the theory of evolution by natural selection. Evolution is a change in the inherited traits of organisms over time. Natural selection is the process by which living things with beneficial traits produce more offspring, so their traits become more common over time.
- During Darwin's voyage on the *Beagle*, he made many observations that helped him form his theory of evolution. Some of his most important observations were made on the Galápagos Islands. They included observations of giant tortoises and finches.
- Darwin was also influenced by his knowledge of artificial selection and the ideas of Lamarck, Lyell, and Malthus.
- Darwin spent many years working on a book about his theory of evolution by natural selection. He finally published *On the Origin of Species* in 1859.

## Lesson Review Questions

### Recall

1. State Darwin's theory of evolution by natural selection.
2. Identify three scientists who influenced Darwin and their contributions to his theory.

### Apply Concepts

3. Apply the concept of artificial selection to explain how new dog breeds come about.

### Think Critically

4. Explain how Darwin's observations on the Galápagos Islands helped him form his theory of evolution by natural selection.

## Points to Consider

On his voyage, Darwin saw fossils of ancient organisms. They showed him that living things had changed over time.

- What are fossils?
- How do fossils form?

# 7.2 Evidence for Evolution

## Lesson Objectives

- Explain what fossils are, how they form, and how they are dated.
- Identify evidence for evolution provided by living organisms.
- Describe recent evolution by natural selection in Darwin's finches.

## Lesson Vocabulary

- absolute dating
- fossil
- molecular clock
- paleontologist
- relative dating
- vestigial structure

## Introduction

In his book *On the Origin of Species*, Darwin included a lot of evidence for evolution. Since then, much more evidence has accumulated. The evidence includes millions of fossils, like the one in **Figure** 7.6. It also includes detailed knowledge of living organisms.

## What Are Fossils?

**Fossils** are the preserved remains or traces of organisms that lived during earlier ages. Remains that become fossils are generally the hard parts of organisms—mainly bones, teeth, or shells. Traces include any evidence of life, such as footprints like the dinosaur footprint in **Figure** 7.7. Fossils are like a window into the past. They provide direct evidence of what life was like long ago. A scientist who studies fossils to learn about the evolution of living things is called a **paleontologist**.

### How Fossils Form

The soft parts of organisms almost always decompose quickly after death. That's why most fossils consist of hard parts such as bones. It's rare even for hard parts to remain intact long enough to become fossils. Fossils form when water seeps through the remains and deposits minerals in them. The remains literally turn to stone. Remains are more likely to form fossils if they are covered quickly by sediments.

FIGURE 7.6
Most of what we know about dinosaurs is based on fossils such as this one.

Once in a while, remains are preserved almost unchanged. For example, they may be frozen in glaciers. Or they may be trapped in tree resin that hardens to form amber. That's what happened to the wasp in **Figure** 7.8. The wasp lived about 20 million years ago, but even its fragile wings have been preserved by the amber.

### How Fossils Are Dated

Fossils are useful for reconstructing the past only if they can be dated. Scientists need to determine when the organisms lived who left behind the fossils. Fossils can be dated in two different ways: absolute dating and relative dating.

- **Absolute dating** determines about how long ago a fossil organism lived. This gives the fossil an approximate age in years. Absolute dating is often based on the amount of carbon-14 or other radioactive element that remains in a fossil. You can learn how carbon-14 dating works by watching this short video:

http://www.scientificamerican.com/video/how-does-radiocarbon-dating-work-i2012-11-30/

FIGURE 7.7
Fossil footprint of a three-toed dinosaur

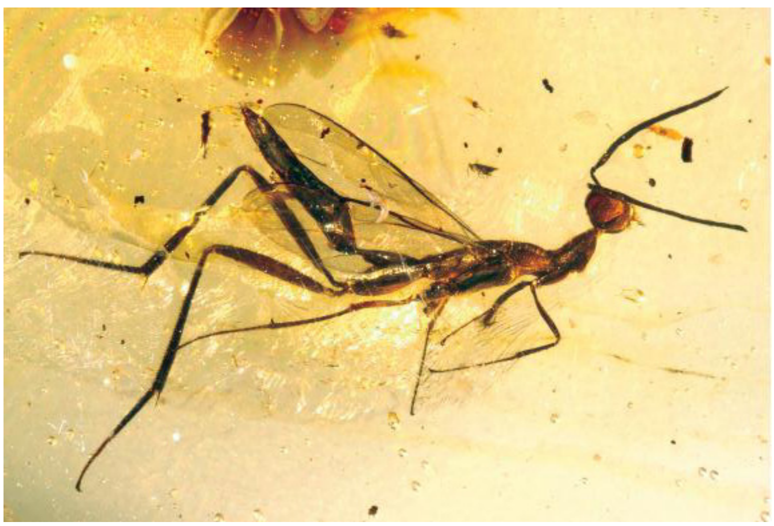


FIGURE 7.8
Wasp encased in amber

- **Relative dating** determines which of two fossils is older or younger than the other but not their age in years. Relative dating is based on the positions of fossils in rock layers. Lower rock layers were laid down earlier, so they are assumed to contain older fossils. This is illustrated in **Figure** 7.9.

### Using Fossils to Understand Evolution

The evolution of whales is a good example of how fossils can help us understand evolution. Scientists have long known that mammals first evolved on land about 200 million years ago. It's been a mystery, however, how whales evolved. Whales are mammals that live completely in the water. Did they evolve from earlier land mammals? Or did they evolve from animals that already lived in the water?

Starting in the late 1970s, a growing number of fossils have allowed scientists to piece together the story of whale evolution. The fossils represent ancient, whale-like animals. They show that an ancient land mammal made its way

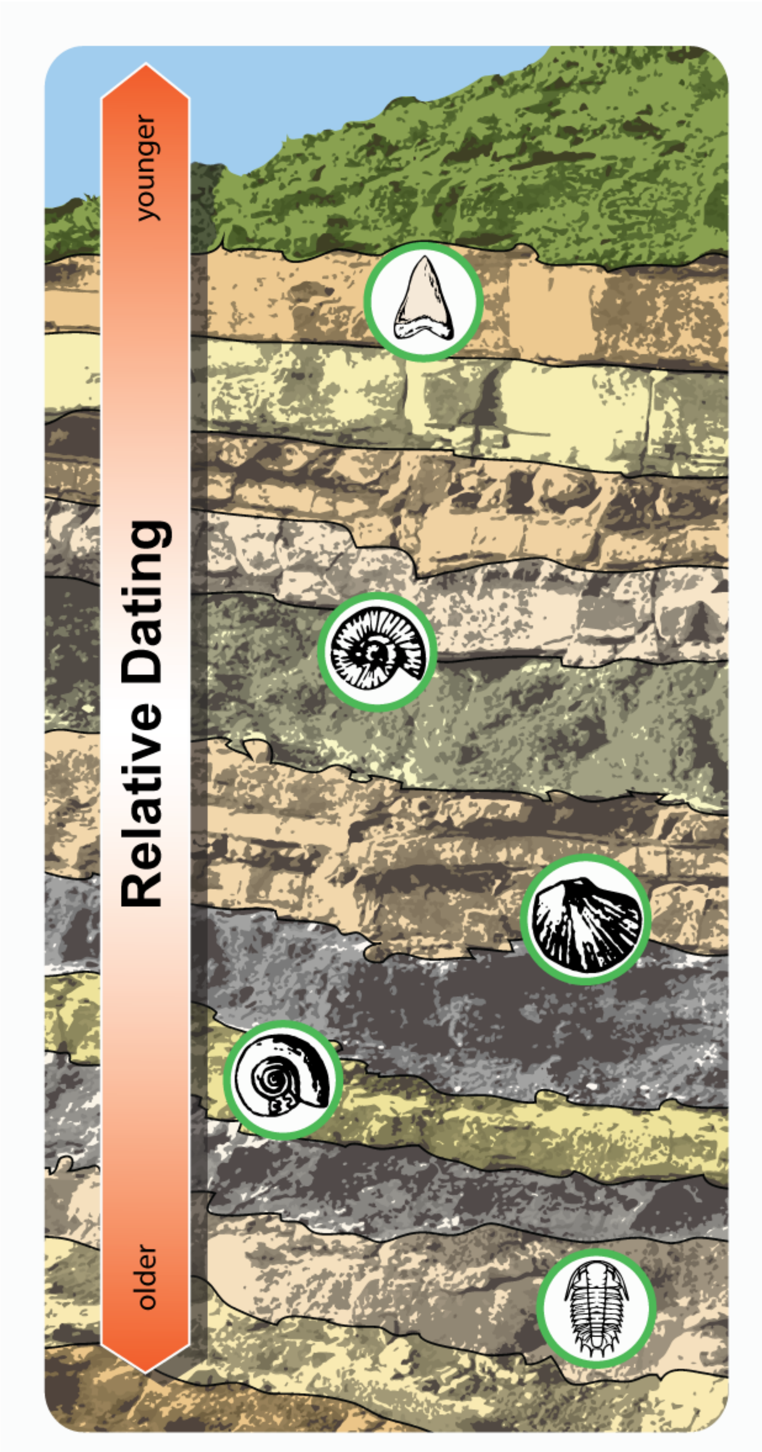



FIGURE 7.9
Fossils found in lower rock layers are generally older than fossils found in rock layers closer to the surface.

back to the sea more than 50 million years ago. It became the ancestor of modern whales. In doing so, it lost its legs and became adapted to life in the water.

In **Figure** 7.10 you can see an artist's rendition of such a whale ancestor. It had legs and could walk on land, but it was also a good swimmer. Watch this short video to learn more about the amazing story of whale evolution based on the fossils:

http://www.pbs.org/wgbh/evolution/library/03/4/l_034_05.html

FIGURE 7.10
This whale ancestor, called *Ambulocetus*, lived about 48 million years ago.

## Evidence from Living Organisms

Scientists have learned a lot about evolution by comparing living organisms. They have compared body parts, embryos, and molecules such as DNA and proteins.

### Comparing Body Parts

Comparing body parts of different species may reveal evidence for evolution. For example, all mammals have front limbs that look quite different and are used for different purposes. Bats use their front limbs to fly, whales use them to swim, and cats use them to run and climb. However, the front limbs of all three animals—as well as humans—have the same basic underlying bone structure. You can see this in **Figure** 7.11. The similar bones provide evidence that all four animals evolved from a common ancestor.

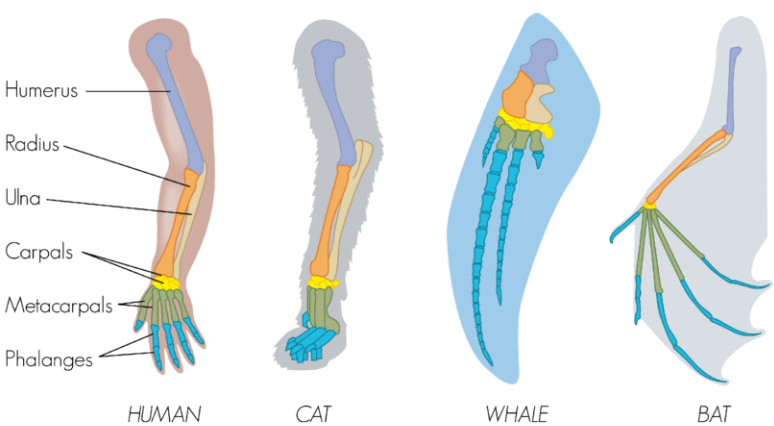



FIGURE 7.11
Front limb bones of different mammals

### Vestigial Structures

Some of the most interesting evidence for evolution comes from **vestigial structures**. These are body parts that are no longer used but are still present in modern organisms. Examples in humans include tail bones and the appendix.

- Human beings obviously don't have tails, but our ancestors did. We still have bones at the base of our spine that form a tail in other, related animals, such as monkeys.

- The appendix is a tiny remnant of a once-larger organ. In a distant ancestor, it was needed to digest food. If your appendix becomes infected, a surgeon can remove it. You won't miss it because it no longer has any purpose in the human body.

### Comparing Embryos

An embryo is an organism in the earliest stages of development. Embryos of different species may look quite similar, even when the adult forms look very different. Look at the drawings of embryos in **Figure** 7.12. They represent very early life stages of a chicken, turtle, pig, and human being. The embryos look so similar that it's hard to tell them apart. Such similarities provide evidence that all four types of animals are related. They help document that evolution has occurred.

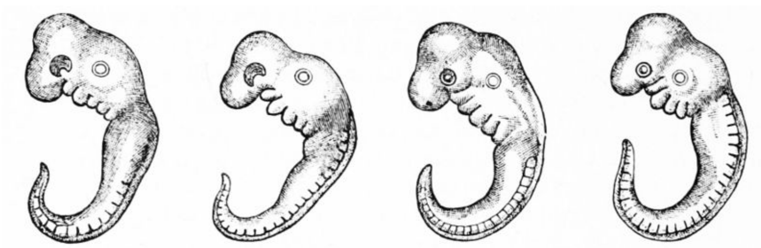


FIGURE 7.12
From left to right, embryos of a chicken, turtle, pig, and human being

### Comparing Molecules

Scientists can compare the DNA or proteins of different species. If the molecules are similar, this shows that the species are related. The more similar the molecules are, the closer the relationship is likely to be. When molecules are used in this way, they are called **molecular clocks**. This method assumes that random mutations occur at a constant rate for a given protein or segment of DNA. Over time, the mutations add up. The longer the amount of time since species diverged, the more differences there will be in their DNA or proteins.

**Table** 7.1 compares the DNA of four different organisms with modern human DNA. The DNA of chimpanzees is almost 99 percent the same as the DNA of modern humans. This shows that chimpanzees are very closely related to us. We are less closely related to the other organisms in the table. It's no surprise that grapes, which are plants, are less like us than the animals in the table.

TABLE 7.1: Comparing DNA sequences

| Organism | Similarity with Human DNA (percent the same) |
|---|---|
| Chimpanzee | 98.8 |
| Cow | 85 |
| Chicken | 65 |
| Honeybee | 44 |
| Grape | 24 |

## Observing Evolution in Action

The best evidence for evolution comes from actually observing changes in organisms through time. In the 1970s, biologists Peter and Rosemary Grant went to the Galápagos Islands to do fieldwork. They wanted to re-study

Darwin's finches. They spent the next 40 years on the project. Their hard work paid off. They were able to document evolution by natural selection taking place in the finches.

A period of very low rainfall occurred while the Grants were on the islands. The drought resulted in fewer seeds for the finches to eat. Birds with smaller beaks could eat only the smaller seeds. Birds with bigger beaks were better off. They could eat seeds of all sizes. Therefore, there was more food available to them. Many of the small-beaked birds died in the drought. More of the big-beaked birds survived and reproduced. Within just a couple of years, the average beak size in the finches increased. This was clearly evolution by natural selection.

## Lesson Summary

- Fossils are the preserved remains or traces of organisms that lived long ago. They form mainly when minerals in water turn remains to stone. Fossils can be dated using methods such as carbon-14 dating or their positions in rock layers.
- Scientists have learned a lot about evolution from species that are living today. They have compared body parts, vestigial organs, embryos, and molecules in different species. Species that are the most similar in these ways are generally the most closely related.
- The best evidence for evolution is seeing it in action. An example is the work of Peter and Rosemary Grant. They documented recent evolution by natural selection in Darwin's finches.

## Lesson Review Questions

### Recall

1. Describe how fossils usually form.
2. What are vestigial structures? Give an example.

### Apply Concepts

3. Apply the molecular clock concept to the data in the table below. Explain which of the three species in the table shared the most recent common ancestor with the human species.

**TABLE 7.2:** Human Percent DNA

| Species | Percent of DNA that is the Same as Human DNA |
|---|---|
| African gorilla | 98.4 |
| Orangutan | 97 |
| Rhesus monkey | 93 |

4.

### Think Critically

4. Compare and contrast relative and absolute dating.
5. How did scientists use fossils to solve the mystery of whale evolution?
6. Explain why Peter and Rosemary Grant were eyewitnesses to evolution.

## Points to Consider

Understanding how evolution occurs requires knowledge of genetics.

- How is variation in traits within a species related to genes?
- How would you define evolution in genetic terms?

# 7.3 The Scale of Evolution

## Lesson Objectives

- Compare and contrast microevolution and macroevolution.
- Identify forces that change allele frequencies in populations.
- Explain how speciation, convergent evolution, and coevolution can occur.
- Describe variation in the rate of evolution.

## Lesson Vocabulary

- allele frequency
- coevolution
- convergent evolution
- gene flow
- gene pool
- genetic drift
- macroevolution
- microevolution
- population
- speciation

## Introduction

Darwin thought that evolution occurs by the process of natural selection. For this process to take place, variation in traits must be passed from parents to their offspring. Darwin didn't know about Mendel's laws of heredity. As a result, he didn't understand how traits are inherited. Mendel's laws only came to light in 1900. That was about 40 years after Darwin published *On the Origin of Species*. Only with knowledge of genetics could scientists fully understand how evolution changes traits over time.

## Two Scales of Evolution

We now know how variation in traits is inherited. Variation in traits is controlled by different alleles for genes. Alleles, in turn, are passed to gametes and then to offspring. Evolution occurs because of changes in alleles over time. How long a time? That depends on the time scale of evolution you consider.

- Evolution that occurs over a short period of time is known as **microevolution**. It might take place in just a couple of generations. This scale of evolution occurs at the level of the population. The Grants observed evolution at this scale in populations of Darwin's finches. Beak size in finch populations changed in just two years because of a serious drought.

- Evolution that occurs over a long period of time is called **macroevolution**. It might take place over millions of years. This scale of evolution occurs above the level of the species. Fossils provide evidence for evolution at this scale. The evolution of the horse family, shown in **Figure** 7.13, is an example of macroevolution.

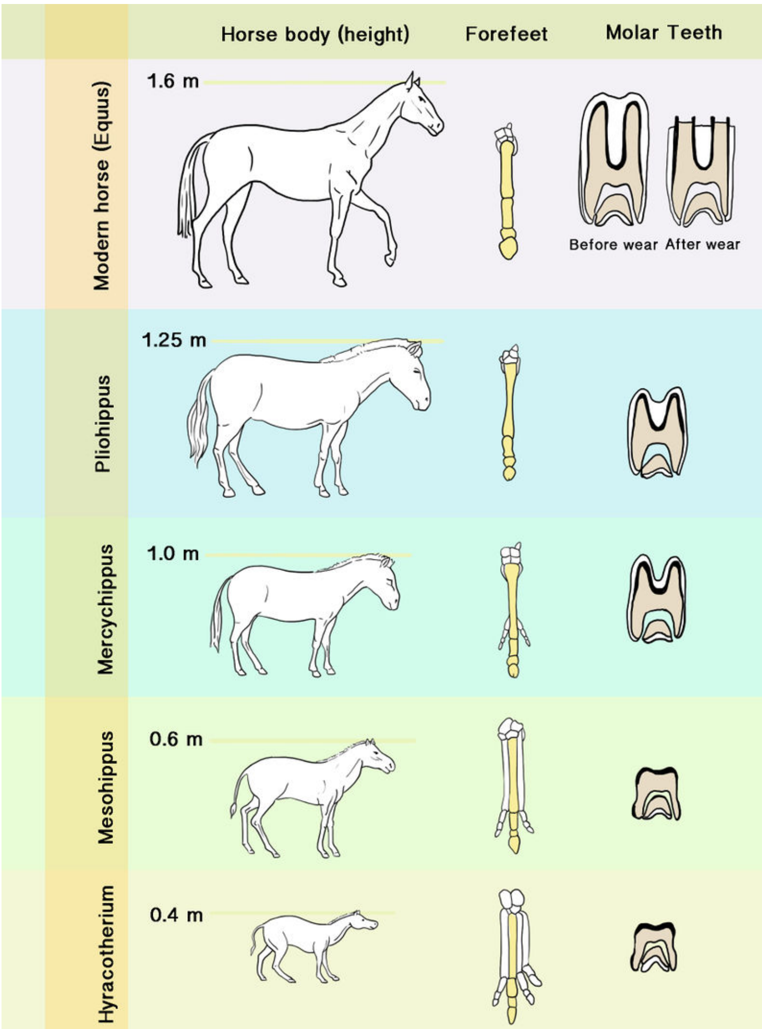



FIGURE 7.13
Fossils show how horses evolved over the past 50 million of years. Horses increased in size. Their teeth and feet also changed.

## Microevolution

Individuals don't evolve. Their alleles don't change over time. The unit of microevolution is the population.

### Genes in Populations

A **population** is a group of organisms of the same species that live in the same area. All the genes in all the members of a population make up the population's **gene pool**. For each gene, the gene pool includes all the different alleles in the population. The gene pool can be described by its **allele frequencies** for specific genes. The frequency of an allele is the number of copies of that allele divided by the total number of alleles for the gene in the gene pool.

A simple example will help you understand these concepts. The data in Table 7.2 represent a population of 100 individuals. For each gene, the gene pool has a total of 200 alleles (2 per individual x 100 individuals). The gene in question exists as two different alleles, *A* and *a*. The number of *A* alleles in the gene pool is 140. Of these, 100 are in the 50 *AA* homozygotes. Another 40 are in the 40 *Aa* heterozygotes. The number of *a* alleles in the gene pool is 60. Of these, 40 are in the 40 *A*a heterozygotes. Another 20 are in the 10 *aa* homozygotes. The frequency of the *A* allele is 140/200 = 0.7. The frequency of the a allele is 60/200 = 0.3.

**TABLE 7.3:** Alleles in a gene pool

| Genotype | Number of Individuals | Number of *A* Alleles | Number of *a* Alleles |
|---|---|---|---|
| *AA* | 50 | 100 (50 x 2) | 0 (50 x 0) |
| *Aa* | 40 | 40 (40 x 1) | 40 (40 x 1) |
| *aa* | 10 | 0 (10 x 0) | 20 (10 x 2) |
| Totals | 100 | 140 | 60 |

Evolution occurs in a population when its allele frequencies change over time. For example, the frequency of the A allele might change from 0.7 to 0.8. If that happens, evolution has occurred. What causes allele frequencies to change? The answer is forces of evolution.

### Forces of Evolution

There are four major forces of evolution that cause allele frequencies to change. They are mutation, gene flow, genetic drift, and natural selection.

- Mutation creates new genetic variation in a gene pool This is how all new alleles first arise. It's the ultimate source of new genetic variation, so it is essential for evolution. However, for any given gene, the chance of a mutation occurring is very small. Therefore, mutation alone does not have much effect on allele frequencies.
- **Gene flow** is the movement of genes into or out of a gene pool It occurs when individuals migrate into or out of the population. How much gene flow changes allele frequencies depends on how many migrants there are and their genotypes.
- **Genetic drift** is a random change in allele frequencies. It occurs in small populations. Allele frequencies in the offspring may differ by chance from those in the parents. This is like tossing a coin just a few times. You may, by chance, get more or less than the expected 50 percent heads or tails. In the same way, you may get more or less than the expected allele frequencies in the small number of individuals in the next generation. The smaller the population is, the more allele frequencies may drift.
- Natural selection is a change in allele frequencies that occurs because some genotypes are more fit than others. Genotypes with greater fitness produce more offspring and pass more copies of their alleles to the next generation. This is the force of evolution that Darwin identified. **Figure** 23.12 shows how Darwin thought natural selection led to variation in finches on the Galápagos Islands.

## Macroevolution

What happens when forces of evolution work over a long period of time? The answer is macroevolution. An example is the evolution of a new species.

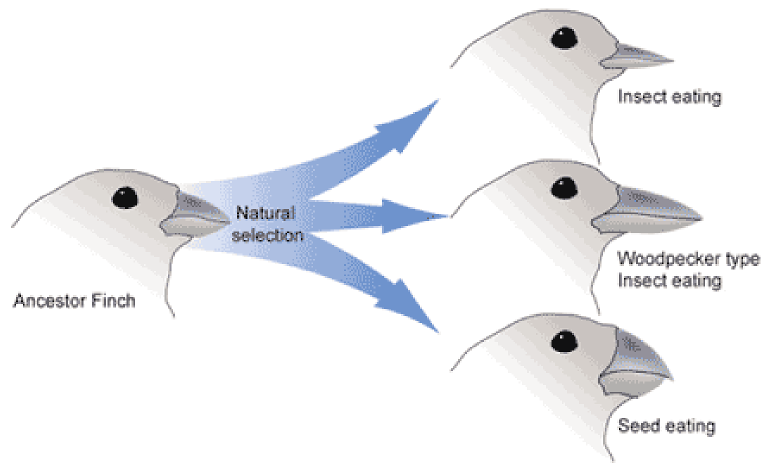



FIGURE 7.14

Darwin's finches evolved new traits by natural selection.

## Speciation

The evolution of a new species is called **speciation**. A species is a group of organisms that can mate and produce fertile offspring together but not with members of other such groups. What must happen for a new species to arise? Some members of an existing species must change so they can no produce fertile offspring with the rest of the species. Speciation often occurs when some members of a species break off from the rest. The splinter group evolves in isolation from the original species. The original species also continues to evolve. Sooner or later, the splinter group becomes too different to breed with members of the original species. At that point, a new species has formed.

A good example of speciation involves anole lizards, like the one pictured in **Figure** 7.15. There are about 150 different species of anole lizards in the Caribbean Islands. Scientists think that a single species of lizard first colonized one of the islands about 50 million years ago. A few lizards from this original species eventually reached each of the other islands, where they evolved in isolation. Anoles in different habitats evolved traits that affected mating. For example, they evolved skin flaps of different colors. Females didn't respond to male anoles with the "wrong" color skin flap. This prevented them from mating. Eventually, all the different species of anoles known today evolved. Watch this interesting video to learn more about anole speciation in the Caribbean:

http://media.hhmi.org/biointeractive/films/OriginSpecies-Lizards.html

## Convergent Evolution

Sometimes two species evolve the same traits. It happens because they live in similar habitats. This is called **convergent evolution**. Caribbean Anoles demonstrate this as well.

On each Caribbean island, anoles in similar habitats evolved the same traits. For example, anoles that lived on the forest floor evolved long legs for leaping and running on the ground. Anoles that lived on tree branches evolved short legs that helped them cling to small branches and twigs. Anoles that lived at the tops of trees evolved large toe pads that allowed them to walk on leaves without falling. On each of the islands, there were anole species that evolved in each of these same ways.

FIGURE 7.15
This male anole lizard is puffing out a flap of yellow skin to attract a mate.

### Coevolution

Two species may often interact with each other and have a close relationship. Examples include flowers and the animals that pollinate them. When one of the two species evolves new traits, the other species may evolve matching traits. This is called **coevolution**. You can see an example of this in **Figure** 7.16. The very long beak of this hummingbird co-evolved with the tubular flowers it pollinates. Only this species of hummingbird can reach nectar deep in the flowers.

FIGURE 7.16
Coevolution of a hummingbird and flowering plant

## Rate of Evolution

Darwin thought that evolution occurs very slowly. This is likely if conditions are stable. But what if conditions are changing rapidly? Evolution is likely to occur more rapidly as well. For example, the Grants showed that evolution occurred in just a couple of years in Darwin's finches. This happened when a severe drought killed off a lot of the plants that the birds needed for food.

Millions of fossils have been found since Darwin's time. They show that evolution may occur in fits and starts. Long period of little or gradual change may be interrupted by bursts of rapid change. The rate of evolution is influenced by how the environment is changing. Today, Earth's climate is changing rapidly. How do you think this might affect the rate of evolution?

## Lesson Summary

- The time scale of evolution can vary. Evolution over a short period of time at the level of the population is called microevolution. Evolution over a long period of time above the level of the species is called macroevolution.
- Microevolution occurs in a population when its allele frequencies change over time. There are four major forces of evolution that cause allele frequencies to change: mutation, gene flow, genetic drift, and natural selection.
- Macroevolution occurs when microevolution takes place over a long period of time. Types of macroevolution include speciation, convergent evolution, and coevolution.
- The rate of evolution is influenced by how quickly the environment is changing. Long periods of gradual evolutionary change may be interrupted by short bursts of rapid change.

## Lesson Review Questions

### Recall

1. List the four major forces of evolution.
2. Define coevolution and give an example.

### Apply Concepts

3. Calculate allele frequencies for the gene pool based on the data in the table below.

**TABLE 7.4:** Gene Pool

| Genotype | Number in Population |
|---|---|
| AA | 10 |
| Aa | 20 |
| aa | 20 |
| Total | 50 |

4.
5. Whales and bats have the trait of echolocation. This is the ability to locate objects in the dark by bouncing sound waves off them. The most recent common ancestor of whales and bats did not have this trait. Apply lesson concepts to explain how the trait evolved in whales and bats.

### Think Critically

5. Compare and contrast microevolution and macroevolution.
6. Explain how speciation can occur.

## Points to Consider

Evolution has been taking place since life first evolved on Earth.

- How old is planet Earth?
- How long has life been evolving on Earth?

# 7.4 History of Life on Earth

## Lesson Objectives

- Describe geologic time and the geologic time scale.
- Give an overview of life's origins and the Precambrian.
- Explain how life evolved during the Paleozoic Era.
- Outline major events in evolution during the Mesozoic Era.
- Describe evolution during the Cenozoic Era.

## Lesson Vocabulary

- Cenozoic Era
- extinction
- geologic time scale
- Last Universal Common Ancestor (LUCA)
- mass extinction
- Mesozoic Era
- Paleozoic Era
- Precambrian

## Introduction

Earth formed 4.6 billion years ago. Life first appeared on Earth about 4 billion years ago. The first life forms were microscopic, single-celled organisms. From these simple beginnings, evolution gradually produced the vast diversity of life today.

In this lesson, you'll read about the history of life from its origins until now. You'll learn that living things had to cope with some astounding changes. Giant meteorites struck Earth's surface. Continents drifted and collided. Several times the majority of Earth's living things went extinct. **Extinction** occurs when a species completely dies out. But life on Earth was persistent. Each time it came back more numerous and diverse than before.

## Geologic Time

It's hard to grasp the vast amounts of time since Earth formed and life first appeared. It may help to think of Earth's history as a 24-hour day.

### Earth in a Day

**Figure** 7.17 shows the history of Earth in a day. In this model, the planet forms at midnight. The first prokaryotes evolve around 3:00 am. Eukaryotes evolve at about 1:00 pm. Animals don't evolve until almost 8:00 pm. Humans appear only in the last minute of the day. Relating these major events in Earth's history to a 24-hour day helps to put them in perspective.

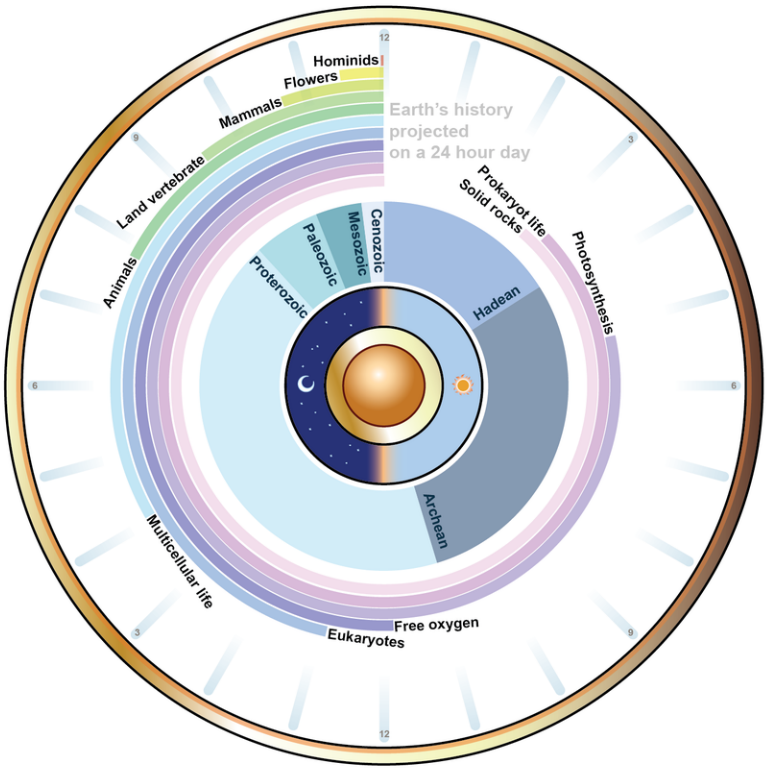



FIGURE 7.17
Earth's history in a day

### Geologic Time Scale

Another tool for understanding the history of Earth and its life is the **geologic time scale**. You can see this time scale in **Figure** 7.18. It divides Earth's history into eons, eras, and periods. These divisions are based on major changes in geology, climate, and the evolution of life. The geologic time scale organizes Earth's history on the basis of important events instead of time alone. It also puts more focus on recent events, about which we know the most.

## Precambrian: Life's Origins

The **Precambrian** Supereon is the first major division of Earth's history (see **Figure** 7.18). It covers the time from Earth's formation 4.6 billion years ago to 544 million years ago. To see how life evolved during the Precambrian and beyond, watch this wonderful video. It's a good introduction to the rest of the lesson.

http://www.youtube.com/watch?v=8SgnnV8nV9g

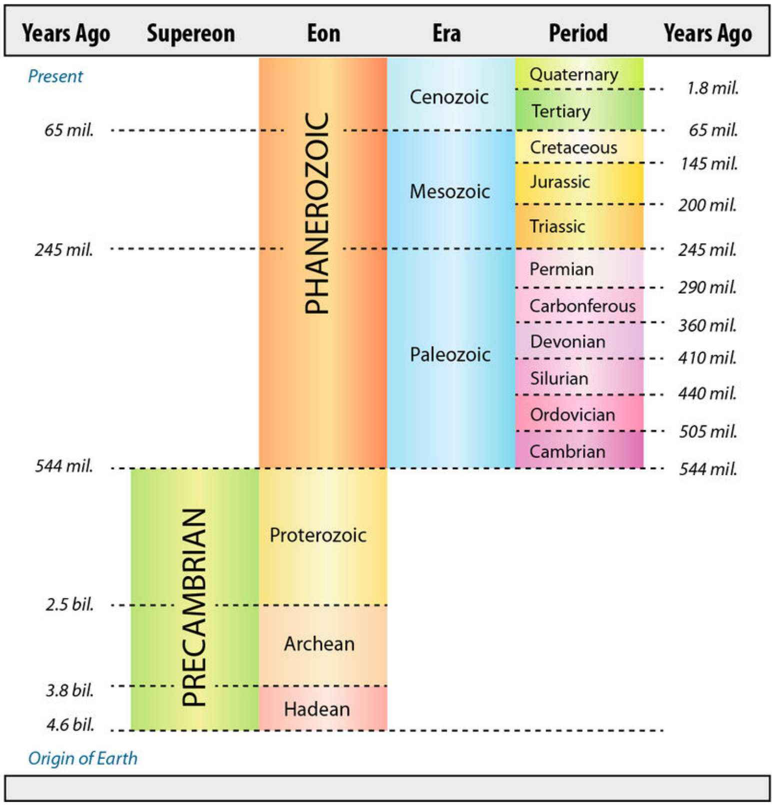
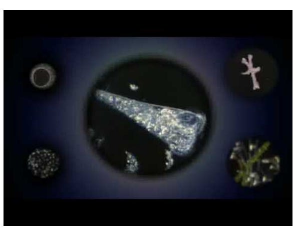



FIGURE 7.18
Geologic time scale



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URL: http://www.ck12.org/flx/render/embeddedobject/149622

## Ancient Earth

When Earth first formed, it was a fiery hot, barren ball. It had no oceans or atmosphere. Rivers of melted rock flowed over its surface. Gradually, the planet cooled and formed a solid crust. Gases from volcanoes formed an atmosphere, although it contained only a trace of oxygen. As the planet continued to cool, clouds formed and rain fell. Rainwater helped form oceans. The ancient atmosphere and oceans would be toxic to modern life, but they set the stage for life to begin.

## First Organic Molecules and Cells

All living things consist of organic molecules. Many scientists think that organic molecules evolved before cells, perhaps as early as 4 billion years ago. It's possible that lightning sparked chemical reactions in Earth's early atmosphere. This could have created a "soup" of organic molecules from inorganic chemicals. Some scientists think that RNA was the first organic molecule to evolve. RNA can not only encode genetic instructions. Some RNA molecules can carry out chemical reactions.

All living things are made of one or more cells. How the first cells evolved is not known for certain. Scientists speculate that lipid membranes grew around RNA molecules. The earliest cells may have consisted of little more than RNA inside a lipid membrane. You can see a model of such a cell in **Figure** 7.19. The first cells probably evolved between 3.8 and 4 billion years ago. Scientists think that one cell, called the **Last Universal Common Ancestor (LUCA)**, gave rise to all of the following life on Earth. LUCA may have existed around 3.5 billion years ago.

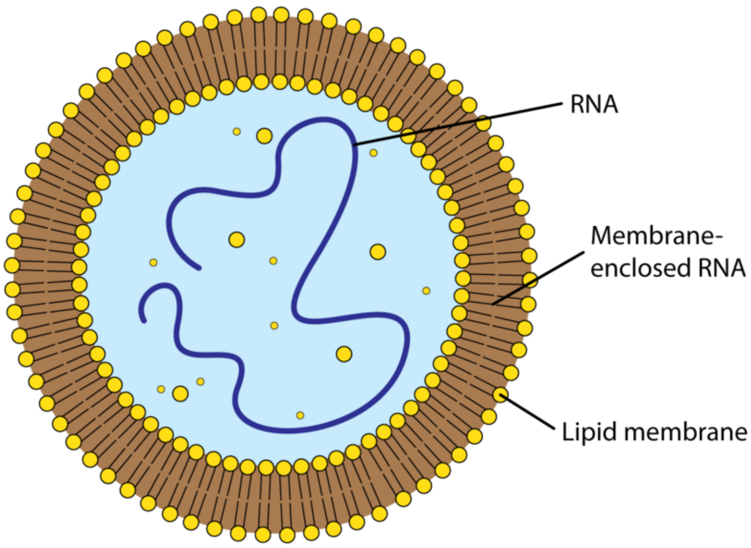


FIGURE 7.19
Model of the earliest cell

## New Adaptations

The earliest cells were heterotrophs. They were unable to make food. Instead, they got energy by "eating" organic molecules in the “soup” around them. The earliest cells were also prokaryotes. They lacked a nucleus and other organelles. Gradually, these and other traits evolved.

- Photosynthesis evolved about 3 billion years ago. After that, certain cells could use sunlight to make food. These were the first autotrophs. They made food for themselves and other cells. They also added oxygen to the atmosphere. The oxygen was a waste product of photosynthesis.
- Oxygen was toxic to many cells. They had evolved in its absence. Many of them died out. The few that survived evolved a new way to use oxygen. They used it to get energy from food. This is the process of cellular respiration.
- The first eukaryotic cells probably evolved about 2 billion years ago. That’s when cells evolved organelles and a nucleus. **Figure** 7.20 shows one theory about the origin of organelles. According to this theory, a large cell engulfed small cells. The small cells took on special roles that helped the large cell function. In return, the small cells got nutrients from the large cell. Eventually, the large and small cells could no longer live apart.
- With their specialized organelles, eukaryotic cells were powerful and efficient. Eukaryotes would go on to evolve sexual reproduction. They would also evolve into multicellular organisms. The first multicellular organisms evolved about 1 billion years ago.

## Precambrian Mass Extinction

At the end of the Precambrian, a mass extinction occurred. In a **mass extinction**, the majority of species die out. The Precambrian mass extinction was the first of six mass extinctions that occurred on Earth. It’s not certain what caused this first mass extinction. Changes in Earth’s geology and climate were no doubt involved.

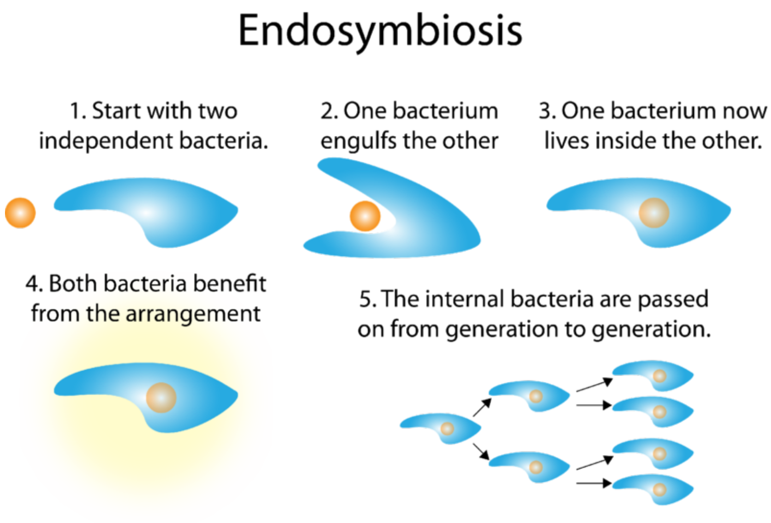


FIGURE 7.20
How eukaryotic cells may have evolved

## Paleozoic Era

The **Paleozoic Era** lasted from 544 to 245 million years ago. It is divided into six periods.

### Cambrian Period

The Precambrian mass extinction opened up many niches for new organisms to fill. As a result, the Cambrian Period began with an explosion of new kinds of living things. For example, many types of simple animals called sponges evolved. Trilobites were also very common. Sponges and trilobites were small ocean invertebrates. These are animals without a backbone. You can see examples of them in **Figure** 7.21.

FIGURE 7.21
Sponges (left) and trilobite fossil (right) from the Cambrian Period

### Ordovician Period

During the Ordovician Period, the oceans became filled with many kinds of invertebrates. The first fish also evolved. Plants colonized the land for the first time. However, animals remained in the water.

### Silurian Period

Corals appeared in the oceans during the Silurian period. Fish continued to evolve. On land, vascular plants appeared. These are plants that have special tissues to circulate water and other substances. This allowed plants to become larger and colonize drier habitats.

### Devonian Period

During the Devonian Period, the first seed plants evolved. Seeds have a protective coat and contain stored food. This was a big advantage over other types of plant reproduction. Seed plants eventually became the most common type of plants on land. In the oceans, fish with lobe fins evolved. These fish could breathe air when they raised their head above water. This was a step in the evolution of animals that could live on land.

### Carboniferous Period

In the Carboniferous Period, forests of huge ferns and trees were widespread. You can see how these first forests might have looked in **Figure** 7.22. After the ferns and trees died, their remains eventually turned to coal. The first amphibians also evolved during this period. They could live on land but had to return to the water to lay their eggs. After amphibians, the earliest reptiles appeared. They were the first animals that could reproduce on land and move away from the water.

FIGURE 7.22
Forest of the Carboniferous Period

### Permian Period

During the Permian Period, all the major landmasses moved together to form one supercontinent. The supercontinent has been named Pangaea. You can see how it looked in **Figure** 7.23. At this time, temperatures were extreme and the climate became very dry. As a result, plants and animals evolved ways to cope with dryness. For example, reptiles evolved leathery skin. This helped prevent water loss. Plants evolved waxy leaves for the same purpose.

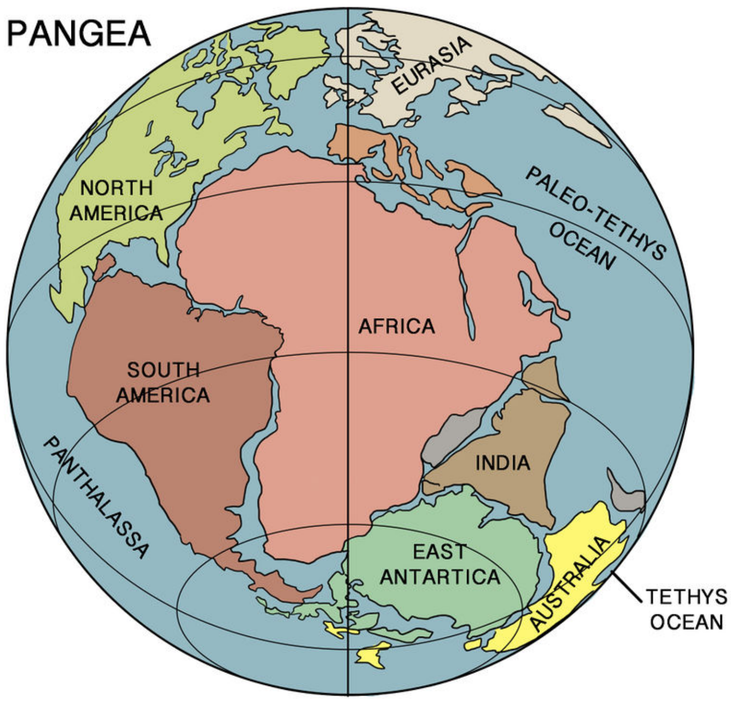


FIGURE 7.23
The supercontinent Pangaea formed during the Permian Period.

The Permian Period ended with Earth's second mass extinction. During this event, most of Earth's species went extinct. It was the most massive extinction ever recorded. It's not clear why it happened. One possible reason is that a very large meteorite struck Earth. Another possibility is the eruption of enormous volcanoes. Either event could create a huge amount of dust. The dust might block out sunlight for months. This would cool the planet and prevent photosynthesis.

## Mesozoic Era

The Permian mass extinction paved the way for another burst of new life at the start of the **Mesozoic Era**. This era is known as the "age of dinosaurs." It is divided into three periods.

### Triassic Period

During the Triassic Period, the first dinosaurs evolved from reptile ancestors. They eventually colonized the air and water in addition to the land. There were also forests of huge seed ferns and cone-bearing conifer trees in the Triassic Period. Modern corals, fish, and insects all evolved in this period as well. The supercontinent of Pangea started to break up. The Triassic Period ended in a mass extinction. The majority of species died out, but dinosaurs were spared.

### Jurassic Period

The Triassic mass extinction gave dinosaurs the opportunity to really flourish during the Jurassic Period. That's why this period is called the "golden age of dinosaurs." The earliest birds also evolved during the Jurassic from dinosaur ancestors. In addition, all the major groups of mammals appeared. Flowering plants also appeared for the first time. New insects evolved to pollinate them. The continents continued to move apart.

### Cretaceous Period

During the Cretaceous Period, the dinosaurs reached their maximum size and distribution. For example, the well-known Tyrannosaurus rex weighed at least 7 tons! You can get an idea of how big it was from the T. rex skeleton in **Figure** 7.24. (Notice how small the person looks in the bottom left of the photo.) By the end of the Cretaceous, the continents were close to their present locations. The period ended with another mass extinction. This time, the dinosaurs went extinct.

FIGURE 7.24
Tyrannosaurus rex skeleton on display in a museum

What happened to the dinosaurs? Some scientists think that a comet or asteroid may have crashed into Earth. This could darken the sky, shut down photosynthesis, and cause climate change. Other factors probably contributed to the mass extinction as well.

## Cenozoic Era

The extinction of the dinosaurs at the end of the Mesozoic Era paved the way for mammals to take over. That's why the **Cenozoic Era** is called the "age of mammals." They soon became the dominant land animals on Earth. The

Cenozoic is divided into two periods.

### Tertiary Period

During the Tertiary Period, many new kinds of mammals evolved. For example, primates and human ancestors first appeared during this period. Many mammals also increased in size. Modern rain forests and grasslands appeared. Flowering plants and insects increased in numbers.

### Quaternary Period

During the Quaternary Period, the climate cooled. This caused a series of ice ages. Glaciers advanced southward from the North Pole. They reached as far south as Chicago and New York City. Sea levels fell because so much water was frozen in glaciers. This exposed land bridges between continents. The land bridges allowed land animals to move to new areas. Some mammals adapted to the cold by evolving very large size and thick fur. An example is the woolly mammoth, shown in **Figure** 7.25. Other mammals moved closer to the equator. Those that couldn't adapt or move went extinct, along with many plants.

FIGURE 7.25
Woolly mammoths lived during the last ice age.

The last ice age ended about 12,000 years ago. By then, our own species, *Homo sapiens*, had evolved. After that, we were eyewitnesses to the story of life. As a result, the recent past is less of a mystery than the billions of years before it.

## Lesson Summary

- Earth formed 4.6 billion years ago. The geologic time scale is used to organize the vast expanse of time since Earth formed. It is based on major events in the history of Earth and its living things.
- The Precambrian Supereon (4.6 billion–544 million years ago) is the first major division of the geologic time scale. The first living cells may have evolved around 4 billion years ago. By 1 million years ago, the first multicellular eukaryotes had evolved. The Precambrian ended with the first of six mass extinctions that occurred during Earth's history.
- The Paleozoic Era (544–245 million years ago) started with an explosion of new kinds of organisms. Major evolutionary events during this era included the first appearance of invertebrates, fish, amphibians, and reptiles.

Plants also colonized the land, and vascular plants and seed plants evolved. The era ended with the Permian mass extinction.
- The Mesozoic Era (245–65 million years ago) is called the "age of dinosaurs." Dinosaurs evolved from reptiles. They flourished after the Triassic mass extinction. They went extinct at the end of the era in the Cretaceous mass extinction. Birds and flowering plants also first appeared during the Mesozoic Era.
- The Cenozoic Era (65 million years ago–present) is called the "age of mammals." Mammals became more diverse, and many increased in size. A series of ice ages affected the evolution of living things during this era. The human species evolved toward the end of the Mesozoic Era.

## Lesson Review Questions

### Recall

1. What is the geologic time scale?
2. List important events in the evolution of life that occurred during the Precambrian.
3. Identify major groups of organisms that first appeared during the Paleozoic Era.

### Apply Concepts

4. Pretend that you have been transported in a time machine to the Mesozoic Era. Describe what you might see.

### Think Critically

5. Discuss how past mass extinctions generally affected the evolution of life on Earth.
6. All the major groups of mammals appeared during the Mesozoic Era. Why is the Cenozoic Era called the age of mammals?

## Points to Consider

The first living things to evolve in the Precambrian were single-celled prokaryotes.

- When did they evolve?
- In which domain(s) of life are they placed?

# 7.5 References


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# Chapter 8 MS Prokaryotes

## Chapter Outline



This photo shows the steaming hot water of Grand Prismatic Spring in Yellowstone National Park of Wyoming. Believe it or not, but tiny organisms live in abundance in the very hot water. What living things can withstand such high temperatures? They are prokaryotes classified as Archaea. Besides hot water, they live in other extreme environments as well. You'll learn more about these fascinating organisms when you read this chapter.

# 8.1 Introduction to Prokaryotes

## Lesson Objectives

- Outline the classification and evolution of prokaryotes.
- Describe the structure of prokaryotic cells.
- Identify variation in the metabolism and habitats of prokaryotes.
- Explain how prokaryotes reproduce and increase genetic variation.

## Lesson Vocabulary

- Archaea Domain
- Bacteria Domain
- biofilm
- cyanobacteria
- flagellum (flagella, plural)
- genetic transfer
- plasmid

## Introduction

No doubt you've had a sore throat before, and you've probably eaten cheese or yogurt. If so, then you've already encountered the amazing world of prokaryotes. Prokaryotes are single-celled organisms that lack a nucleus. They also lack other membrane-bound organelles. Prokaryotes are tiny. They can only be viewed with a microscope (see **Figure** 8.1). But they are the most numerous organisms on Earth. Without them, the world would be a very different place.

## Prokaryote Classification and Evolution

Prokaryotes are currently placed in two domains. A domain is the highest taxon in the classification of living things. It's even higher than the kingdom.

### Classification of Prokaryotes

The prokaryote domains are the **Bacteria Domain** and **Archaea Domain**, shown in **Figure** 8.2. All other living things are eukaryotes and placed in the domain Eukarya. (Unlike prokaryotes, eukaryotes have a nucleus in their cells.)

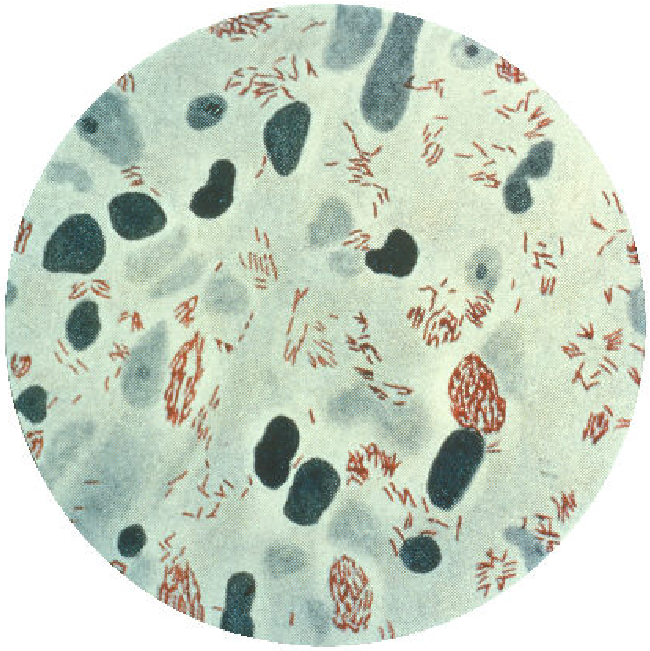

FIGURE 8.1
The tiny red rods in this micrograph are prokaryotes that cause the disease known as leprosy.

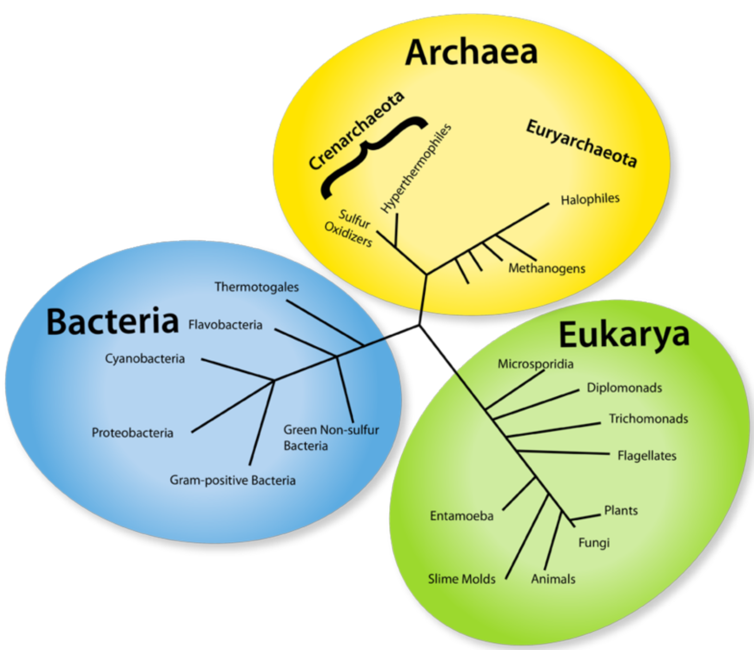


FIGURE 8.2
The three domains of life include two prokaryote domains: Bacteria and Archaea.

## Evolution of Prokaryotes

Prokaryotes were the first living things to evolve on Earth, probably around 3.8 billion years ago. They were the only living things until the first eukaryotic cells evolved about 2 billion years ago. Prokaryotes are still the most numerous organisms on Earth.

It's not certain how the three domains of life are related. Archaea were once thought to be offshoots of Bacteria that were adapted to extreme environments. For their part, Bacteria were considered to be ancestors of Eukarya.

Scientists now know that Archaea share several traits with Eukarya that Bacteria do not share. How can this be explained? One hypothesis is that the first Eukarya formed when an archaean cell fused with a bacterial cell. By fusing, the two prokaryotic cells became the nucleus and cytoplasm of a new eukaryotic cell. If this hypothesis is correct, both prokaryotic domains are ancestors of Eukarya.

## Prokaryote Structure

All prokaryotes consist of just one cell. They share a number of other traits as well. Watch this entertaining video from the Amoeba Sisters to see how prokaryotes differ in structure from eukaryotes: http://www.youtube.com/watch?v=ruBAHiij4EA .


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### Size and Shape of Prokaryotes

Most prokaryotic cells are much smaller than eukaryotic cells. Prokaryotic cells are typically only 0.2-2.0 micrometer in diameter. Eukaryotic cells are about 50 times as big.

Prokaryotic cells have a variety of different cell shapes. **Figure** 8.3 shows three of the most common shapes: spirals (helices), spheres, and rods. Bacteria may be classified by their shape.


FIGURE 8.3

Prokaryotic cell shapes

### Flagella

Most prokaryotes have one or more long, thin "whips" called **flagella (flagellum, plural)**. You can see flagella in **Figure** 8.4. Flagella help prokaryotes move toward food or away from toxins. Each flagellum spins around a fixed base. This causes the cell to roll and tumble.

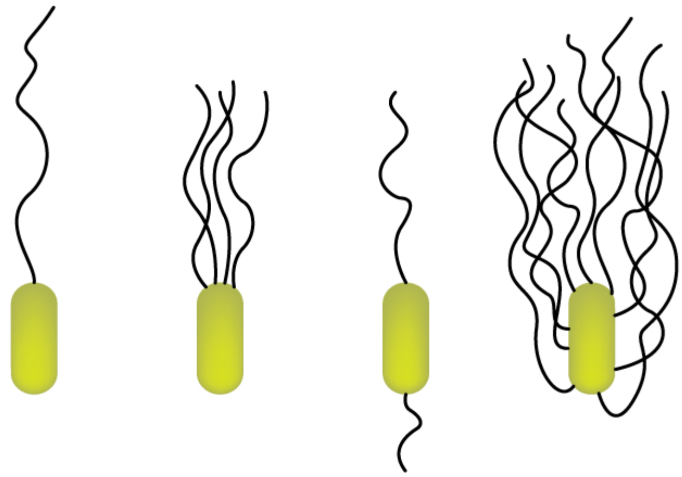

FIGURE 8.4
Prokaryote flagella

## Outer Layers of a Prokaryote Cell

The cells of prokaryotes have two or three outer layers.

- Like all other living cells, prokaryotes have a cell membrane. It controls what enters and leaves the cell. It's also the site of many metabolic reactions. For example, cellular respiration takes place in the cell membrane.
- Most prokaryotes also have a cell wall. It lies just outside the cell membrane. It makes the cell stronger and more rigid.
- Many prokaryotes have another layer, called a capsule, outside the cell wall. The capsule protects the cell from chemicals and drying out. It also allows the cell to stick to surfaces and to other cells.

You can see a model of a prokaryotic cell in **Figure** 8.5. Find the cell membrane, cell wall, and capsule in the figure.

## Cell Structures

Several other prokaryotic cell structures are also shown in **Figure** 8.5. They include:

- cytoplasm. Like all other cells, prokaryotic cells are filled with cytoplasm. It includes watery cytosol and other structures.
- ribosomes. This is the site where proteins are made.
- cytoskeleton. This is a network of fibers and tubules that crisscrosses the cytoplasm. The cytoskeleton helps the cell keep its shape.
- pili. These are hair-like projections from the surface of the cell. They help the cell hold on to surfaces or do other jobs for the cell.

## Prokaryotic DNA

All prokaryotic cells contain DNA, as you can see in **Figure** 8.6. Most of the DNA is in the form of a single large loop. This DNA coils up in the cytoplasm to form a structure called a **nucleoid**. There is no membrane surrounding it.

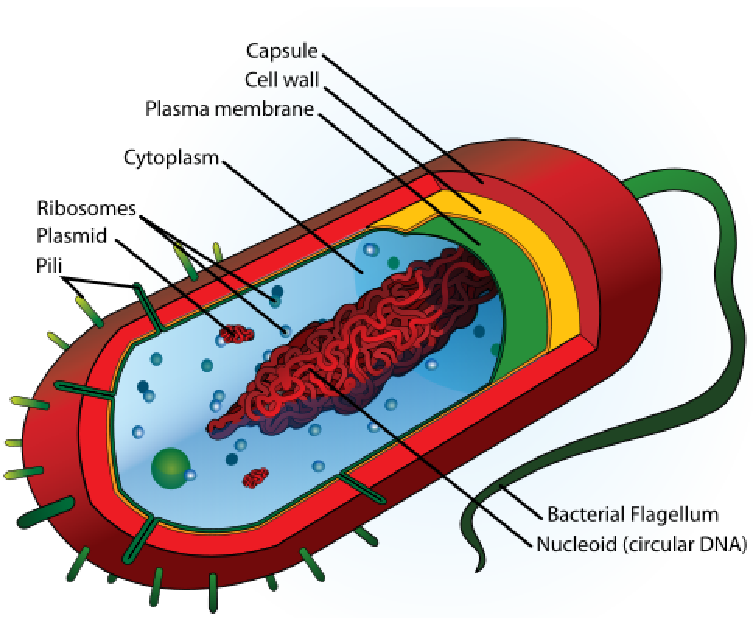


FIGURE 8.5
Model of a prokaryotic cell

Most prokaryotes also have one or more small loops of DNA. They are called **plasmids**.

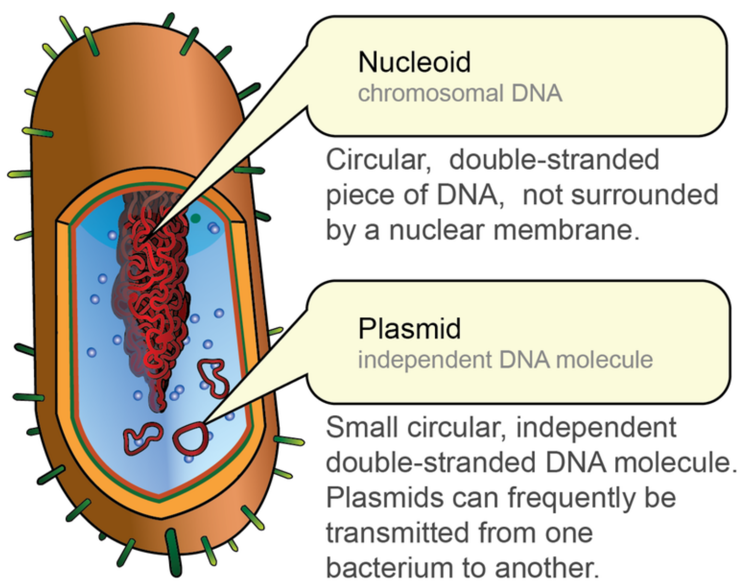


FIGURE 8.6
DNA in a prokaryotic cell

## Biofilms

Some prokaryotes form structures consisting of many individual cells, like the cells in **Figure** 8.7. This is called a biofilm. A **biofilm** is a colony of prokaryotes that is stuck to a surface. The surface might be a rock or a host's tissues. The sticky plaque that collects on your teeth between brushings is a biofilm. It consists of millions of prokaryotic cells.

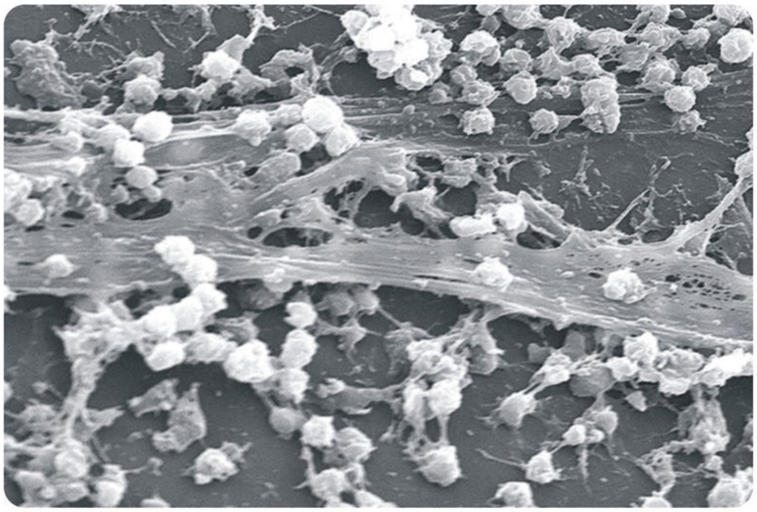

FIGURE 8.7
Microscopic view of a bacterial biofilm

## Prokaryote Metabolism and Habitats

Like all living things, prokaryotes need energy and carbon. They meet these needs in a variety of ways and in a range of habitats.

### Metabolism in Prokaryotes

Prokaryotes may have just about any type of metabolism. They may get energy from light or from chemical compounds. They may get carbon from carbon dioxide or from other living things.

- Most prokaryotes get both energy and carbon from other living things. Many of them are decomposers. They break down wastes and remains of dead organisms. In this way, they help to recycle carbon and nitrogen through ecosystems.
- Some prokaryotes use energy in sunlight to make food from carbon dioxide. They do this by the process of photosynthesis. They are important producers in aquatic ecosystems. Look at the green streaks on the lake in **Figure** 8.8. They consist of billions of photosynthetic bacteria called **cyanobacteria**.

### Habitats of Prokaryotes

Prokaryotes live in a wide range of habitats. For example, they may live in habitats with or without oxygen.

- Prokaryotes that need oxygen are described as aerobic. They use oxygen for cellular respiration. Examples include the prokaryotes that live on your skin.
- Prokaryotes that don't need oxygen or are poisoned by it are described as anaerobic. They use fermentation or other anaerobic processes rather than cellular respiration. Examples include many of the prokaryotes that live inside your body.

Like most other living things, prokaryotes have a temperature range that they "like" best.

FIGURE 8.8
Green cyanobacteria on a lake make food by photosynthesis.

- Thermophiles are prokaryotes that prefer a temperature above 45 °C (113 °F). They might be found in a compost pile.
- Mesophiles are prokaryotes that prefer a temperature of about 37 °C (98 °C). They might be found inside the body of an animal such as you.
- Psychrophiles are prokaryotes that prefer a temperature below 20 °C (68 °F). They might be found deep in the ocean.

## Prokaryote Reproduction

Prokaryotes reproduce asexually. This can happen by binary fission or budding.

- In binary fission, a cell splits in two. First, the large circular chromosome is copied. Then the cell divides to form two new daughter cells. Each has a copy of the parent cell's chromosome.
- In budding, a new cell grows from a bud on the parent cell. It only breaks off to form a new cell when it is fully formed.

### Genetic Transfer

For natural selection to take place, organisms must vary in their traits. Asexual reproduction results in offspring that are all the same. They are also identical to the parent cell. So how can prokaryotes increase genetic variation? They can exchange plasmids. This is called **genetic transfer**. It may happen by direct contact between cells. Or a "bridge" may form between cells. Genetic transfer mixes the genes of different cells. It creates new combinations of alleles.

## Lesson Summary

- Prokaryotes are single-celled organisms that lack a nucleus. They are placed in two domains: the Bacteria Domain and the Archaea Domain. They were the first organisms to evolve. It's not certain how they are related to each other or to eukaryotes.

- Prokaryotic cells are extremely small and have a variety of shapes. Most have flagella and a cell wall. They have several other cell structures as well. Their DNA exists as large and small loops. Some prokaryotes form biofilms, which are colonies of cells stuck to a surface.
- Prokaryotes can have just about any type of metabolism. They may get energy from light or from chemical compounds. They may get carbon from carbon dioxide or from other living things. They also live in a wide range of habitats. For example, some are aerobic and others are anaerobic.
- All prokaryotes reproduce by asexual means. This may occur by binary fission or budding. They can increase their genetic variation by genetic transfer. In this process, cells exchange plasmids.

## Lesson Review Questions

### Recall

1. How are prokaryotes classified?
2. Identify traits of prokaryotes.
3. What is a biofilm? Give an example.

### Apply Concepts

4. A certain prokaryote lives inside the gut of an animal that has a body temperature of about 37 °C. Classify the prokaryote in terms of its need for oxygen and its temperature preference.

### Think Critically

5. Compare and contrast aerobic and anaerobic prokaryotes.
6. Explain how and why ideas about the relationships of the Bacteria, Archaea, and Eukarya Domains have changed.
7. Why is genetic transfer important for the evolution of prokaryotes?

## Points to Consider

Prokaryotes in the Bacteria Domain cause many diseases in humans.

1. What are some bacterial diseases?
2. How can they be treated?

# 8.2 Bacteria

## Lesson Objectives

- Describe the abundance of bacteria on Earth.
- Outline how bacteria are classified.
- Identify relationships between bacteria and people.

## Lesson Vocabulary

- antibiotic drug
- antibiotic resistance
- bacteria (bacterium, singular)
- pathogen
- vector

## Introduction

The rod-shaped organisms in **Figure** below are bacteria called *Salmonella*. **Bacteria (bacterium, singular)** are prokaryotes in the Bacteria Domain. The word *Salmonella* may sound familiar. That's because *Salmonella* is a common cause of food poisoning. Many other types of bacteria also cause human diseases. But not all bacteria are harmful to people. In fact, we could not survive without many of the trillions of bacteria that live in or on the human body. You'll learn why when you read this lesson.

## Counting Bacteria

Bacteria are the most abundant living things on Earth. They live in almost all environments. They are found in the air, ocean, soil, and intestines of animals. They are even found in rocks deep below Earth's surface. Any surface that has not been sterilized is likely to be covered with bacteria. The total number of bacteria in the world is amazing. It's estimated to be about 5 million trillion trillion. If you write that number in digits, it has 30 zeroes!

## Classifying Bacteria

Bacteria are the most diverse organisms on Earth. Thousands of species of bacteria have been discovered. Many more are thought to exist. The known species are classified on the basis of various traits. For example, they may be classified by the shape of their cells. They may also be classified by how they react to a dye called Gram stain.

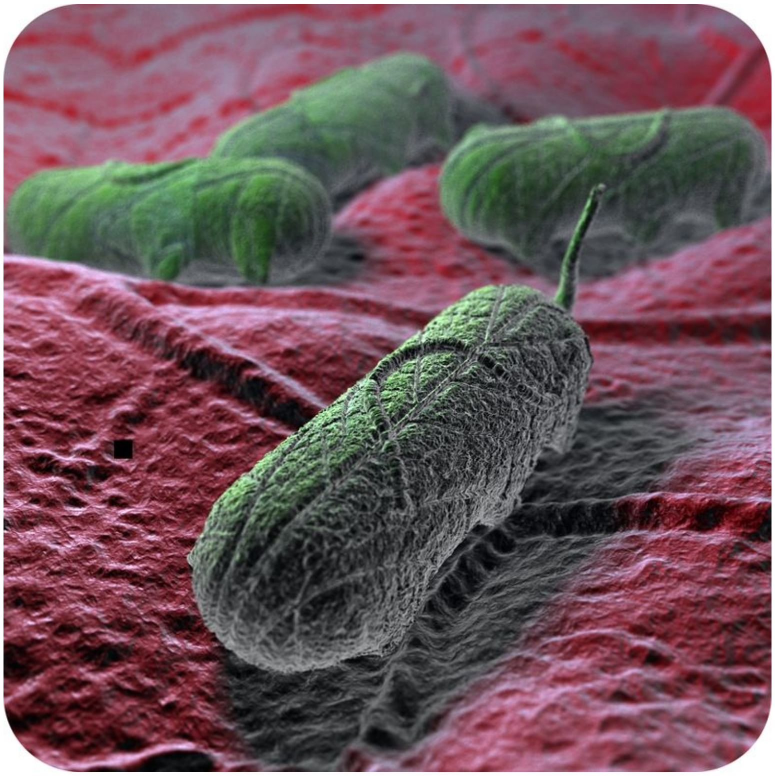

FIGURE 8.9
Salmonella bacteria

### Classifying Bacteria by Shape

Bacteria come in several different shapes. The different shapes can be seen by examining bacteria under a light microscope. Therefore, it's relatively easy to classify them by shape. There are three types of bacteria based on shape:

- bacilli (bacillus, singular), or rod shaped.
- cocci (coccus, singular), or sphere shaped.
- spirilli (spirillus, singular), or spiral shaped.

You can see a common example of each type of bacteria in **Figure** 8.10.

### Gram-Positive and Gram-Negative Bacteria

Different types of bacteria stain a different color when Gram stain is applied to them. This makes them easy to identify. Some stain purple and some stain red, as you can see in **Figure** 8.11. The two types differ in their outer layers. This explains why they stain differently.

- Bacteria that stain purple are called gram-positive bacteria. They have a thick cell wall without an outer membrane.
- Bacteria that stain red are called gram-negative bacteria. They have a thin cell wall with an outer membrane.

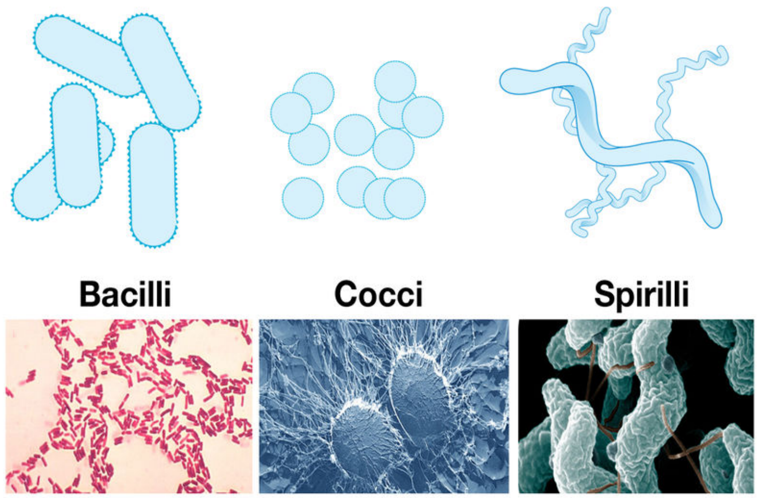


FIGURE 8.10
Bacteria classified by shape

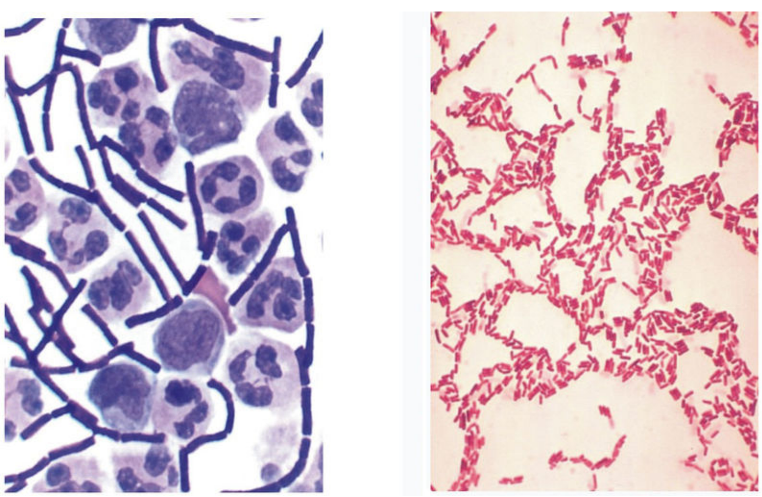

FIGURE 8.11
Gram-positive (left) and gram-negative (right) bacteria

## Bacteria and People

Bacteria and people have many important relationships. Bacteria make our lives easier in a variety of ways. In fact, we could not survive without them. On the other hand, many bacteria can make us sick. Some of them are even deadly. For a dramatic overview of the many roles of bacteria, watch this stunning video: http://www.youtube.com/watch?v=qCn92mbWxd4 .

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## Benefits of Bacteria

Bacteria help us—and all other living things—by decomposing wastes. In this way, they recycle carbon and nitrogen in ecosystems. In addition, photosynthetic cyanobacteria are important producers. On ancient Earth, they added oxygen to the atmosphere and changed the course of evolution forever.

There are billions of bacteria inside the human digestive tract. They help us digest food. They also make vitamins and play other important roles. We use bacteria in many other ways as well. For example, we use them to:

- create medical products such as vaccines.
- transfer genes in gene therapy.
- make fuels such as ethanol.
- clean up oil spills.
- kill plant pests.
- ferment foods.

Do you eat any of the fermented foods pictured in **Figure** 8.12? If so, you are eating bacteria and their wastes. Yum!


FIGURE 8.12
Bacteria are used to make fermented foods such as these.

## Bacteria and Disease

You have ten times as many bacterial cells as human cells in your body. Luckily for you, most of these bacteria are harmless. However, some of them can cause disease. Any organism that causes disease is called a **pathogen**. Diseases caused by bacterial pathogens include food poisoning, strep throat, and Lyme disease.

Bacteria that cause disease may spread directly from person to person. For example, they may spread when people shake hands with, or sneeze on, other people. Bacteria may also spread through food, water, or objects that have become contaminated with them.

Some bacteria are spread by vectors. A **vector** is an organism that spreads bacteria or other pathogens. Most vectors are animals, commonly insects. For example, deer ticks like the one in **Figure** 8.13 spread Lyme disease. Ticks carry Lyme disease bacteria from deer to people when they bite them.

FIGURE 8.13
Deer ticks are vectors for the bacteria that cause Lyme disease. The ticks are actually very small and may go unnoticed.

### Controlling Bacteria

Bacteria in food or water usually can be killed by heating it to a high temperature. Generally, this temperature is at least 71 °C (160 °F). Bacteria on surfaces such as countertops and floors can be killed with disinfectants, such as chlorine bleach. Bacterial infections in people can be treated with **antibiotic drugs**. These drugs kill bacteria and may quickly cure the disease. If you've ever had strep throat, you were probably prescribed an antibiotic to treat it.

Some bacteria have developed **antibiotic resistance**. They have evolved traits that make them resistant to one or more antibiotic drugs. You can see how this happens in **Figure** 8.14. It's an example of natural selection. Some bacteria are now resistant to most common antibiotic drugs. These infections are very hard to treat.

## Lesson Summary

- Bacteria are prokaryotes in the Bacteria Domain. They are the most abundant organisms on Earth. They are in or on almost everything.
- Bacteria are the most diverse organisms on Earth. They are often classified by shape or how they react to Gram stain.
- We can't live without bacteria because they provide so many benefits. However, some bacteria cause diseases. Bacteria may be controlled with high temperatures, disinfectants, or antibiotic drugs. Some bacteria have evolved antibiotic resistance.

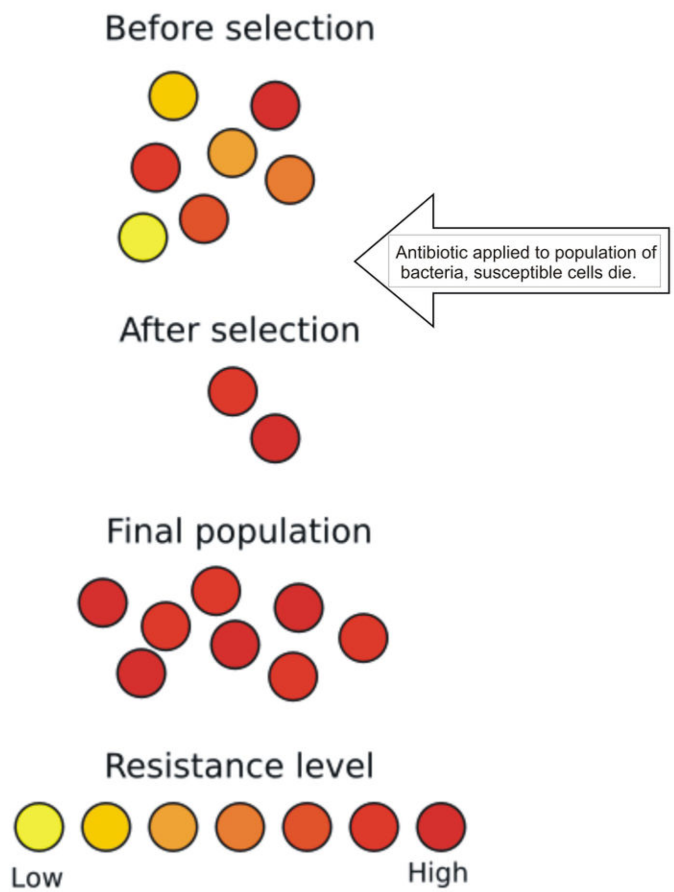


FIGURE 8.14
Evolution of Antibiotic Resistance in Bacteria. This diagram shows how antibiotic resistance evolves by natural selection.

## Lesson Review Questions

### Recall

1. How numerous are bacteria?
2. Describe two ways of classifying bacteria.
3. Identify benefits of bacteria to ecosystems.
4. What are some uses of bacteria to people?

### Apply Concepts

5. Apply the concepts of pathogen and vector to explain what causes Lyme disease and how it is spread.

### Think Critically

6. Discuss how the first appearance of cyanobacteria on early Earth changed the course of evolution forever.
7. Explain how bacteria evolve resistance to antibiotic drugs.

## Points to Consider

Many Archaea live in extreme conditions. For example, some of them live in boiling hot water.

1. In what other extreme conditions do you think Archaea live?
2. Why might Archaea have evolved to live in extreme conditions?

# 8.3 Archaea

## Lesson Objectives

- Define archaean.
- Identify types of archaean extremophiles.
- Describe the range of habitats and ecological roles of archaeans.

## Lesson Vocabulary

- archaean
- extremophile
- methanogen

## Introduction

Look at the orange water in **Figure** 8.15. It's acidic water draining out of an old mine. What could live in such disgusting water? Surprisingly, many species of archaeans can. They thrive in the acid.

FIGURE 8.15
Archaeans live in acidic water draining from an old mine.

## What Are Archaeans?

Archaeans are prokaryotes in the Archaea Domain. They were first discovered in extreme environments such as hot springs. For a long time, they were classified as bacteria. As more was learned about them, they were found to be quite different from bacteria. They were finally placed in their own domain in the late 1970s. You can see the incredible story of their discovery in this brief video: http://www.youtube.com/watch?v=lTvPb4shgVI .

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The study of archaeans is in its infancy. Scientists still know relatively little about them. New species of archaeans are being discovered all the time.

## Extremophiles

Many archaeans are extremophiles. **Extremophiles** are organisms that live in extreme conditions. For example, some archaeans live around hydrothermal vents. A hydrothermal vent is a crack on the ocean floor. You can see one in **Figure** 8.16. Boiling hot, highly acidic water pours out of the vent. These extreme conditions don't deter archaeans. They have evolved adaptations for coping with them. These conditions are like those on ancient Earth. This suggests that archaeans may have evolved very early in Earth's history.

There are four types of archaean extremophiles. Each type is described below. Extreme conditions pose many challenges to living cells. Archaeans have evolved adaptations that allow them to deal with the challenges.

### Halophiles

Halophiles are organisms that "love" salt. They can survive in very salty water. For example, they have been found in the Great Salt Lake in Utah and the Dead Sea between Israel and Jordan. Both of these bodies of water are much saltier than the ocean.

### Hyperthermophiles

Hyperthermophiles are organisms that "love" heat. Some archaeans can survive at very high temperatures. For example, they can grow in hot springs and geysers. One archaean species can even reproduce at 122 °C (252 °F). This is higher than the boiling point of water. It is the highest recorded temperature for any organism.

### Acidophiles

Acidophiles are organisms that "love" acids. They live in very acidic environments, such as acid mine drainage. They are also found near vents of volcanoes. The most acidophilic archaeans can thrive at negative pH values. No other organisms can survive in such acidic conditions.

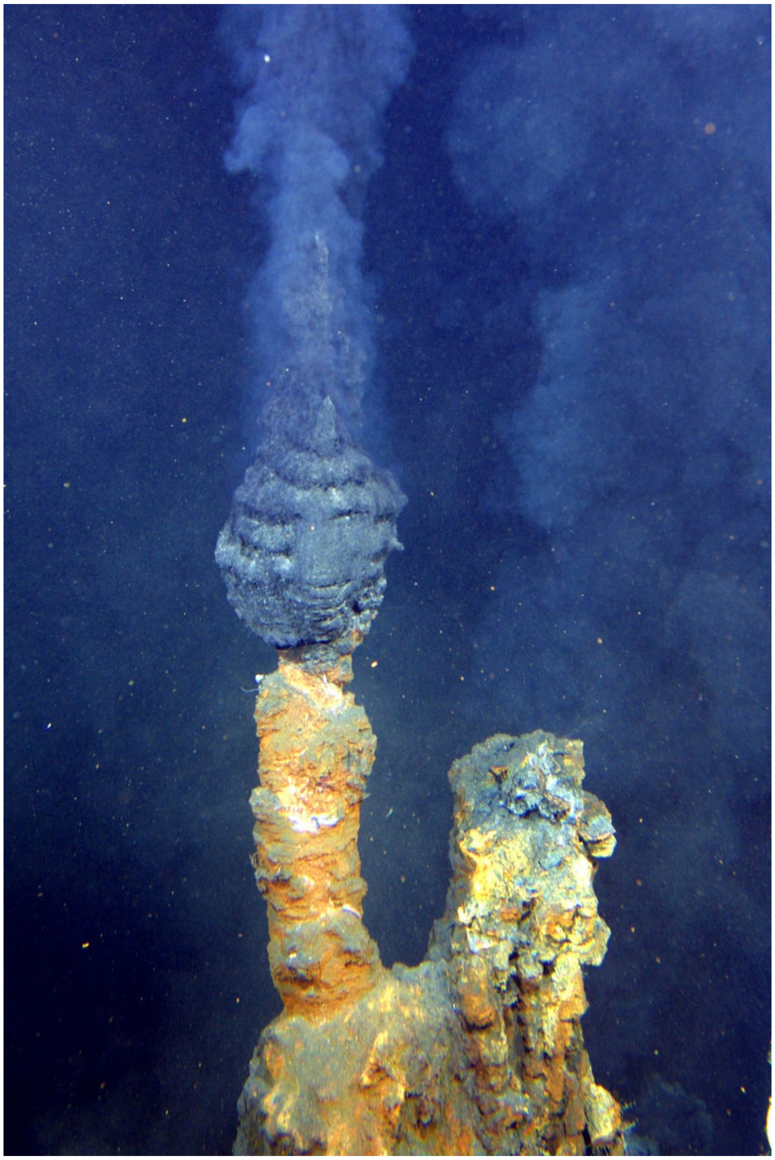

FIGURE 8.16
Archaea that live around hydrothermal vents like this one must be able to withstand extreme heat and acidity.

### Alkaliphiles

Alkaliphiles are organisms that "love" bases. Bases are like the opposite of acids. Basic environments where archaeans are found include Mono Lake in California, pictured in **Figure** 8.17. Mono Lake is the oldest lake in North America. The water is not only unusually basic. It's also saltier than the ocean. So archaeans that live in the water of Mono Lake must have adaptations to both salty and basic conditions. They are haloalkaliphiles.

## Archaea in the Environment

Not all archaeans live in extreme conditions. In fact, archaeans are now known to live just about everywhere on Earth. They make up as much as 20 percent of Earth's total mass of living things.

FIGURE 8.17
The water in Mono Lake is alkaline, or basic.

### Archaean Habitats

Archaeans have been found in a broad range of habitats. For example, they live in soils, bodies of water, and marshlands. They even live in the human belly button! Archaeans are very common in the ocean. Archaeans in plankton may be some of the most abundant organisms on Earth.

### Ecological Roles of Archaeans

Like bacteria, archaeans are important decomposers. For example, archaeans help break down sewage in waste treatment plants. As decomposers, they help recycle carbon and nitrogen.

Many archaeans live in close relationships with other organisms. For example, large numbers live inside animals, including humans. Unlike many bacteria, archaeans don't harm their hosts. None of them is known to cause human disease. Archaeans are more likely to help their hosts. For example, archaeans called **methanogens** live inside the gut of cows (see **Figure** 8.18). They help cows digest tough plant fibers made of cellulose. They produce methane gas as a waste product.

FIGURE 8.18
Cows like this one can digest cellulose only with the help of archaean methanogens.

## Lesson Summary

- Archaeans are prokaryotes in the Archaea Domain. They were first discovered in extreme environments. They were classified as bacteria until placed in their own domain in the 1970s.
- Many archaeans are extremophiles. They include organisms that thrive in extremely salty, hot, acidic, or basic conditions. Some archaeans thrive in more than one type of extreme condition.
- Archaeans are now known to live just about everywhere on Earth. They are important decomposers. Many live in close relationships with other organisms. They are generally harmless and often beneficial.

## Lesson Review Questions

### Recall

1. What are archaeans?
2. Define extremophile.
3. Identify four types of archaean extremophiles.

### Apply Concepts

4. You have a stomach ache and diarrhea. You think you have been infected by a prokaryote. Which type of prokaryote is it likely to be, a bacterium or an archaean? Explain your answer.

### Think Critically

5. Explain the ecological role of methanogens that live in animals like cows.

## Points to Consider

All prokaryotes are single-celled organisms.

1. Are all single-celled organisms prokaryotes?
2. Are any eukaryotes single-celled organisms? It there are, what are they?

# 8.4 References


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4. Zachary Wilson. Prokaryotic flagella . CC BY-NC 3.0
5. Mariana Ruiz Villarreal (User:LadyofHats/Wikimedia Commons). Model of a prokaryotic cell . Public Domain
6. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. CK-12 Foundation . CC BY-NC 3.0
7. . Bacterial biofilm under microsocope . Public Domain
8. Courtesy of Jesse Allen/NASA. Cyanobacteria are photosynthetic prokaryotes . Public Domain
9. Image copyright MichaelTaylor, 2014. Salmonella bacteria . Used under license from Shutterstock.com
10. Diagrams: Mariana Ruiz Villarreal (User:LadyofHats/Wikimedia Commons); Bottom left: Courtesy of Dr. William A. Clark/CDC; Bottom center: Courtesy of Eric Erbe and Christopher Pooley/USDA; Bottom right: Courtesy of De Wood and Christopher Pooley/USDA. Bacterial shapes . Public Domain
11. Gram cell wall: User:JulianOnions/Wikimedia Commons; Gram-positive: JA Jernigan et al./Centers for Disease Control and Prevention; Gram-negative: William A. Clark/Centers for Disease and Control. Gram positive and negative bacteria . Public Domain
12. Left to right: Flickr:LWY; Flickr:dustingrzesik; Christian Bauer; User:Omernos/Wikimedia Commons. Fermented foods . Left to right: CC BY 2.0; CC BY 2.0; CC BY 2.0; Public Domain
13. USDA, photo by Scott Bauer. Deer ticks are the vectors for Lyme disease . public domain
14. User:Wykis/Wikimedia Commons, modified by CK-12 Foundation. Evolution of antibiotic resistance . Public Domain
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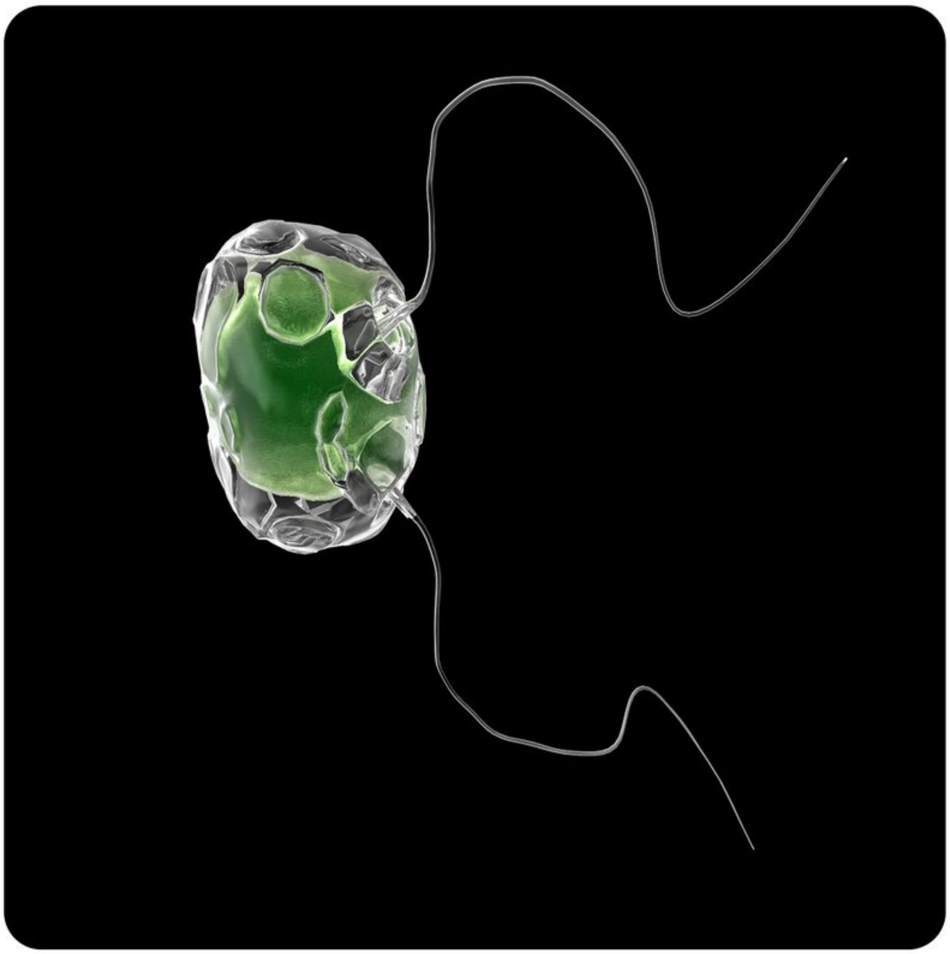
17. clr_flckr. Mono Lake contains haloalkaliphiles . CC-By 2.0
18. Stuart Chalmers. Cows digest cellulose with the aid of methanogens . CC BY 2.0

# CHAPTER 9 MS Protists and Fungi

## Chapter Outline





This organism consists of a single cell with whip-like flagella. These are traits of prokaryotes such as bacteria. However, this organism has another trait that defines it as a eukaryote. It has a nucleus. This places it in the Eukarya Domain, the domain that also includes humans.

# 9.1 Protists

## Lesson Objectives

- Outline the classification and evolution of protists.
- Describe general traits of protists.
- Compare and contrast different types of protists.
- Identify human diseases caused by protists.

## Lesson Vocabulary

- alga (algae, plural)
- cilium (cilia, plural)
- life cycle
- protist
- Protist Kingdom
- protozoan (protozoa, plural)
- pseudopod

## Introduction

Most single-celled eukaryotes are protists. **Protists** are the simplest eukaryotes.

## Protist Classification and Evolution

Protists are placed in the **Protist Kingdom**. This kingdom is one of four kingdoms in the Eukarya domain. The other three Eukarya kingdoms are the Fungi, Plant, and Animal Kingdoms.

### Classification of Protists

The Protist Kingdom is hard to define. It includes many different types of organisms. You can see some examples of protists in **Figure** 9.1. The Protist Kingdom includes all eukaryotes that don't fit into one of the other three eukaryote kingdoms. For that reason, it's sometimes called the "trash can" kingdom.

The number of species in the Protist Kingdom is unknown. It could range from as few as 60,000 to as many as 200,000 species. For a beautiful introduction to the amazing world of protists, watch this video: http://www.youtube.com/watch?v=0-6dzU4gOJo .

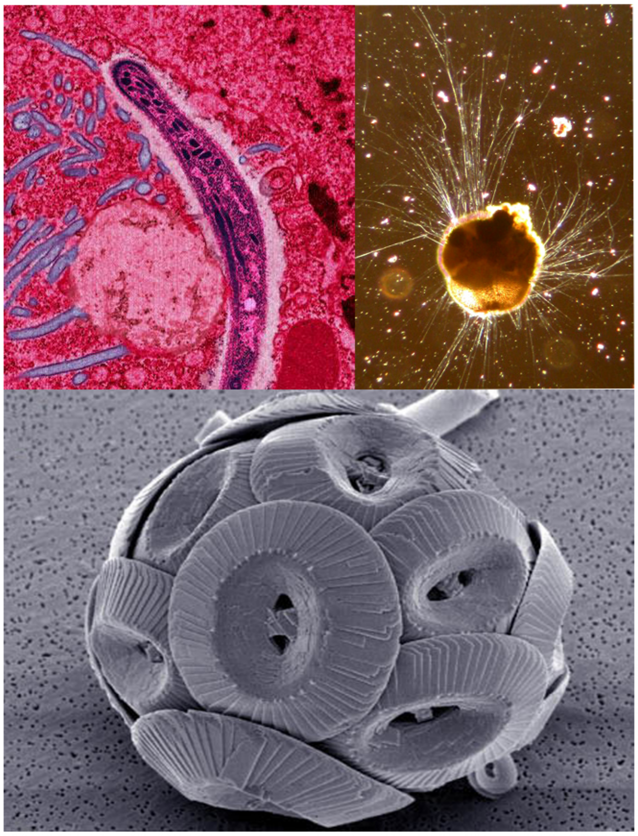
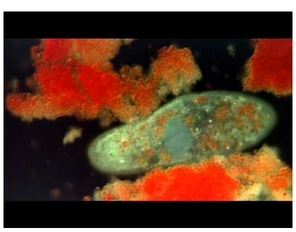


FIGURE 9.1

These examples of protists show how varied they are.



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## Evolution of Protists

Scientists think that protists are the oldest eukaryotes. If so, they must have evolved from prokaryotes. How did this happen? How did cells without organelles acquire them? What was the origin of mitochondria, chloroplasts, and other organelles?

The most likely way organelles evolved is shown in **Figure** 9.2. First, smaller prokaryotic cells invaded, or were engulfed by, larger prokaryotic cells. The smaller cells benefited by getting nutrients and a safe place to live. The larger cells benefited by getting some of the organic molecules or energy released by the smaller cells. Eventually, the smaller cells evolved into organelles in the larger cells. After that, neither could live without the other.

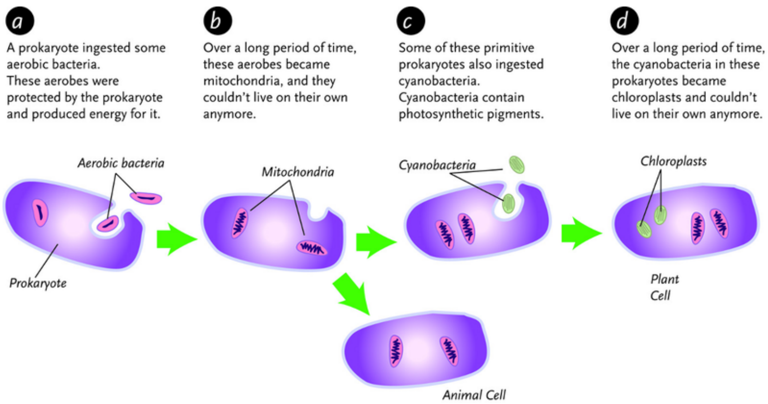


FIGURE 9.2
How cells with organelles may have evolved

## General Traits of Protists

Despite the diversity of protists, they do share some traits.

- The cells of all protists have a nucleus. They also have other membrane-bound organelles. For example, all of them have mitochondria, and some of them have chloroplasts.
- Most protists consist of a single cell. Some are multicellular but they lack specialized cells.
- Most protists live in wet places. They are found in oceans, lakes, swamps, or damp soils.
- Many protists can move.

Most protists also have a complex life cycle. The **life cycle** of an organism is the cycle of phases it goes through until it returns to the starting phase. The protist life cycle includes both sexual and asexual reproduction. Why reproduce both ways? Each way has benefits. Asexual reproduction is fast. It allows rapid population growth when conditions are stable. Sexual reproduction increases genetic variation. This helps ensure that some organisms will survive if conditions change.

## Types of Protists

Protists are classified based on traits they share with other eukaryotes. There are animal-like, plant-like, and fungus-like protists. The three groups differ mainly in how they get carbon and energy.

### Animal-Like Protists

Animal-like protists are called **protozoa (protozoan, singular)**. Most protozoa consist of a single cell. Protozoa are probably ancestors of animals.

Protozoa are like animals in two ways:

1. Protozoa are heterotrophs. Heterotrophs get food by eating other organisms. Some protozoa prey on bacteria. Some are parasites of animals. Others graze on algae. Still others are decomposers that break down dead organic matter.
2. Almost all protozoa can move. They have special appendages for this purpose. You can see different types in **Figure** 9.3. **Cilia (cilium, singular)** are short, hair-like projections. **Pseudopods** are temporary extensions of the cytoplasm. Flagella are long, whip-like structures. Flagella are also found in most prokaryotes.

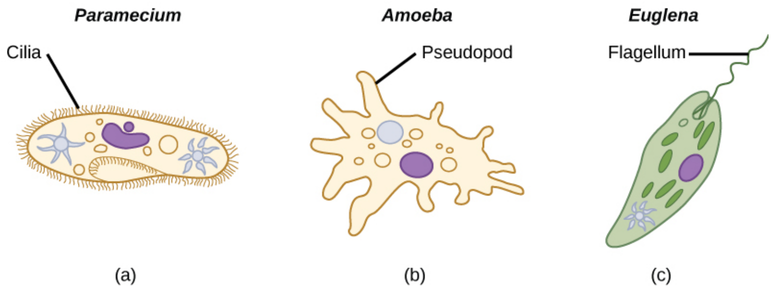


FIGURE 9.3
Three types of appendages for movement in protozoa

## Plant-Like Protists

Plant-like protists are commonly called **algae (alga, singular)**. Some algae consist of single cells. They are called diatoms. Other algae are multicellular. An example is seaweed. Seaweed called kelp can grow as large as trees. You can see both a diatom and kelp in **Figure** 9.4. Algae are probably ancestors of plants.

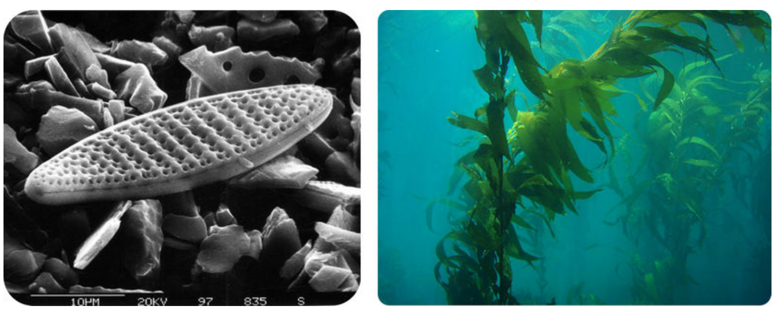

FIGURE 9.4
Diatom (left) and kelp (right)

Algae are like plants mainly because they contain chloroplasts. This allows them to make food by photosynthesis. Algae are important producers in water-based ecosystems such as the ocean. On the other hand, algae lack other plant structures. For example, they don't have roots, stems, or leaves. Also unlike plants, some algae can move. They may move with pseudopods or flagella.

## Fungus-Like Protists

Fungus-like protists include slime molds and water molds, both shown in **Figure** 9.5. They exist as individual cells or as many cells that form a blob-like colony. They are probably ancestors of fungi. Like fungi, many fungus-like protists are decomposers. They absorb nutrients from dead logs, compost, and other organic remains

- Slime molds are commonly found on rotting organic matter such as compost. Swarms of cells move very slowly over the surface. They digest and absorb nutrients as they go.
- Water molds are commonly found in moist soil and surface water. Many water molds are plant pathogens or fish parasites.

FIGURE 9.5
The slime mold (top) is called "dog vomit" mold. The water mold (bottom) is a plant parasite that has infiltrated a potato.

## Protists and Human Diseases

Many human diseases are caused by protists. Most of them are caused by protozoa. They are parasites that invade and live in the human body. The parasites get a place to live and nutrients from the human host. In return, they make the host sick. Examples of human diseases caused by protozoa include giardiasis and malaria.

- Protozoa that cause giardiasis are spread by contaminated food or water. They live inside the intestine. They may cause abdominal pain, fever, and diarrhea.
- Protozoa that cause malaria are spread by a vector. They enter the blood through the bite of an infected mosquito. They live inside red blood cells. They cause overall body pain, fever, and fatigue. Malaria kills several million people each year. Most of the deaths occur in children.

## Lesson Summary

- Protists are eukaryotes in the Protist Kingdom. Most are single-celled organisms. Protists are thought to be the oldest eukaryotes. They probably evolved when some prokaryotic cells invaded or were engulfed by others.
- Traits of most protists include the ability to move, living in wet places, and complicated life cycles. Most reproduce both asexually and sexually.
- Protists are classified as animal-like, plant-like, or fungus-like. The three groups differ mainly in how they obtain carbon and energy.
- Several protozoa are human parasites. They cause diseases such as giardiasis and malaria.

## Lesson Review Questions

### Recall

1. Define protist.
2. List general traits of most protists.
3. What human diseases are caused by protists?

### Apply Concepts

4. Create a table comparing and contrasting the three types of protists.

### Think Critically

5. Explain how protists are thought to have evolved.

## Points to Consider

Fungus-like protists resemble fungi.

- What are fungi?
- How do fungi differ from plants and animals?

# 9.2 Fungi

## Lesson Objectives

- Define and give examples of fungi.
- Explain how fungi are classified and how they evolved.
- Describe fungal hyphae and mycelia.
- Outline how fungi reproduce.
- Identify roles of fungi in ecosystems.
- List uses human uses of fungi and examples of fungal diseases.

## Lesson Vocabulary

- chitin
- fungus (fungi, plural)
- Fungus Kingdom
- hypha (hyphae, plural)
- lichen
- mold
- mycelium (mycelia, plural)
- mycorrhiza
- spore
- yeast

## Introduction

Look at the gray fuzz growing on the bread in **Figure** 9.6. It's a type of fungus. It looks gross and it spoils the bread. But fungi like this actually play important roles in many ecosystems. There are also many human uses of fungi, which you'll learn when you read this lesson.

## What Are Fungi?

**Fungi (fungus, singular)** are relatively simple eukaryotic organisms. They are placed in their own kingdom, the **Fungus Kingdom**. Most fungi are multicellular organisms. These fungi are called **molds**. However, some fungi exist as single cells. These fungi are called **yeasts**. You can see examples of different types of fungi in **Figure** 9.7. For a funny, fast-paced overview of fungi, watch this video: http://www.youtube.com/watch?v=m4DUZhnNo4s .

FIGURE 9.6
The fuzzy growth on this bread is a fungus.


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## Classification and Evolution of Fungi

For a long time, scientists classified fungi as members of the Plant Kingdom. Fungi share several obvious traits with plants. For example, both fungi and plants lack the ability to move. Both grow in soil, and both have cell walls. Some fungi even look like plants.

### Fungi Classification

Today, fungi are no longer classified as plants. We now know that they have important traits that set them apart from plants. That's why they are placed in their own kingdom. How do fungi differ from plants?

- The cell walls of fungi are made of chitin. **Chitin** is a tough carbohydrate that also makes up the outer skeleton of insects. The cell walls of plants are made of cellulose.
- Fungi are heterotrophs that absorb food from other organisms. Plants are autotrophs that make their own food.

The Fungus Kingdom is large and diverse. It may contain more than a million species. However, fewer than 100,000 species of fungi have been identified.


FIGURE 9.7
Examples of fungi

### Fungi Evolution

The earliest fungi evolved about 600 million years ago. They lived in the water. Fungi colonized the land around the same time as plants. That was probably between 400 and 500 million years ago. After that, fungi became very abundant on land. By 250 million years ago, they may have been the dominant life forms on land.

## Structure of Fungi

Yeasts grow as single cells. Other fungi grow into multicellular, thread-like structures. These structures are called **hyphae (hypha, singular)**. You can see a photo of hyphae in **Figure** 9.8. They resemble plant roots. Each hypha consists of a group of cells surrounded by a tubular cell wall.

A mass of hyphae make up the body of a fungus. The body is called the **mycelium (mycelia, plural)**. A mycelium may range in size from microscopic to very large. In fact, the largest living thing on Earth is the mycelium of a single fungus. Nicknamed the "humongous fungus," it grows in a forest in Oregon. A small part of the fungus is pictured in **Figure** 9.9. The giant fungus covers an area of 2384 acres. That's about the size of 1,665 football fields! The fungus is estimated to be at least 2400 years old, but it could be much older.

## Fungi Reproduction

Most fungi reproduce both asexually and sexually. In both types of reproduction, they produce spores. A **spore** is a special reproductive cell. When fungi reproduce asexually, they can spread quickly. This is good when conditions

FIGURE 9.8
White hyphae of a fungus

FIGURE 9.9
These mushrooms are a visible part of the humongous fungus in Oregon. Most of the fungus is underground in the soil. It spreads by sending out hyphae into the surrounding soil.

are stable. They can increase their genetic variation by sexual reproduction. This is beneficial when conditions are changing. Variation helps ensure that at least some organisms survive the changing conditions.

**Figure** 9.10 shows how asexual and sexual reproduction occur in fungi. Refer to the figure as you read about each of them below.

### Asexual Reproduction in Fungi

During asexual reproduction, fungi produce haploid spores by mitosis of a haploid parent cell. A haploid cell has just one of each pair of chromosomes. The haploid spores are genetically identical to the parent cell. Spores may be spread by moving water, wind, or other organisms. Wherever the spores land, they will develop into new hyphae only when conditions are suitable for growth.

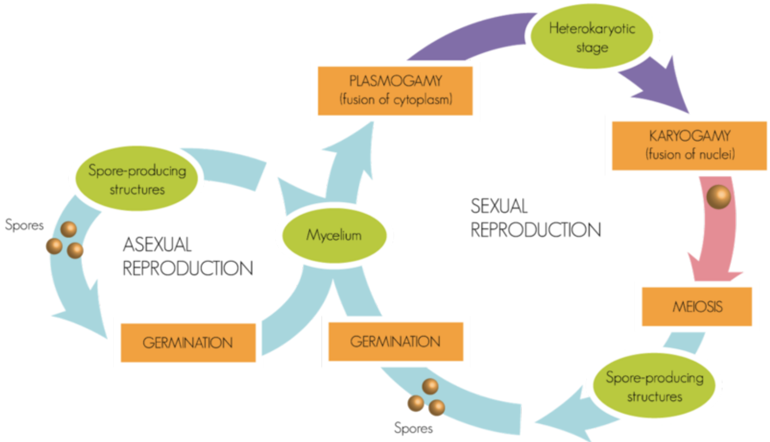


FIGURE 9.10
Sexual and asexual reproduction in fungi

Yeasts are an exception. They reproduce asexually by budding instead of by producing spores. An offspring cell forms on a parent cell. After it grows and develops, it buds off to form a new cell. The offspring cell is genetically identical to the parent cell. You can see yeast cells budding in **Figure** 9.11.

FIGURE 9.11
Yeast cells budding

### Sexual Reproduction in Fungi

Sexual reproduction also occurs in most fungi. It happens when two haploid hyphae mate. During mating, two haploid parent cells fuse. The single fused cell that results is a diploid spore. It is genetically different from both parents. The spore undergoes meiosis to form haploid daughter cells. These haploid cells develop into new hyphae.

## Roles of Fungi in Ecosystems

Most fungi grow on moist soil or rotting vegetation such as dead logs. Some fungi live in water. Others live in or on other organisms. Fungi get their nutrition by absorbing organic compounds from other organisms. The other organisms may be dead or alive, depending on the fungus.

### Fungi as Decomposers

Most fungi get organic compounds from dead organisms. Fungi use their hyphae to penetrate deep into decaying organic matter. They produce enzymes at the tips of their hyphae. The enzymes digest the organic matter so the fungal cells can absorb it. Fungi are the main decomposers in forests. They are the only decomposers that can break down cellulose and wood. They have special enzymes for this purpose.

### Fungi Symbiosis

Many fungi get organic compounds from living organisms. They have close relationships with other species. A close relationship between two species is called a symbiotic relationship. Two symbiotic relationships in fungi are mycorrhiza and lichen. These relationships are beneficial for both species.

- **Mycorrhiza** is a relationship between a fungus and a plant. The fungus grows in or on the plant's roots. The fungus benefits from easy access to food made by the plant. The plant benefits because the fungal hyphae absorb water and nutrients from the soil that the plant needs.
- **Lichen** is a relationship between a fungus and cyanobacteria or green algae. The fungus grows around the bacterial or algal cells. The fungus benefits by getting some of the food made by the photosynthetic cells. The bacteria or algae benefit by getting some of the water and nutrients absorbed by the fungus. You can see a picture of lichen in **Figure** 9.12.

FIGURE 9.12
Lichen growing on a rock

Some fungi have a different kind of relationship with plants. They are plant parasites. They get food from the plants and cause harm to the plants in return. Fungi are the major causes of disease in agricultural crops. They may eventually kill their plant hosts.

Some fungi are animal parasites. The wasp in **Figure** 9.13 is infected with a fungus. The fungus is the white fuzzy matter on the dark brown moth.

FIGURE 9.13
Wasp infected by a parasitic white fungus

## Fungi and People

Fungi may cause disease in people as well as other organisms. On the other hand, people have been using fungi for thousands of years.

### Human Uses of Fungi

One way we use fungi is by eating them. Many species of mushrooms are edible. Yeasts are used for break making. Other fungi are used to ferment foods, such as soy sauce and cheeses. You can see the fungus growing through the blue cheese in **Figure** 9.14. The fungus gives the cheese its distinctive appearance and taste.

FIGURE 9.14
Blue cheese is blue because of the fungus growing throughout it.

People also use fungi:

- to produce antibiotics.
- to produce human hormones such as insulin.
- as natural pesticides.

- as model research organisms.

### Fungi and Human Diseases

Several common human diseases are caused by fungi. They include ringworm and athlete's foot, both shown in **Figure** 9.15. Ringworm isn't caused by a worm. It's a skin infection by a fungus that leads to a ring-shaped rash. The rash may occur on the head, neck, trunk, arms, or legs. Athlete's foot is caused by the same fungus as ringworm. But in athlete's foot, the fungus infects the skin between the toes. Athlete's foot is the second most common skin disease in the U.S.


FIGURE 9.15
Ringworm (left) and athlete's foot (right) are fungal infections of the skin.

## Lesson Summary

- Fungi are eukaryotes in the Fungus Kingdom. Fungi include molds, which are multicellular, and yeasts, which are single-celled.
- Fungi are similar in some ways to plants but have unique traits that set them apart from plants. Fungi first evolved about 600 million years ago.
- Most fungi grow into multicellular threadlike hyphae. A mass of hyphae makes up the body, or mycelium, of the fungus.
- Most fungi reproduce both asexually and sexually. Asexual reproduction is by haploid spores (or by budding in yeasts). Sexual reproduction is by diploid spores.
- Most fungi are decomposers. They are the main decomposers in forests. Many fungi have symbiotic relationships with other species.
- People use fungi for food and other purposes. Some fungi cause human diseases.

## Lesson Review Questions

### Recall

1. What are fungi? What are two examples of fungi?
2. Describe the hyphae and mycelium of a fungus.
3. Give an overview of fungi reproduction.
4. What are some ways that people use fungi?

### Apply Concepts

5. Assume that you notice fungi growing on a wooden fence in your backyard. You want the fence to last as long as possible. Should you remove the fungi or leave them alone? Explain your answer.

### Think Critically

6. Fungi used to be placed in the Plant Kingdom. Explain why they are now placed in their own kingdom.
7. Compare and contrast mycorrhiza and lichen.

## Points to Consider

Fungi share certain traits with plants.

- How do plants differ from fungi?
- What are some other traits of plants?

# 9.3 References


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2. Christopher Auyeung. Endosymbiosis, how cells with organelles may have evolved . CC BY-NC 3.0
3. Miranda Dudzik. Three types of appendages for movement in protozoa . CC BY 3.0
4. Diatoms: Hannes Grobe; Kelp: Claire Fackler, NOAA. Diatom and kelp . Diatoms: CC BY 3.0; Kelp: CC BY 2.0
5. Top: User:Algirdas/Wikimedia Commons; Bottom: United States Department of Agriculture. Molds . Public Domain
6. User:Ciar/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Moldy_old_bread.JPG . Public Domain
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8. Lex vB. White hyphae of a fungus . Public Domain
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10. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
11. National Institute of Allergy and Infectious Diseases/National Institutes of Health. Yeast cells budding . Public Domain
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14. Stuart Webster. Blue cheese is blue because of the fungus growing throughoutit. . CC BY 2.0
15. Ringworm: Dr. Lucille K. Georg/Centers for Disease Control and Prevention; Athlete's foot: User:Falloonb/Wikipedia. Ringworm and athlete's foot are fungal infections of the skin. . Public Domain

# CHAPTER 10 MS Plants

## Chapter Outline



These interesting yellow flowers grow on a plant called a skunk cabbage. It's named for its odor, which smells like rotten meat. The plant stores food in its fleshy roots all winter so it can flower very early in the spring. When the flowers bloom, there may still be snow on the ground. However, the plant produces enough heat to melt the snow.

Why does the skunk cabbage put so much energy into producing its unusual, smelly blooms? The purpose is to attract flies and other insects that will pollinate its flowers. The production of flowers for reproduction was one of the most important traits to evolve in plants.

# 10.1 Introduction to Plants

## Lesson Objectives

- Describe plants, their needs, and their importance.
- Identify three major types of plant tissues.
- Describe the structure and function of roots, stems, and leaves.
- Explain how plants grow.
- Outline the general life cycle of plants.

## Lesson Vocabulary

- alternation of generations
- dermal tissue
- gametophyte
- ground tissue
- leaf
- plant
- Plant Kingdom
- root
- sporophyte
- stem
- stoma (stomata, plural)
- transpiration
- vascular tissue

## Introduction

Most modern plants, like the skunk cabbage, produce flowers. However, flowers evolved relatively late in the history of plants. The earliest plants not only lacked flowers. They also lacked leaves, roots, and stems. They probably resembled the alga in **Figure** 10.1.

If the earliest plants were so different from modern plants, why are they even considered plants? What traits define a plant? Before reading the answer to this question, watch this amazing visual introduction to plants: http://www.youtube.com/watch?v=_F8kYkn49Ec .

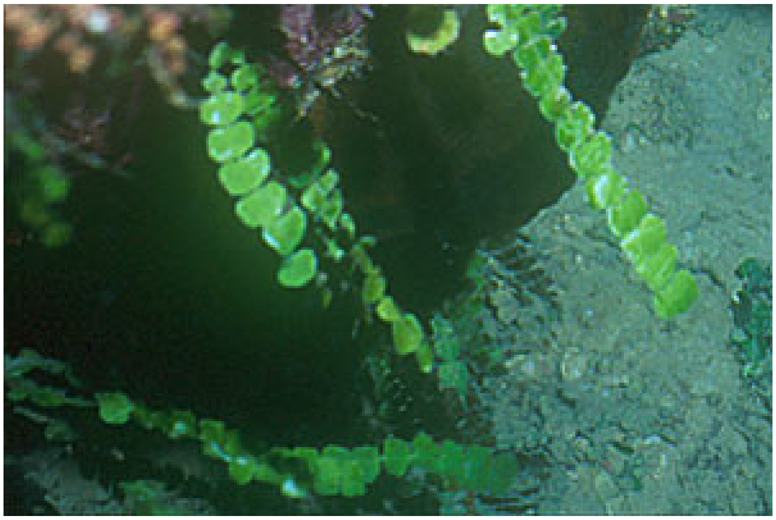

FIGURE 10.1
The earliest plants may have resembled this modern-day alga. It grows under the water.

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## What Are Plants?

**Plants** are multicellular eukaryotes that are placed in the **Plant Kingdom**. Plant cells have cell walls that are made of cellulose. Plant cells also have chloroplasts. They allow plants to make food by photosynthesis. In addition, plants have specialized reproductive organs that produce gametes. Male reproductive organs produce sperm. Female reproductive organs produce eggs. Male and female reproductive organs may be on the same plant or on different plants.

### Needs of Plants

Plants are somewhat limited by temperature in terms of where they can grow. They need temperatures above freezing while they are actively growing. They also need light, carbon dioxide, and water. These substances are required for photosynthesis. Like most other living things, plants need oxygen. Oxygen is required for cellular respiration. In addition, plants need minerals. The minerals are required to make proteins and other organic molecules.

### Importance of Plants

Life as we know it would not be possible without plants. Why are plants so important?

- Plants supply food to nearly all land organisms, including people. We mainly eat either plants or other living things that eat plants.
- Plants produce oxygen during photosynthesis. Oxygen is needed by all aerobic organisms.

- Plants absorb carbon dioxide during photosynthesis. This helps control the greenhouse effect and global warming.
- Plants recycle matter in ecosystems. For example, they are an important part of the water cycle. They take up liquid water from the soil through their roots. They release water vapor to the air from their leaves. This is called **transpiration**.
- Plants provide many products for human use. They include timber, medicines, dyes, oils, and rubber.
- Plants provide homes for many other living things. For example, a single tree may provide food and shelter to many species of animals, like the birds in **Figure** 10.2.

FIGURE 10.2
Many birds build their nests in trees. Plant materials are often used to build them.

## Plant Tissues

A tissue is a group of specialized cells of the same kind that perform the same function. Modern plants have three major types of tissues. They're called dermal, ground, and vascular tissues.

### Dermal Tissue

**Dermal tissue** covers the outside of a plant. It's like the plant's skin. Cells of dermal tissue secrete a waxy substance called cuticle. Cuticle helps prevent water loss and damage to the plant.

### Ground Tissue

**Ground tissue** makes up much of the inside of a plant. The cells of ground tissue carry out basic metabolic functions and other biochemical reactions. Ground tissue may also store food or water.

### Vascular Tissue

**Vascular tissue** runs through the ground tissue inside a plant. It transports fluids throughout the plant. Vascular tissue actually consists of two types of tissues, called xylem and phloem. The two types of vascular tissue are packaged together in bundles. You can see them in the celery in **Figure** 10.3.

- Xylem carries water and dissolved minerals from the roots upward to the leaves.
- Phloem carries water and dissolved sugar from the leaves to other parts of the plant.

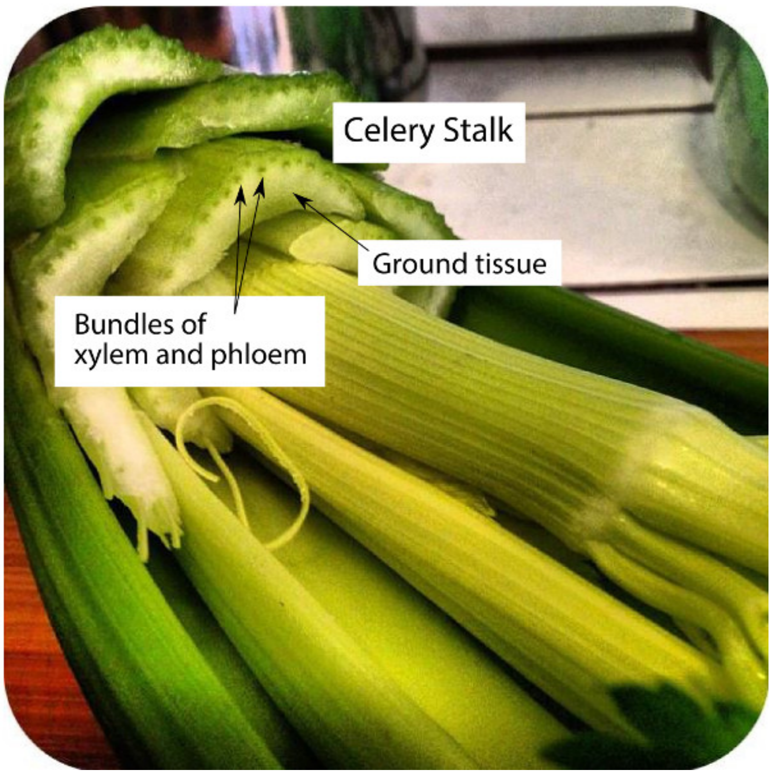



FIGURE 10.3
These stalks of celery contain bundles of vascular tissue inside ground tissue.

## Plant Organs

An organ is a structure composed of two or more types of tissues that work together to do a specific task. Most modern plants have several organs that help them survive and reproduce in a variety of habitats. Major organs of most plants include roots, stems, and leaves. These and other plant organs generally contain all three major tissue types.

### Roots

**Roots** are important organs in most modern plants. There are two types of roots: primary roots, which grow downward; and secondary roots, which branch out to the sides. Together, all the roots of a plant make up the plant's root system. **Figure** 10.4 shows two different types of plant root systems. A taproot system has a very long primary root, called a taproot. A fibrous root system has many smaller roots and no large, primary root.

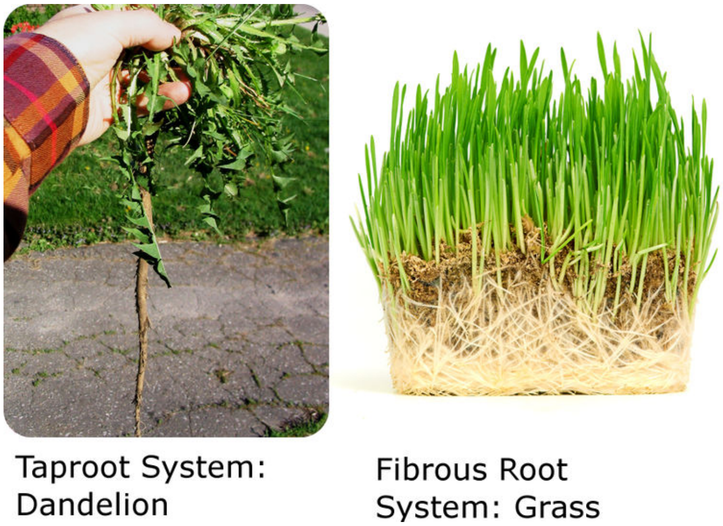



FIGURE 10.4
Two types of root systems

The roots of plants have three major jobs: absorbing water and minerals, anchoring and supporting the plant, and storing food.

- Roots are covered with thin-walled dermal cells and tiny root hairs. These features are well suited to absorb water and dissolved minerals from the soil.
- Root systems help anchor plants to the ground. They allow plants to grow tall without toppling over. A tough covering may replace the dermal cells in older roots. This makes them ropelike and even stronger.
- In many plants, ground tissue in roots stores food produced by the leaves during photosynthesis.

### Stems

**Stems** are organs that hold plants upright. They allow plants to get the sunlight and air they need. Stems also bear leaves, flowers, cones, and smaller stems. These structures grow at points called nodes. The stem between nodes is called an internode. (See **Figure** 10.5.)

Stems are needed for transport and storage. Their vascular tissue carries water and minerals from roots to leaves. It carries dissolved sugar from the leaves to the rest of the plant. Without this connection between roots and leaves, plants could not survive high above the ground in the air. In many plants, ground tissue in stems also stores food or water during cold or dry seasons.

### Leaves

**Leaves** are the keys not only to plant life but to virtually all life on land. The primary role of leaves is to collect sunlight and make food by photosynthesis. Leaves vary in size, shape, and how they are arranged on stems. You can see examples of different types of leaves in **Figure** 10.6.

Each type of leaf is well suited for the plant's environment. It maximizes light exposure while conserving water, reducing wind resistance, or benefiting the plant in some other way in its particular habitat. For example, some leaves are divided into many smaller leaflets. This reduces wind resistance and water loss.

Leaves are basically factories for photosynthesis.

- A factory has specialized machines to produce a product. In a leaf, the "machines" are the chloroplasts.

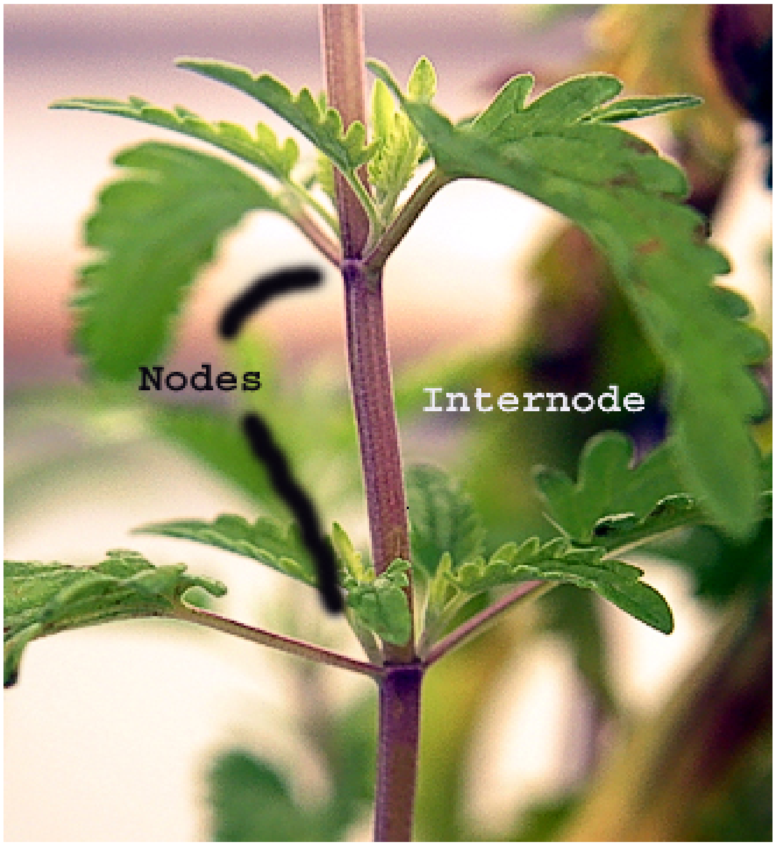



FIGURE 10.5
Nodes and internode of a stem

- A factory is connected to a transportation system that supplies it with raw materials and carries away the finished product. In a leaf, transport is carried out by veins containing vascular tissue. Veins carry water and minerals to the cells of leaves. They carry away dissolved sugar.
- A factory has bricks, siding, or other external protection. A leaf is covered with dermal cells. They secrete waxy cuticle to prevent evaporation of water from the leaf.
- A factory has doors and windows to let some materials enter and leave. The surface of the leaf has tiny pores called stomata (stoma, singular). They can open and close to control the movement of gases between the leaves and the air. You can see a close-up of a stoma in **Figure** 10.7.

## How Plants Grow

Most plants continue to grow throughout their lives. Like other multicellular organisms, plants grow through a combination of cell growth and cell division. Cell growth increases cell size. Cell division increases the number of cells.

As plant cells grow, they also become specialized into different cell types. Once cells become specialized, they can no longer divide. So how do plants grow after that? The key to continued growth is meristem. Meristem is a type of plant tissue consisting of undifferentiated cells that can continue to divide.

- Meristem at the tips of roots and stems allows them to grow in length. This is called primary growth. The stem (trunk) of the giant sequoia tree in **Figure** 10.8 has achieved amazing growth in length during its many years of life.

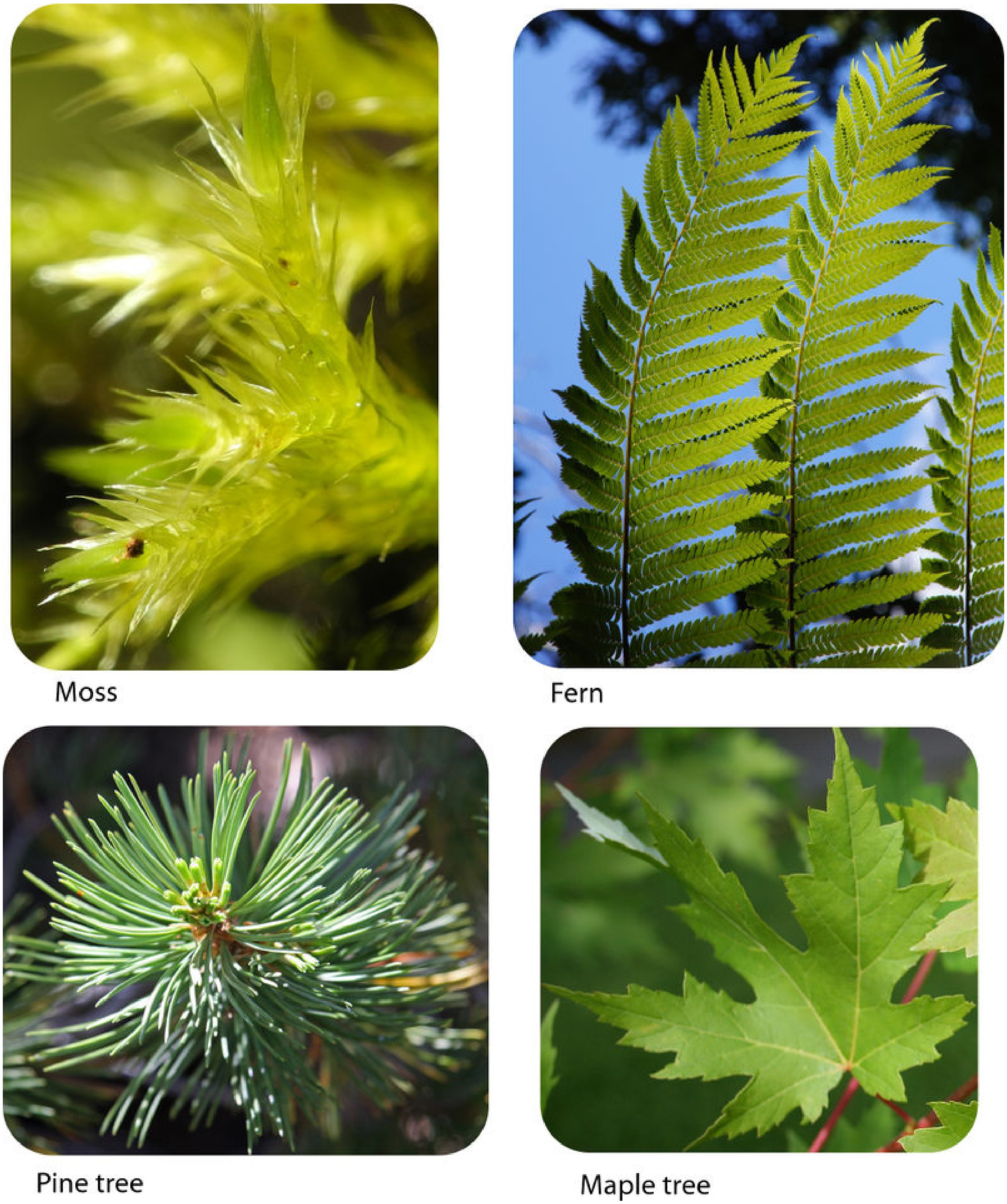



FIGURE 10.6

Variation in plant leaves

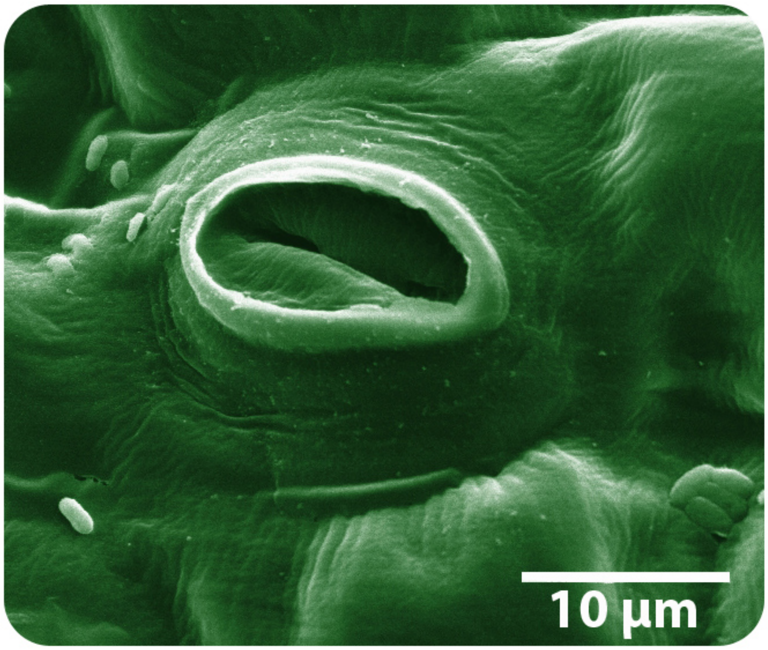


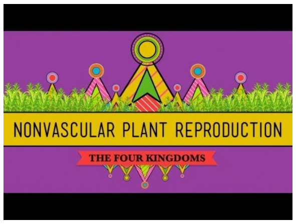

FIGURE 10.7
Stoma on the surface of a leaf, greatly enlarged

- Meristem within and around vascular tissues allows growth in width. This is called secondary growth. The rings in the tree stump in **Figure** 10.8 show secondary growth in a tree. Each ring represents one year of growth.

FIGURE 10.8
Tree height (left) represents growth in length. Tree rings (right) represent growth in width.

## Life Cycle of Plants

All plants have a life cycle that includes **alternation of generations**. You can see a general plant life cycle in **Figure** 10.9. For an entertaining introduction to alternation of generations, watch this video: http://www.youtube.com/watch?v=iWaX97p6y9U .

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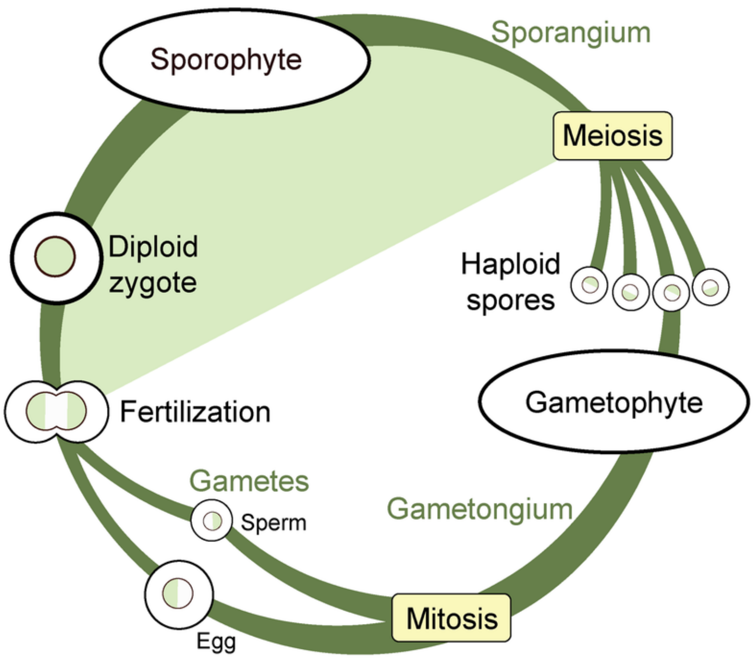


FIGURE 10.9

This diagram shows the general life cycle of a plant. There is variation in the details of the life cycle of different plant species.

### Alternation of Generations

Plants alternate between haploid and diploid generations. Haploid cells have one of each pair of chromosomes. Diploid cells have two of each pair.

- Plants in the haploid generation are called **gametophytes**. They form from haploid spores. They have male and/or female reproductive organs and reproduce sexually. They produce haploid gametes by mitosis. Fertilization of gametes produces diploid zygotes. Zygotes develop into the diploid generation.
- Plants in the diploid generation are called **sporophytes**. They form from the fertilization of gametes. They reproduce asexually. They have a structure called a sporangium that produces haploid spores by meiosis. Spores develop into the haploid generation. Then the cycle repeats.

### Variation in the Life Cycle of Plants

One of the two generations of a plant's life cycle is usually dominant. Individuals in the dominant generation generally live longer and grow larger. They are the organisms that you would recognize as a fern, tree, or other plant. Individuals in the nondominant generation tend to be smaller and shorter-lived. They often live in or on the dominant plant. They may go unnoticed.

Early plants spent most of their life cycle as gametophytes. Some modern plants such as mosses still have this type of life cycle. However, almost all modern plants spend most of their life cycle as sporophytes.

## Lesson Summary

- Plants are multicellular eukaryotes in the Plant Kingdom. They have cell walls of cellulose and chloroplasts for photosynthesis. Life as we know it depends on plants. They feed most other organisms. They also perform many other services.
- Modern plants have three different types of tissues. They are called dermal, ground, and vascular tissues. Each type of tissue has a different function.
- The three types of tissues work together in most plant organs. Three organs commonly found in modern plants are roots, stems, and leaves.
- Plants continue to grow throughout life. Cells increase in both size and number. Undifferentiated cells in meristem tissue can keep dividing. They allow growth to continue.
- All plants have a life cycle that alternates between haploid and diploid generations. Plants vary in terms of which generation is dominant. Most modern plants have a dominant diploid generation.

## Lesson Review Questions

### Recall

1. What are plants? What do plants need?
2. How do plants grow?
3. Outline the general life cycle of a plant.

### Apply Concepts

4. Choose one of the three main organs of plants: roots, stems, or leaves. State the primary function of the organ. Then explain how the organ's structure suits it for its function.
5. A certain plant spends most of its life cycle as a haploid organism. Is the plant a flowering plant such as a daisy or is it a species of moss? Explain your answer.

### Think Critically

6. Compare and contrast dermal, ground, and vascular tissues of plants.
7. Why would life as we know it be impossible without plants?

## Points to Consider

The earliest plants were similar to green algae and lived in water.

1. What do you think the earliest plants might have been like?
2. What traits might plants have evolved after they colonized the land?

# 10.2 Evolution and Classification of Plants

## Lesson Objectives

- Describe the first plants.
- Discuss colonization of land by plants.
- Describe the early evolution of vascular plants.
- Explain why the evolution of seeds was such an important event.
- Explain why the evolution of flowers made flowering plants so successful.
- Outline the classification of modern plants.

## Lesson Vocabulary

- angiosperm
- cone
- embryo
- flower
- fruit
- germination
- gymnosperm
- petal
- pistil
- pollen
- pollinator
- seed
- stamen

## Introduction

The first plants lived in water. As shown in **Figure** 10.10, plants are thought to have evolved from aquatic green algae. Plants were the first organisms to move from water to land. They evolved important adaptations for life out of water. These adaptations included vascular tissue, seeds, and flowers. Each of these major adaptations made plants better suited for dry land and much more successful. For a good introduction to the origin and diversity of plants, watch this short video: http://www.youtube.com/watch?v=iJk4n2pl-ro .


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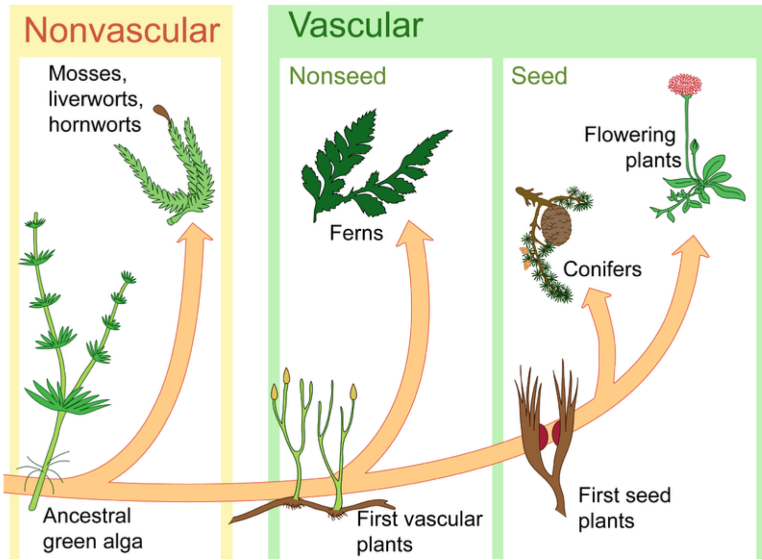



FIGURE 10.10

Evolution of plants

## The First Plants

The first plants were probably similar to the stoneworts in **Figure** 10.11. Stoneworts are green algae. Like stoneworts, the first plants were aquatic. They may have had stalks but not stems. They also may have had hair-like structures called rhizoids but not roots. The first plants probably had male and female reproductive organs and needed water to reproduce. In stoneworts, sperm need at least a thin film of moisture to swim to eggs.

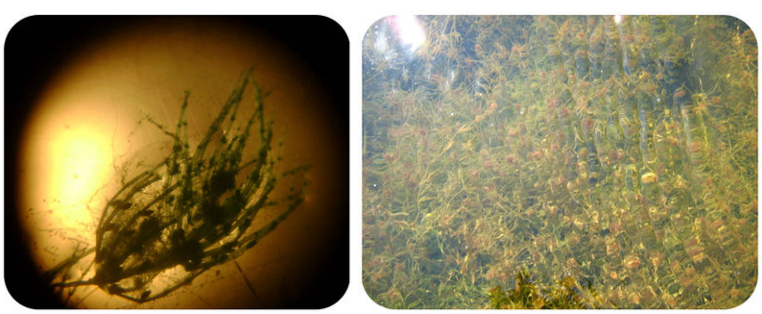


FIGURE 10.11

Individual stonewort alga (left) and an underwater field of stoneworts (right)

## Colonizing the Land

By the time the earliest plants evolved, animals were already the dominant living things in the water. Plants were also limited to the upper layer of water. Only near the top of the water column is there enough sunlight for photosynthesis. So plants never became dominant aquatic organisms.

### Moving From Water to Land

All that changed when plants moved from water to land. This may have happened by 500 million years ago or even earlier. On land, everything was wide open. There were no other living things. Without plants, there was nothing for other organisms to eat. Land could not be colonized by other organisms until land plants became established. The earliest land plants may have resembled the modern liverworts in **Figure** 10.12.


FIGURE 10.12
Liverworts are small plants that grow close to the ground.

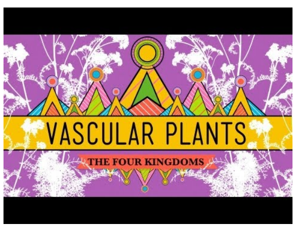
### Life Is Hard Without Water

Moving to the land was a huge step in plant evolution. Until then, virtually all life had evolved in water. Dry land was a very different kind of place. The biggest problem was the dryness. Simply absorbing enough water to stay alive was a huge challenge. It kept early plants small and low to the ground. Water was also needed for sexual reproduction, so sperm could swim to eggs.

There were other hardships on land besides dryness. For example, sunlight on land was strong and dangerous. Solar radiation put land organisms at high risk of mutations.

## Evolution of Vascular Plants

After they left the water, plants evolved adaptations that helped them withstand the harsh conditions on land. One of the earliest and most important adaptations to evolve was vascular tissue. For a fast-paced introduction to vascular plants and their successes, watch this video: http://www.youtube.com/watch?v=h9oDTMXM7M8 .

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### Evolution of Vascular Tissues

Vascular tissue forms a plant's "plumbing system." It carries water and dissolved minerals from the soil to all the other cells of the plant. It also carries food (sugar dissolved in water) from photosynthetic cells to other cells in the plant for growth or storage.

The evolution of vascular tissue revolutionized the plant kingdom. Vascular tissue greatly improved the ability of plants to absorb and transfer water. This allowed plants to grow larger and taller. They could also liver in drier habitats and survive periods of drought. Early vascular plants probably resembled the fern in **Figure** 10.13.

### Other Adaptations in Vascular Plants

Other early adaptations to life on land included the evolution of true leaves and roots. Leaves allowed plants to take better advantage of sunlight for photosynthesis. Roots helped plants absorb water and minerals from soil.

Early land plants also evolved a dominant sporophyte generation. Sporophytes are diploid, so they have two copies of each gene. This gives them a "back-up" copy in case of mutation. This was important for coping with the strong solar radiation and higher risk of mutations on land.

### Success of Vascular Plants

With all these adaptations, it's easy to see why vascular plants were very successful. They spread quickly and widely on land. As vascular plants spread, many nonvascular plants went extinct. Vascular plants became and remain the dominant land plants on Earth.

FIGURE 10.13
Modern ferns are similar to early vascular plants. The yellow structures on this fern are sporangia. They produce spores for reproduction.

## Evolution of Seed Plants

Early vascular plants still needed moisture. They needed it in order to reproduce. Sperm had to swim from male to female reproductive organs for fertilization. Even spores needed some water to grow and often to disperse as well. In addition, dryness and other harsh conditions made it very difficult for tiny new offspring plants to survive.

With the evolution of seeds in vascular plants, all that changed. Seed plants evolved a number of adaptations that made it possible to reproduce without water. Seeds also nourished and protected tiny new offspring. As a result, seed plants were wildly successful. They exploded into virtually all of Earth's habitats.

### Why Seeds Are Adaptive on Land

A **seed** is a reproductive structure that contains an embryo and a food supply, called endosperm. Both the embryo and endosperm are enclosed within a tough outer coating, called a hull (or shell). You can see these parts of a seed in **Figure** 10.14. An **embryo** is a zygote that has already started to develop and grow. Early growth and development of a plant embryo inside a seed is called **germination**. The seed protects and nourishes the embryo and gives it a huge head start in the "race" of life.

Both a parent plant and its offspring are better off if they don't grow too closely together. That way, they will not need to compete for resources. Many seeds have structures that help them travel away from the parent plant. You can see some examples in **Figure** 10.15. Some seeds can also wait to germinate until conditions are favorable for growth. This increases the offspring's chances of surviving even more.

### Other Reproductive Adaptations in Seed Plants

Seed plants also evolved other reproductive structures. These included ovules, pollen, and pollen tubes.

- An ovule is a female reproductive structure in seed plants. It contains a tiny female gametophyte. The gametophyte produces an egg cell. After the egg is fertilized by sperm, the ovule develops into a seed.

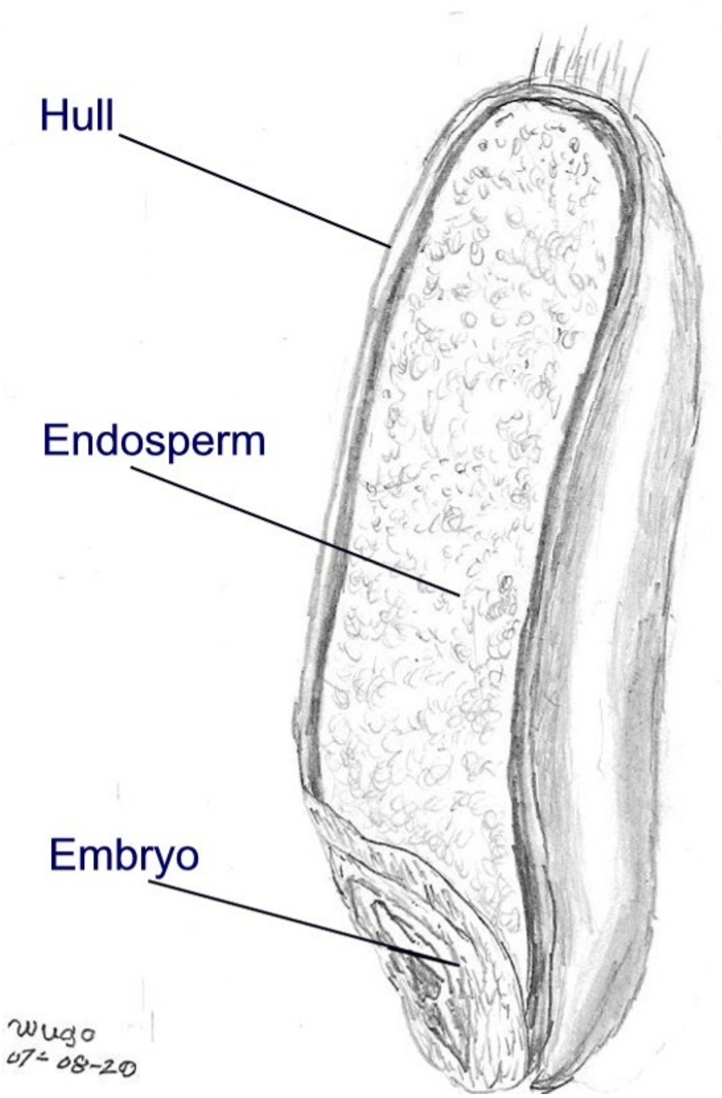


FIGURE 10.14
Parts of a seed

- **Pollen** is a tiny male gametophyte enclosed in a tough capsule. Pollen carries sperm to an ovule while preventing the sperm from drying out. Pollen grains can't swim, but they are very light, so the wind can carry them. Therefore, they can travel through air instead of water.
- Pollen also evolved the ability to grow a tube, called a pollen tube. Sperm could be transferred through the tube directly from the pollen grain to the egg. This allowed sperm to reach an egg without swimming through a film of water. It finally freed plants from depending on moisture to reproduce.

### Early Seed Plants

The first seed plants formed seeds in cones, like the cone in **Figure** 10.16. **Cones** are reproductive structures made of overlapping scales. Scales are modified leaves. Male cones contain pollen. Female cones contain eggs. They are also where seeds develop. The seeds in cones are "naked." They aren't protected inside an ovary, which was a later adaptation of seed plants.

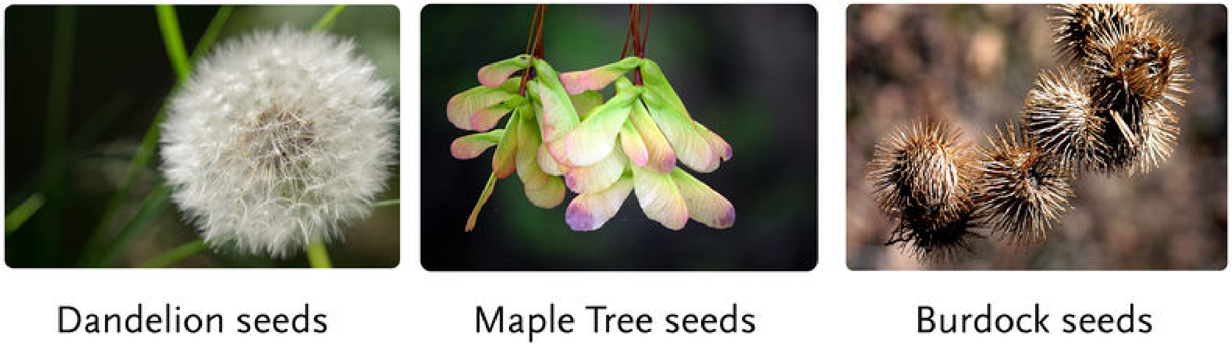


FIGURE 10.15
Dandelion seeds have tiny "parachutes" that let the wind carry them. Maple tree seeds have "wings" that act like little gliders. Burdock seeds are covered with tiny hooks that cling to animal fur.

FIGURE 10.16
Seed-bearing cone and loose, naked seeds

## Evolution of Flowering Plants

Some seed plants evolved another major adaptation. This was the formation of seeds in flowers. **Flowers** are plant structures that contain male and/or female reproductive organs.

### Parts of a Flower

You can see the parts of a typical flower in **Figure** 10.17.

- The male reproductive organ in a flower is the **stamen**. It has a stalk-like filament that ends in an anther. The anther is where pollen forms.
- The female reproductive organ in a flower is the **pistil**. It consists of a stigma, style, and ovary. The stigma is the top of the pistil. It is sticky to help it "catch" pollen. The style connects the stigma to the ovary. The ovary

is where eggs form and seeds develop. As seeds develop, the ovary turns into a **fruit**. The fruit protects the seeds. It also attracts animals that may eat the fruit and help disperse the seeds.

- **Petals** are usually the most visible parts of a flower. They may be large and showy and are often brightly colored. Leaf-like green sepals protect the flower while it is still a bud.

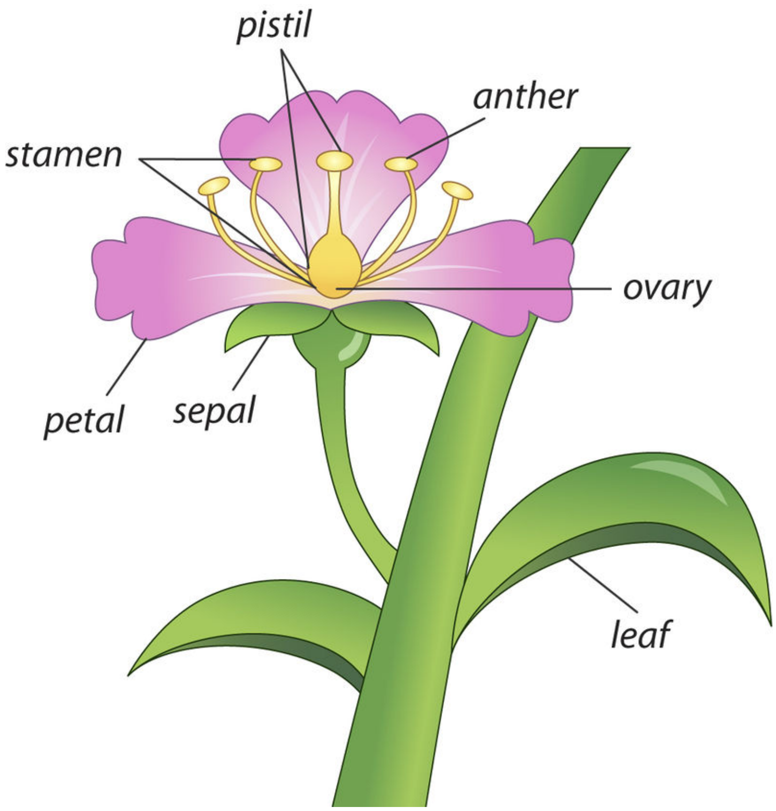


FIGURE 10.17
Parts of a typical flower

### Pollinators

The showy petals of flowers evolved to help attract pollinators. Wind-blown pollen might land just anywhere and be wasted. A **pollinator** is an animal that picks up pollen on its body and carries it directly to another flower of the same species. This helps ensure that pollination occurs. Pollinators are usually small animals such as bees, butterflies, and bats. You can see an example in **Figure** 10.18.

## Classification of Modern Plants

The most basic division of modern plants is between nonvascular and vascular plants. Vascular plants are further divided into those that reproduce without seeds and those that reproduce with seeds. Seed plants, in turn, are divided into those that produce naked seeds in cones and those that produce seeds in the ovaries of flowers.

### Nonvascular Plants

Modern nonvascular plants are called bryophytes. There are about 17,000 bryophyte species. They include liverworts, hornworts, and mosses. Mosses are the most numerous group of bryophytes. You can see an example of

FIGURE 10.18
This bee is peppered with yellow pollen grains that it will carry to other flowers of the same species.

moss in **Figure** 10.19. Like the moss in the figure, most bryophytes are small. They lack not only vascular tissues. They also lack true roots, leaves, seeds, and flowers. Bryophytes live in moist habitats. Without the adaptations of vascular plants, bryophytes are not very good at absorbing water. They also need water to reproduce.

FIGURE 10.19
Modern nonvascular plant: moss

### Vascular Plants

Today's vascular plants are called tracheophytes. Their vascular tissue is specialized to transport fluid. This allows them to grow tall and take advantage of sunlight high up in the air. It also allows them to live in drier habitats. Most modern plants are tracheophytes. There are hundreds of thousands of species of them.

Seedless vascular plants include plants such as ferns. You can see a fern in **Figure** 10.20. Ferns reproduce with spores instead of seeds. The black dots on the back of the fern leaf in **Figure** 10.20 are spores.

FIGURE 10.20
Modern seedless vascular plant: fern

### Seed Plants

Seed plants are vascular plants that reproduce with seeds. Modern seed plants are called spermatophytes. Seeds allow the plants to reproduce without water. Most vascular plants today are seed plants.

Modern seed plants include gymnosperms and angiosperms.

- **Gymnosperms** are seed plants that produce naked seeds in cones. There are about 1000 species of gymnosperms. Conifers are the most common group of gymnosperms. The spruce tree in **Figure** 10.21 is an example of a conifer.
- **Angiosperms** are seed plants that produce seeds in the ovaries of flowers. Today, they are by far the most diverse type of seed plants. In fact, the vast majority of all modern plants are angiosperms. There are hundreds of thousands of species of them. The apple tree in **Figure** 10.21 is an example of a common angiosperm.

## Lesson Summary

- The first plants probably evolved from aquatic green algae. They had male and female reproductive organs. However, they lacked true stems, roots, and leaves.
- Plants were the first living things to move from water to land. They had to cope with dryness and strong solar radiation.
- The first major adaptation that evolved in land plants was vascular tissue. This type of tissue helped land plants cope with dryness. Vascular plants also evolved true stems, roots, and leaves.
- Some vascular plants evolved seeds. This freed them from needing water to reproduce. Early seed plants produced naked seeds in cones.
- Some seed plants evolved flowers for the production of seeds. Flowers contain both male and female reproductive organs, including an ovary where eggs form and seeds develop. Flowers also attract pollinators.
- The most basic division of modern plants is between nonvascular and vascular plants. Vascular plants are further divided into those that reproduce without seeds and those that reproduce with seeds. Seed plants, in turn, are divided into those that produce naked seeds in cones (gymnosperms) and those that produce seeds in the ovaries of flowers (angiosperms).


FIGURE 10.21

Modern seed plants: gymnosperm (spruce) and angiosperm (apple)

## Lesson Review Questions

### Recall

1. List traits of the first plants.
2. What hazards did plants face when they colonized the land?
3. Identify the parts of a typical flower and their role in reproduction.

### Apply Concepts

4. Plants that are pollinated by wind rather than pollinators may have modest or insignificant flowers. Apply lesson concepts to explain why.

### Think Critically

5. Why was the evolution of vascular tissue such an important adaptation for life on land?
6. Explain why a dominant diploid generation is adaptive for plants that live on land.

## Points to Consider

Plants can't move away from danger.

1. Does this mean that plants are helpless?
2. How might plants be able to protect themselves from pathogens?

# 10.3 Plant Responses and Special Adaptations

## Lesson Objectives

- Explain how plants respond to stimuli in their environment.
- Identify special adaptations in plants.

## Lesson Vocabulary

- aquatic plant
- carnivorous plant
- epiphyte
- gravitropism
- phototropism
- tropism
- xerophyte

## Introduction

Like all living things, plants detect and respond to stimuli in their environment. Unlike animals, plants can't run, fly, or swim toward food or away from danger. They are usually rooted firmly in the soil, like the tree in **Figure** 10.22.

FIGURE 10.22
These tree roots grip the ground like a hand.

## Plant Responses

Instead of fleeing, a plant's primary way of responding is to change how it is growing. One way is by tropisms.

### Plant Tropisms

A **tropism** is a turning toward, or away from, a stimulus in the environment. Examples of tropisms in plants include gravitropism and phototropism. You can see both tropisms in action in this amazing time-lapse video: http://www.youtube.com/watch?v=F3Oj2er-91s .

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- **Gravitropism** is a response to gravity. Plant roots always grow downward because of the pull of Earth's gravity. Specialized cells in the tips of plant roots detect and respond to gravity in this way.
- **Phototropism** is a response to light. Plant stems and leaves grow toward a light source. The house plant in **Figure** 10.23 shows the effects of phototropism. The plant receives light mainly from the left so it grows in that direction.

FIGURE 10.23

Example of phototropism

### Daily and Seasonal Responses of Plants

Plants also detect and respond to the daily cycle of light and darkness. For example, some plants open their leaves during the day to collect sunlight and then close their leaves at night to prevent water loss.

Many plants respond to the days growing shorter in the fall by going dormant. They suspend growth and development in order to survive the extreme coldness and dryness of winter. Part of this response causes the leaves of many trees to change color and then fall off (see **Figure** 10.24). Dormancy ensures that plants will grow and produce seeds only when conditions are favorable.

FIGURE 10.24
The leaves of many trees turn brilliant colors of red and yellow when days grow shorter in the fall.

### Plant Responses to Disease

Plants don't have an immune system, but they do respond to disease. Typically, their first line of defense is the death of cells surrounding infected tissue. This prevents the infection from spreading.

Many plants also produce hormones and toxins to fight pathogens. For example, willow trees, like the one in **Figure** 10.25, produce salicylic acid to kill bacteria. The same compound is used in many acne products for the same reason.

Exciting new research suggests that plants may even produce chemicals that warn other, nearby plants of threats to their health. The warnings allow nearby plants to prepare for their own defense. As these and other responses show, plants may be rooted in place, but they are far from helpless.

## Plants with Special Adaptations

Plants live just about everywhere on Earth. To live in so many different habitats, they have evolved adaptations that allow them to survive and reproduce under a diversity of conditions. Some plants have evolved special adaptations that let them live in extreme environments.

### Aquatic Plants

All plants are adapted to live on land. Or are they? All living plants today have land-plant ancestors. But some plants now live in the water. They have had to evolve new adaptations for their watery habitat.

FIGURE 10.25
This willow tree produces a compound that fights bacteria.

Modern plants that live in water are called **aquatic plants**. Living in water has certain advantages for plants. One advantage is, well, the water. There's plenty of it and it's all around. Therefore, most aquatic plants do not need adaptations for absorbing, transporting, and conserving water. They can save energy and matter by not growing extensive root systems, vascular tissues, or thick cuticle on leaves. Support is also less of a problem because of the buoyancy of water. As a result, adaptations such as strong woody stems and deep anchoring roots are not necessary for most aquatic plants.

Living in water does present challenges to plants, however. For one thing, pollination by wind or animals isn't feasible under water. Sunlight also can't penetrate very far below the water surface. That's why some aquatic plants have adaptations that help them keep their flowers and leaves above water. An example is the water lily, shown in **Figure** 10.26. The water lily has bowl-shaped flowers and broad, flat leaves that float. Plants that live in moving water, such as streams or rivers, may have different adaptations. For example, the cattails shown in **Figure** 10.26 have narrow, strap-like leaves that reduce their resistance to moving water.


FIGURE 10.26
Water lilies and cattails have different adaptations for life in the water.

### Xerophytes

Plants that live in extremely dry environments have the opposite problem: how to get and keep water. Plants that are adapted to very dry environments are called **xerophytes**. Their adaptations may help them increase water intake, decrease water loss, or store water when it's available.

The saguaro cactus pictured in **Figure** 10.27 has adapted in all three ways. When it was still a very small plant, just a few inches high, its shallow roots already reached out as much as 2 meters (7 feet) from the base of the stem. By now, its root system is much more widespread. It allows the cactus to gather as much moisture as possible from rare rainfalls. The saguaro doesn't have any leaves to lose water by transpiration. It also has a large, barrel-shaped stem that can store a lot of water. Thorns protect the stem from thirsty animals that might try to get at the water inside.

FIGURE 10.27
A saguaro cactus is adapted for extreme dryness.

### Epiphytes

Plants called **epiphytes** grow on other plants. They obtain moisture from the air instead of the soil. Most epiphytes are ferns or orchids that live in rainforests. Host trees provide support for the plants. They allow epiphytes to get air and sunlight high above the forest floor. This lets the plants get out of the shadows on the forest floor so they can get enough light for photosynthesis. Being elevated may also reduce the risk of being eaten by herbivores. In addition, it may increase the chances of pollination by wind.

### Carnivorous Plants

**Carnivorous plants** are plants that get some or most of their nutrients (but not energy or carbon compounds) from other organisms. They trap and digest insects or other small animals or protozoa. However, they still need sunlight in order to make food by photosynthesis. Carnivorous plants have adapted to grow in places where the soil is thin or poor in nutrients. They are found in places such as bogs and rock outcroppings. Venus fly traps, like those in **Figure** 10.28, are well-known carnivorous plants. Watch this amazing video trailer to see these and other carnivorous plants in action: http://www.youtube.com/watch?v=_1eOs9909v0 .

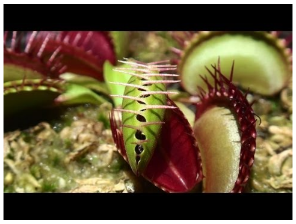

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FIGURE 10.28

Venus fly traps are carnivorous plants.

## Lesson Summary

- A plant's main response to stimuli in its environment is to change how it is growing. For example, plant roots grow toward Earth's gravity. Stems and leaves bend toward sunlight. Plants also respond to daily and seasonal changes and to disease.
- Some plants have evolved special adaptations to extreme environments. Such plants include aquatic plants, xerophytes, epiphytes, and carnivorous plants.

## Lesson Review Questions

### Recall

1. What is a tropism? What are two types of tropisms in plants?
2. How do plants respond to daily and seasonal changes?
3. Define and give examples of xerophytes and epiphytes.

### Apply Concepts

4. Many modern medicines have been discovered in trees and other plants. Why do you think so many disease-fighting compounds are found in plants?

### Think Critically

5. Identify two challenges faced by aquatic plants. Explain how they have evolved to adapt to the challenges.
6. Carnivorous plants are classified as producers. Why aren't they classified as consumers?

## Points to Consider

Like plants, animals are multicellular eukaryotes. However, animals differ from plants in other important ways.

1. What are some ways that animals differ from plants?
2. The most basic division of plants is between vascular and nonvascular plants. How are animals divided?

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# CHAPTER 11 MS Introduction to Animals

## Chapter Outline



Do you know what this photo shows? Is it a strange tree branch? A cactus? Maybe a fungus? Actually, it's an animal called a sea sponge. A sea sponge doesn't look anything like the animals you're probably familiar with—animals like ducks and dogs, fish and frogs. Why is a sea sponge considered an animal? What traits must an organism have to be classified in the Animal Kingdom? You'll find out in this chapter. You'll learn just what it means to be an animal.

# 11.1 What Are Animals?

## Lesson Objectives

- Identify basic traits of animals.
- Outline the classification of animals.

## Lesson Vocabulary

- animal
- Animal Kingdom
- invertebrate
- larva (larvae, plural)
- vertebral column
- vertebrate

## Introduction

There is great variation among species that are called animals. You can see some of the variation in **Figure** 11.1. Despite this variation, there are a number of traits that are shared by all animals. What traits do all animals share? Read on to find out.

## Basic Animal Traits

Animals are multicellular eukaryotes in the Animal Kingdom. All animals are heterotrophs. They eat other living things because they can't make their own food. All animals also have specialized cells that can do different jobs. Most animals have higher levels of organization as well. They may have specialized tissues, organs, and even organ systems. Having higher levels of organization allows animals to perform many complex functions. For a visual introduction to what makes a living thing an animal, watch this short video: https://www.youtube.com/watch?v=DXPhJUHooP8 .

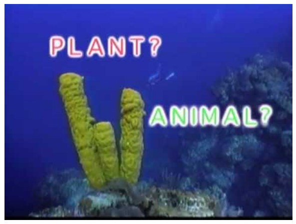


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FIGURE 11.1
Diversity of the Animal Kingdom: (left to right) jellyfish, worm, snail, beetle, gorilla, and snake.

## Specialized Cells

Like the cells of all eukaryotes, animal cells have a nucleus and other membrane-bound organelles. Unlike the cells of eukaryotes in the Plant and Fungus Kingdoms, animal cells lack a cell wall. This gives animal cells flexibility. It lets them take on different shapes. This in turn allows them to become specialized for particular jobs.

The human nerve cell in **Figure** 11.2 is a good example of a specialized animal cell. Its shape suits it for its function of sending nerve signals to other cells. A nerve cell couldn't take this shape if it were surrounded by a rigid cell wall.

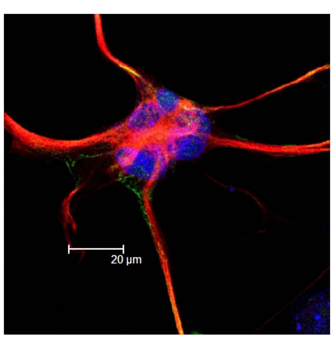



FIGURE 11.2
Human nerve cell

## What Animals Can Do

With their specialized cells and higher levels of organization, animals can do several things that other eukaryotes cannot.

- Animals can detect and quickly respond to a variety of stimuli. They have specialized nerve cells that can detect light, sound, touch, or other stimuli. Most animals also have a nervous system that can direct the body to respond to the stimuli.
- All animals can move, at least during some stage of their life cycle. Specialized muscle and nerve tissues work together to allow movement. Being able to move lets animals actively search for food and mates. It also helps them escape from predators and other dangers.
- Virtually all animals have internal digestion of food. Animals consume other organisms and may use special tissues and organs to digest them. (Other heterotrophs, such as fungi, absorb nutrients directly from the environment.)

## General Life Cycle of Animals

Many animals have a relatively simple life cycle. A general animal life cycle is shown in **Figure** 11.3. Most animals spend the majority of their life as diploid organisms. Just about all animals reproduce sexually. Diploid adults undergo meiosis to produce haploid sperm or eggs. Fertilization occurs when a sperm and an egg fuse. The diploid zygote that forms develops into an embryo. The embryo eventually develops into an adult, often going through one or more larval stages on the way. A larva (larvae, plural) is a distinct juvenile form that many animals go through before becoming an adult. The larval form may be very different from the adult form. For example, a caterpillar is the larval form of an insect that becomes a butterfly as an adult.

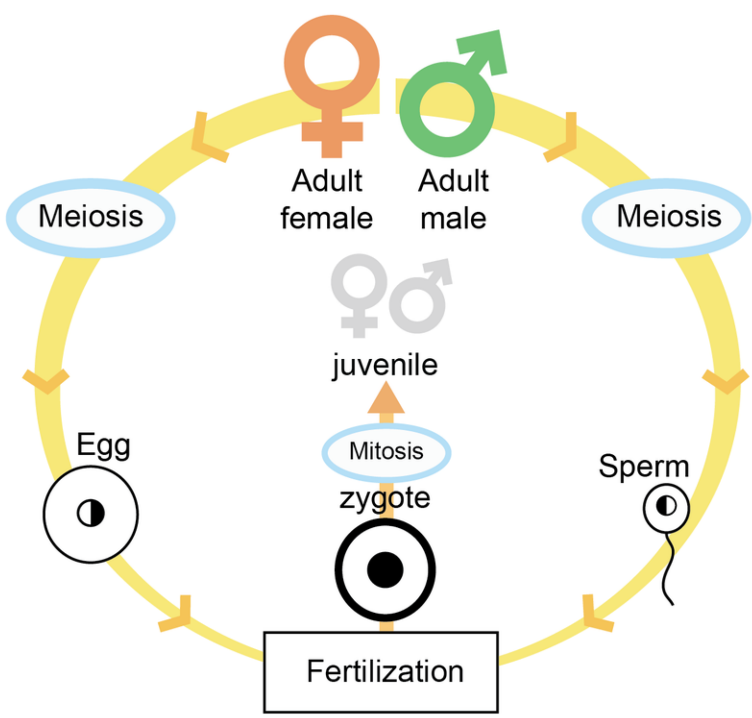



FIGURE 11.3
Animal Life Cycle.

## How Animals Are Classified

The Animal Kingdom is one of four kingdoms in the Eukarya Domain. The Animal Kingdom, in turn, is divided into almost 40 phyla. **Table** 11.1 lists the 9 animal phyla that contain the largest numbers of species. Each phylum in the table has at least 10,000 species.

**TABLE 11.1:** Major Phyla of the Animal Kingdom

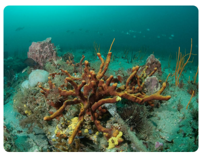
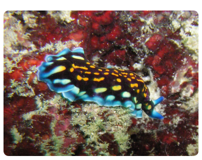
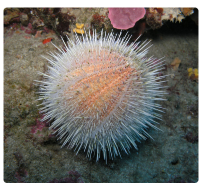
| | Phylum | Animals It Includes |
|---|---|---|
|  | Porifera | sponges |
|  | Cnidaria | jellyfish, corals |
|  | Platyhelminthes | flatworms, tapeworms, flukes |
|  | Nematoda | roundworms |
|  | Mollusca | snails, clams, squids |

**TABLE 11.1:** (continued)

| | Phylum | Animals It Includes |
|---|---|---|
|  | Annelida | earthworms, leeches, marine worms |
|  | Arthropoda | insects, spiders, crustaceans, centipedes |
|  | Echinodermata | sea stars, sea urchins, sand dollars, sea cucumbers |
|  | Chordata | tunicates, lancelets, fish, amphibians, reptiles, birds, mammals |

One basic way to divide animals is between invertebrates and vertebrates.

- Invertebrates are animals that lack a vertebral column, or backbone. All the phyla in **Table** 11.1, except the Phylum Chordata, consist only of invertebrates. Even the Phylum Chordata includes some invertebrate taxa. Invertebrates make up about 95 percent of all animal species.
- Vertebrates are animals that have a backbone. All of them are placed in the Phylum Chordata. Modern vertebrates include fish, amphibians, reptiles, birds, and mammals. Only about 5 percent of animal species are vertebrates.

## Lesson Summary

- Animals are multicellular eukaryotes in the Animal Kingdom. They are heterotrophic, meaning that they consume other organisms. Animals have specialized cells and often higher levels of organization. This allows them to do things that other eukaryotes cannot, such as move and digest food internally. Animals generally have a simple life cycle.
- The Animal Kingdom is one of four kingdoms in the Eukarya Domain. The Animal Kingdom, in turn, is divided into almost 40 modern phyla. The Animal Kingdom can also be divided into two basic groups: invertebrates and vertebrates. Most animal species are invertebrates, which lack a backbone.

## Lesson Review Questions

### Recall

1. What are animals?
2. What can animals do that other eukaryotes cannot?
3. Describe a general animal life cycle.

### Apply Concepts

4. Assume you must classify a mystery organism. What questions could you ask about the organism that would help you decide whether it is an animal?

### Think Critically

5. Explain why animals can develop specialized cells.
6. Compare and contrast invertebrates and vertebrates.

## Points to Consider

The first animal trait to evolve was the presence of multiple cells.

1. How do you think this trait might have evolved?
2. Why do you think this trait was adaptive?

# 11.2 How Animals Evolved

## Lesson Objectives

- State when major events in animal evolution occurred.
- Outline major trends in invertebrate evolution.
- Explain how the first vertebrates evolved.
- Identify adaptations that helped animals colonize the land.

## Lesson Vocabulary

- amniote
- aquatic
- chordate
- coelom
- cranium
- exoskeleton
- notochord
- pseudocoelom
- segmentation
- symmetry
- terrestrial

## Introduction

The creepy, crawly millipede in **Figure** 11.4 is a modern-day animal. It belongs to Phylum Arthropoda. It also represents a major event in animal evolution: the move from water to land. The earliest animals were aquatic, which means they lived in the water. The first terrestrial, or land-living, animals were probably arthropods like the millipede. However, the move to the land occurred relatively late in animal evolution. The story of animal evolution actually began at least 200 million years before the first animals went ashore. For a good visual introduction to the evolution of animals, watch this short video: https://www.youtube.com/watch?v=dsVWJ7Rm0pA .

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FIGURE 11.4
This modern millipede probably resembles the first animals to live on land.

## Timing of Animal Evolution

The partial geologic time scale in **Figure** 11.5 shows when some of the major events in animal evolution took place. The oldest animal fossils are about 630 million years old, so presumably animals evolved around that time or somewhat earlier. The earliest animals were aquatic invertebrates. The first vertebrates evolved around 550 million years ago. By 500 million years ago, most modern phyla of animals had evolved. The first terrestrial animals evolved about 50 million years after that.

## Trends in Invertebrate Evolution

Animals evolved many important traits that set them apart from other eukaryotes. The traits—and the order in which they evolved—include:

- multicellularity and cell specialization;
- tissues and higher levels of organization;
- body symmetry;
- third embryonic cell layer (mesoderm);
- digestive system;
- fluid-filled body cavity (coelom);
- segmented body; and
- notochord.

Each of these traits is described below. All of them evolved in invertebrates. Each major trait to evolve led to a new stage in animal evolution. The phyla in **Table** 11.1 represent modern animals at each of these major stages. Refer back to the table as you read about the evolution of these traits.

### Multicellularity

The first animal trait to evolve was multicellularity. This is the presence of multiple cells in a single organism. Scientists think that the earliest animals with multiple cells evolved from animal-like protists that lived in colonies. Some of the cells in the colonies became specialized for different jobs. After a while, the specialized cells came to need each other for survival. Thus, the first multicellular animals evolved.

Multicellularity was highly adaptive. Multiple cells could do different jobs. They could evolve special adaptations that allowed them to do a particular job really well. Modern animals that represent this stage of animal evolution are sponges. They are placed in Phylum Porifera (see **Table** 11.1). They have multiple specialized cells, but their cells are not organized into tissues.

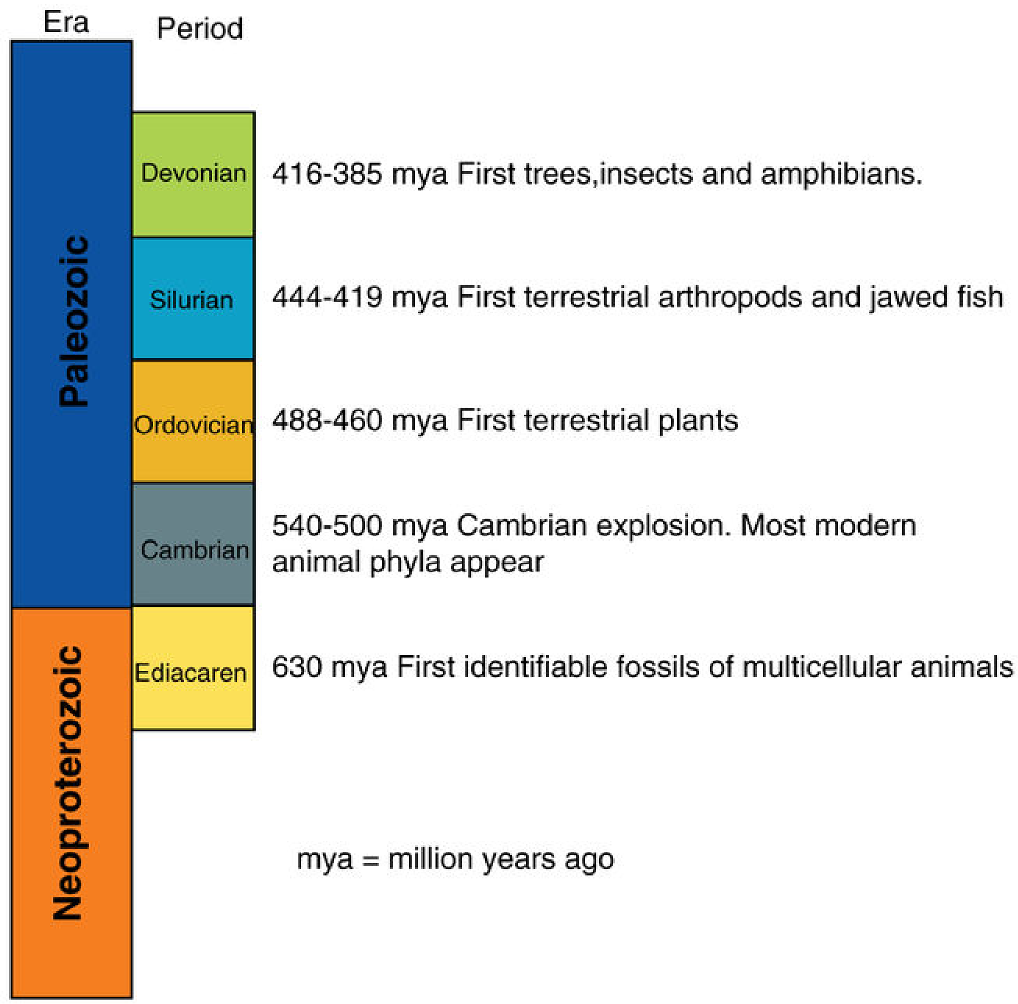


FIGURE 11.5

Some major events in animal evolution

## Tissues

The next major stage of animal evolution was the evolution of tissues. It was the first step in the evolution of organs and organ systems. At first, invertebrates developed tissues from just two embryonic cell layers. There was an outer cell layer called ectoderm and an inner cell layer called endoderm. The two cell layers allowed different types of tissues to form. Modern animals that represent this stage of evolution include jellyfish. They are placed in Phylum Cnidaria.

### Body Symmetry

Another trait that evolved early was symmetry. A symmetrical organism can be divided into two identical halves. Both the coral and the beetle in **Figure** 11.6 have symmetry, while the sponge lacks symmetry.

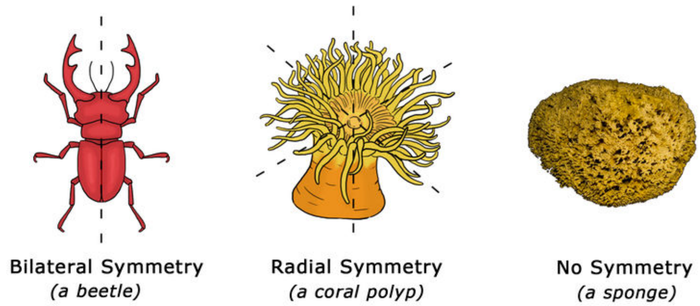


FIGURE 11.6
Symmetry in invertebrates.

There are two types of symmetry: radial and bilateral.

- Radial symmetry is demonstrated by the coral in **Figure** 11.6. It can be divided into identical halves along any diameter, just like a circular pie. Radial symmetry was the first type of symmetry to evolve. Animals with radial symmetry, such as cnidarians, have no sense of left or right. This makes controlled movement in these directions impossible.
- Bilateral symmetry is demonstrated by the beetle in **Figure** 11.6. It can be divided into identical halves just down the middle from top to bottom. Bilateral symmetry could come about only after animals evolved a distinctive head region where nerve tissue was concentrated. The concentration of nerve tissue in the head region was the first step in the evolution of a brain. Animals with bilateral symmetry can tell left from right. This gives them better control over the direction of their movements.

### Mesoderm

The next major trait to evolve was mesoderm. This is a third embryonic layer of cells between the ectoderm and the endoderm. Modern animals that represent this stage of evolution are the flatworms. They are placed in Phylum Platyhelminthes. You can see the mesoderm in a flatworm in **Figure** 11.7. Evolution of this new cell layer allowed animals to develop new types of tissues, such as muscle tissue.

### Digestive System

Even early invertebrates had a digestive system. However, the earliest digestive system was incomplete. There was just one opening for food to enter the body and waste to leave the body. In other words, the same opening was both mouth and anus. A modern jellyfish has this type of digestive system, as shown in **Figure** 11.8.

Eventually a complete digestive system with two body openings evolved, as shown in **Figure** 11.8. With a separate mouth and anus, food could move through the body in just one direction. This made digestion more efficient. An animal could keep eating while digesting food and getting rid of waste. Different parts of the digestive tract could also become specialized for different digestive functions. This led to the evolution of digestive organs. Modern animals that represent this stage of evolution are roundworms. They are placed in Phylum Nematoda.

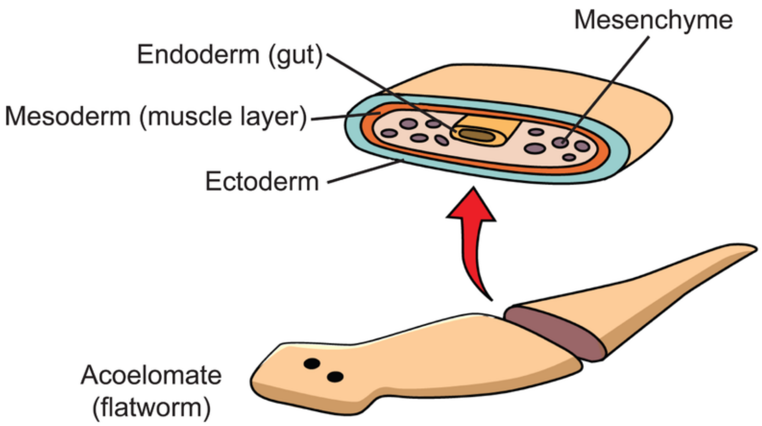


FIGURE 11.7
Three Cell Layers in a Flatworm. A flatworm has three cell layers.

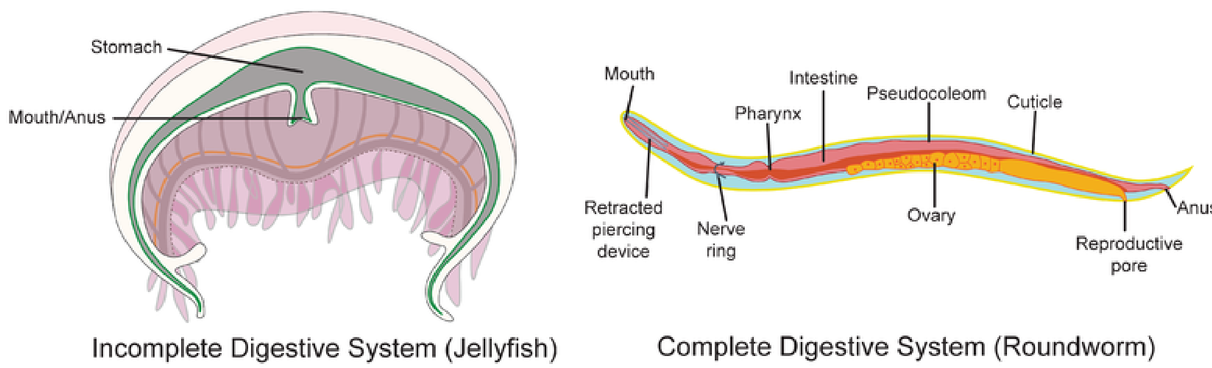


FIGURE 11.8
Two Types of Digestive Systems in Invertebrates. On the left is an incomplete digestive system, found in a jellyfish; on the right is the complete digestive system of a roundworm. Invertebrates may have either of these two types of digestive system.

## Fluid-Filled Body Cavity

The next major animal trait to evolve was a body cavity filled with fluid. At first, this was just a partial body cavity, called a pseudocoelom. A pseudocoelom isn't completely enclosed by mesoderm. However, it still allows room for internal organs to develop. The fluid in the cavity also cushions the internal organs. The pressure of the fluid provides stiffness as well. It gives the body internal support. Modern invertebrates with a pseudocoelom include roundworms. Flatworms lack this trait. This difference explains why roundworms are round whereas flatworms are flat.

Later, a true coelom evolved. This is a fluid-filled body cavity that is completely enclosed by mesoderm. The coelom lies between the digestive cavity and body wall. You can see it in the invertebrate in **Figure** 11.9. Modern invertebrates with a coelom include mollusks (Phylum Mollusca) and annelids (Phylum Annelida).

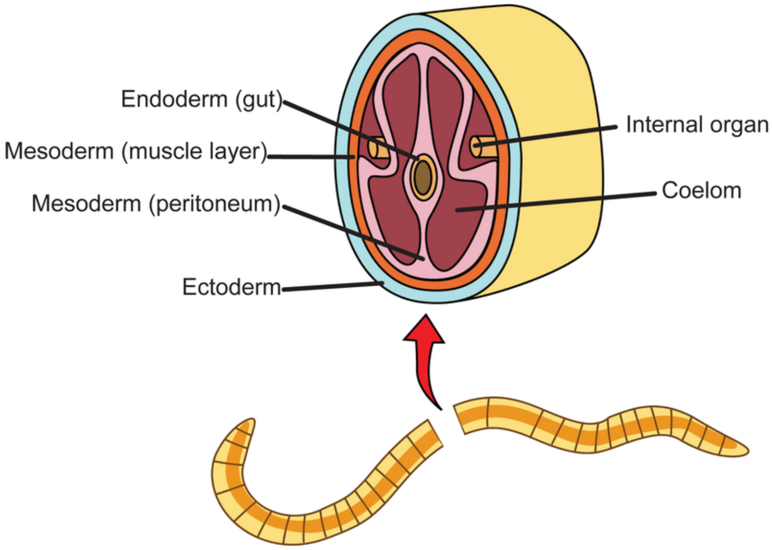


FIGURE 11.9
Cross Section of an invertebrate with a coelom. The coelom forms within the mesoderm.

### Segmented Body

Segmentation evolved next. Segmentation is the division of the body into multiple parts, or segments. Both the earthworm (Phylum Annelida) in **Figure** 11.10 and ant (Phylum Arthropoda) in **Figure** 11.11 have segmented bodies. The earthworm has many small segments. The ant has three larger segments. Segmentation increases an animal's flexibility. It allows a wider range of motion. Different segments can also be specialized for different functions. All modern annelids and arthropods are segmented.

FIGURE 11.10
A segmented invertebrate: earthworm (annelid)

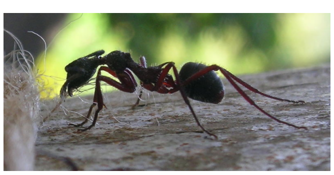

FIGURE 11.11
A segmented invertebrate: ant (arthropod)

Arthropods also evolved jointed appendages. For example, they evolved jointed legs for walking and jointed "feelers" (antennae) for sensing. Notice the ant's jointed legs and antennae in **Figure** 11.11 .

### Notochord

Some invertebrates evolved a rigid rod along the length of their body. This rod is called a notochord. You can see the notochord in the tunicates in **Figure** 11.12. The notochord gives the body support and shape. It also provides a place for muscles to attach. It can counterbalance the pull of the muscles when they contract. Animals with a notochord are called chordates. All of them are placed in Phylum Chordata. Some early chordates eventually evolved into vertebrates.

FIGURE 11.12
Tunicates have a notochord. It appears here as a line running down the length of the body.

## Evolution of Vertebrates

The earliest vertebrates evolved around 550 million years ago. It happened when some chordates evolved a backbone to replace the notochord after the embryo stage. They also evolved a cranium, or bony skull. The cranium enclosed and protected the brain. The earliest vertebrates probably looked like the hagfish in **Figure** 11.13.

FIGURE 11.13
This hagfish is a simple vertebrate. It may resemble the earliest vertebrates.

## Colonizing the Land

Invertebrates were the first animals to colonize the land. The move to land occurred about 450 million years ago. It required new adaptations. For example, animals needed a way to keep their body from drying out. They also needed a way to support their body on dry land without the buoyancy of water.

### Evolution of the Exoskeleton

One way early land invertebrates solved these problems was with an exoskeleton. This is a non-bony skeleton that forms on the outside of the body. It supports the body and helps it retain water. As the organism grows, it sheds its old exoskeleton and grows a new one. **Figure** 11.14 shows the discarded exoskeleton of a dragonfly.

FIGURE 11.14
Exoskeleton shed by a dragonfly

### Evolution of Amphibians

The first vertebrates moved onto land about 365 million years ago. They were early amphibians. They were the first animals to have true lungs and limbs for life on land. However, they still had to return to the water to reproduce. That's because their eggs lacked a waterproof covering and would dry out on land.

### Evolution of Amniotes

The first vertebrates to live fully on land were amniotes. Amniotes are animals that produce eggs with waterproof membranes. The membranes let gases but not water pass through. They allow embryos to breathe without drying out. Amniotic eggs were the first eggs that could be laid on land. The earliest amniotes evolved about 350 million years ago. Amniotes would eventually evolve into modern reptiles, mammals, and birds.

## Lesson Summary

- The oldest animal fossils are about 630 million years old. The earliest animals were aquatic invertebrates. The first vertebrates evolved around 550 million years ago. By 500 million years ago, most modern phyla of animals had evolved.
- Invertebrates evolved many traits that set animals apart from other eukaryotes. They include multicellularity, tissues and higher levels of organization, body symmetry, mesoderm, digestive system, coelom, segmented body, and notochord.
- The earliest vertebrates evolved when some chordates evolved a backbone to replace the notochord after the embryo stage.
- Invertebrates colonized the land about 450 million years ago. This required new adaptations, such as an exoskeleton. Vertebrates colonized the land about 365 million years ago. They were amphibians that had to return to the water to reproduce. The first vertebrates to live fully on land were amniotes.

## Lesson Review Questions

### Recall

1. When did the first animals evolve?
2. List five important animal traits that evolved in invertebrates.
3. What are chordates?
4. How did vertebrates evolve?

### Apply Concepts

5. Assume that animals remained aquatic organisms and never colonized the land. Which animal traits do you think might not have evolved?

### Think Critically

6. Compare and contrast radial and bilateral symmetry.
7. Explain why having a segmented body is adaptive.

## Points to Consider

Some of the earliest animals evolved multiple, specialized cells. However, they lacked other animal traits, such as tissues. These traits evolved later.

1. What modern animals are like early animals, with specialized cells but not tissues?
2. Where do these modern animals live?

# 11.3 References


1. CK-12 Foundation. CK-12 Foundation - from originals Jellyfish (NOAA, http://commons.wikimedia.org/wiki/Jellyfish#mediaviewer/File:Chrysaora_jelly.jpg, CC-BY 2.0);Worm (Thomas Brown, http://commons.wikimedia.org/wiki/File:Hammerhead_Worm_Arrowhead_Flatworm_(Bipalium_sp.%3F)_(7113330279).jpg,CC-BY 2.0); Snail (Dhruvaraj S, http://commons.wikimedia.org/wiki/File:Snail_2.jpg, CC-BY 2.0); Beetle (Keith Weller, USDA, http://commons.wikimedia.org/wiki/File:Adult_citrus_root_weevil,_Diaprepes_abbreviatus.jpg, CC-BY 2.0); Gorilla (Aaron Logan, http://commons.wikimedia.org/wiki/File:Lightmatter_silverback_gorilla.jpg, CC-BY 2.0); Snake (Patrick JEAN/muséum d'histoire naturelle de Nantes, http://commons.wikimedia.org/wiki/File:Couleuvre_collier_62.JPG, CC-BY 2.0) . CC BY 2.0
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5. CK-12 Foundation. CK-12 Foundation . CC BY-NC 3.0
6. Laura Guerin, using sponge image by Pixabay:Josch13. CK-12 Foundation (sponge: http://pixabay.com/en/natural-sponge-sponge-sea-sponge-232368/) . CC BY-NC 3.0 (sponge available in the public domain)
7. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
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10. s shepherd. http://commons.wikimedia.org/wiki/File:Earthworm_on_stone.jpg . CC BY 2.0
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13. Charles Keith, NOAA. http://commons.wikimedia.org/wiki/File:Atlantic_Hagfish_(Myxine_glutinosa).jpg . public domain
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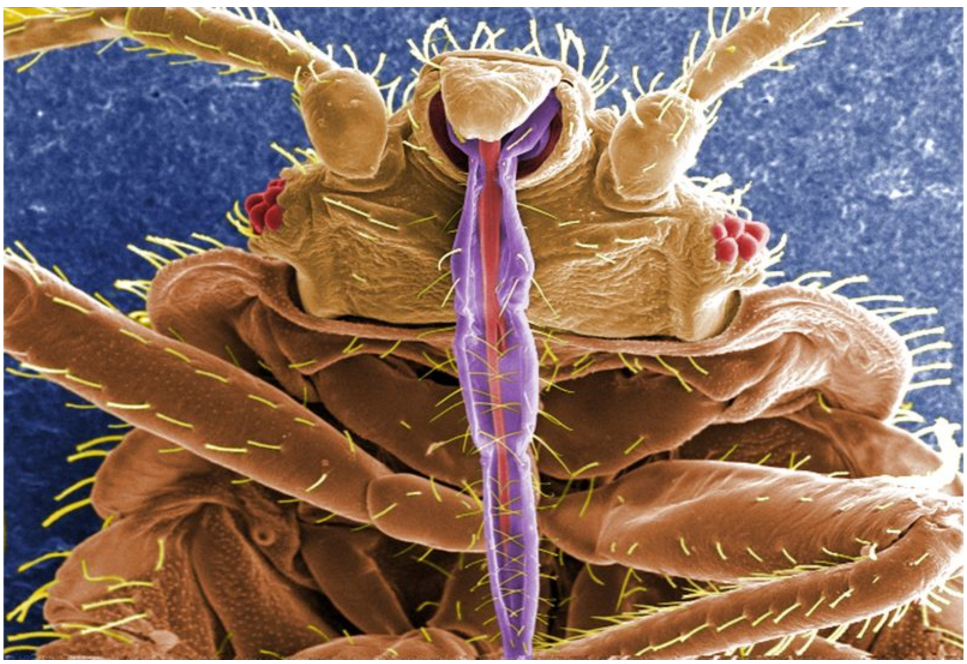
# CHAPTER 12 MS Invertebrates

## Chapter Outline





What could this creature possibly be? Here's a hint. The picture is greatly magnified. The creature is actually only a few millimeters long. Now can you guess what it is?

The organism in the microphoto is an insect commonly called a bedbug. Insects are invertebrates in Phylum Arthropoda. Insects may "just" be invertebrates, but they are surprisingly sophisticated animals. They have a brain, for example, and multiple sensory organs. Some insects even live in complex societies. Insects evolved relatively late in invertebrate evolution, so they are fairly complex as invertebrates go. Many other invertebrates are much simpler. The simplest invertebrates are sponges and cnidarians.

# 12.1 Sponges and Cnidarians

## Lesson Objectives

- Describe the structure and function of sponges.
- Outline cnidarian adaptations, reproduction, and ecology.

## Lesson Vocabulary

- bioluminescence
- cnidarian
- coral
- coral reef
- endoskeleton
- jellyfish
- medusa (medusae, plural)
- polyp
- sponge

## Introduction

What are sponges and cnidarians? You can see an example of a sponge in **Figure** 12.1 and a jellyfish example in **Figure** 12.2. Sponges are also called sea sponges. Cnidarians include jellyfish and corals. Invertebrates in these phyla have existed virtually unchanged for hundreds of millions of years. This shows that they are well adapted for their habitats. They are also very interesting animals, as you will find out when you read this lesson.

## Sponges

Sponges are aquatic invertebrates that make up Phylum Porifera. The word porifera means "pore-bearing." As you can see from the close-up view in **Figure** 12.3, a sponge has a porous body with many small holes in it. There are at least 5000 living species of sponges. Almost all of them inhabit the ocean. Most live on coral reefs or the ocean floor. Adult sponges are unable to move from place to place. They have root-like projections that anchor them to surfaces. They may live in colonies of many sponges. You can visit the incredible world of sponges by watching this short video: https://www.youtube.com/watch?v=BW05vMziy2o .

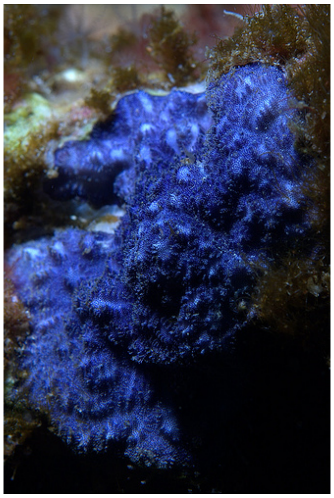


FIGURE 12.1
Sponge

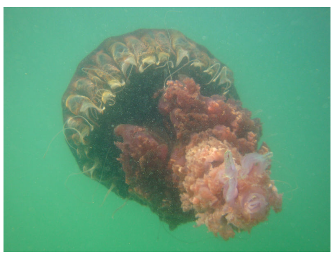


FIGURE 12.2
Jellyfish

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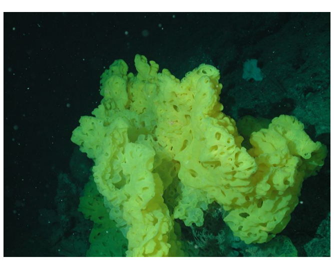

FIGURE 12.3
A sponge has many pores in its body

### Specialized Cells in Sponges

Sponges have several different types of specialized cells, although they lack tissues. You can see the basic sponge body plan and specialized cells in **Figure** 12.4.

- Some of the specialized cells grow short, sharp projections called spicules. Spicules make up the sponge's internal skeleton, or endoskeleton. The endoskeleton helps to support and protect the sponge.
- Other specialized cells are involved in feeding. Sponges are filter feeders. They filter food out of the water as it flows through them. Sponges pump water into their body through specialized pore cells called porocytes.
- The water flows through a large central cavity. As it flows by, specialized cells called collar cells trap and digest food particles in the water.
- Specialized cells called amebocytes carry nutrients from the digested food to the rest of the cells in the sponge.
- As water flows through the sponge, oxygen diffuses from the water to the sponge's cells. The cells also expel wastes into the water. The water then flows out of the sponge through an opening called the osculum.

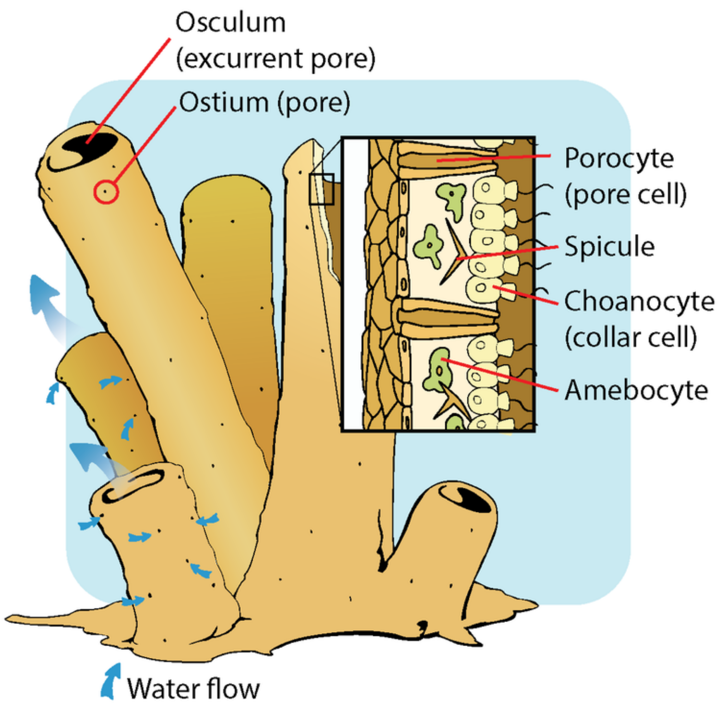


FIGURE 12.4
Body plan and specialized cells of a sponge

## How Sponges Reproduce

Sponges reproduce both asexually and sexually. Asexual reproduction occurs by budding. Sexual reproduction occurs by the production of eggs and sperm. Males release sperm into the water through the osculum. Sperm may enter a female sponge through a pore and fertilize her eggs. The resulting zygotes develop into larvae.

Unlike sponge adults, sponge larvae can swim. They have cilia that propel them through the water. As larvae develop and grow, they become more similar to an adult sponge and lose their ability to swim.

## Sponges and Other Organisms

Many sponges live on coral reefs, like the one in **Figure** 12.5. Reef sponges typically have symbiotic relationships with other reef species. For example, the sponges provide shelter for algae, shrimp, and crabs. In return, they get nutrients from the metabolism of the organisms they shelter.

Sponges are a source of food for many species of fish. Because sponges are anchored to a reef or rock, they can't

FIGURE 12.5
Orange sponges on a coral reef

run away from predators. However, their sharp spicules provide some defense. They also produce toxins that may poison predators that try to eat them.

## Cnidarians

Cnidarians are invertebrates such as jellyfish and corals. They belong to Phylum Cnidaria. All cnidarians are aquatic. Most of them live in the ocean. Cnidarians are a little more complex than sponges. Besides specialized cells, they have tissues and radial symmetry. There are more than 10,000 cnidarian species, see **Figure** 12.6.

### Special Features of Cnidarians

An interesting feature of all cnidarians is one or more stingers called nematocysts. You can see a nematocyst in the sketch of a hydra in **Figure** 12.7. The nematocyst is long and thin and has a poison barb on the end. When not in use, it lies coiled inside a special cell. Nematocysts are used to attack prey or defend against predators. Watch this awesome animation to see a nematocyst in action: http://commons.wikimedia.org/wiki/File:Nematocyst.gif

Another interesting feature of many cnidarians is the ability to produce light. The production of light by living things is called bioluminescence. A more familiar example of bioluminescence is the light produced by fireflies. In cnidarians, bioluminescence may be used to startle predators or to attract prey or mates. Watch this short video to see an amazing light show put on by a jellyfish at the Monterey Aquarium in Monterey, California: https://www.youtube.com/watch?v=kdufLq2P1Ag .

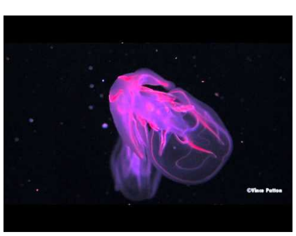

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FIGURE 12.6
Diversity of cnidarians: (clockwise from top left) jellyfish, anemones, hydra and corals.

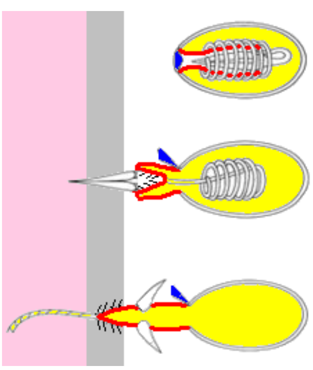

FIGURE 12.7
Cnidarian nematocyst firing

### Medusa and Polyp

Cnidarians have two basic body forms, called medusa and polyp:

- The medusa (medusae, plural) is a bell-shaped form. It is typically able to move.
- The polyp is a tubular form. It is usually attached to a surface and unable to move.

As you can see in **Figure** 12.8, both body plans have radial symmetry. Some cnidarian species alternate between medusa and polyp forms. Other species exist in just one form or the other.

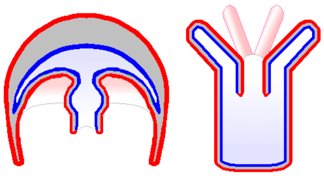

FIGURE 12.8
Medusa (left) and polyp (right) forms of a cnidarian

## Digestive and Nervous Systems

Cnidarians have an incomplete digestive system with a single opening. The opening is surrounded by tentacles, which are covered with nematocyst cells and used to capture prey. Digestion takes place in the digestive cavity. Nutrients are absorbed and gases are exchanged through the cells lining this cavity. Fluid in the cavity supports and stiffens the cnidarian body.

Cnidarians have a simple nervous system. It consists of a net of nerves that can sense touch. You can see a sketch of the nerve net in a hydra in **Figure** 12.9. Some cnidarians also have other sensory structures. For example, jellyfish have light-sensing structures and gravity-sensing structures.

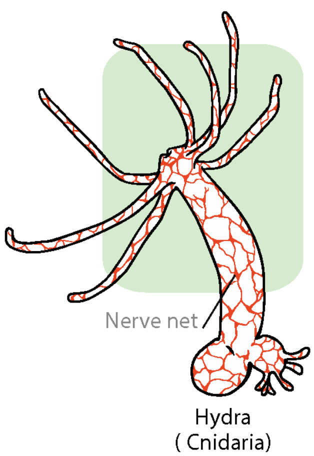


FIGURE 12.9
Nerve net in a hydra

## How Cnidarians Reproduce

Cnidarians in the polyp form usually reproduce asexually. One type of asexual reproduction in polyps leads to the formation of new medusae. Medusae usually reproduce sexually with sperm and eggs. Fertilization forms a zygote. The zygote develops into a larva, and the larva develops into a polyp. There are many variations on this general life cycle. Obviously, species that exist only as polyps or medusae have a life cycle without the other form.

## Cnidarian Ecology

Cnidarians can be found in almost all ocean habitats. A few species live in fresh water.

- Jellyfish spend most of their lives as medusae. They live virtually everywhere in the ocean. They prey on zooplankton, other invertebrates, and the eggs and larvae of fish.

- Corals form large colonies in shallow tropical water. They are confined to shallow water because they have a symbiotic relationship with algae that live inside of them. The algae need sunlight for photosynthesis, so they must stay relatively close to the surface of the water to get enough light. Corals exist only as polyps. They catch plankton with their tentacles.
- Many corals form a hard, mineral exoskeleton. Over time, this builds up to become a coral reef. A coral reef is pictured in **Figure** 12.10. Coral reefs provide food and shelter to many other ocean organisms. Watch this beautiful National Geographic video to learn more about corals, coral reefs, and coral reef life: http://video.nationalgeographic.com/video/coral-reefs


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FIGURE 12.10

Coral reef in the Red Sea

## Lesson Summary

- Sponges are aquatic invertebrates in Phylum Porifera. Sponges have specialized cells and an endoskeleton, but they lack tissues and body symmetry. Many live on coral reefs and have symbiotic relationships with other reef species.
- Cnidarians are aquatic invertebrates in Phylum Cnidaria. They include jellyfish and corals, both of which have radial symmetry. All cnidarians have nematocysts, and many are bioluminescent. They may exist in medusa and/or polyp form. Corals build hard exoskeletons that grow to become coral reefs.

## Lesson Review Questions

### Recall

1. Describe the ability of sponges and cnidarians to move.
2. Identify specialized cells in sponges, and state their functions.
3. What is a nematocyst? What is its role?

### Apply Concepts

4. Besides cnidarians, many other ocean organisms are bioluminescent. What is bioluminescence? Why do you think it is relatively common in ocean organisms such as cnidarians?

### Think Critically

5. Compare and contrast the medusa and polyp forms of cnidarians, including how they reproduce.
6. Explain why coral reefs are found only in shallow water.

## Points to Consider

Cnidarians such as jellyfish have radial symmetry. Flatworms and roundworms, which you will read about next, have bilateral symmetry.

1. What did flatworms and roundworms need to evolve first in order to develop bilateral symmetry?
2. Why is bilateral symmetry adaptive?

# 12.2 Flatworms and Roundworms

## Lesson Objectives

- Describe flatworm adaptations, reproduction, and ecology.
- Outline roundworm traits, and explain how roundworms reproduce and "make a living."

## Lesson Vocabulary

- flatworm
- roundworm

## Introduction

That's not a tape measure in **Figure** 12.11. It's a tapeworm! A tapeworm may grow to more than 20 meters in length—all while living inside a human intestine! A tapeworm is a type of flatworm. Many flatworms are parasites, as you'll learn in this lesson.

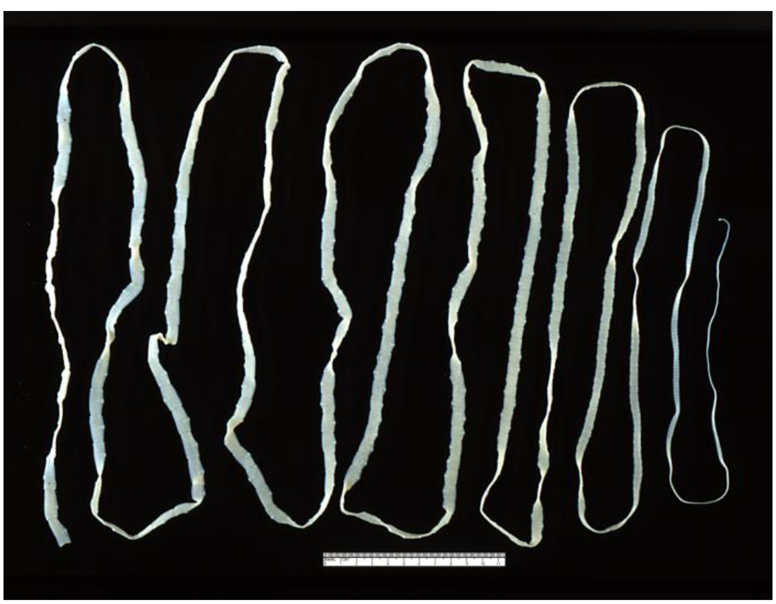

FIGURE 12.11
Tapeworm

## Flatworms

Flatworms are invertebrates that belong to Phylum Platyhelminthes. There are more than 25,000 species in the flatworm phylum. Not all flatworms are as long as tapeworms. Some are only about a millimeter in length.

### Flatworm Adaptations

Flatworms have a flat body because they lack a fluid-filled body cavity. They also have an incomplete digestive system with a single opening. However, flatworms represent several evolutionary advances in invertebrates. They have the following adaptations:

- Flatworms have three embryonic cell layers. They have a mesoderm layer in addition to ectoderm and endoderm layers. The mesoderm layer allows flatworms to develop muscle tissues so they can move easily over solid surfaces.
- Flatworms have a concentration of nerve tissue in the head end. This was a major step in the evolution of a brain. It was also needed for bilateral symmetry.
- Flatworms have bilateral symmetry. This gives them a better sense of direction than radial symmetry would.

Watch this amazing flatworm video to learn about some of the other "firsts" these simple animals achieved, including being the first hunters: http://shapeoflife.org/video/flatworms-first-hunter

Multimedia

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### How Flatworms Reproduce

Flatworms reproduce sexually. In most species, the same individuals produce both eggs and sperm. After fertilization occurs, the fertilized eggs pass out of the adult's body and hatch into larvae. There may be several different larval stages. The final larval stage develops into the adult form. Then the life cycle repeats.

### Ecology of Flatworms

Some flatworms live in water or moist soil. They eat invertebrates and decaying animals. Other flatworms, such as tapeworms, are parasites that live inside vertebrate hosts. Usually, more than one type of host is needed to complete the parasite's life cycle, as shown in **Figure** 12.12.

## Roundworms

Roundworms are invertebrates in Phylum Nematoda. This is a very diverse phylum. It has more than 80,000 known species. Roundworms range in length from less than 1 millimeter to over 7 meters in length. You can see an example of a roundworm in **Figure** 12.13.

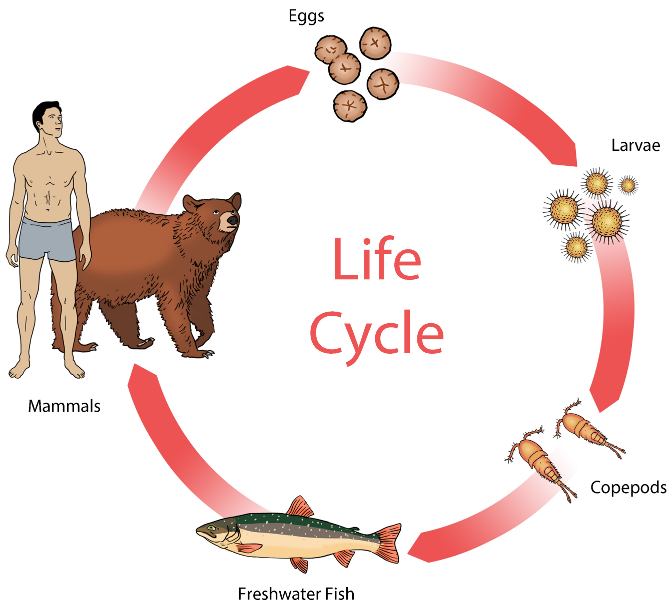


FIGURE 12.12
Tapeworm life cycle.

FIGURE 12.13
This roundworm named ascaris is the largest and most common parasitic worm in humans.

## Roundworm Adaptations

Roundworms have a round body because they have a partial fluid-filled body cavity (pseudocoelom). This is one way that roundworms differ from flatworms. Another way is their complete digestive system. It allows them to eat, digest food, and eliminate wastes all at the same time.

Roundworms have a tough covering of cuticle on the surface of their body. It prevents their body from expanding. This allows the buildup of fluid pressure in their partial body cavity. The fluid pressure adds stiffness to the body. This provides a counterforce for the contraction of muscles, allowing roundworms to move easily over surfaces.

## Roundworm Reproduction

Roundworms reproduce sexually. Sperm and eggs are produced by separate male and female adults. Fertilization takes place inside the female organism. Females lay huge numbers of eggs, sometimes as many as 100,000 per day! The eggs hatch into larvae, which develop into adults. Then the life cycle repeats.

### How Roundworms "Make a Living"

Roundworms may be free-living or parasitic organisms. Free-living worms are found mainly in freshwater habitats. Some live in moist soil. They generally feed on bacteria, fungi, protozoa, or decaying organic matter. By breaking down organic matter, they play an important role in the carbon cycle.

Parasitic roundworms may have plant, invertebrate, or vertebrate hosts. Several roundworm species infect humans. Besides ascaris, they include hookworms. Hookworms are named for the hooks they use to grab onto the host's intestines. You can see the hooks in **Figure** 12.14. Hookworm larvae enter the host through the skin. They migrate to the intestine, where they mature into adults. Female adults lay large quantities of eggs. Eggs pass out of the host in feces. Eggs hatch into larvae in the feces or soil. Then the cycle repeats. You can learn more about parasitic roundworms in humans by watching this short video: https://www.youtube.com/watch?v=Dl2WUH2m69I .

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URL: http://www.ck12.org/flx/render/embeddedobject/57252

FIGURE 12.14

Hooks on the mouth end of a hookworm

## Lesson Summary

- Flatworms are invertebrates in Phylum Platyhelminthes. Flatworm adaptations include mesoderm, muscle tissues, a head region, and bilateral symmetry. Flatworms are free-living heterotrophs or parasites.
- Roundworms are invertebrates in Phylum Nematoda. Roundworms have a pseudocoelom and complete digestive system. They are free-living heterotrophs or parasites.

## Lesson Review Questions

### Recall

1. Describe reproduction in flatworms.
2. Outline the life cycle of a parasitic tapeworm.
3. Identify the phylum of roundworms.

### Apply Concepts

4. Explain why going barefoot outside might increase the risk of hookworm infection in people.

### Think Critically

5. Explain why flatworms are flat and roundworms are round.
6. Explain the role of roundworms in the carbon cycle.

## Points to Consider

In the next lesson, you'll read about worms called annelids. Mollusks such as snails are also described in the next lesson.

1. How do you think annelids might be different from flatworms and roundworms?
2. Why do you think annelids are placed in a lesson with mollusks instead of with flatworms and roundworms?

# 12.3 Mollusks and Annelids

## Lesson Objectives

- Outline the traits, reproduction, and ecology of mollusks.
- Describe annelid segmentation, organ systems, reproduction, and feeding strategies.

## Lesson Vocabulary

- annelid
- mollusk

## Introduction

Mollusks are invertebrates such as the common snail. Most mollusks have shells. Annelids are worms such as the familiar earthworm. They have segmented bodies. Annelids look like roundworms on the outside, but on the inside they are more like mollusks.

## Mollusks

Have you ever been to the ocean or eaten seafood? If you have, then you've probably encountered members of Phylum Mollusca. In addition to snails, mollusks include squids, slugs, scallops, and clams. You can see a clam in **Figure** 12.15. There are more than 100,000 known species of mollusks. Some mollusks are nearly microscopic. The largest mollusk, the colossal squid, may be as long as a school bus and weigh over half a ton! Watch this short video to see an amazing diversity of mollusks: http://www.youtube.com/watch?v=VnWXgAGUHJQ .

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URL: http://www.ck12.org/flx/render/embeddedobject/140768

### Traits of Mollusks

Mollusks have a true coelom and complete digestive system. They also have circulatory and excretory systems. They have a heart that pumps blood, and organs that filter out wastes from the blood.

FIGURE 12.15
Example of a mollusk: clam

You can see some other traits of mollusks in the garden snail in **Figure** 12.16.

- Like the snail, many other mollusks have a hard outer shell. It is secreted by special tissue called mantle on the outer surface of the body. The shell covers the top of the body and encloses the internal organs.
- Most mollusks have a distinct head region. The head may have tentacles for sensing the environment and grasping food.
- Mollusks generally have a muscular foot, which may be used for walking or other purposes.

FIGURE 12.16
Garden snail

A unique feature of mollusks is the radula. This is a feeding organ with teeth made of chitin. It is located in front of the mouth in the head region. It can be used to scrape algae off rocks or drill holes in the shells of prey. You can see the radula of the sea slug in **Figure** 12.17.

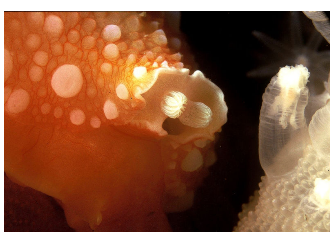

FIGURE 12.17
Radula of a sea slug

## Mollusk Reproduction

Mollusks reproduce sexually. Most species have separate male and female sexes. Fertilization may be internal or external, depending on the species. Fertilized eggs develop into larvae. There may be one or more larval stages. Each one is different from the adult stage.

### Mollusk Ecology

Mollusks live in most terrestrial, freshwater, and marine habitats. However, the majority of species live in the ocean. They can be found in both shallow and deep water and from tropical to polar latitudes. They have a variety of ways of getting food. Some are free-living heterotrophs. Others are internal parasites. Mollusks are also eaten by many other organisms, including humans.

## Annelids

Annelids are segmented worms in Phylum Annelida. There are about 15,000 species of annelids. They range in length from less than a millimeter to more than 3 meters. To learn more about the amazing diversity and adaptations of annelids, watch this excellent video: http://shapeoflife.org/video/annelids-powerful-and-capable-worms


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URL: http://www.ck12.org/flx/render/embeddedobject/137112

### Annelid Segments

Annelids are divided into many repeating segments. The earthworm in **Figure** 12.18 is an annelid. You can clearly see its many segments. Segmentation of annelids is highly adaptive. Each segment has its own nerve and muscle tissues. This allows the animal to move very efficiently. Some segments can also be specialized to carry out particular functions. They may have special structures on them. For example, they might have tentacles for sensing or feeding, "paddles" for swimming, or suckers for clinging to surfaces.

FIGURE 12.18

Segmented earthworm

### Annelid Organ Systems

Annelids have a large coelom. They also have several organ systems. These include a:

- circulatory system;
- excretory system;
- complete digestive system; and

- nervous system, with a brain and sensory organs.

### Annelid Reproduction

Most annelids can reproduce both asexually and sexually. Asexual reproduction may occur by budding or fission. Sexual reproduction varies by species. Some species go through a larval stage before developing into adults. Other species grow to adult size without going through a larval stage.

### How Annelids Feed

Annelids live in a diversity of freshwater, salt-water, and terrestrial habitats. They vary in what they eat and how they get their food.

- Some annelids, such as earthworms, eat soil and extract organic material from it.
- Annelids called leeches are either predators or parasites. Some leeches capture and eat other invertebrates. Others feed off the blood of vertebrate hosts.
- Annelids called polychaete worms live on the ocean floor. They may be filter feeders, predators, or scavengers. The amazing feather duster worm in **Figure** 12.19 is a polychaete that has a fan-like crown of tentacles for filter feeding.

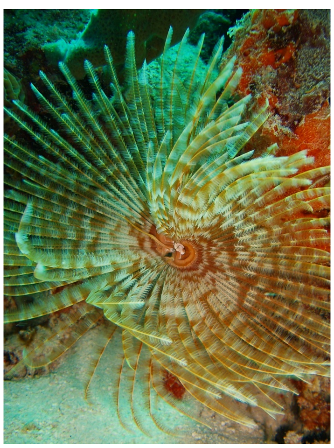

FIGURE 12.19
Polychaete worm: feather duster

## Lesson Summary

- Mollusks are mainly aquatic invertebrates in Phylum Mollusca. They include snails, squids, and clams. Mollusks have a coelom and several organ systems. Most also have a shell, head, foot, and radula, which is a feeding organ. Mollusks are either free-living heterotrophs or parasites.
- Annelids are segmented invertebrates in Phylum Annelida. They include earthworms, polychaete worms, and leeches. Annelids have a coelom and several organ systems. Their body segments may have a variety of different structures such as tentacles or suckers. Annelids may be predators, parasites, filter feeders, or decomposers.

## Lesson Review Questions

### Recall

1. Give examples of mollusks.
2. What are some mollusk traits?
3. Describe how annelids feed.

### Apply Concepts

4. Earthworms are often added to compost bins. Explain why.

### Think Critically

5. Compare and contrast mollusks and annelids.
6. Explain why annelid segmentation is adaptive.

## Points to Consider

The majority of mollusks and annelids live in the water or inside hosts. Arthropods are invertebrates that include insects. The majority of arthropods live on land.

1. What special challenges might arthropods face on land?
2. What adaptations might they have evolved to meet these challenges?

# 12.4 Insects and Other Arthropods

## Lesson Objectives

- Describe arthropod characteristics and life cycles.
- Identify special traits of insects, and explain why they have been so successful.

## Lesson Vocabulary

- arthropod
- cocoon
- incomplete metamorphosis
- insect
- metamorphosis
- molting
- pupa

## Introduction

The animal pictured in **Figure** 12.20 is an insect called a weevil. Insects belong to the phylum of invertebrates called Phylum Arthropoda. This phylum is not only the largest phylum of invertebrates. It's the largest phylum in the entire Animal Kingdom. Obviously, animals in this phylum have been very successful.

## What Are Arthropods?

Arthropods are invertebrates in Phylum Arthropoda. There are more than a million known species of arthropods. However, scientists estimate that only about a tenth of all arthropod species have been identified. In addition to insects, arthropods include animals such as spiders, centipedes, and lobsters. You can see why arthropods were successful both in the water and on land, by watching these excellent videos:

http://shapeoflife.org/video/marine-arthropods-successful-design


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FIGURE 12.20
Weevil: an insect in Phylum Arthropoda

http://shapeoflife.org/video/terrestrial-arthropods-conquerors


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There are several traits shared by all arthropods. Arthropods have a complete digestive system. They also have a circulatory system and a nervous system. In addition, they have special organs for breathing and excreting wastes. Other traits of arthropods include:

- segmented body;
- hard exoskeleton; and
- jointed appendages.

### Body Segments of Arthropods

Most arthropods have three body segments. The segments are the head, thorax, and abdomen. You can see the three segments in a range of arthropods in **Figure** 12.21. In some arthropods, the head and thorax are joined together.

### Arthropod Exoskeleton

The exoskeleton (or external skeleton) of an arthropod consists of several layers of cuticle. The exoskeleton prevents water loss. It also protects and supports the body. In addition, it acts as a counterforce for the contraction of muscles.

The exoskeleton doesn't grow larger as the animal grows. Eventually, it must be shed and replaced with a new one. This happens periodically throughout an arthropod's life. The shedding of the exoskeleton is called molting. You can see a time-lapse video of an insect molting at this link: http://commons.wikimedia.org/wiki/File:Cicada_molting_animated-2.gif?fastcci_from=9630

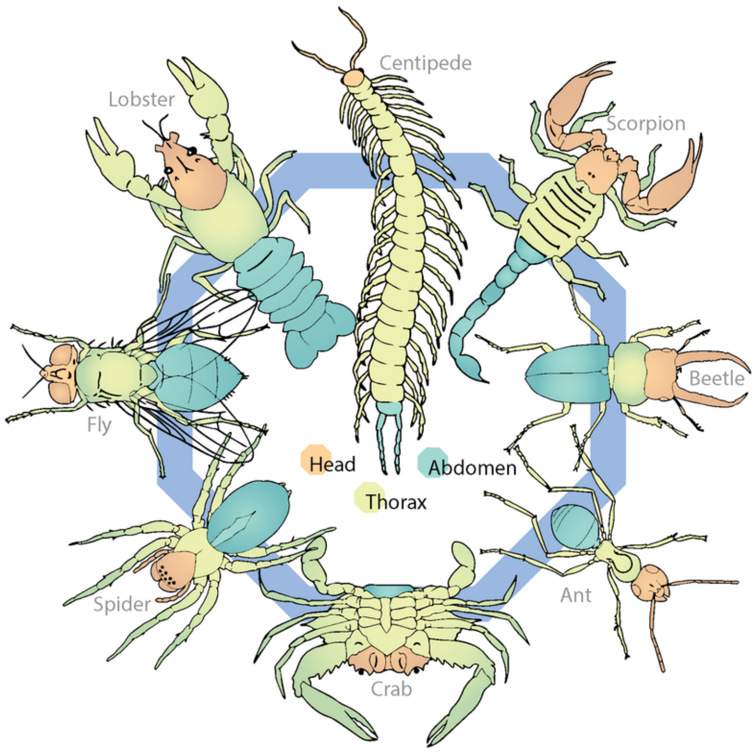


FIGURE 12.21
Arthropods have three body segments.

## Arthropod Appendages

Because arthropod appendages are jointed, they can bend. This makes them flexible. Jointed appendages on the body are usually used as legs for walking or jumping. Jointed appendages on the head may be modified for other purposes. Head appendages often include upper and lower jaws. Jaws are used for eating and may also be used for defense. Sensory organs such as eyes and antennae are also found on the head. You can see some of these head appendages on the bee in **Figure** 12.22.

## Arthropod Life Cycles

Arthropods reproduce sexually. Male and female adults produce gametes. If fertilization occurs, eggs hatch into offspring.

After hatching, most arthropods go through one or more larval stages before reaching adulthood. The larvae may look very different from the adults. They change into the adult form in a process called metamorphosis. During metamorphosis, the arthropod is called a pupa. It may or may not spend this stage inside a special container called a cocoon. A familiar example of arthropod metamorphosis is the transformation of a caterpillar (larva) into a butterfly (adult) (see **Figure** 12.23). Distinctive life stages and metamorphosis are highly adaptive. They allow functions to be divided among different life stages. Each life stage can evolve adaptations to suit it for its specific functions without affecting the adaptations of the other stages.

In some arthropods, newly hatched offspring look like small adults. These arthropods don't go through larval stages. They just grow larger until they reach adult size. This type of life cycle is called incomplete metamorphosis. You can see incomplete metamorphosis in a grasshopper in **Figure** 12.24.

FIGURE 12.22
Bee head appendages include jaws, eyes, and antennae.

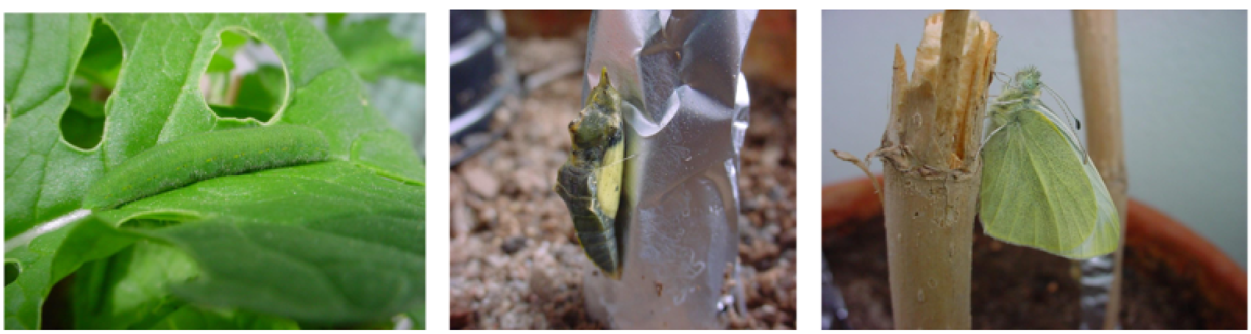

FIGURE 12.23
Metamorphosis of a caterpillar into a butterfly

## Insects

The majority of arthropods are insects (Class Insecta). In fact, more than half of all known organisms are insects. There may be more than 10 million insect species in the world, although most of them have not yet been identified. In terms of their numbers and diversity, insects clearly are the dominant animals in the world.

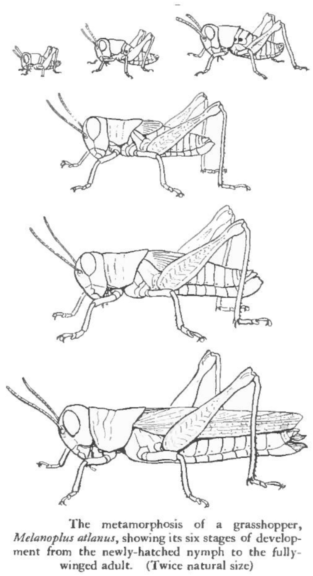


FIGURE 12.24
Incomplete metamorphosis in a grasshopper

## Insect Traits

Like other arthropods, insects have three body segments and many jointed appendages. The abdomen contains most of the internal organs. Six legs are attached to the thorax. There are several appendages on the insect's head:

- The head has a pair of antennae. Insects use their antennae to smell and taste chemicals. Some insects can also use their antennae to hear sounds.
- The head generally has several simple eyes and a pair of compound eyes. Simple eyes have a single lens, like the human eye. Compound eyes have many lenses.
- For feeding, the insect head contains one pair of lower jaws and two pairs of upper jaws. Insects have also evolved a wide range of specialized mouthparts for eating certain foods. You can see some examples in **Figure** 12.25.

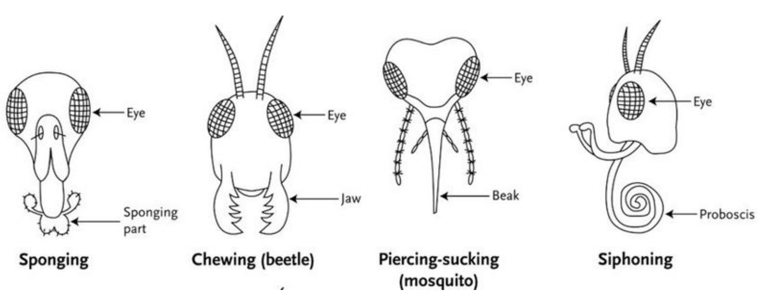


FIGURE 12.25
Specialized mouthparts for eating in insects

### Insect Flight

The main reason that insects have been so successful is their ability to fly. Insects are the only invertebrates that can fly. They were also the first animals to evolve flight. The ability to fly is highly adaptive. It's a guaranteed means of escape from nonflying predators. It's also useful for finding food and mates.

Insects that fly have wings, like the dragonfly in **Figure** 12.26. Insects generally have two pairs of wings. They are attached to the thorax. The wings form from the exoskeleton. You can learn how insects fly—and how scientists study insect flight—by watching this short video: http://www.nytimes.com/video/science/100000002475937/the-flight-of-the-fly.html


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FIGURE 12.26

Dragonfly wings

### Insects and People

Most humans interact with insects every day. Many of these interactions are harmless and often go unnoticed. However, insects can also cause humans a lot of harm. Some insects are vectors for human diseases. The mosquito in **Figure** 12.27 is a vector for malaria. Malaria kills millions of people each year. Many other insects feed on food crops. Growers may need to apply chemical pesticides to control them. On the other hand, without insects to pollinate them, many flowering plants, including important food crops, could not reproduce.

## Lesson Summary

- Arthropods are invertebrates in the Phylum Arthropoda. They include insects, spiders, centipedes, and lobsters. Traits of arthropods include three body segments, a hard exoskeleton, and jointed appendages. The arthropod life cycle may include larva and pupa stages and the process of metamorphosis.
- The majority of arthropods are insects. All insects have six legs and multiple head appendages and sensory organs. The main reason for the success of insects is the ability of many insects to fly. Insects both help and harm human beings.

FIGURE 12.27
Anopheles mosquitos like this one are vectors for malaria.

## Lesson Review Questions

### Recall

1. List five traits of arthropods.
2. Describe the arthropod exoskeleton and its functions.
3. Identify types of appendages you might see on an insect.

### Apply Concepts

4. It might be said of insects that we can't live with them or without them. Do you agree or disagree? Apply lesson concepts to explain why.

### Think Critically

5. Why are distinctive life stages and metamorphosis adaptive?
6. Explain the significance of flight in insects.

## Points to Consider

One species in a mystery phylum is called a starfish, but it's not a fish. Another species in the same phylum is called a sea cucumber, but it's not a plant.

1. Which phylum includes both starfish and sea cucumbers?
2. What are some traits of organisms in this phylum?

# 12.5 Echinoderms and Invertebrate Chordates

## Lesson Objectives

- Describe echinoderms, their traits, and their reproduction.
- Define chordates and list chordate traits.
- Identify invertebrate chordates and their traits.

## Lesson Vocabulary

- echinoderm
- lancelet
- tunicate

## Introduction

What do the sea creatures in **Figure** 12.28 have in common? Both of them are invertebrates known as echinoderms.

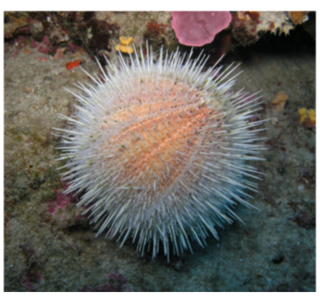

FIGURE 12.28
Echinoderms are some of the most distinctive organisms in the Animal Kingdom: sea urchin (left) and sea cucumber (right).

## Echinoderms

Echinoderms are invertebrates in Phylum Echinodermata. All of them are ocean dwellers. They can be found in marine habitats from the equator to the poles. They live at all depths of water. There are about 6000 living species of echinoderms. Besides sea urchins and sea cucumbers, they include sea stars (starfish), feather stars, and sand dollars. Learn more about the amazing world of echinoderms and why they are called the "ultimate animal" by watching this video: http://shapeoflife.org/video/echinoderms-ultimate-animal

Multimedia

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### Spiny Skin and Tube Feet

The term echinoderm means "spiny skin." An echinoderm's spines aren't actually made of skin. They are part of the animal's endoskeleton and just covered with a thin layer of skin. Most adult echinoderms have radial symmetry. This is clear from the sea star pictured in **Figure** 12.29. However, echinoderms evolved from an ancestor with bilateral symmetry. You can tell because echinoderm larvae have bilateral symmetry and only develop radial symmetry as adults.

FIGURE 12.29

Adult sea stars—like other adult echinoderms—have spiny skin, radial symmetry, and tube feet. This photo shows the underside of a sea star.

Another unique trait of echinoderms is a network of internal canals. Most of the canals have projections called tube feet. The end of each tube foot has a sucker. The suckers can stick to surfaces and help the animal crawl. The suckers can also be used to pry open the shells of prey. You can see suckers on the sea star in **Figure** 12.29.

Although echinoderms have a well-developed coelom and complete digestive system, they lack a centralized nervous system and do not have a heart. Some echinoderms have simple eyes that can sense light. Like annelids, echinoderms can regrow a missing body part. In fact, a complete starfish can regrow from a single "arm."

### How Echinoderms Reproduce

Some echinoderms can reproduce asexually by fission. However, most echinoderms reproduce sexually. They generally have separate sexes that produce sperm and eggs. Fertilization typically occurs outside the body in the water. Eggs hatch into larvae that have bilateral symmetry and can swim. The larvae undergo metamorphosis to change into the adult form. During metamorphosis, their bilateral symmetry changes to radial symmetry.

### What Are Chordates?

Chordates are animals in Phylum Chordata. They are animals that have a notochord and certain other traits. The notochord is a rigid rod that runs down the back of the body. Phylum Chordata is a large and diverse phylum. It includes at least 60,000 species, including the human species. For a visual introduction to chordates, watch this video: http://video.about.com/animals/What-Is-Phylum-Chordata-.htm

### General Characteristics of Chordates

Chordates have three embryonic cell layers: endoderm, mesoderm, and ectoderm. They also have a segmented body with a complete coelom and bilateral symmetry. In addition, chordates have a complete digestive system, central nervous system, and circulatory system.

### Defining Phylum Chordata

There are four traits that are unique to chordates and define Phylum Chordata. The four traits are a post-anal tail, dorsal hollow nerve cord, notochord, and pharyngeal slits. You can see the four traits in **Figure** 12.30.

1. The post-anal tail is at the end of the organism opposite the head. It extends beyond the anus.
2. The hollow nerve cord runs along the top (dorsal) side of the animal. (In nonchordate animals, the nerve cord is solid and runs along the bottom side.)
3. The notochord lies between the dorsal nerve cord and the digestive tract. It provides stiffness to counterbalance the pull of muscles.
4. The pharyngeal slits are located in the pharynx. The pharynx is the tube that joins the mouth to the digestive and respiratory tracts.

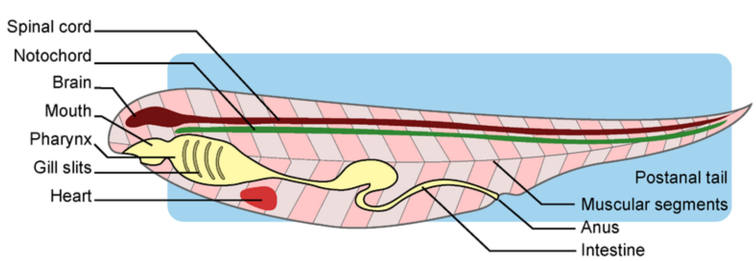


FIGURE 12.30
Typical chordate body plan

In some chordates, all four of these defining traits last throughout life and have important functions. For example, in some chordates, pharyngeal slits are used to filter food out of water. In many chordates, however, including humans, all four traits are present only in the embryo. After that, some of the traits disappear or develop into other structures. For example, in humans, pharyngeal slits are present in the embryo but later develop into parts of the ear.

## Invertebrate Chordates

Living chordates are mainly vertebrates. In vertebrates, the notochord develops into a backbone, or vertebral column, after the embryonic stage. A small percentage of chordates are invertebrates. Their notochord never develops into a backbone. Invertebrate chordates include tunicates and lancelets. Both groups of animals are small and relatively primitive. They are probably similar to the earliest chordates that evolved more than 500 million years ago.

### Tunicates

Tunicates are invertebrate chordates that lose some of the four defining chordate traits by adulthood. Tunicates are also called sea squirts. There are about 3000 living species of tunicates. All are ocean dwellers and live in shallow water. You can see examples of tunicates in **Figure** 12.31.

FIGURE 12.31
A colony of orange tunicates

As larvae, tunicates can swim freely to find food. As adults, tunicates lack a post-anal tail and notochord, and they can no longer swim. Instead, they remain in one place and are filter feeders. Tunicates can reproduce both sexually and asexually. The same adults produce sperm and eggs. However, fertilization always involves gametes from different parents. Asexual reproduction is by budding.

### Lancelets

Lancelets are invertebrate chordates that retain all four defining chordate traits as adults. There are only about 25 species of living lancelets. Lancelets resemble tunicates in several ways. For example:

- lancelets live in shallow ocean water;
- lancelet larvae can swim to find food; and
- lancelet adults are filter feeders that can no longer swim.

Adult lancelets spend most of their time buried in sand on the ocean floor. Lancelets reproduce sexually, with separate sexes producing sperm and eggs.

## Lesson Summary

- Echinoderms are ocean-dwelling invertebrates in Phylum Echinodermata. They include such animals as sea stars and sand dollars. They have a spiny endoskeleton, radial symmetry (as adults), and tube feet with suckers. They reproduce asexually or sexually.
- Chordates are animals in Phylum Chordata. Their defining traits are a notochord, post-anal tail, hollow dorsal nerve cord, and pharyngeal slits. Some of these traits may disappear after the embryonic stage. Chordates include all of the vertebrates, in which the notochord develops into a backbone, as well as some invertebrates.
- Invertebrate chordates include tunicates and lancelets. These animals are small and primitive and live in shallow ocean water. Lancelets retain all four defining chordate traits throughout life. Tunicates lose some of these traits by adulthood. Both tunicate and lancelet larvae are free swimming, whereas the adults are filter feeders that cannot swim.

## Lesson Review Questions

### Recall

1. What are echinoderms?
2. List the four defining traits of chordates.
3. How do echinoderms use their tube feet?

### Apply Concepts

4. Sea tulips and sea daisies are both invertebrates that live on the ocean floor. Sea tulips live along coasts at a maximum depth of about 80 meters. Sea daisies live in the deepest ocean. One of these two invertebrates is a tunicate and the other is an echinoderm. Which animal should be classified in each taxon? Explain your answer.

### Think Critically

1. Echinoderm adults have radial symmetry. What evidence shows that they evolved from an ancestor with bilateral symmetry?
2. Explain what distinguishes vertebrate chordates from invertebrate chordates.
3. Compare and contrast tunicates and lancelets.

## Points to Consider

Other than tunicates and lancelets, all chordates are vertebrates.

1. What are some examples of modern vertebrates?
2. Besides having a backbone, how do you think vertebrates might differ from invertebrates?

# 12.6 References


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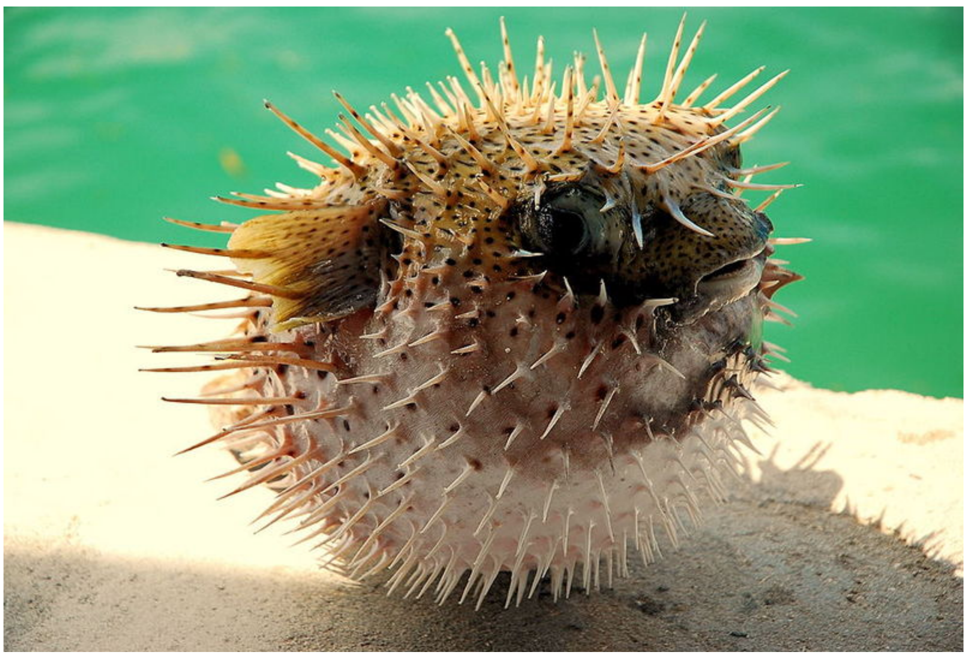
# Chapter 13 MS Fishes, Amphibians, and Reptiles

## Chapter Outline





This odd-looking creature is a fish called a puffer fish. Like all fish, puffer fish are vertebrates. The puffer fish puffs up by rapidly filling its stretchy stomach with water. The reason? Getting bigger makes the fish seem larger to potential predators. Just to be on the safe side, the puffer fish also produces venom. In fact, it's the second-most-poisonous vertebrate in the world after the poison dart frog. In this chapter, you'll learn more about vertebrates such as these. You'll find out that vertebrates are a diverse and fascinating group of animals.

# 13.1 Introduction to Vertebrates

## Lesson Objectives

- Describe traits of vertebrates.
- Identify three reproductive strategies of vertebrates.
- Explain how vertebrates are classified.
- Outline the evolution of vertebrates.

## Lesson Vocabulary

- bone
- cartilage
- ectothermy
- endothermy
- ovipary
- ovovivipary
- vertebra (vertebrae, plural)
- vivipary

## Introduction

Vertebrates are animals in Phylum Chordata. Modern vertebrates include fish, amphibians, reptiles, birds, and mammals. You can see examples of all these groups of vertebrates in **Figure** 13.1.

## What Are Vertebrates?

Like all chordates, vertebrates are animals with four defining traits, at least during the embryonic stage. The four traits are:

- a notochord;
- a dorsal hollow nerve cord;
- a post-anal tail; and
- pharyngeal slits.

Some invertebrates also have these traits and are classified as chordates. What traits do vertebrates have that set them apart from invertebrate chordates?

FIGURE 13.1
Examples of Vertebrates: (left to right) Fish, Amphibian, Reptile, Bird, and Mammal.

### Vertebral Column

The main trait that sets vertebrates apart from invertebrate chordates is their vertebral column, or backbone. It develops from the notochord after the embryonic stage. As you can see in **Figure** 13.2 the vertebral column runs from head to tail along the dorsal (top) side of the body. The vertebral column is made up of repeating units of bone called vertebrae (vertebra, singular). The vertebral column helps the vertebrate body hold its shape. It also protects the spinal (nerve) cord that runs through it.

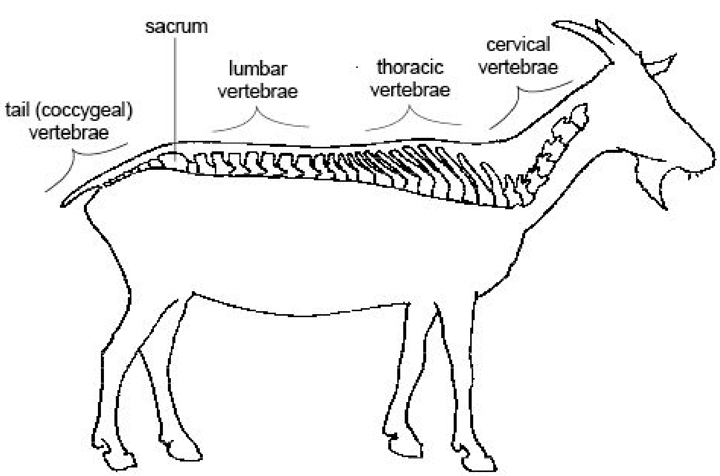



FIGURE 13.2
This sketch of the vertebral column of a goat shows the groups of vertebrae into which the vertebral column is commonly divided.

## Vertebrate Endoskeleton

The vertebral column is the core of the vertebrate endoskeleton, or internal skeleton. You can see a human skeleton as an example of the vertebrate endoskeleton in **Figure** 13.3. In addition to the vertebral column, the vertebrate endoskeleton includes:

- a cranium, or bony skull, that encloses and protects the brain;
- two pairs of limbs (in humans, arms and legs);
- limb girdles that connect the limbs to the rest of the endoskeleton (in humans, shoulders and hips).

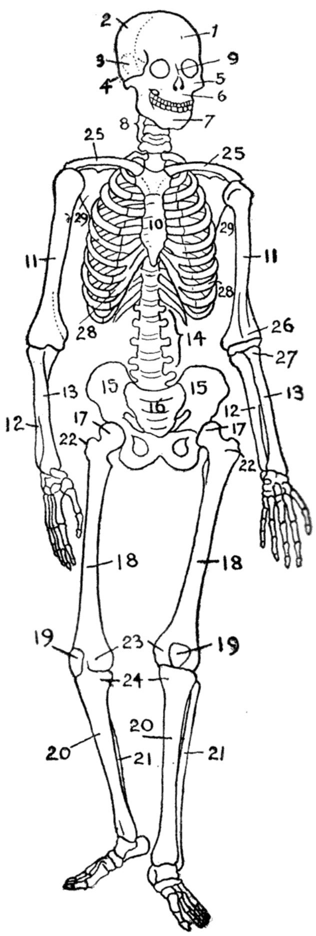



FIGURE 13.3
Human endoskeleton

## Bone and Cartilage

The vertebrate endoskeleton is made of bone and cartilage. Cartilage is a tough, flexible tissue that contains a protein called collagen. Bone is a hard tissue consisting of a collagen framework that is filled in with minerals such as calcium. Bone is less flexible than cartilage but stronger. A bony endoskeleton allows an animal to grow larger and heavier than a cartilage endoskeleton would. Bone also provides more protection for soft tissues and internal organs.

### Other Traits of Vertebrates

Most vertebrates share several other traits. The majority of vertebrates have:

- scales, feathers, fur, or hair covering their skin;
- muscles attached to the endoskeleton to allow movement;
- a circulatory system with a heart that pumps blood through a closed network of blood vessels;
- an excretory system that includes a pair of kidneys for filtering wastes out of the blood;
- a central nervous system with a brain, spinal cord, and nerve fibers throughout the body;
- an adaptive immune system that learns to recognize specific pathogens and launch tailor-made attacks against them; and
- an endocrine system with glands that secrete chemical messenger molecules called hormones.

## How Vertebrates Reproduce

Vertebrates reproduce sexually. Most have separate male and female sexes. Vertebrates have one of three reproductive strategies: ovipary, ovovivipary, or vivipary.

- Ovipary refers to the development of an embryo within an egg outside the mother's body. This occurs in most fish, amphibians, and reptiles. It also occurs in all birds.
- Ovovivipary refers to the development of an embryo inside an egg within the mother's body. The egg remains inside the mother's body until it hatches, but the mother provides no nourishment to the developing embryo inside the egg. This occurs in some species of fish and reptiles.
- Vivipary refers to the development and nourishment of an embryo within the mother's body but not inside an egg. Birth may be followed by a period of parental care of the offspring. This reproductive strategy occurs in almost all mammals including humans.

## Vertebrate Diversity

There are about 50,000 living species of vertebrates. They are placed in nine different classes. **Table** 13.1 lists these vertebrate classes and some of their traits. Five of the classes are fish. The other four classes are amphibians, reptiles, birds, and mammals.

**TABLE 13.1:** Classes of Vertebrates

| Class | Distinguishing Traits | Example |
| --- | --- | --- |
| Hagfish | They have a cranium but no backbone; they do not have jaws; their endoskeleton is made of cartilage; they are ectothermic. | hagfish  |

**TABLE 13.1:** (continued)

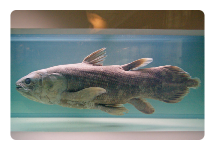
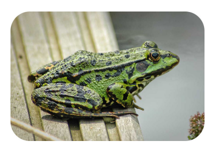
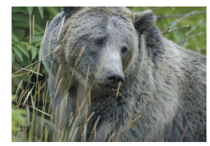
| Class | Distinguishing Traits | Example |
|---|---|---|
| Lampreys | They have a partial backbone; they do not have jaws; their endoskeleton is made of cartilage; they are ectothermic. | lamprey  |
| Cartilaginous Fish | They have a complete backbone; they have jaws; their endoskeleton is made of cartilage; they are ectothermic. | shark  |
| Ray-Finned Fish | They have a backbone and jaws; their endoskeleton is made of bones; they have thin, bony fins; they are ectothermic. | perch  |
| Lobe-Finned Fish | They have a backbone and jaws; their endoskeleton is made of bones; they have thick, fleshy fins; they are ectothermic. | coelacanth  |
| Amphibians | They have a bony endoskeleton with a backbone and jaws; they have gills as larvae and lungs as adults; they have four limbs; they are ectothermic | frog  |
| Reptiles | They have a bony endoskeleton with a backbone and jaws; they breathe only with lungs; they have four limbs; their skin is covered with scales; they have amniotic eggs; they are ectothermic. | alligator  |

**TABLE 13.1:** (continued)

| Class | Distinguishing Traits | Example |
|---|---|---|
| Birds | They have a bony endoskeleton with a backbone but no jaws; they breathe only with lungs; they have four limbs, with the two front limbs modified as wings; their skin is covered with feathers; they have amniotic eggs; they are endothermic. | bird  |
| Mammals | They have a bony endoskeleton with a backbone and jaws; they breathe only with lungs; they have four limbs; their skin is covered with hair or fur; they have amniotic eggs; they have mammary (milk-producing) glands; they are endothermic. | bear  |

## Vertebrate Evolution

The earliest vertebrates were jawless fish. They evolved about 550 million years ago. They were probably similar to modern hagfish (see **Table** 13.1). The tree diagram in **Figure** 13.4 summarizes how vertebrates evolved from that time forward.

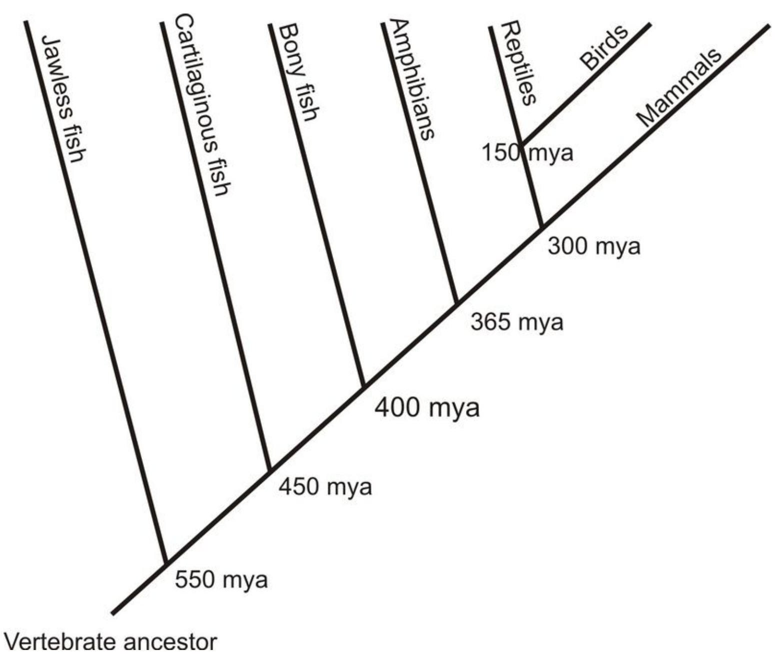



FIGURE 13.4
Phylogenetic Tree of Vertebrate Evolution. The earliest vertebrates evolved almost 550 million years ago. Which class of vertebrates evolved last?

### How Fish Evolved

The earliest fish had an endoskeleton made of cartilage rather than bone. They also lacked a complete vertebral column. The first fish with a complete vertebral column evolved about 450 million years ago. These fish had jaws. They may have been similar to living sharks. About 400 million years ago, the first fish with a bony endoskeleton evolved. A bony skeleton could support a bigger body. Early bony fish evolved into modern ray-finned fish and lobe-finned fish.

### How Other Vertebrate Classes Evolved

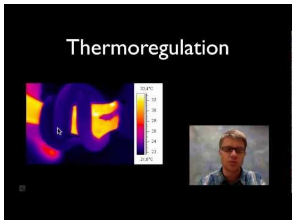
The earliest amphibians evolved from a lobe-finned fish ancestor. This occurred about 365 million years ago. Amphibians were the first terrestrial vertebrates. They lived on land as adults, but they had to return to the water to reproduce. The earliest reptiles evolved from an amphibian ancestor. This occurred at least 300 million years ago. Reptiles were the first vertebrates that did not need water to reproduce. That's because they laid waterproof amniotic eggs. These eggs allowed the embryo inside to breathe without drying out. Mammals and birds both evolved from reptile-like ancestors. The first mammals appeared about 200 million years ago. The earliest birds evolved about 150 million years ago.

### Ectothermy and Endothermy

Early vertebrates were ectothermic. Ectothermy means controlling body temperature to just a limited extent from the outside by changing behavior. For example, an ectotherm might stay in the shade to keep cool on a hot, sunny day. On a cold day, an ectotherm might bask in the sun to warm up, like the snake in **Figure** 13.5. Almost all living fish, amphibians, and reptiles are ectothermic. They can raise or lower their body temperature by their behavior but not by very much. In cold weather, an ectotherm cools down. As its body temperature drops, its metabolism slows down and it becomes inactive.

FIGURE 13.5
A water snake climbs onto a rock to bask and warm up in the sun.

Both mammals and birds evolved endothermy. Endothermy means controlling body temperature within a narrow range from the inside through biochemical or physical means. For example, on a cold day, an endotherm may produce more body heat by increasing its rate of metabolism. On a hot day, it may give off more heat by increasing blood flow to the surface of the body. That way, some of the heat can radiate into the air from the body's surface. Endothermy requires more energy (and food) than ectothermy. However, it allows the animal to stay active regardless of the temperature outside. You can learn more about how vertebrates regulate their temperature by watching this video: https://www.youtube.com/watch?v=TSUCdLkI474 .

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## Lesson Summary

- Vertebrates are chordates with a vertebral column and endoskeleton of cartilage and bone. Vertebrates also have several organ systems.
- Vertebrates reproduce sexually. They have one of three reproductive strategies: ovipary, ovovivipary, or vivipary.
- There are about 50,000 living species of vertebrates. They are placed in nine classes: five classes of fish plus amphibians, reptiles, birds, and mammals.
- The first vertebrates evolved about 550 million years ago. The evolution of amphibians, reptiles, mammals, and birds occurred over the next 400 million years. The first vertebrates were ectotherms; endothermy evolved later. Modern fish, amphibians, and reptiles are ectotherms. Modern birds and mammals are endotherms.

## Lesson Review Questions

### Recall

1. What traits set vertebrates apart from invertebrate chordates?
2. Describe how living vertebrates are classified.
3. Outline vertebrate evolution.

### Apply Concepts

4. What can you do as an endotherm that you could not do if you were an ectotherm?

### Think Critically

5. Compare and contrast the three reproductive strategies of vertebrates.

## Points to Consider

Fish were the first vertebrates to evolve. The earliest fish lived in the water, and modern fish are still aquatic.

1. What are some examples of modern fish?
2. What traits do you think fish have that adapt them for life in the water?

# 13.2 Fish

## Lesson Objectives

- Identify traits of fish.
- Explain how fish reproduce.
- Outline the classification of fish.
- Describe where fish live and what they eat.

## Lesson Vocabulary

- fin
- fish
- gill
- spawning
- swim bladder

## Introduction

If the word fish makes you think of cute little goldfish in a tank, check out the anglerfish pictured in **Figure** 13.6. It's also called a black sea devil. Surprisingly, goldfish and angler fish aren't all that different from each other as far as fish diversity goes. Both fish are placed in the same fish class. Clearly, fish are a diverse and interesting group of vertebrates.

## What Are Fish?

Fish are aquatic vertebrates. They make up more than half of all living vertebrate species. Most fish are ectothermic. They share several adaptations that suit them for life in the water.

### Aquatic Adaptations

You can see some of the aquatic adaptations of fish in **Figure** 13.7. For a video introduction to aquatic adaptations of fish, go to this link: https://www.youtube.com/watch?v=WrZEViYbkNc .

FIGURE 13.6
Anglerfish

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- Fish are covered with scales. Scales are overlapping tissues, like shingles on a roof. They reduce friction with the water. They also provide a flexible covering that lets fish move their body to swim.
- Fish have gills. Gills are organs behind the head that absorb oxygen from water. Water enters through the mouth, passes over the gills, and then exits the body.
- Fish typically have a stream-lined body. This reduces water resistance.
- Most fish have fins. Fins function like paddles or rudders. They help fish swim and navigate in the water.
- Most fish have a swim bladder. This is a balloon-like organ containing gas. By inflating or deflating their swim bladder, fish can rise or sink in the water.

### Organ Systems of Fish

Fish have a circulatory system with a heart. They also have a complete digestive system. It includes several organs and other structures. Fish with jaws use their jaws and teeth to chew food before swallowing it. This allows them to eat larger prey animals.

Fish have a nervous system with a brain. Fish brains are small compared with the brains of other vertebrates. However, they are large and complex compared with the brains of invertebrates. Fish also have highly developed sense organs. They include organs to see, hear, feel, smell, and taste.

FIGURE 13.7
Aquatic adaptations in fish: gill cover; scales; fins

## How Fish Reproduce

Almost all fish have sexual reproduction, generally with separate sexes. Each fish typically produces large numbers of sperm or eggs. Fertilization takes place in the water outside the body in the majority of fish. Most fish are oviparous. The embryo develops in an egg outside the mother's body.

### Spawning and Brooding

Many species of fish reproduce by spawning. Spawning occurs when many adult fish group together and release their sperm or eggs into the water at the same time. You can see fish spawning in **Figure** 13.8. Spawning increases the changes that fertilization will take place. It typically results in a large number of embryos forming at once. This makes it more likely that at least some of the embryos will avoid being eaten by predators. You can watch trout spawning in Yellowstone Park in this interesting video: http://video.nationalgeographic.com/video/trout_spawning


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URL: http://www.ck12.org/flx/render/embeddedobject/137120

FIGURE 13.8
Adult salmon gather near the water surface to spawn.

With spawning, fish parents can't identify their own offspring. Therefore, in most species, there is no parental care of offspring. However, there are exceptions. Some species of fish carry their fertilized eggs in their mouth until they hatch. This is called mouth brooding.

### Larvae and Metamorphosis

Fish eggs hatch into larvae. Each larva swims around attached to a yolk sac from the egg (see **Figure** 13.9). The yolk sac provides it with food. Fish larvae look different from adult fish of the same species. They must go through metamorphosis to change into the adult form.

FIGURE 13.9
Salmon larvae, each with a yolk sac attached to it.

## Classification of Fish

There are about 28,000 living species of fish. They are placed in five different classes. The classes are commonly called hagfish, lampreys, cartilaginous fish, ray-finned fish, and lobe-finned fish. **Table** 13.2 shows pictures of fish in each class. It also provides additional information about the classes.

**TABLE 13.2:** Five Living Classes of Fish

| Class | Distinguishing Traits | Example |
|---|---|---|
| Hagfish | Hagfish are very primitive fish. They lack scales and fins. They even lack a backbone, but they do have a cranium. They secrete large amounts of thick, slimy mucus. This makes them slippery, so they can slip out of the jaws of predators. | hagfish  |
| Lampreys | Lampreys lack scales but have fins and a partial backbone. Their mouth is surrounded by a large round sucker with teeth. They use the sucker to suck the blood of other fish. | lampreys  |
| Cartilaginous Fish | Cartilaginous fish include sharks, rays, and ratfish. Their endoskeleton is made of cartilage instead of bone. They also lack a swim bladder. However, they have a complete vertebral column and jaws. They also have a relatively big brain. | shark  |

**TABLE 13.2:** (continued)

| Class | Distinguishing Traits | Example |
|---|---|---|
| Ray-Finned Fish | Ray-finned fish make up the majority of living fish species. They are a type of bony fish, with an endoskeleton made of bone instead of cartilage. Their fins consist of webs of skin over flexible bony spines, called rays. They have a swim bladder. | puffer  |
| Lobe-Finned Fish | Lobe-finned fish include only coelacanths and lungfish. They are bony fish with an endoskeleton made of bone. Their fleshy fins contain bone and muscle. Lungfish are named for a lung-like organ that they can use for breathing air. It evolved from the swim bladder. It allows them to survive for long periods of time out of water. | lungfish  |

## Fish Ecology

Fish vary in the types of places they live and what they eat. Many fish live in the salt water of the ocean. Other fish live in freshwater lakes, ponds, rivers, or streams. Most fish are predators, but they may differ in their prey and how they get it.

- Hagfish are deep-ocean bottom dwellers. They feed on other fish, either living or dead. They enter the body of their prey through the mouth or anus. Then they literally eat their prey from the inside out.
- Lampreys generally live in shallow water, either salty or fresh. They eat small invertebrates or suck the blood of larger fish.
- Cartilaginous fish, such as sharks, mainly live in the ocean. They prey on other fish and aquatic mammals, or else they eat plankton. Their jaws and teeth allow them to eat large prey.
- Bony fish, such as ray-finned or lobe-finned fish, may live in salt water or fresh water. They may eat algae, smaller fish like the butterfly fish in **Figure** 13.10, or dead organisms. To see how one species of predatory bony fish catches its prey, watch this amazing video: http://video.nationalgeographic.com/video/stonefish-predation


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FIGURE 13.10
Butterfly fish like this one have "fake" eyespots. The eyespots may confuse larger predators long enough for the butterfly fish to escape.

## Lesson Summary

- Fish are aquatic vertebrates. They make up more than half of all vertebrate species. Most fish are ectothermic. They share several adaptations that suit them for life in the water, such as gills and fins.
- Almost all fish have sexual reproduction, generally with separate sexes. Most fish are oviparous. Many species reproduce by spawning. Eggs hatch to form larvae, which undergo metamorphosis to become adults.
- There are about 28,000 species of living fish. They are placed in five different classes: hagfish, lampreys, cartilaginous fish, ray-finned fish, and lobe-finned fish.
- Fish may live in salt water or fresh water. Most are predators.

## Lesson Review Questions

### Recall

1. Identify aquatic adaptations of fish.
2. Outline how fish are classified.
3. Describe how cartilaginous fish such as sharks feed.

### Apply Concepts

4. An unknown fish lives in shallow fresh water and eats small invertebrates. In which class would you place the unknown fish?

### Think Critically

5. Summarize how fish generally reproduce.
6. Compare and contrast lobe-finned and ray-finned fish.

## Points to Consider

Amphibians evolved from lobe-finned fish.

1. What are some examples of modern amphibians?
2. What traits of lobe-finned fish made them good candidates for amphibian ancestors?

# 13.3 Amphibians

## Lesson Objectives

- Define amphibians and identify their traits.
- Describe how amphibians reproduce.
- Outline how amphibians are classified.
- Explain the roles of amphibians in ecosystem and why they are at risk of extinction.

## Lesson Vocabulary

- amphibian
- cloaca
- keratin
- tadpole

## Introduction

Golden toads, like the one pictured in **Figure** 13.11, haven't been seen since 1989. It's feared that this beautiful and unusual amphibian has gone extinct. It's just one example of a much larger problem. As many as one-third of all amphibian species are presently at risk of extinction. Reasons include loss of habitat, pollution, and climate change. Amphibians are especially sensitive to such changes. In this lesson, you'll learn why. You'll also learn what you can do to help save them.

FIGURE 13.11
Golden toad

## What Are Amphibians?

Amphibians are vertebrates that live part of the time in fresh water and part of the time on land. They were the first vertebrates to evolve four legs and colonize the land. They most likely evolved from lobe-finned fish. Modern amphibians include frogs, toads, salamanders, newts, and caecilians. They are ectotherms, so they have little control over their body temperature. This allows them to be active in warm weather, but they become sluggish when the temperature cools.

### Amphibian Skin

Amphibians have moist skin without scales. The skin is kept moist by mucus, which is secreted by mucous glands. In some species, the mucous glands also secrete toxins that make the animal poisonous to predators. The blue poison-dart frogs in **Figure** 13.12 are a good example. The toxin in their mucus is used by native people in South America to poison the tips of their hunting arrows.

FIGURE 13.12
Blue poison-dart frogs

Amphibian skin contains keratin, a protein that is also found in the outer covering of most other four-legged vertebrates. The keratin in amphibians is not too tough to allow gases and water to pass through their skin. Most amphibians breathe with gills as larvae and with lungs as adults. However, extra oxygen is absorbed through the skin.

### Organ Systems in Amphibians

All amphibians have digestive, excretory, and reproductive systems. All three of these organ systems use a single body cavity, called the cloaca. Wastes enter the cloaca from the digestive and excretory systems. Gametes enter the cloaca from the reproductive system. A single external opening in the cloaca allows the wastes and gametes to exit the body. (Many other four legged vertebrates also have a cloaca.)

Amphibians have relatively complex circulatory and nervous systems. They have sensory organs for smelling and tasting, as well as eyes and ears. Frogs also have a larynx, or voice box, that allows them to make sounds. The purpose of frog calls varies. Some calls are used to attract mates, some are used to scare off other frogs, and some are signals of distress.You can hear a collection of frog calls at this link: http://animaldiversity.ummz.umich.edu/collections/frog_calls/

## How Amphibians Reproduce

Amphibians reproduce sexually. Fertilization may take place inside or outside the body. Amphibians are oviparous. Embryos develop in eggs outside the mother's body.

### Laying Eggs

Amphibians do not produce amniotic eggs with waterproof membranes. Therefore, they must lay their eggs in water. The eggs are usually covered with a jelly-like substance that helps keep them moist and offers some projection from predators. You can see a mass of frog eggs in jelly in **Figure** 13.13. Amphibians generally lay large numbers of eggs. Often, many adults lay eggs in the same place at the same time. This helps ensure that the eggs will be fertilized. Once eggs are laid, amphibian parents typically provide no parental care.

FIGURE 13.13
Frog eggs in a pond

### Larvae and Metamorphosis

Most amphibians go through a larval stage that is different from the adult form. In frogs, for example, the early larval stage resembles a fish, as you can see in **Figure** 13.14. Frogs at this stage of development are called tadpoles. Tadpoles live in the water. They lack legs and have a long tail that helps them swim. They also have gills, which absorb oxygen from the water.

During metamorphosis, the tadpole changes to the form of an adult frog. It grows legs, loses its tail, and develops lungs. All of these changes prepare it to live on the land. In **Figure** 13.15, you can see how a frog larva looks as it changes to the adult form.

FIGURE 13.14
Tadpoles swimming in shallow water

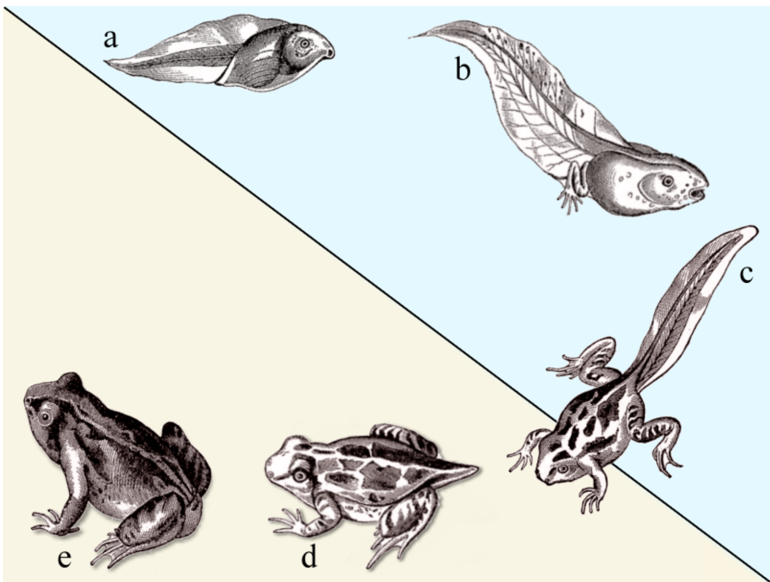


FIGURE 13.15
Metamorphosis of a frog larva

## How Amphibians are Classified

There are only about 6200 known species of amphibians. They are placed in three orders: frogs, salamanders, and caecilians. **Table** 13.4 shows a picture of an amphibian in each order. It also provides additional information about the orders.

TABLE 13.3: Classes of Vertebrates

| Class | Distinguishing Traits | Example |
|---|---|---|
| Frogs | The frog order also includes toads. Unlike other amphibians, frogs and toads lack a tail by adulthood. Their back legs are also longer because they are specialized for jumping. Frogs can jump as far as 20 times their body length. That's like you jumping more than the length of a basketball court! | red-eyed tree frog  |

**TABLE 13.3:** (continued)

| Class | Distinguishing Traits | Example |
|---|---|---|
| Salamanders | The salamander order also includes newts. Salamanders and newts keep their tails as adults. They have a long body with short legs. They are adapted for walking and swimming rather than jumping. Unlike other vertebrates, salamanders can regrow legs or other body parts if they are bitten off by a predator. | smooth newt  |
| Caecilians | The caecilian order is the amphibian order with the fewest species. Caecilians are closely related to salamanders. They have a long, worm-like body. They are the only amphibians without legs. Caecilians evolved from a four-legged ancestor but lost their legs later in their evolution. As adults, they often burrow into the soil. That's one reason why Caecilians tend to be less well known than other amphibians. | microcaecilia  |

## Ecology of Amphibians

Amphibians live in freshwater and moist-soil habitats throughout the world. The only continent that lacks amphibians is Antarctica. Amphibians are especially common in temperate lakes and ponds and in tropical rainforests.

### Predator and Prey

Amphibians are the prey of many other vertebrates, including birds, snakes, raccoons, and fish. Amphibians are also important predators. As larvae, they may eat water insects and algae. As adults, they typically eat invertebrates, including worms, snails, and insects. You can watch a frog catching an invertebrate in the slow-motion video at the following link. At its real speed, you would barely see it because it happens so quickly.

https://www.youtube.com/watch?v=BAUqC8Uvfts

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### The Threat of Extinction

Why are so many amphibian species threatened by extinction, and why should you care? The second question is easy. Amphibians control pests, may be a source of new medicines, and help feed many other animals. The nature of amphibian skin may help explain why so many amphibian species are at risk. Their skin easily absorbs substances from the environment, such as pollutants in water or air. Therefore, they may suffer from poor environmental quality before other animals do. As such, they may provide an early-warning system of environmental damage.

What can you do to help save amphibians?

- Protect the natural environment. For example, reduce your use of energy to curb greenhouse gases and global warming.
- Avoid the use of garden pesticides. Poisoned insects may be eaten by amphibians that are also harmed by the poison.
- Make a backyard habitat. A small pond surrounded by native vegetation provides a place for amphibians to live.
- Help raise awareness. Start a letter-writing campaign to politicians, asking them to support conservation activities for amphibians.
- For more ideas about what you can do to help save amphibians, check out this website: http://www.amphibianark.org/the-crisis/what-can-i-do-to-help/

## Lesson Summary

- Amphibians are vertebrates that live part of the time in fresh water and part of the time on land. They were the first vertebrates to evolve four legs and colonize the land. They are ectothermic. They have permeable skin and several organ systems.
- Amphibians reproduce sexually. Fertilization may take place inside or outside the body. Eggs are laid in water. They hatch into larvae that live in the water until they undergo metamorphosis to the adult form.
- There are only about 6200 known species of amphibians. They are placed in three orders: frogs, salamanders, and caecilians. Frogs include toads and have the most species. Caecilians have the fewest species.
- Amphibians are the prey of many other vertebrates. They are also important predators. Many amphibian species are threatened by extinction. There are many steps individuals can take to help protect amphibians.

## Lesson Review Questions

### Recall

1. What are amphibians?
2. Describe the skin of amphibians.
3. State how amphibians reproduce and develop into adults.

### Apply Concepts

4. Create a public serve announcement to help raise awareness about the importance of amphibians, their risk of extinction, and what individuals can do to help.

### Think Critically

5. Compare and contrast the three living orders of amphibians.
6. Explain the ecological roles of amphibians, including both larval and adult stages.

## Points to Consider

Amphibians were the dominant land vertebrates until they gave rise to reptiles.

1. What are some examples of modern reptiles?
2. How do you think reptiles differ from amphibians?

# 13.4 Reptiles

## Lesson Objectives

- List terrestrial adaptations of reptiles.
- Describe how reptiles reproduce.
- Explain how reptiles are classified.
- Identify where reptiles live and what they eat.

## Lesson Vocabulary

- carnivore
- crocodilian
- diaphragm
- herbivore
- omnivore
- reptile

## Introduction

Loggerhead turtles spend most of their life in the ocean. Adult female loggerheads go ashore briefly to lay their eggs in the sand. Then they return to the water and leave the eggs to hatch on their own. **Figure** 13.16 shows baby loggerheads on a beach shortly after hatching. The baby turtles must make their way back to the water, hopefully without being snatched up by a predator. Loggerhead turtles are reptiles. Unlike amphibians, turtles and other reptiles can lay their eggs on dry land. That's because they produce amniotic eggs. Amniotic eggs have waterproof membranes to prevent them from drying out.

## What Are Reptiles?

Reptiles are ectothermic, four-legged vertebrates that produce amniotic eggs. The reptile class is one of the largest classes of vertebrates. Besides turtles, it includes crocodiles, alligators, lizards, and snakes. Although some turtles and other reptiles now live mainly in the water, reptiles evolved many adaptations for life on land. For an amusing overview of reptiles, watch this Bill Nye the Science Guy reptile video: http://www.youtube.com/watch?v=DCLvwk3zhh8 .

FIGURE 13.16
Newly hatched loggerhead turtles start crossing the sand to the ocean.

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## Adaptations for Life on Land

Reptiles were the first vertebrates to lay amniotic eggs. This freed them from returning to the water to reproduce. In addition to amniotic eggs, reptiles have several other adaptations for living on land. For example, reptile skin is covered with scales. You can see how the scales overlap and cover the snake in **Figure** 13.17. Reptile scales are made of very tough keratin. They help protect reptiles from injury as well as loss of water.

Because of their tough scales, reptiles can't absorb oxygen through their skin as amphibians can. However, reptiles have more efficient lungs for breathing air. They also have various ways of moving air into and out of their lungs. For example, their chest muscles contract to push air out of the lungs. The muscles relax to allow air to rush into the lungs. Another muscle, called the diaphragm, which lies below the lungs, also helps move air into and out of the lungs. (Mammals also have a diaphragm for breathing air.)

## Reptile Organ Systems

Reptiles have a circulatory system with a heart that pumps blood. Reptiles also have a centralized nervous system with a brain. Their brain is relatively small, but the parts of the brain that control the senses and learning are larger than in amphibians. Reptiles have good senses of sight and smell. They use their tongue to smell scents. That's what the blue-tongued lizard in **Figure** 13.18 is doing. Some reptiles also have a heat-sensing organ that helps them locate the warm bodies of prey animals such as birds and small mammals.

FIGURE 13.17
Like other reptiles, this tree viper snake is covered with overlapping, waterproof scales.

FIGURE 13.18
This lizard, called a skink, is flicking out its blue tongue to sniff the air.

## How Reptiles Reproduce

Most reptiles have sexual reproduction with internal fertilization. Reptiles have a body cavity called a cloaca that is involved in reproduction. Sperm or eggs are released into an adult reptile's cloaca. Males have one or two penises that pass sperm from their cloaca to the eggs in the cloaca of a female, where fertilization takes place. In most reptile species, once fertilized the eggs leave the body through an opening in the cloaca. These reptiles are oviparous. Eggs develop and hatch outside the mother's body.

Young reptiles, like the baby alligator in **Figure** 13.19, look like smaller versions of the adults. They don't have a larval stage as most amphibians do. Baby reptiles are able to move and search for food but are at high risk of predation. Adult reptiles rarely provide any care for their offspring once the eggs are laid. The only exceptions are female alligators and crocodiles. They defend their eggs and hatchlings from predators and help them reach the water.

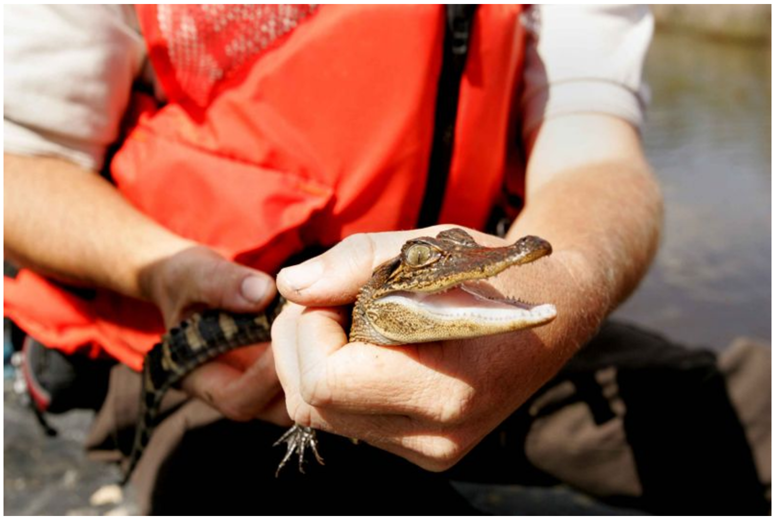

FIGURE 13.19
This baby alligator, being held gently by a game warden, looks just like an adult alligator but on a much smaller scale.

## How Reptiles are Classified

There are over 8200 living species of reptiles. They are classified in four orders, called Crocodilia, Sphenodontia, Squamata, and Testudines. **Table** 13.4 shows a picture of a reptile in each order. It also provides additional information about the orders. For an online gallery of amazing photos of reptiles, go to this link: http://video.nationalgeographic.com/video/magazine/my-shot-minute/ngm-reptiles-msm


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**TABLE 13.4:** Classes of Vertebrates

| Class | Distinguishing Traits | Example |
| --- | --- | --- |
| Crocodilia | Reptiles in the Crocodilia Order are called crocodilians. They include crocodiles, alligators, caimans, and gharils. They have four sprawling legs that allow them to run surprisingly fast. They have strong jaws and replace their teeth throughout life. Crocodilians have relatively complex brains and greater intelligence than other reptiles. | crocodile  |

**TABLE 13.4:** (continued)

| Class | Distinguishing Traits | Example |
|---|---|---|
| Sphenodontia | The Sphenodontia Order includes only tuataras like the one in this photo. They resemble lizards but are the least specialized of all living reptiles. Their brain is similar to the amphibian brain. | tuatara  |
| Squamata | The Squamata order includes lizards and snakes. Lizards have four legs for running or climbing, and they can also swim. Many change their color when threatened. Snakes do not have legs, although they evolved from a four-legged ancestor. They have a very flexible jaw for swallowing large prey whole. Some inject poison into their prey through fangs. | lizard  |
| Testudines | The Testudines Order includes turtles, tortoises, and terrapins. They have four legs for walking. They have a hard shell covering most of their body. | terrapin  |

## Reptile Ecology

Modern reptiles live in many different habitats. They can be found on every continent except Antarctica.

### Reptile Habitats

Many turtles are aquatic. They may live in the ocean or in fresh water. Other turtles are terrestrial and live on land. All lizards are terrestrial. Their habitats may range from deserts to rainforests. They may live in a range of places, from underground burrows to the tops of trees. Most snakes are terrestrial, but some are aquatic. Crocodilians live in and around swamps or bodies of water. The water may be fresh or salty, depending on the species of crocodilian.

### What Reptiles Eat

All reptiles are heterotrophs, and the majority eats other animals. Heterotrophs that eat only or mainly animals are called carnivores. Large carnivorous reptiles such as crocodilians are the top predators in their ecosystems. They prey on large birds, fish, deer, turtles, and sometimes farm livestock. Their powerful jaws are strong enough to crush bones and turtle shells. Smaller carnivorous reptiles—including tuataras, snakes, and many lizards—are lower-level predators. They prey on small animals such as insects, frogs, birds, and mice.

Most terrestrial turtles eat plants. Heterotrophs that eat only or mainly plants are called herbivores. Herbivorous turtles graze on grasses, leaves, flowers, and fruits. Marine turtles and some lizards feed on both plants and animals. Heterotrophs that eat a variety of foods including both plants and animals are called omnivores.

## Lesson Summary

- Reptiles are a class of ectothermic, four-legged vertebrates that produce amniotic eggs. They include turtles, crocodiles, lizards, and snakes. Reptiles were the first vertebrates to live full time on land, and they evolved many terrestrial adaptations.
- Most reptiles reproduce sexually and have internal fertilization. They lay eggs on land and generally do not provide parental care. Reptile hatchlings look like miniature adults. They lack a larval stage and do not go through metamorphosis.
- There are over 8200 living species of reptiles. They are classified in four orders: Crocodilia, Sphenodontia, Squamata, and Testudines.
- Reptiles live in a wide range of habitats. Some are aquatic, but most are terrestrial. Most reptiles are carnivores, but some are herbivores or omnivores.

## Lesson Review Questions

### Recall

1. What are reptiles?
2. Identify some of the terrestrial adaptations of reptiles.
3. Describe how reptiles reproduce.

### Apply Concepts

4. In many parts of the world, beaches are being used for new homes and condominiums. Such beach development may put aquatic turtle populations at risk. Explain why.

### Think Critically

5. Compare and contrast the Crocodilia and Squamata Orders of reptiles.
6. Explain the ecosystem roles of carnivorous reptiles.

## Points to Consider

Birds evolved from a reptile ancestor, but modern birds and reptiles are very different. Birds are now the most numerous four-limbed reptiles on Earth.

1. How do modern birds differ from reptiles?
2. Why do you think birds have been so successful?

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# CHAPTER 14 MS Birds and Mammals

## Chapter Outline



What is this flying animal? Is it a bird? Look closely and you'll see that it's actually a bat, the only type of mammal that evolved true flight. Other than its ability to fly, a bat isn't much more birdlike than you are. For example, like you and other mammals, a bat has jaws with teeth rather than a beak. Its body is also covered with fur rather than feathers. Bats are adapted for flight. But the vertebrate masters of flight are the birds.

# 14.1 Birds

## Lesson Objectives

- Define the bird class.
- Identify adaptations of birds for flight.
- Describe how birds reproduce and care for their young.
- Compare and contrast birds that are specialists and birds that are generalists.

## Lesson Vocabulary

- bipedal
- bird
- courtship
- generalist
- incubation
- specialist

## Introduction

Birds are some of the most colorful and diverse animals on Earth. Look at the birds in **Figure** 14.1. The colors of the macaw and lorikeet are as different as they are beautiful. The range in size of birds is also impressive. The tiny hummingbird is just a few centimeters (couple of inches) long. The big ostrich stands almost 3 meters (about 9 feet) tall.

## What Are Birds?

Birds are four-limbed, endothermic vertebrates. The upper pair of limbs are wings that most birds use for flying. The lower pair of limbs are legs with feet that birds use for walking. Because birds walk on two legs, they are called bipedal. (Humans are bipedal too.) Birds also have feathers and beaks, and they produce amniotic eggs.

Of all vertebrate classes, birds are the most numerous, even though they evolved most recently. Why have birds been so successful? The answer is flight. Being able to fly opened up a whole new world to birds: the world of the air above the land and water.

Other than insects, virtually no other animals can inhabit the airy world. Flying is a sure-fire way to escape from all but the quickest nonflying predators. Flying also gives birds a good view for finding food and mates.

FIGURE 14.1
Diversity of birds: (from left to right) Macaw, Lorikeet, Hummingbird, and Ostrich.

## Adaptations for Flight

Wings and feathers are two adaptations for flight that evolved in birds. Both are clearly displayed in the flying gull in **Figure** 14.2. Wings evolved from the front limbs of a four-legged ancestor. The wings are controlled by large flight muscles in the chest. Feathers also help birds fly. They provide air resistance and lift. In addition, they provide insulation and serve other roles.

### Organ Systems

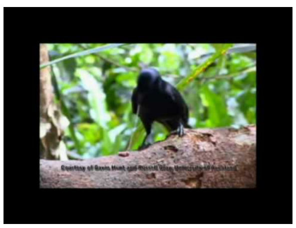
To keep their flight muscles well supplied with oxygen, birds evolved specialized respiratory and circulatory systems. Birds have special air sacs for storing extra air and pumping it into the lungs. They also have a relatively large heart and a rapid heart rate. These adaptations keep plenty of oxygenated blood circulating to the flight muscles.

### Bird Brains

Birds have relatively big brains for their body size. This is reflected in their high level of intelligence and complex behavior. Some birds, including crows, are more intelligent than many mammals. They are smart enough to use "tools" to solve problems. You can see this in the video below. However, the part of the brain that is most developed in birds is the part that controls flying. This is another adaptation for flight.

https://www.youtube.com/watch?v=3RCcVJvZF0I

FIGURE 14.2
This gull depends on its feathered wings and large flight muscles to fly



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## How Birds Reproduce

Birds reproduce sexually and have separates sexes. Fertilization occurs internally, so males and females must mate. Many bird species have special behaviors, such as unique songs or visual displays, for attracting mates. These special behaviors are called courtship. The white peacock in **Figure** 14.3 is putting on a stunning display of his amazing tail feathers to court a mate.

### Nest Building

After mating and fertilization occur, eggs are laid, usually in a nest. Most birds build nests for their eggs and hatchlings, and each species has a certain way of doing it. You can see examples of different types of bird nests in **Figure** 14.4. Nests range from little more than a depression in the ground (killdeer) to elaborately built structures (weaver bird). You can see how skillful a weaver bird is at weaving its nest by watching this video: http://www.youtube.com/watch?v=6svAIgEnFvw .

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FIGURE 14.3
A white peacock spreads out his tail feathers to attract a mate.

FIGURE 14.4
Variation in bird nests: Killdeer with eggs in nest on ground (left) and Weaver bird weaving elaborate nest in tree (right).

### Parental Care

In most species, one or both parents take care of the eggs. They sit on the eggs to keep them warm until they hatch. This is called incubation. After the eggs hatch, the parents generally continue their care. They feed the hatchlings until they are big enough to feed on their own. This is usually at a younger age in ground-nesting birds such as ducks than in tree-nesting birds such as robins.

## Classification of Birds

There are about 10,000 living species of birds. Almost all of them can fly. Very few birds are flightless.

## Flying Birds

Birds that can fly are classified in 29 orders. Birds in the different orders vary in their physical traits and how they behave. You can see seven of the most common orders of flying birds in **Table** 14.1. The majority of flying birds are perching birds, described in the last row of the table. There are more species in this order than in all other bird orders combined. Many perching birds are familiar songbirds such as the mockingbird. You can hear a mockingbird's amazing and complex song in this video: http://youtu.be/NNNX3f3_svo

TABLE 14.1: Orders of Flying Birds

| Order | Description | Example |
|---|---|---|
| Landfowl: turkeys, chickens, pheasants | They are large in size; they spend most of their time on the ground; they usually have a thick neck and short, rounded wings; their flight tends to be brief and close to the ground. | turkey  |
| Waterfowl: ducks, geese, swans | They are large in size; they spend most of their time on the water surface; they have webbed feet and are good swimmers; most are strong flyers. | ducks  |
| Shorebirds: puffins, gulls, plovers | They range from small to large; most live near the water, and some are sea birds; they have webbed feet and are good swimmers; most are strong flyers. | puffin  |
| Diurnal Raptors: hawks, falcons, eagles | They range from small to large; they are active during the day and sleep during the night; they have a sharp, hooked beak and strong legs with clawed feet; they hunt by sight and have excellent vision. | hawk  |
| Nocturnal Raptors: burrowing owls, barn owls, horned owls | They range from small to large; they are active during the night and sleep during the day; they have a sharp, hooked beak and strong legs with clawed feet; they have large, forward-facing eyes; they have excellent hearing and can hunt with their sense of hearing alone. | burrowing owl  |

**TABLE 14.1:** (continued)

| Order | Description | Example |
|---|---|---|
| Parrots: cockatoos, parrots, parakeets | They range from small to large; they are found in tropical regions; they have a strong, curved bill; they stand upright on strong legs with clawed feet; many are brightly colored; they are very intelligent. | cockatoo  |
| Perching Birds: honeyeaters, sparrows, crows | They are small in size; they perch above the ground in trees and on buildings and wires; they have four toes for grasping a perch; many are songbirds. | honeyeater  |

### Flightless Birds

Some birds lost the ability to fly during their evolution. They include the ostrich, pictured above in **Figure** 14.1, as well as the kiwi, rhea, cassowary, and moa. All of these birds have long legs that are adapted for running. Penguins, like the one pictured in **Figure** 14.5, are also flightless, but they have a very different body shape. They are adapted for swimming instead of running.

FIGURE 14.5

Penguins are flightless birds that are strong swimmers and spend much of their time in the water.

## Bird Ecology

Birds are endothermic. They can maintain a warm body temperature even in a cold climate. Therefore, they can live in a wider range of habitats than ectothermic vertebrates such as amphibians and reptiles.

### Where Birds Live

Birds live and breed in most terrestrial habitats on Earth. They can be found on all seven continents, from the Arctic to Antarctica. However, the majority of bird species are native to tropical areas of the planet.

### What Birds Eat

Birds may be specialists or generalists in terms of what they eat. Generalists are organisms that eat many different types of food. Birds that are generalists include the red-winged blackbird in **Figure** 14.6. It has a basic beak that can eat many different foods. Red-winged blackbirds are omnivores. They may eat a wide variety of seeds as well as insects and other small animals such as snails and frogs.

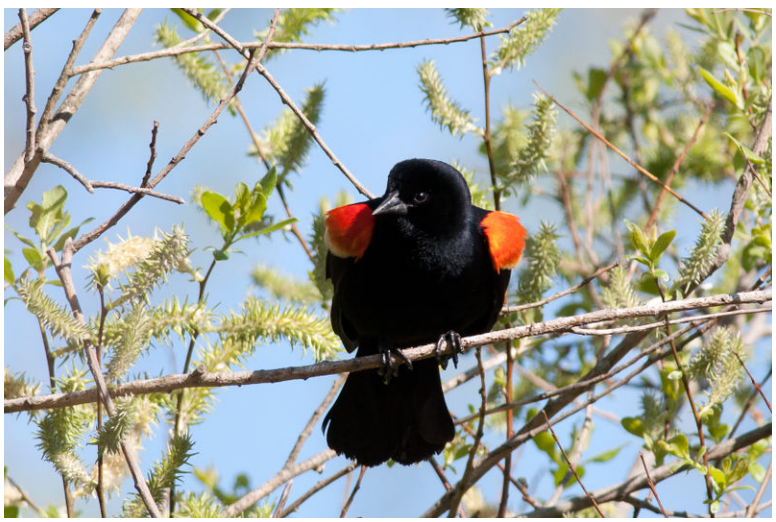

FIGURE 14.6
A red-winged blackbird is a generalist that eats a variety of plant and animal foods.

Specialists are organisms that eat just one type of food. Birds that are specialists include ospreys, which eat only live fish. You can see an osprey in **Figure** 14.7. The osprey's feet are very well-adapted for catching fish. Its eyes are also well-adapted for seeing fish under the water. Its beak is well suited for gripping and ripping into fish flesh. Ospreys are so well-adapted to catching fish that they can't catch anything else!

## Lesson Summary

- Birds are four-limbed, endothermic vertebrates with wings and feathers. They produce amniotic eggs and are the most numerous class of vertebrates.
- Birds have several adaptations for flight. These include wings, feathers, and large flight muscles. Birds also have specialized respiratory and circulatory systems to keep their flight muscles well supplied with oxygen.

FIGURE 14.7
This osprey is specialized for catching and eating live fish.

- Birds reproduce sexually and have separate sexes. Many birds have courtship behaviors to attract mates. Most birds build nests for their eggs and feed their hatchlings.
- There are about 10,000 living species of birds. Almost all of them can fly. Flying birds are classified in 29 orders. Most species belong to the order of perching birds. A few birds are flightless, such as the ostrich and penguin, but they evolved from a flying ancestor.
- Birds live and breed in most terrestrial habitats on Earth. Some birds are generalists. They eat a variety of foods and do not have specialized beaks. Other birds are specialists. They eat a single type of food and have specialized beaks and other special adaptations for the food source on which they depend.

## Lesson Review Questions

### Recall

1. What is a bird?
2. Describe adaptations of birds for flight.
3. Define courtship in birds. Give an example.
4. How do most bird parents take care of their eggs and hatchlings?
5. Describe the order of flying birds that contains the largest number of species.

### Apply Concepts

6. Look at the bird in the photo below. Do you think this bird is a generalist or a specialist? Explain your answer.

### Think Critically

7. Discuss bird intelligence.
8. Explain why birds have been so successful.

## Points to Consider

Birds aren't the only endothermic vertebrates. Mammals are also endotherms.

1. What are some examples of mammals?
2. Besides endothermy, what other traits do mammals have?

# 14.2 Mammals

## Lesson Objectives

- Identify traits of mammals.
- Explain how mammals keep their body temperature stable.
- Describe variation in mammalian diets.
- Compare and contrast monotreme, marsupial, and placental mammals.
- Outline the classification of mammals.

## Lesson Vocabulary

- alveolus (alveoli, plural)
- frugivore
- insectivore
- lactation
- mammal
- mammary gland
- marsupial
- monotreme
- placenta
- placental mammal
- sweat

## Introduction

The dogs in **Figure** 14.8 are playing. Most mammals engage in play, especially when they're young. Play is just one of many complex behaviors displayed by mammals. Mammals are amazing vertebrates, and they include you!

## What Are Mammals?

Mammals are endothermic vertebrates with four limbs. Examples of mammals include bats, whales, mice, and humans. Clearly, mammals are a very diverse group. Nonetheless, they share several traits that set them apart from other vertebrates.

### Defining Mammals

Two traits are used to define the mammal class. They are fur or hair and mammary glands in females.

FIGURE 14.8
Like all young mammals, these young dogs like to play.

- All mammals have fur or hair on their skin. It provides insulation and helps keep the body warm. It also can be used for sensing. For example, cats can feel with their whiskers.
- All female mammals have mammary glands. Mammary glands are glands that produce milk after the birth of offspring. Producing milk for offspring is called lactation. The colt in **Figure** 14.9 is getting milk from its mother.

FIGURE 14.9
Nursing colt and mother horse

## Other Mammal Traits

Most mammals share several other traits. These include:

- a large, complex brain and relatively great intelligence;
- ears with specialized structures that make them extremely good at hearing;
- four different types of teeth (reptiles have just one type), allowing them to eat a wide range of foods;
- tiny air sacs called alveoli (alveolus, singular) in the lungs for enhanced gas exchange; and

- glands in the skin that produce sweat, a salty fluid that helps cool down the body.

### How Mammals Move

Mammals are noted for the many ways they can move. Some mammals are well known for their speed. The fastest land animal is a mammal, the cheetah. It can race at speeds of up to 112 kilometers (70 miles) per hour.

The limbs of most mammals are specialized for a particular way of moving. They may be specialized for running, jumping, climbing, flying, gliding, or swimming. The limbs of some mammals are even specialized for swinging through tree tops. You can see mammals with some of these specializations in **Figure** 14.10.

FIGURE 14.10
Some ways that mammals move: (left) the flying squirrel has webbed skin between its legs that allows it to glide from trees to the ground; (middle) the kangaroo rat has large lower limbs for jumping and can jump farther than any other mammal for its size; (right) the dolphin is well adapted for moving in the water - it has a streamlined body to reduce water resistance and fins to help it swim.

## How Mammals Control Their Temperature

Mammals have a variety of ways to keep their body temperature stable.

### Staying Warm

Mammals stay warm in cool weather in two general ways. One way is by generating more heat. The other way is by conserving the heat that is generated.

Mammals generate heat mainly by maintaining a high rate of metabolism. Compared with the cells of other animals, the cells of mammals have more mitochondria. Mitochondria are the cell organelles that generate energy. Mammals may also produce little bursts of heat by shivering. Shivering occurs when many muscles all contract slightly at the same time. The muscle contractions generate a small amount of heat.

Mammals conserve heat with their hair or fur. It works like the layer of insulation in the walls of a house. It traps warm air next to the skin so it can't escape into the environment. Like the squirrel in **Figure** 14.11, most mammals can make their hair or fur stand up from the skin. This makes it a better insulator. Mammals also have a layer of insulating fat beneath their skin. Other vertebrates lack this layer of fat.

FIGURE 14.11

Raised fur to conserve heat makes this squirrel look bigger than it actually is.

### Losing Heat

In hot weather, mammals may need to lose excess body heat. One way they do this is by increasing blood flow to the body surface. The increased blood flow warms the skin, which gives off heat to the environment. Most mammals also sweat to lose excess heat. Sweating wets the skin. Evaporation of the sweat requires heat. The heat comes from the body and cools it down. Animals with fur, like the dogs in **Figure** 14.12, may pant instead of sweat to lose body heat. Water evaporates from the tongue and other moist surfaces of the mouth, using heat from the body. Watch this video to learn about some unique ways that elephants lose excess heat: http://www.youtube.com/watch?v=NJEBfl_LKno .

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## What Do Mammals Eat?

Generating body heat to stay warm takes a lot of energy. Mammals are heterotrophs that get their energy by eating other organisms. Mammals eat a wide range of different foods. Except for leaf litter and wood, almost any kind of organic matter is consumed by some type of mammal. The organic matter typically comes from plants, other animals, or some mix of these sources.

### Mammals that Eat Plants

Many mammals are herbivores. Herbivores are heterotrophs that eat only or mainly plant foods (or algae). Depending on the species of mammals, they may eat leaves, shoots, stems, roots, seeds, nuts, fruits, flowers, and/or grasses. Some mammals even eat conifer needles or tree bark. Mammals that are herbivores include rabbits, mice, sheep, zebras, deer, kangaroos, and monkeys. The manatee in **Figure** 14.13 is also a herbivorous mammal. It eats mainly kelp (seaweed).

FIGURE 14.12
Dogs pant to lose excess body heat.

FIGURE 14.13
Manatee eating kelp

### Mammals that Eat Other Animals

Some mammals are carnivores. Carnivores are heterotrophs that eat only or mainly animal foods. Depending on their species, carnivorous mammals may eat other mammals, birds, reptiles, amphibians, fish, mollusks, worms, and/or insects. Mammals that are carnivores include anteaters, whales, hyenas, wolves, and seals. The bat in **Figure** 14.14 is also a carnivorous mammal. It eats insects. Carnivores that eat mainly insects are classified as insectivores.

FIGURE 14.14
This big-eared Townsend bat is an insect eater.

### Mammals that Eat Both Plants and Animals

Some mammals are omnivores. Omnivores are heterotrophs that eat a mix of plant and animal foods. Mammals that are omnivores include bears, foxes, rats, pigs, and human beings. The chimpanzees in **Figure** 14.15 are also omnivorous mammals. In the wild, they eat mainly plant foods, but they supplement plants with birds, bird eggs, insects, small monkeys, and other small mammals. Their favorite and most common food, however, is fruit. Animals that eat mainly fruit are called frugivores.

FIGURE 14.15
These chimpanzees are omnivores that eat mainly fruit.

## How Mammals Reproduce

Mammals have separate sexes and reproduce sexually. They produce eggs or sperm and must mate in order for fertilization to occur. A few mammals are oviparous. They lay eggs, which later hatch. These mammals are called monotremes. Most mammals are viviparous and give birth to live young. These mammals are either placental mammals or marsupials. Placental mammals give birth to relatively large and well-developed fetuses. Marsupials give birth to smaller, less-developed embryos. In both placental and marsupial mammals, the young grow and develop inside the mother's body in an organ called the uterus. At birth, they pass through a tube-like organ called the birth canal, or vagina.

### Placental Mammals

Placental mammals get their name from the placenta. This is a spongy structure that develops during pregnancy only in placental mammals. You can see where a human placenta forms in **Figure** 14.16. The placenta sustains the fetus while it grows inside the mother's uterus. It consists of membranes and blood vessels from both mother and fetus. It allows substances to pass between the mother's blood and that of the fetus. The fetus gets oxygen and nutrients from the mother. It passes carbon dioxide and other wastes to the mother.

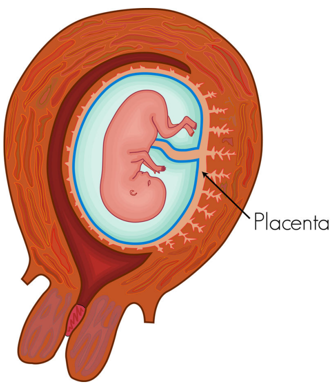



FIGURE 14.16
Human placenta and fetus inside the uterus

The placenta permits a long period of fetal growth. As a result, the fetus can become relatively large and mature before birth. This increases its chances of survival. On the other hand, supporting a growing fetus may be difficult for the mother. She has to eat more while pregnant and may become less mobile as the fetus grows larger. Giving birth to a large infant is also risky.

### Marsupial Mammals

By giving birth to tiny embryos, marsupial mothers are at less risk. However, the tiny newborn marsupial may be less likely to survive than a newborn placental mammal. The marsupial embryo completes its growth and development outside the mother's body in a pouch. It gets milk by sucking on a nipple in the pouch. There are very few living species of marsupials. They include kangaroos, koalas, and opossums. You can see a baby koala peeking out of its mother's pouch in **Figure** 14.17.

### Monotreme Mammals

There are very few living species of monotremes, or egg-laying mammals. They include the echidna and platypus, both pictured in **Figure** 14.18. Monotremes are found only in Australia and the nearby island of New Guinea.

Female monotremes lack a uterus and vagina. Instead, they have a cloaca with one external opening, like the cloaca of reptiles and birds. The opening is used to excrete wastes as well as lay eggs. The eggs of monotremes have a leathery shell, like the eggs of reptiles. Female monotremes have mammary glands but not nipples. They secrete milk to feed their young from a patch on their belly. This form of reproduction is least risky for the mother but most risky for the offspring.

FIGURE 14.17
Koala mother and baby in pouch

FIGURE 14.18
Monotremes: echidnas (left) and a platypus (right)

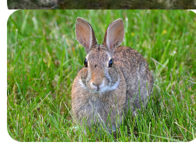
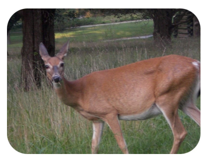
## Classification of Mammals

Mammals are a class in Phylum Chordata. Monotremes, marsupials, and placental mammals are subclasses of mammals. Almost all living mammals are placental mammals. Placental mammals, in turn, are divided into many orders. Some of the larger orders are described in **Table** 14.2.

TABLE 14.2: Orders of Placental Mammals (Traditional Classification)

| Order | Example | Sample Trait |
|---|---|---|
| Insectivora | mole  | small sharp teeth |
| Chiroptera | bat  | digits support membranous wings |

**TABLE 14.2:** (continued)

| Order | Example | Sample Trait |
| --- | --- | --- |
| Carnivora | coyote  | long pointed canine teeth |
| Rodentia | mouse | incisor teeth grow continuously |
| Lagomorpha | rabbit  | chisel-like incisor teeth |
| Artiodactyla | deer  | even-toed hooves |
| Cetacea | whale  | paddle-like forelimbs |
| Primates | monkey  | five digits on hands and feet |

The orders in **Table** 14.2 are still widely used, but ideas about mammal classification are constantly changing. Traditional classifications are based on similarities and differences in physical traits. More recent classifications are based on similarities and differences in DNA. The latter are more useful for determining how mammals evolved.

## Lesson Summary

- Mammals are endothermic vertebrates that have four limbs and produce amniotic eggs. Defining traits of mammals are fur or hair and mammary glands. Mammals are noted for the many different ways they can move and their specialized limbs.
- Mammals have a variety of ways to keep their body temperature stable. They generate heat with a high rate of metabolism and shivering, and they conserve heat with insulating hair or fur and a layer of fat under the skin. They lose excess heat by increasing blood flow to the skin and by sweating or panting.
- Mammals may be herbivores, carnivores, or omnivores. Some carnivore mammals eat mainly insects and are called insectivores. Some omnivore mammals eat mainly fruits and are called frugivores.
- Mammals have separate sexes and reproduce sexually. Monotreme mammals lay eggs, but most mammals give birth to live young. Placental mammals give birth to relatively large, well-developed fetuses. Marsupials give birth to smaller, less-developed embryos.
- Monotremes, marsupials, and placental mammals are subclasses of mammals. Almost all living mammals are placental mammals, which are divided into many orders.

## Lesson Review Questions

### Recall

1. Describe the two traits that define the mammal class.
2. Outline variation in the foods that mammals eat.
3. Identify three orders of placental mammals.

### Apply Concepts

4. When working out in the heat, you need to drink extra fluids to avoid dehydration. Explain why.
5. Which type of mammalian diet do you eat?

### Think Critically

6. Explain how shivering helps to keep you warm on a cold day.
7. Contrast pros and cons to mother and offspring of the reproductive methods of placental, marsupial and monotreme mammals.

## Points to Consider

Human beings are mammals. Like other mammals, we have hair and mammary glands. The subclass in which the human species is classified is the placental mammals.

1. In which placental mammal order is the human species placed?
2. What are some unique traits of this order of mammals?

# 14.3 Primates

## Lesson Objectives

- Define primates, and identify primate traits.
- Describe primate habitats and diets.

## Lesson Vocabulary

- brachiation
- opposable thumb
- primate
- prosimian

## Introduction

In many ways, humans are unique among mammals. For example, we have bigger brains and a greater ability to learn than any other species in the mammalian class. In many ways, however, we are typical of the mammalian order to which we belong. That order is the Primate Order. To fully understand what it means to be human, you need to know more about this fascinating order of mammals.

## What Is a Primate?

A primate is a mammal in the Primate Order of placental mammals. In addition to human beings, this order consists of lemurs, tarsiers, monkeys, and apes. It includes mammals that range in size from the tiny mouse lemur, which weighs only 30 g (about an ounce), to the majestic gorilla, an ape that may weigh as much as 200 kg (440 lb). Both a mouse lemur and gorilla are pictured in **Figure** 14.19.

### Primate Groups

Primates are generally divided into prosimian and non-prosimian primates.

- Primates called prosimians are generally smaller. There are also far fewer of them. Prosimians include lemurs, such as the mouse lemur in **Figure** 14.19, and lorises. Prosimians are thought to be more similar to the earliest primates.
- All other primates are non-prosimian primates. They are placed in groups that include tarsiers, New World (Central and South America) monkeys, Old World (Africa and Asia) monkeys, apes, and humans. You can see examples of non-prosimian primates in **Figure** 14.20.

FIGURE 14.19
Primates: mouse lemur (left) and gorilla (right)

FIGURE 14.20
Non-prosimian primates: (from left to right) Tarsier, Squirrel monkey (New World monkey), Vervet (Old World monkey), Orangutan (ape).

## Primate Traits

A number of traits set primates apart from other orders of placental mammals. Primates evolved from tree-living, or arboreal, ancestors. As a result, many primate traits are adaptations for life in the trees. Living in trees requires good grasping ability. Being able to judge distances is also important.

- Primates have five digits (fingers or toes) on each extremity. Unlike the hooves of horses or the paddles of whales, the digits of primates are relatively unspecialized. Therefore, they can be used to do a variety of tasks, including grasping branches and holding tools.
- Most primates have opposable thumbs. An opposable thumb can be brought into opposition with the other fingers of the same hand. This allows the hand to grasp and hold things.
- Primates usually rely more on the sense of vision rather than the sense of smell, which is the dominant sense in many other mammals. The importance of vision in primates is reflected by the bony socket that surrounds and protects the primate eye. Primates have widely spaced eyes in the same plane that give them stereoscopic (3-D) vision, needed for judging distances. Some primates, including humans, have also evolved color vision.
- Primates tend to have bigger brains for their body size than other mammals. This is reflected in their relatively high level of intelligence and their ability to learn new behaviors.
- Primates have slower rates of development than other mammals their size. They reach maturity later and have longer lifespans. Being dependent on adults for a long maturation period gives young primates plenty of time to learn from their elders.

## Primate Habitats and Diets

Except for humans and a few other species, most modern primates still live in trees at least some of the time. They live primarily in tropical rain forests of Central and South America, Africa, and South Asia. Some primates, such as the gibbon in **Figure** 14.21, have long arms and curving fingers that allow them to swing from branch to branch high up in trees. This way of traveling is called brachiation. You can watch a gibbon brachiating in this amazing video: http://www.arkive.org/white-handed-gibbon/hylobates-lar/video-06a.html

Multimedia

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Fruit is the preferred food for almost all primates except humans. However, most primate species are omnivorous and consume a variety of plant and animal foods. For example, they may eat leaves, seeds, bird eggs, insects, and other small animals. Chimpanzees may band together and hunt for animals to kill and eat. They may even sharpen sticks and use them as spears when they hunt. Watch this video to see the incredible teamwork of a group of chimpanzees hunting a monkey: https://www.youtube.com/watch?v=A1WBs74W4ik .

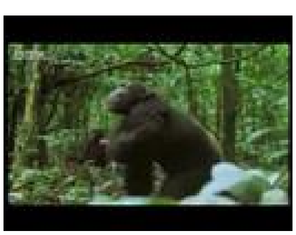

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FIGURE 14.21
This gibbon is specialized for swinging through trees from branch to branch.

## Lesson Summary

- A primate is a mammal in the Primate Order of placental mammals. Primates include lemurs, lorises, tarsiers, New and Old World monkeys, apes, and humans. Primate traits, such as five digits on each extremity and stereoscopic vision, may reflect their arboreal origins.
- Most modern primates, except for humans, live in tropical rainforests. Most also subsist on an omnivorous diet. They may prefer fruit but also consume a variety of other plant and animal foods.

## Lesson Review Questions

### Recall

1. What are primates?
2. Identify three primate traits.
3. Describe the distribution and diet of primates.

### Apply Concepts

4. Why do you think stereoscopic vision is important to an animal that brachiates? What activities do you do for which stereoscopic vision is important?

### Think Critically

5. Compare and contrast prosimian and non-prosimian primates.
6. Relate the rate of primate development to the importance of learning in primates.

## Points to Consider

Mammals in general and primates in particular are noted for their ability to learn.

1. Are mammals the only animals that can learn?
2. How do animals learn new behaviors?

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# CHAPTER 15 MS Animal Behavior

## Chapter Outline



The ants in this picture are known as leafcutter ants. They cut leaves and carry them back to their nest. In the nest, ants will chew the leaves and then use them as a garden for growing fungi. The fungi will provide food for ant larvae in the nest.

Are young leafcutter ants taught how to cut and carry leaves by older ants? Or do they just "know" how to do it when they hatch? Animals have different behaviors for different reasons. Some of the behaviors are learned. Some of the behaviors animals know how to do without any teaching or training. In the case of leafcutter ants, the ants know from the time they hatch how to cut and carry leaves. No one needs to teach them how to do it. Is this different from human behaviors? Are there certain behaviors you know how to do from birth? Or do you have to learn every new behavior? You'll find answers to questions such as these when you read this chapter.

# 15.1 Understanding Animal Behavior

## Lesson Objectives

- Describe how animal behaviors can increase fitness and evolve through natural selection.
- Define innate behavior, and give examples of innate behaviors in humans and other animals.
- Define learned behavior, and explain different ways that animals can learn new behaviors.

## Lesson Vocabulary

- animal behavior
- conditioning
- habituation
- innate behavior
- insight learning
- instinct
- learned behavior
- observational learning
- reflex behavior

## Introduction

Animal behavior is any way that an animal interact with other animals or the environment. An animal may carry out behaviors alone or with other animals. The photos in **Figure** 15.1 show just a few of the ways that animals behave. Look at the pictures and read about the behaviors they represent. Why do you think the animals are behaving in these ways? And how do the behaviors come about? Which, if any of them, have to be learned?

## Animal Behavior and Natural Selection

Why do animals behave in the ways pictured in **Figure** 15.1? The specific answer depends on what the behavior is. Male flamingoes put on a noisy group show in order to attract females for mating. Frogs call out to attract mates or to warn other frogs to stay away from their territory. Baby ducks follow their mother to stay close to her for protection and survival. Male elephant seals fight to defend their hunting territory from each other. All of these behaviors have the purpose of promoting reproduction or survival.

Like the animals pictured above, all animals have behaviors that help them achieve these basic ends. Behaviors that help animals reproduce or survive increase their fitness. Animals with greater fitness have a better chance of passing their genes to the next generation. If genes control behaviors that increase fitness, the behaviors become more common in the species. In other words, they evolve by natural selection.

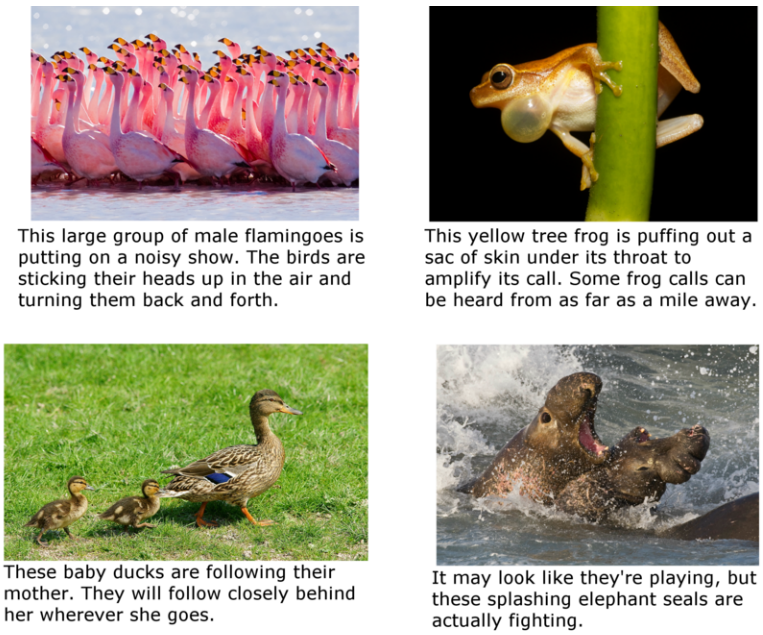


FIGURE 15.1

Examples of animal behavior: (clockwise from top left) flamingoes, frog, elephant seals, ducks.

## Innate Behaviors

All of the animal behaviors pictured in **Figure** 15.1 are ways that animals act without being taught to act in these ways. Such behaviors are called innate. An innate behavior is any behavior that occurs naturally in all the animals of a given species. An innate behavior is also called an instinct. The first time an animal performs an innate behavior, the animal does it well. The animal doesn't have to practice the behavior in order to get it right or to become better at doing it. Innate behaviors are also predictable. All members of a species perform an innate behavior in the same way.

### Other Examples of Innate Behaviors

There are many other examples of innate behaviors in animals. Even behaviors that seem complex and difficult may be innate. For example, honeybees perform dances in order to communicate about food sources. When a honeybee, like the one in **Figure** 15.2, finds a food source, it returns to its hive and does a dance, called the waggle dance. The way the bee moves during its dance tells other bees in the hive where to find the food. Honeybees can do the waggle dance without learning it from other bees, so it is an innate behavior. Watch this video to see the waggle dance and find out what it communicates: http://video.nationalgeographic.com/video/weirdest-bees-dance


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Three other examples of innate behavior are pictured in **Figure** 15.3. If an animal were to perform such behaviors incorrectly, it might be less likely to survive or reproduce. Can you explain why each behavior pictured in the figure

FIGURE 15.2
This honeybee will do a waggle dance when it returns to the hive to let the other bees in the hive know where it found food.

is important for reproduction or survival?

FIGURE 15.3
Examples of innate behaviors in animals: (left to right) wasp building a nest, caterpillar making a cocoon, and baby birds gaping for food.

### Innate Behaviors in Humans

Innate behaviors occur in all animals. However, the more intelligent a species is, the fewer innate behaviors it generally has. The human species is the most intelligent animal species, and it has very few innate behaviors. The only innate behaviors in humans are reflex behaviors. A reflex behavior is a simple response that always occurs when a certain stimulus is present.

Human reflex behaviors occur mainly in babies. You may have seen a baby exhibit the grasp reflex shown in **Figure** 15.4. Whenever an object, such as someone's finger, is placed in the baby's palm, the baby grasps it. Babies respond this way from birth to about 6 months of age. It's easy to see why this might help a baby survive. Grabbing onto something could keep a baby from falling and being injured.

FIGURE 15.4
The grasp reflex in a human baby

## Learned Behavior

Other than infant reflexes, human behaviors are mainly learned rather than innate behaviors. Learned behavior is behavior that occurs only after experience or practice. Did you ever teach a dog to sit on command? That's an example of a learned behavior. The dog wasn't born knowing that it should sit when it hears the word sit. The dog had to learn the behavior.

Most animals are capable of learning, but animals that are more intelligent are better at learning and depend more on learned behaviors. The big advantage of learned behaviors over innate behaviors is that learned behaviors are flexible. They can be changed to suit changing conditions.

Human beings depend on learned behaviors more than any other species. Think about some of the behaviors you have learned. They might include making a bed, riding a bicycle, using a computer, and playing a sport, to name just a few. You may have learned each of the behaviors in different ways. There are several different ways in which animals learn. They include habituation, observational learning, conditioning, learning through play, and insight learning.

### Habituation

One of the simplest ways of learning that occurs in just about all animals is habituation. Habituation means learning to get used to something after being exposed to it repeatedly. It usually involves getting used to something that is frightening or annoying but not dangerous.

Look at the crows in **Figure** 15.5. They are no longer afraid of the scarecrow. They have gotten used to a "human" in this location and know that it won't hurt them. Habituation lets animals ignore things that won't harm them. It allows them to avoid wasting time and energy escaping from things that aren't really dangerous.

### Observational Learning

Do you remember how you learned to tie your shoe laces? You may have watched and copied the behavior of your mom or an older sibling. Learning by watching and copying the behavior of someone else is called observational learning. Human children learn many behaviors this way.

Other animals also learn through observational learning. For example, the wolves in **Figure** 15.6 learned how to hunt in a group by watching and copying the hunting behaviors of older wolves in their pack.

FIGURE 15.5
These crows have learned through habituation that the scarecrow is harmless. They have become used to its being in this spot and learned that it is not dangerous.

FIGURE 15.6
Observational learning explains how wolves know how to hunt as a group.

### Conditioning

Conditioning is a way of learning that involves a reward or punishment. If you ever trained a dog to obey a command, you probably gave the dog a tasty treat each time he performed the desired behavior. It may not have been very long before the dog would reliably follow the command in order to get the treat. This is an example of conditioning that involves a reward.

Conditioning does not always involve a reward. It can involve a punishment instead. For example, a dog might be scolded each time she jumps up on the sofa. After repeated scolding, she may learn to stay off the sofa.

Conditioning occurs in nature as well. Here are just two examples:

- Bees learn to find nectar in certain types of flowers because they have found nectar in those types of flowers before. In this case, the behavior is learned because it is rewarded with nectar.
- Many birds learn to avoid eating monarch butterflies, like the one pictured in **Figure** 15.7. Monarch butterflies taste bad and make birds sick. In this case, the behavior is learned because it is punished with a nasty taste and illness.

FIGURE 15.7
Birds learn through conditioning to avoid eating monarch butterflies.

### Learning Through Play

Many animals, especially mammals, spend a lot of time playing when they are young. Although playing is fun, it's likely that animals play for other reasons as well. Learning behaviors that will be important in adulthood is one likely outcome of play. Bear cubs, like the two bear cubs in **Figure** 15.8, frequently play together. They often pretend to be fighting. By play fighting they may be learning skills such as fighting and hunting that they will need as adults.

FIGURE 15.8
Bear cubs play fighting

Other young animals may play in different ways. For example, young deer play by running and kicking up their hooves. This may help them learn how to escape from predators. Human children learn by playing as well. For example, playing games and sports may help them learn how to follow rules and work with others.

### Insight Learning

Insight learning is learning from past experiences and reasoning. It generally involves coming up with new ways to solve problems. Insight learning generally happens quickly. An animal has a sudden flash of insight. Insight learning requires relatively great intelligence. Human beings use insight learning more than any other species. They have used it to invent the wheel to land astronauts on the moon.

Think about problems you have solved. You may have figured out how to solve a new type of math problem or how to get to the next level of a video game. If you relied on your past experiences and reasoning to do it, then you were using insight learning.

One type of insight learning is making tools to solve problems. Scientists used to think that humans were the only animals intelligent enough to make tools. In recent decades, however, there have been many observations of other animal species using tools. They range from monkeys and chimpanzees to crows.

You can see a monkey using a stone tool in **Figure** 15.9. She is using the stone to crack open the shells of marine invertebrates such as oysters. Chimpanzees have been observed using sticks to "fish" for termites in a termite mound. Crows have been seen bending wire to form a hook in order to pull food out of a tube. Behaviors such as these show that other species of animals besides humans can use their experience and reasoning to solve problems. They can learn through insight.

FIGURE 15.9

Monkey using a stone tool to crack oyster shells

## Lesson Summary

- Animal behavior is any way that animals interact with each other or their environment. Many animal behaviors promote fitness by increasing the chances of surviving or reproducing. If such behaviors are controlled by genes, they evolve by natural selection.
- Innate behavior is any behavior that occurs naturally in all the animals of a given species. It doesn't have to be learned, and it occurs in the same way in all members of the species. Examples of innate behaviors include the waggle dance in honeybees and the grasp reflex in human babies.
- Learned behavior is any behavior that occurs only after experience or practice. The more intelligent a species is, the more it depends on learned behaviors, which have the advantage of being flexible. Ways in which animals learn behaviors include habituation, observational learning, conditioning, learning through play, and insight learning.

## Lesson Review Questions

### Recall

1. Define animal behavior.
2. Identify three examples of innate behavior, including one in humans.
3. Describe three different ways that an animal might learn a new behavior.

### Apply Concepts

4. Explain how you could use conditioning to teach a dog to lie down on command.

### Think Critically

5. Compare and contrast innate and learned behaviors.
6. Explain how innate behaviors evolve through natural selection.

## Points to Consider

Some animal behaviors have the purpose of sharing information with other animals. This is called communication.

1. What are some ways animals communicate?
2. Why do animals communicate? What purposes might it serve?

# 15.2 Types of Animal Behavior

## Lesson Objectives

- Describe ways that animals may communicate, and explain why communication is essential for social animals.
- Give examples of social animals and how they cooperate.
- Identify animal behaviors involved in reproduction.
- Describe defensive behaviors, and explain why they occur.
- Give an overview of behaviors that occur in annual or daily cycles.

## Lesson Vocabulary

- biological clock
- circadian rhythm
- communication
- cooperation
- diurnal
- hibernation
- language
- mating
- migration
- nocturnal
- social animal
- territorial

## Introduction

The man in the foreground of **Figure** 15.10 is a sign language interpreter. He's communicating the remarks of the speaker behind him to people who can't hear. When you think of communication, you may think of spoken or written language. But as the figure shows, communication can take other forms as well.

Although humans may be the only species of animal to communicate with spoken or written language, we are far from being the only species of animal that communicates. What other animal species can communicate? And how and why do they do it? In this chapter, you'll find out.

## Communication

Communication is any way that animals share information. Many animals live in social groups. For these animals, being able to communicate is essential. Communicating increases the ability of group members to cooperate and

FIGURE 15.10
A sign language interpreter mainly uses his hands to communicate.

avoid conflict. Communication may help animals work together to find food and defend themselves from predators. It also helps them find mates and care for their offspring. In addition, communication helps adult animals teach the next generation learned behaviors. Therefore, communication generally improves the chances of animals surviving and reproducing.

### How Nonhuman Animals Communicate

Different animal species use a range of senses for communicating. They may communicate using hearing, sight, or smell.

- Animals that communicate by making and hearing sounds include frogs, birds, and monkeys. Frogs call out to attract mates. Birds may use calls to warn other birds to stay away or to tell them to flock together. Monkeys use warning calls to tell other troop members that a predator is near.
- Animals may communicate by sight with gestures, body postures, or facial expressions. Look at the cat in **Figure** 15.11. There's no mistaking the meaning of its arched back, standing hair, and exposed fangs. It's clearly saying "stay away, or else!" Bees communicate with a waggle dance. They use it to tell other bees where food is located.
- A wide range of animals communicate by releasing chemicals they can smell or detect in some other way. They include animals as different as ants and dogs. An ant, for example, releases chemicals to mark the trail to a food source. Other ants in the nest can detect the chemicals with their antennae and find the food. Look at the dog in **Figure** 15.12. It's marking its territory with a chemical that it releases in urine. It does this to keep other dogs out of its yard.

### How Humans Communicate

Humans communicate with each other in a variety of ways. Chiefly, however, we use sound and sight to share information.

The most important way that humans communicate is with language. Language is the use of symbols to communicate. In human languages, the symbols are words. Words may stand for things, people, actions, feelings, or ideas. By combining words in sentences, language can be used to express very complex thoughts.

Another important way that humans communicate is with facial expressions. Look at the facial expressions of the

FIGURE 15.11
A cat uses body language and a hissing sound as a threat to potential predators.

FIGURE 15.12
A dog urinates on a tree to mark its territory.

girl in **Figure** 15.13. You can probably tell what emotion she is trying to convey with each expression. From left to right, she looks happy, sad, and angry.

FIGURE 15.13
Human facial expressions can communicate a range of emotions.

Humans also commonly use gestures and body postures to communicate. You might answer a question by shrugging your shoulders, which means "I don't know." You might use a thumbs-up gesture when a friend scores a goal to mean "Good job." Can you think of other gestures you commonly use to communicate with others?

## Social Behaviors

Without communication, animals would not be able to live together in groups. Animals that live in groups with other members of their species are called social animals. Social animals include many species of insects, birds, and mammals. Specific examples are ants, bees, crows, wolves, and human beings.

### Social Animals

Some species of animals are very social. In these species, members of the group depend completely on one another. That's because different animals within the group have different jobs. Therefore, group members must work together for the good of all. Most species of bees and ants are highly social animals.

Look at the honeybees in **Figure** 15.14. Honeybees live in colonies that may consist of thousands of individual bees. Generally, there are three types of adult bees in a colony: workers, a queen, and drones.

- Most of the adult bees in a colony are workers. They cooperate to build the hive, collect food, and care for the young. Each worker has a specific task to perform, depending on its age. Young worker bees clean the hive and feed the offspring. Older worker bees build the waxy honeycomb or guard the hive. The oldest worker bees leave the hive to find food.
- Each colony usually has one queen. Her only job is to lay eggs.
- The colony also has a relatively small number of male drones. Their only job is to mate with the queen.

FIGURE 15.14
Some of the worker bees in a honeybee colony

### Cooperation

Bees and other social animals must cooperate to live together successfully. Cooperation means working together with others. Members of the group may cooperate by dividing up tasks, defending each other, and sharing food. The ants in **Figure** 15.15 are sharing food. One ant is transferring food directly from its mouth to the mouth of another colony member.

Besides social insects, animals in many other species also cooperate. For example, in meerkat colonies, young female meerkats act as babysitters. They take care of the baby meerkats while their parents are out looking for food.

## Reproductive Behaviors

Some of the most important behaviors in animals involve reproduction. They include behaviors to attract mates and behaviors for taking care of the young.

FIGURE 15.15
Mouth-to-mouth transfer of food is common in some species of ants.

## Courtship and Mating

Mating is the pairing of an adult male and an adult female for the purpose of reproduction. In many animal species, females choose the males they will mate with. For their part, males try to show females that they would be better mates than other males. To be chosen as mates, males may perform courtship behaviors. These are special behaviors that help attract a mate. Male courtship behaviors are meant to get the attention of females and show off a male's traits.

Different species of animals have different courtship behaviors. An example of courtship behavior in birds is shown in **Figure** 15.16. The bird in the picture is a male sharp-tailed grouse, and he's doing a courtship dance. Each year in the spring, as many as two dozen grouse males gather in a grassy area to perform their courtship dance. Female grouse watch the dance and then mate with the males that put on the best display. You can see a group of male grouse performing their courtship dance in this short video: https://www.youtube.com/watch?v=T27c3OvorZk .

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## Caring for Offspring

In most species of birds and mammals, one or both parents care for the young. This may include building a nest or other shelter. It may also include feeding the young and protecting them from predators. Caring for the young increases their chances of surviving. This, in turn, increases the parents' fitness, so such behaviors evolve by natural selection.

Emperor penguins make great sacrifices to take care of their young. After laying an egg, a penguin mother returns to the sea for two months to feed. Her mate stays behind to keep the egg warm. He balances the egg on top of his feet to keep it warm for the entire time the mother is away. During this time, he goes without food. To survive the cold, he huddles together with other males. If the chick hatches before the mother returns, the father feeds it with a high-protein, high-fat substance he produces just for this purpose. You can see an emperor penguin father feeding his chick in **Figure** 15.17.

FIGURE 15.16

A male sharp-tailed grouse does a courtship dance to attract a female for mating.

FIGURE 15.17

An emperor penguin father feeds his chick.

## Defensive Behaviors

Some species of animals are territorial. This means that they defend an area that typically includes their nest and enough food for themselves and their offspring. Animals generally don't fight to defend their territory. Instead, they are more likely to put on a defensive display. For example, male gorillas may pound on their chest and thump the ground to warn other male gorillas to stay away from their territory. This gets the message across without physical conflict, which would be riskier and take more energy. You can see a male gorilla putting on a defensive display in this video: https://www.youtube.com/watch?v=pSif5MR9nq8 .

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## Behaviors that Happen in Cycles

Many animal behaviors occur in repeated cycles. Some cycles of behavior repeat each year. Other cycles of behavior repeat each day.

### Annual Cycles

Examples of behaviors with annual cycles include migration and hibernation. Both are innate behaviors. They are triggered by changes in the environment, such as the days growing shorter in the fall.

- Migration is the movement of animals from one place to another. Migration is most common in birds, fish, and insects. In the Northern Hemisphere, many species of birds, such as finches and swallows, travel south for the winter. They migrate to areas where it is warmer and where more food is available. They return north in the spring. Migrating animals generally follow the same route each year. They may be guided by the position of the sun, Earth's magnetic field, or other clues in the environment.
- Hibernation is a state in which an animal's body processes slow down and its body temperature falls. A hibernating animal uses less energy than usual. This helps it survive during a time of year when food is scarce. Hibernation may last for weeks or even months. Examples of animals that hibernate include some species of bats, squirrels, snakes, and insects (see **Figure** 15.18).

FIGURE 15.18

This ladybug is looking for a safe place to hibernate over the winter.

### Daily Cycles

Many animals go through daily cycles. Daily cycles of behavior are called circadian rhythms. For example, most animals go to sleep when the sun sets down and wake up when the sun rises. These animals are active during the day and called diurnal. Other animals go to sleep when the sun rises and wake up when the sun sets. These animals are active during the night and called nocturnal. Many owls, like the owls in **Figure** 15.19, are nocturnal. Like some other nocturnal animals, they have large eyes that are specially adapted for seeing when light levels are low.

FIGURE 15.19
By hunting at night, owls can avoid competing with other hunting birds such as hawks.

In many species, including the human species, circadian rhythms are controlled by a tiny structure called the biological clock. It is located in the hypothalamus, which is a gland at the base of the brain. The biological clock sends signals to the body. The signals cause regular changes in behavior and body processes. The biological clock, in turn, is controlled by changes in the amount of light entering the eyes. That's why the biological clock causes changes that repeat every 24 hours.

## Lesson Summary

- Communication is any way that animals share information. For animals that live in social groups, communication is essential. Animals may use a range of senses for communicating. The most important way that humans communicate is with language.
- Social animals are animals that live in groups with other members of their species. Different animals within the group may have different jobs so group members must cooperate for the good of all.
- Some of the most important behaviors in animals involve reproduction. They include mating and courtship behaviors as well as behaviors for protecting and feeding offspring.
- Some species of animals are territorial and defend their territory. They are more likely to put on a defensive display than engage in actual physical conflict.
- Many animal behaviors occur in repeated cycles. Migration and hibernation are examples of behaviors with annual cycles. Sleeping and waking are examples of behaviors with daily cycles.

## Lesson Review Questions

### Recall

1. What is communication? Give an example of communication in nonhuman animals.
2. What is the purpose of courtship behaviors in animals?
3. Why do animals such as male gorillas put on defensive displays?

### Apply Concepts

4. What are two different ways you could communicate an emotion such as fear to another person.

### Think Critically

5. Explain how honeybees in a colony work together to promote the survival of all colony members.
6. Why does providing care for offspring increase the fitness of adult animals?
7. Compare and contrast behaviors with annual cycles and behaviors with daily cycles.

## Points to Consider

Human beings have the biggest brains for their body size and are the most intelligent animals. As a result, they depend more than other animals on learned behaviors.

1. Besides their big brains and intelligence, how else might human beings differ from other animals?
2. What organ systems do you think make up the human body?

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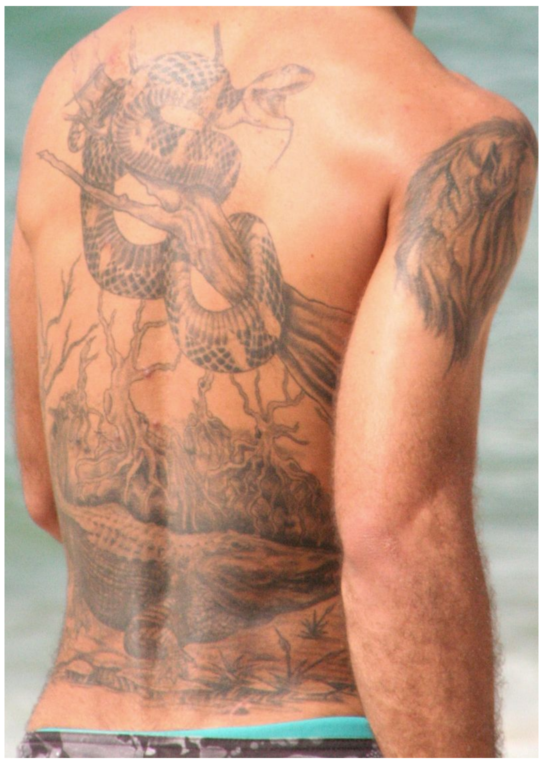
# CHAPTER 16 MS Skin, Bones, and Muscles

## Chapter Outline





The man in this photo has decorated his skin with tattoos. He's using his skin like an artist's canvas. It's a large canvas to cover. The skin is thin but there's so much of it that it makes up the human body's largest organ. You'll learn more about the skin and other organs of the human body when you read this chapter.

# 16.1 Introduction to the Human Body

## Lesson Objectives

- Describe the levels of organization of the human body.
- Explain how human organ systems work together to maintain homeostasis.

## Lesson Vocabulary

- connective tissue
- epithelial tissue
- muscle tissue
- nervous tissue

## Introduction

The human body has often been compared to a machine. Think about common household machines, such as printers and washing machines. What do they have in common? Each machine consists of many parts, and the parts work together to perform a particular job. The human body is like a machine in these ways. It could be called the most fantastic machine on Earth. Read on to learn more about the human "machine" and its parts. See whether you agree that the human body is fantastic.

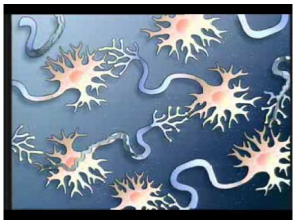
## Organization of the Human Body

The basic building blocks of the human body are cells. Human cells are organized into tissues, tissues are organized into organs, and organs are organized into organ systems.

### Human Cells

The average human adult consists of an incredible 100 trillion cells! Cells are the basic units of structure and function in the human body, as they are in all living things. Each cell must carry out basic life processes in order to survive and help keep the body alive.

Most human cells also have characteristics for carrying out other, special functions. For example, muscle cells have extra mitochondria to provide the energy needed to move the body. You can see examples of these and some other specialized human cells in **Figure** 16.1. To learn more about specialized human cells and what they do, watch this video: http://www.youtube.com/watch?v=I8uXewS9dJU .



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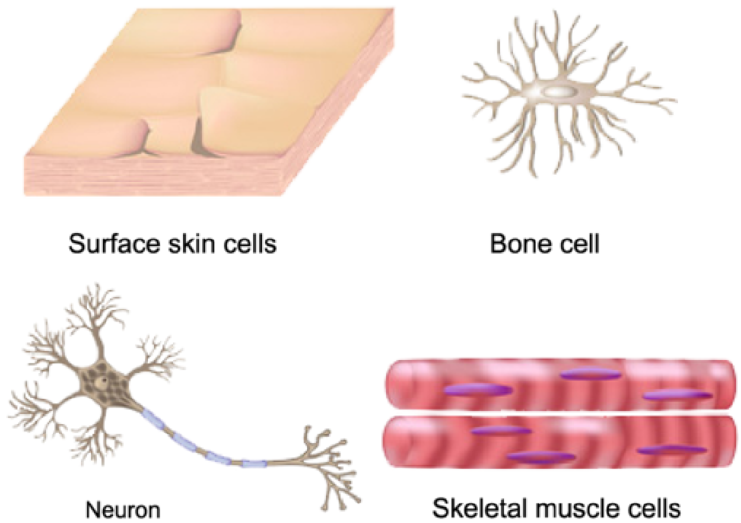



FIGURE 16.1

Different types of cells in the human body are specialized for specific jobs.

### Human Tissues

Specialized cells are organized into tissues. A tissue is a group of specialized cells of the same kind that perform the same function. There are four basic types of human tissues: connective, epithelial, muscle, and nervous tissues. The four types are shown in **Figure** 16.2.

- Connective tissue consists of cells that form the body's structure. Examples include bone and cartilage, which protect and support the body. Blood is also a connective tissue. It circulates and connects cells throughout the body.
- Epithelial tissue consists of cells that cover inner and outer body surfaces. Examples include skin and the linings of internal organs. Epithelial tissue protects the body and its internal organs. It also secretes substances such as hormones and absorbs substances such as nutrients.
- Muscle tissue consists of cells that can contract, or shorten. Examples include skeletal muscle, which is attached to bones and makes them move. Other types of muscle include cardiac muscle, which makes the heart beat, and smooth muscle, which is found in other internal organs.
- Nervous tissue consists of nerve cells, or neurons, which can send and receive electrical messages. Nervous tissue makes up the brain, spinal cord, and other nerves that run throughout the body.

### Human Organs

The four types of tissues make up all the organs of the human body. An organ is a structure composed of two or more types of tissues that work together to perform the same function. Examples of human organs include the skin,

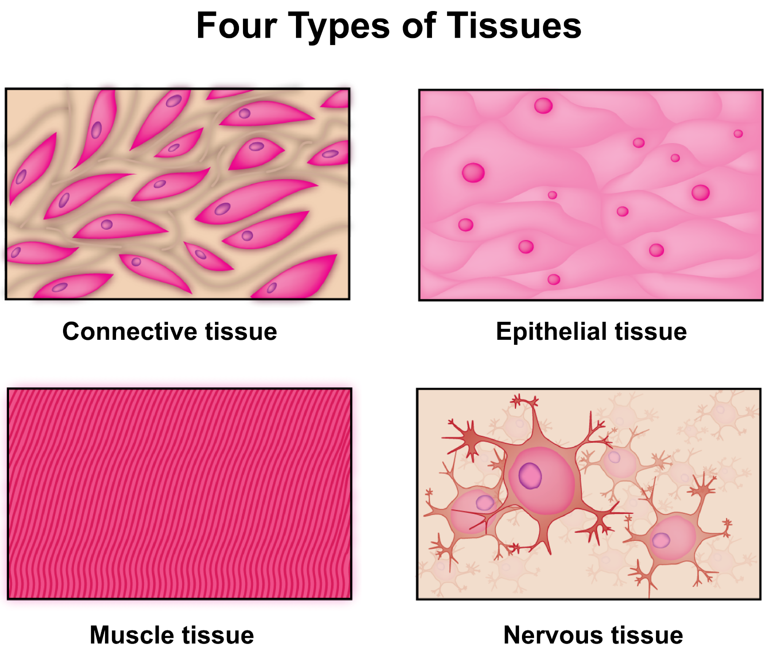



FIGURE 16.2
The human body consists of these four tissue types.

brain, lungs, kidneys, and heart. Consider the heart as an example. **Figure** 16.3 shows how all four tissue types work together to make the heart pump blood.

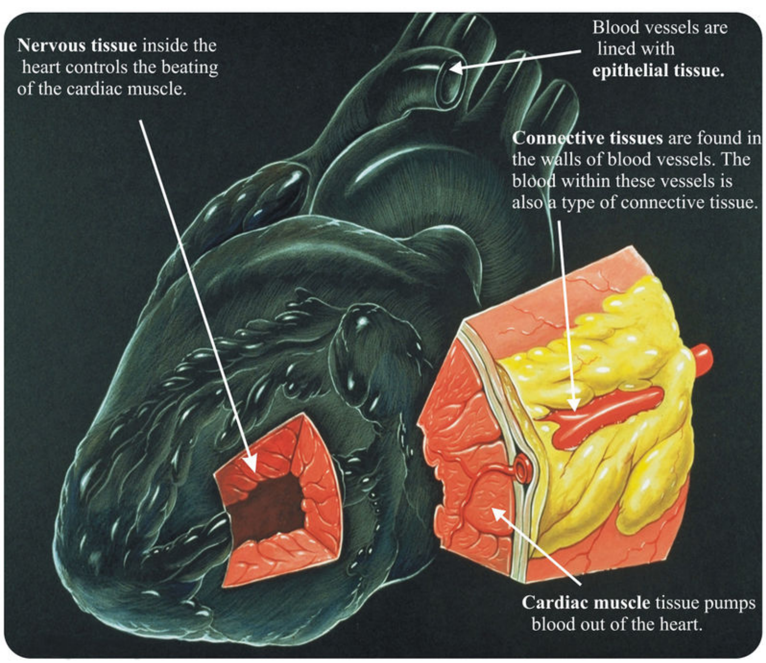



FIGURE 16.3
Tissues in the heart work together to pump blood.

## Human Organ Systems

Human organs are organized into organ systems. An organ system is a group of organs that work together to carry out a complex function. Each organ of the system does part of the overall job. For example, the heart is an organ in the circulatory system. The circulatory system also includes the blood vessels and blood. There are many different human organ systems. **Figure** 16.4 shows six of them and gives their functions.

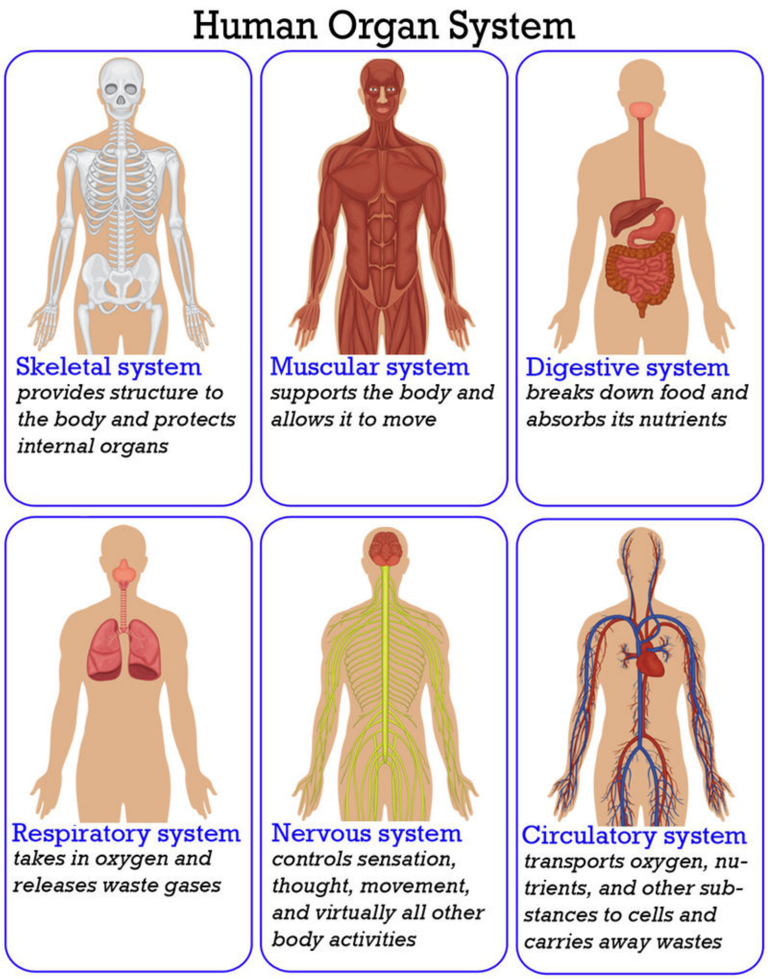



FIGURE 16.4
Six human organ systems

## How Human Organ Systems Work Together

The organ systems of the body work together to carry out life processes and maintain homeostasis. The body is in homeostasis when its internal environment is kept more-or-less constant. For example, levels of sugar, carbon dioxide, and water in the blood must be kept within narrow ranges. This requires continuous adjustments. For example:

- After you eat and digest a sugary snack, the level of sugar in your blood quickly rises. In response, the endocrine system secretes the hormone insulin. Insulin helps cells absorb sugar from the blood. This causes the level of sugar in the blood to fall back to its normal level.
- When you work out on a hot day, you lose a lot of water through your skin in sweat. The level of water in the blood may fall too low. In response, the excretory system excretes less water in urine. Instead, the water is returned to the blood to keep water levels from falling lower.

What happens if homeostasis is not maintained? Cells may not get everything they need, or toxic wastes may build up in the body. If homeostasis is not restored, it may cause illness or even death.

## Lesson Summary

- The basic building blocks of the human body are cells. Human cells are organized into tissues, tissues are organized into organs, and organs are organized into organ systems.
- The organ systems of the body work together to carry out life processes and maintain homeostasis.

## Lesson Review Questions

### Recall

1. Outline how the human body is organized.
2. List three examples of specialized human cells.
3. What are the four types of human tissues?
4. Identify and state the functions of three human organ systems.

### Apply Concepts

5. Describe an example of two or more organ systems working together to maintain homeostasis.

### Think Critically

6. Compare and contrast muscle tissue and epithelial tissue.

## Points to Consider

The skin is a familiar organ made of epithelial tissue.

1. To which organ system does the skin belong?
2. What other organs are in this organ system?

# 16.2 The Integumentary System

## Lesson Objectives

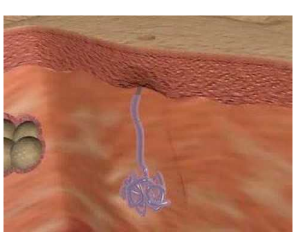
- List organs of the integumentary system
- Describe the two layers of the skin.
- Identify functions of the skin.
- Explain what you can do to help keep your skin healthy.
- Outline the structure and functions of hair and nails.

## Lesson Vocabulary

- acne
- dermis
- epidermis
- hair follicle
- integumentary system
- melanin
- melanocyte
- sebaceous gland
- sebum
- sweat gland

## Introduction

The skin is the major organ of the integumentary system. Hair and nails are also part of this organ system. All three organs provide a protective covering for the body. They also help the body maintain homeostasis. For a good video overview of the integumentary system, watch this video: http://www.youtube.com/watch?v=IAAt_MfIJ-Y .



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## Structure of the Skin

From the outside, the skin looks plain and simple, as you can see in **Figure** 16.5. But at a cellular level, there's nothing plain or simple about it. A single square inch of skin contains about 20 blood vessels, hundreds of sweat glands, and more than a thousand nerve endings. It also contains tens of thousands of pigment-producing cells. Clearly, there is much more to skin than meets the eye! For a dramatic introduction to the skin, watch this video: http://www.youtube.com/watch?v=uH_uzjY2bEE .

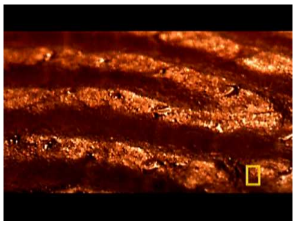

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FIGURE 16.5

The skin is much more complex that it appears from the outside.

The skin is only about 2 mm thick, or about as thick as the cover of a book. Although it is very thin, it consists of two distinct layers, called the epidermis and the dermis. You can see both layers and some of their structures in **Figure** 16.6. Refer to the figure as you read about the epidermis and dermis below.

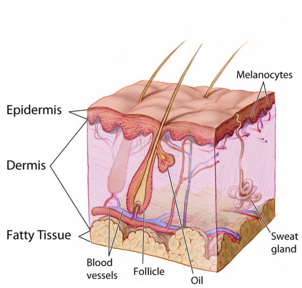


FIGURE 16.6

Layers and structures of the skin

## Epidermis

The epidermis is the outer layer of skin. It consists almost entirely of epithelial cells. There are no blood vessels, nerve endings, or glands in this skin layer. Nonetheless, this layer of skin is very active. It is constantly being renewed. How does this happen?

1. The cells at the bottom of the epidermis are always dividing by mitosis to form new cells.
2. The new cells gradually move up through the epidermis toward the surface of the body. As they move, they produce the tough, fibrous protein called keratin.
3. By the time the cells reach the surface, they have filled with keratin and died. On the surface, the dead cells form a protective, waterproof layer.
4. Dead cells are gradually shed from the surface of the epidermis. As they are shed, they are replaced by other dead cells that move up from below.

The epidermis also contains cells called melanocytes. You can see a melanocyte in **Figure** 16.7. Melanocytes produce melanin. Melanin is a brown pigment that gives skin much of its color. Everyone's skin has about the same number of melanocytes per square inch. However, the melanocytes of people with darker skin produce more melanin. The amount of melanin that is produced depends partly on your genes and partly on how much ultraviolet light strikes your skin. The more light you get, the more melanin your melanocytes produce. This explains why skin tans when it's exposed to sunlight.

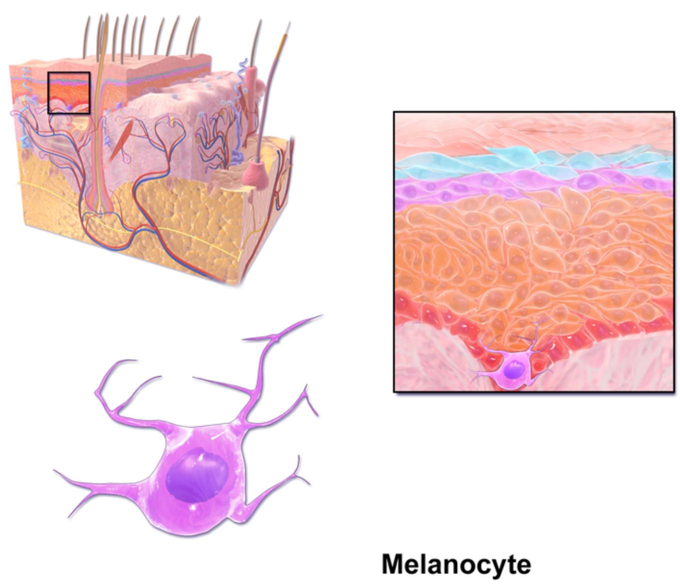


FIGURE 16.7
Melanocytes are located at the bottom of the epidermis.

## Dermis

The dermis is the inner layer of skin. It is made of tough connective tissue. The dermis is attached to the epidermis by fibers made of the protein collagen. The dermis is where most skin structures are located. Look again at **Figure** 16.7. You'll see that the dermis has blood vessels and nerve endings. The nerve endings explain why skin can sense pain, pressure, and temperature. If you cut your skin and it bleeds, the cut has penetrated the dermis and damaged a blood vessel. The cut probably hurts as well because of the nerve endings in this skin layer.

The dermis also contains hair follicles and two types of glands. You can see some of these structures in **Figure** 16.8.

- Hair follicles are structures where hairs originate. Each hair grows out of a follicle, passes up through the epidermis, and extends above the skin surface.
- Sebaceous glands are commonly called oil glands. They produce an oily substance called sebum. Sebum is secreted into hair follicles. Then it makes its way along the hair shaft to the surface of the skin. Sebum waterproofs the hair and skin and helps prevent them from drying out.
- Sweat glands produce the salty fluid known as sweat. Sweat contains excess water, salts, and other waste products. Each sweat gland has a duct that passes through the epidermis. Sweat travels from the gland through the duct and out through a pore on the surface of the skin.

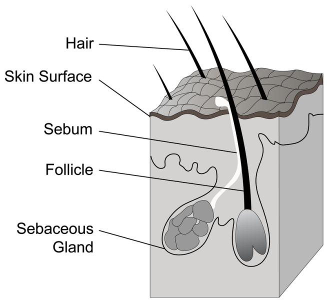


FIGURE 16.8

Structures in the dermis include hair follicles and sebaceous glands, which produce sebum.

## Skin Functions

You couldn't survive without your skin. It has many important functions. In several ways, it helps maintain homeostasis. The main function of the skin is controlling what enters and leaves the body. It prevents the loss of too much water from the body. It also prevents bacteria and other microorganisms from entering the body. Melanin in the epidermis absorbs ultraviolet light. This prevents the light from reaching and damaging the dermis.

The skin helps maintain a constant body temperature. It keeps the body cool in two ways. Sweat from sweat glands in the skin evaporates to cool the body. Blood vessels in the skin dilate, or widen, increasing blood flow to the body surface. This allows more heat to reach the surface and radiate into the environment. The opposite happens to retain body heat. Blood vessels in the skin constrict, or narrow, decreasing blood flow to the body surface. This reduces the amount of heat that reaches the surface so less heat is lost to the environment.

## Keeping Skin Healthy

What can you do to keep your skin healthy? The most important step you can take is to protect your skin from sun exposure. On sunny days, wear long sleeves and pants and a hat with a brim. Also apply sunscreen to exposed areas of skin. Protecting your skin in these ways will reduce damage to your skin by ultraviolet light. This is important because skin that has been damaged by ultraviolet light is at greater risk of developing skin cancer. This is true whether the damage is due to sunlight or the light in tanning beds.

About 85 percent of teens develop acne, like the boy in **Figure** 16.9. Acne is a condition in which pimples form on the skin. It is caused by a bacterial infection. It happens when the sebaceous glands secrete too much sebum. The excess oil provides a good place for bacteria to grow. Keeping the skin clean helps prevent acne. Over-the-counter products or prescription drugs may be needed if the problem is serious or doesn't clear up on its own.

FIGURE 16.9
Acne on a teenaged boy's forehead

## Hair and Nails

You may spend a lot of time and money on your hair and nails. You may think of them as accessories, like clothes or jewelry. However, like the skin, the hair and nails also play important roles in helping the body maintain homeostasis.

### Hair

Only mammals have hair. Hair is a fiber made mainly of the tough protein keratin. The cells of each hair are filled with keratin and no longer alive. The dead cells overlap each other, almost like shingles on a roof. They work like shingles as well, by helping shed water from hair.

Head hair helps protect the scalp from sun exposure. It also helps insulate the body. It traps air so heat can't escape from the head. Hair in eyelashes and eyebrows helps keep water and dust out of the eyes. Hairs inside the nostrils of the nose trap dust and germs in the air so they can't reach the lungs.

### Nails

Fingernails and toenails are made of specialized cells that grow out of the epidermis. They too are filled with keratin. The keratin makes them tough and hard. Their job is to protect the ends of the fingers and toes. They also make it easier to feel things with the sensitive fingertips by acting as a counterforce when things are handled.

## Lesson Summary

- The integumentary system consists of the skin, hair, and nails. All three organs provide a protective covering for the body and help maintain homeostasis.
- The skin consists of two distinct layers, an outer layer called the epidermis and an inner layer called the dermis. The epidermis is constantly being renewed as dead cells on the surface are shed. This layer contains melanin-producing melanocytes. The dermis contains blood vessels, nerve endings, hair follicles, and sebaceous and sweat glands.
- The skin prevents loss of water from the body and keeps out microorganisms. Melanin in the epidermis protects the dermis from damaging ultraviolet light. By dilating or contracting its blood vessels and releasing sweat, skin helps maintain a constant body temperature.
- The most important way to keep your skin healthy is to protect it from ultraviolet light. Over-exposure to ultraviolet light can cause skin cancer. Keeping the skin clean can help prevent acne.
- Head hair protects the scalp from ultraviolet light exposure and loss of body heat. Hair in eyelashes, eyebrows, and nostrils traps water, dust, and other irritants. Nails protect the ends of fingers and toes and enhance the sense of touch.

## Lesson Review Questions

### Recall

1. What is the integumentary system?
2. Outline how the epidermis is constantly being renewed.
3. Identify three functions of the skin.
4. How do sebaceous glands and sweat glands help maintain homeostasis?

### Apply Concepts

5. Why does it usually hurt to cut the skin but not the hair or nails?

### Think Critically

6. Compare and contrast the epidermis and dermis.
7. Explain the role of melanocytes in the skin.

## Points to Consider

You can see all the organs of your integumentary system because they cover the outside surface of your body. Most of the organs of your other body systems are hidden inside your body. For example, your skeletal system is completely hidden by your skin and other tissues.

1. What organs do you think make up the skeletal system?
2. What are some of the functions of the skeletal system?

# 16.3 The Skeletal System

## Lesson Objectives

- Identify components of the skeletal system.
- List functions of the skeletal system.
- Describe the structure of bone, and explain how bones grow and develop.
- Describe different types of joints, and explain how they function.
- Identify skeletal system problems and ways to prevent them.

## Lesson Vocabulary

- bone fracture
- bone marrow
- compact bone
- joint
- ligament
- ossification
- osteoporosis
- periosteum
- skeletal system
- spongy bone
- sprain

## Introduction

Can you imagine what you would look like without bones? You would be a soft, wobbly pile of skin, muscles, and internal organs. Clearly, bones are needed to support and shape the body. They have several other important roles as well. You'll learn what they are when you read this lesson. But first, sit back and be entertained by this very informative and funny video about the skeletal system: http://www.youtube.com/watch?v=RW46rQKWa-g .


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## Components of the Skeletal System

Bones are the main organs of the skeletal system. In adults, the skeleton consists of a whopping 206 bones, many of them in the hands and feet. You can see many of the bones of the human skeleton in **Figure** 16.10. The skeletal system also includes cartilage and ligaments.

- Cartilage is a tough, flexible connective tissue that contains the protein collagen. It covers the ends of bones where they meet. The gray tissue in **Figure** 16.10 is cartilage.
- A ligament is a band of fibrous connective tissue. Ligaments connect bones of the skeleton and hold them together.

## Functions of the Skeletal System

Your skeletal system supports your body and gives it shape. What else does it do?

- The skeletal system makes blood cells. Most blood cells are produced inside certain types of bones.
- The skeletal system stores calcium and helps maintain normal levels of calcium in the blood. Bones take up and store calcium when blood levels of calcium are high. They release some of the stored calcium when blood levels of calcium are low.
- The skeletal system works with muscles to move the body. Try to walk without bending your knees and you'll see how important the skeletal system is for movement.
- The skeletal system protects the soft organs of the body. For example, the skull surrounds and protects the brain. The ribs protect the heart and lungs.

## Bones

Some people think bones are like chalk: dead, dry, and brittle. In reality, bones are very much alive. They consist of living tissues and are supplied with blood and nerves.

### Bone Structure

Bones are organs. Like other organs, they are made up of more than one kind of tissue. There are four different kinds of tissues in bones, as shown in **Figure** 16.11. From the outside of the bone to the center, the tissues are periosteum, compact bone, spongy bone, and bone marrow.

- Periosteum is a tough, fibrous membrane that covers and protects the outer surfaces of bone.
- Compact bone lies below periosteum. It is very dense and hard. Compact bone gives bones their strength.
- Spongy bone lies below compact bone. It is less dense than compact bone. Spongy bone contains many tiny holes, or pores, which provide spaces for blood vessels and bone marrow.
- Bone marrow is a soft connective tissue inside pores and cavities in spongy bone. Bone marrow makes blood cells.

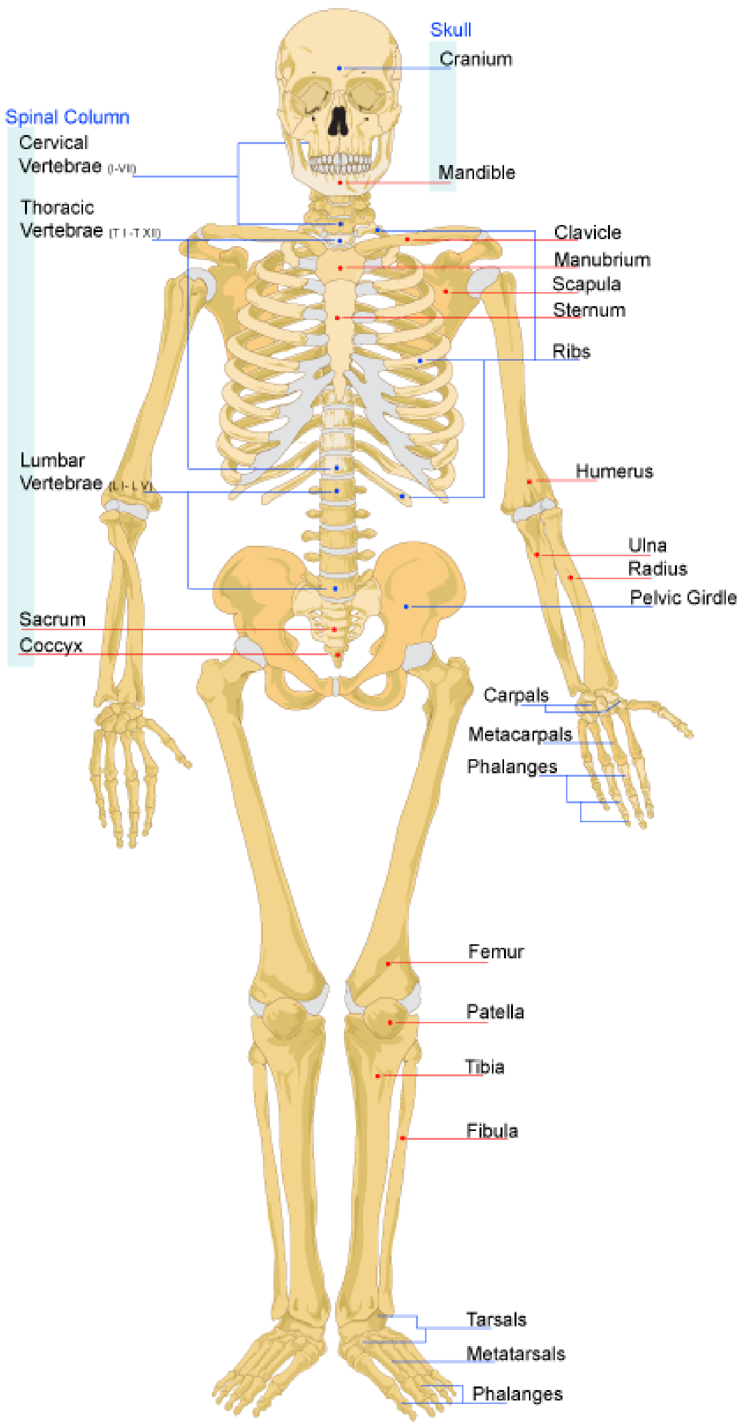


**FIGURE 16.10**

The human skeleton includes bones and cartilage.

## How Bones Grow and Develop

Early in the development of a human fetus, the skeleton is made entirely of cartilage. The relatively soft cartilage gradually changes to hard bone through ossification. This is a process in which mineral deposits replace cartilage in bone. At birth, several areas of cartilage remain, including the ends of the long bones in the arms and legs. This allows these bones to keep growing in length during childhood.

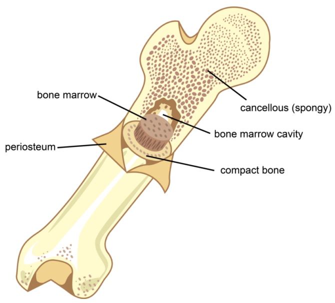


FIGURE 16.11
Types of tissues in bone

By the late teens or early twenties, all of the cartilage has been replaced by bone. Bones cannot grow in length after this point has been reached. However, bones can continue to grow in width. They are stimulated to grow thicker when they are put under stress by muscles. Weight-bearing activities such as weight lifting can increase growth in bone width.

## Joints

A joint is a place where two or more bones of the skeleton meet. There are three different types of joints based on the degree to which they allow movement of the bones: immovable, partly movable, and movable joints.

- Immovable joints do not allow the bones to move at all. In these joints, the bones are fused together by very tough collagen. Examples of immovable joints include the joints between bones of the skull. You can see them in **Figure** 16.12.
- Partly movable joints allow very limited movement. In these joints, the bones are held together by cartilage, which is more flexible than collagen. Examples of partly moveable joints include the bones of the rib cage.
- Movable joints allow the greatest movement and are the most common. In these joints, the bones are connected by ligaments. The surfaces of the bones at the joints are covered with a smooth layer of cartilage. It reduces friction between the bones when they move. The space between the bones is also filled with a liquid called synovial fluid. It helps to cushion the bones. There are several different types of movable joints. You can see three of them in **Figure** 16.13. Move these three joints in your own skeleton to experience the range of motion each allows.

FIGURE 16.12
Example of immovable joint: skull

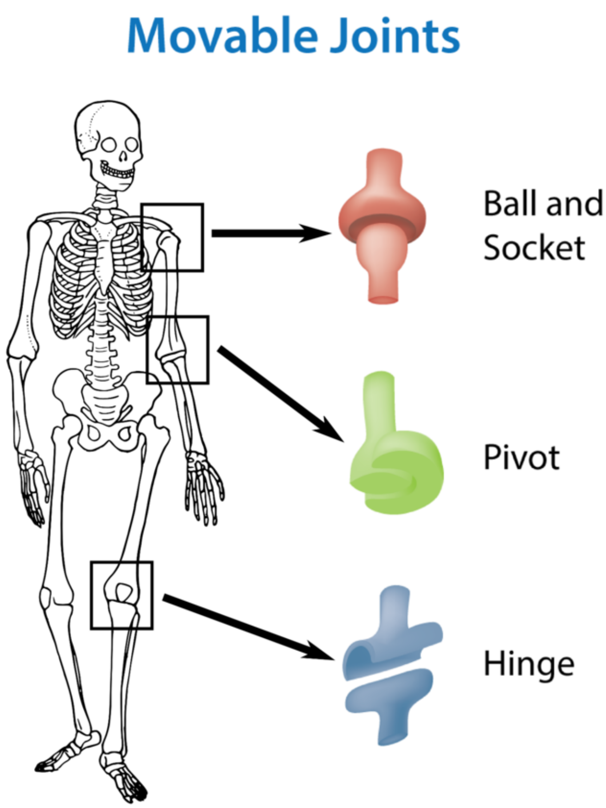


FIGURE 16.13
Examples of movable joints: shoulder, elbow, and knee

## Skeletal System Problems and How to Prevent Them

What you eat as a teen can affect how healthy your skeletal system is not only now but also in the future. Eating a diet with plenty of calcium and vitamin D can help keep your bones strong. If you don't get enough calcium and vitamin D in your diet as a teen, you will be more likely to develop osteoporosis when you are older.

### Osteoporosis

Osteoporosis is a disease in which the bones become porous and weak because they do not contain enough calcium. The graph in **Figure** 16.14 shows how the mass of calcium in bone peaks around age 30 and declines after that, especially in women. Maximizing the calcium in your bones while you're young will reduce your risk of developing osteoporosis later in of life.

### Fractures

People with osteoporosis have an increased risk of bone fractures. A bone fracture is a crack or break in bone. Even if you have healthy bones, you may fracture a bone if too much stress is placed on it. This could happen in a car crash or while playing a sport. Wearing a seatbelt when you ride in a motor vehicle and wearing safety gear when you play sports may help prevent bone fractures.

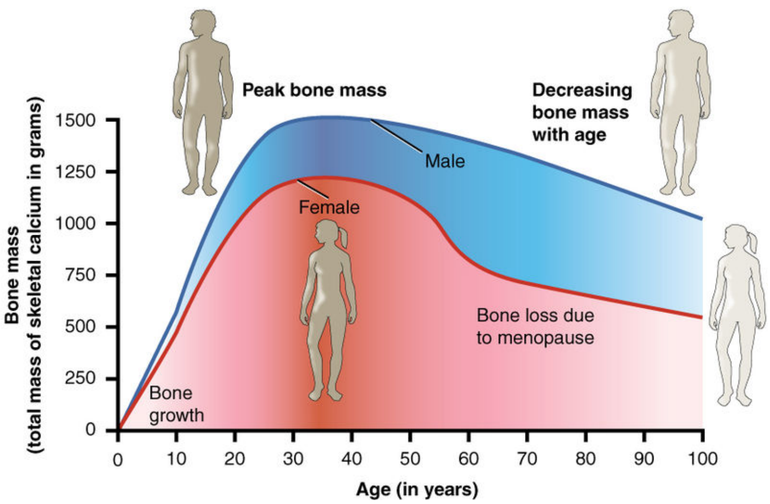


FIGURE 16.14
Bone mass declines with age, leading to osteoporosis in many people by old age.

Bone fractures heal naturally as new bone tissue forms at the site of the fracture. However, the bone may have to be placed in a cast or have rods or screws inserted into it to keep it correctly aligned until it heals. The healing process usually takes several weeks or even months.

### Sprains

Another type of skeletal system injury is a sprain. A sprain is a strain or tear in a ligament that has been twisted or stretched too far. Ankle sprains are a common type of sprain. Athletes often strain a ligament in the knee called the ACL. Warming up adequately and stretching before playing sports may reduce the risk of a sprain. Ligament injuries can take a long time to heal. Rest, ice, compression, and elevation of the sprained area may help the healing process.

## Lesson Summary

- Bones are the main organs of the skeletal system. The skeletal system also includes cartilage and ligaments.
- Functions of the skeletal system include supporting and shaping the body, allowing movement, producing blood cells, and storing calcium.
- Bones consist of four different types of tissue: periosteum, compact bone, spongy bone, and bone marrow. Ossification gradually changes the cartilage skeleton of the fetus to the bony skeleton of the adult.
- Joints may be immovable, partly movable, or movable. Types of movable joints include ball-and-socket, hinge, and pivot joints.
- Skeletal system problems include osteoporosis, bone fractures, and ligament sprains. A diet rick in calcium and vitamin D may reduce the risk of osteoporosis and related bone fractures. Following safe practices may also reduce the risk of fractures as well as sprains.

## Lesson Review Questions

### Recall

1. List components of the skeletal system.
2. What are three functions of the skeletal system?
3. Outline how human bones grow and develop, from the fetus to the adult.
4. Identify three types of joints based on the degree of movement they allow, and give examples of each type.

### Apply Concepts

5. Regular weight-bearing exercise can reduce the risk of osteoporosis. Apply lesson concepts to explain why.

### Think Critically

6. Make a table comparing and contrasting the four types of tissues in bones.
7. Contrast fractures with sprains.

## Points to Consider

The skeletal system allows the body to move, but the muscular system is also needed.

1. How do muscles and bones work together to move the body?
2. Not all muscles work with bones to move the body. Some muscles have other jobs. What are some other jobs of muscles?

# 16.4 The Muscular System

## Lesson Objectives

- Define muscle.
- Explain how muscles contract.
- Identify three types of muscle tissue.
- Describe the structure and function of skeletal muscles.
- List ways to keep the muscular system healthy.

## Lesson Vocabulary

- cardiac muscle
- muscle
- muscle fiber
- muscular system
- myofibril
- skeletal muscle
- smooth muscle
- tendon

## Introduction

You may think of muscles as the end result of exercises, like the pushups the soldier in **Figure** 16.15 is doing. Muscles in the arms and shoulders, which move the body, are easy to see and feel. However, they aren't the only type of muscles. Many muscles are deep inside the body, mostly in the walls of organs. For example, your heart is almost completely muscle. These muscles don't directly move your body, but you couldn't survive without them.

## What Are Muscles?

Muscles are the main organs of the muscular system. Muscles are composed primarily of cells called muscle fibers. A muscle fiber is a very long, thin cell, as you can see in **Figure** 16.16. It contains multiple nuclei and many mitochondria, which produce ATP for energy. It also contains many organelles called myofibrils. Myofibrils allow muscles to contract, or shorten. Muscle contractions are responsible for virtually all the movements of the body, both inside and out.

FIGURE 16.15
A soldier prepares for a fitness challenge by doing one-arm pushups.

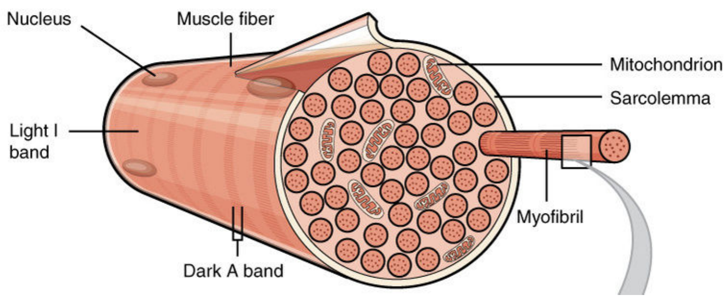


FIGURE 16.16
A muscle fiber is a single cell that can contract. Each muscle fiber contains many myofibrils.

## How a Muscle Contracts

To understand how a muscle contracts, you need to dive deeper into the structure of muscle fibers. You can see in **Figure** 16.16 that a muscle fiber is full of myofibrils.

- Each myofibril is made up of two types of proteins, called actin and myosin. These proteins form thread-like filaments.
- The myosin filaments use energy from ATP to pull on the actin filaments. This causes the actin filaments to slide over the myosin filaments and shorten a section of the myofibril. You can see a simple animation of the process at this link: http://commons.wikimedia.org/wiki/File:Actin_Myosin.gif
- The sliding-and-shortening process occurs all along many myofibrils and in many muscle fibers. It causes the muscle fibers to shorten and the muscle to contract.

## Types of Muscle Tissue

There are three different types of muscle tissue in the human body: cardiac, smooth, and skeletal muscle tissues. All three types consist mainly of muscle fibers, but the fibers have different arrangements. You can see how each type of muscle tissue looks in **Figure** 16.17.

- Cardiac muscle is found only in the walls of the heart. It is striated, or striped, because its muscle fibers are arranged in bundles. Contractions of cardiac muscle are involuntary. This means that they are not under conscious control. When cardiac muscle contracts, the heart beats and pumps blood.
- Smooth muscle is found in the walls of other internal organs such as the stomach. It isn't striated because its muscle fibers are arranged in sheets rather than bundles. Contractions of smooth muscle are involuntary. When smooth muscles in the stomach contract, they squeeze food inside the stomach. This helps break the food into smaller pieces.
- Skeletal muscle is attached to the bones of the skeleton. It is striated like cardiac muscle because its muscle fibers are arranged in bundles. Contractions of skeletal muscle are voluntary. This means that they are under conscious control. Whether you are doing pushups or pushing a pencil, you are using skeletal muscles. Skeletal muscles are the most common type of muscles in the body. You can read more about them below.

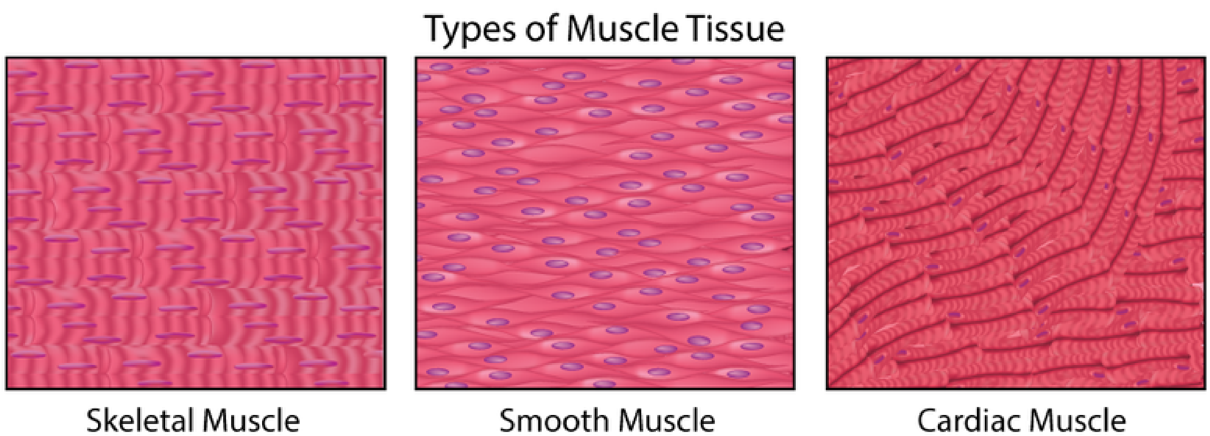


FIGURE 16.17

Three types of human muscle tissue

## A Closer Look at Skeletal Muscles

The human body has more than 600 skeletal muscles. You can see some of them in **Figure** 16.18. A few of the larger muscles are labeled in the figure.

### Structure and Function of Skeletal Muscles

You can see the bundles of muscle fibers that make up a skeletal muscle in **Figure** 16.19. You can also see in the figure how the muscle is attached to a bone by a tendon. Tendons are tough connective tissues that anchor skeletal muscles to bones throughout the body.

Many skeletal muscles are attached to the ends of bones where they meet at a joint. The muscles span the joint and connect the bones. When the muscles contract, they pull on the bones, causing them to move.

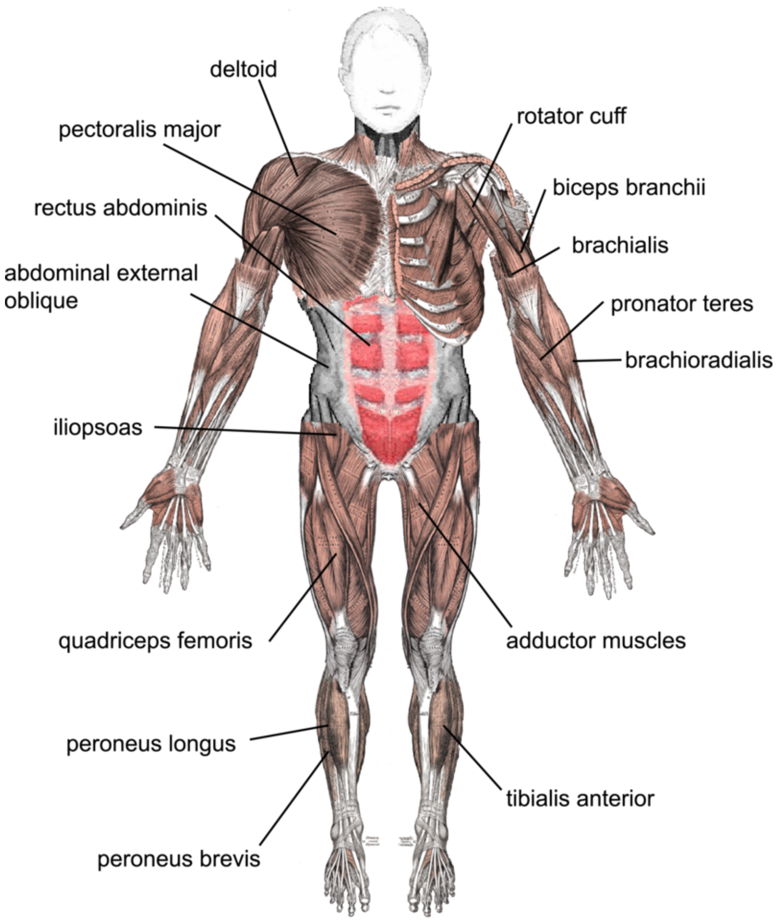


FIGURE 16.18

Human Skeletal Muscles. Skeletal muscles enable the body to move.

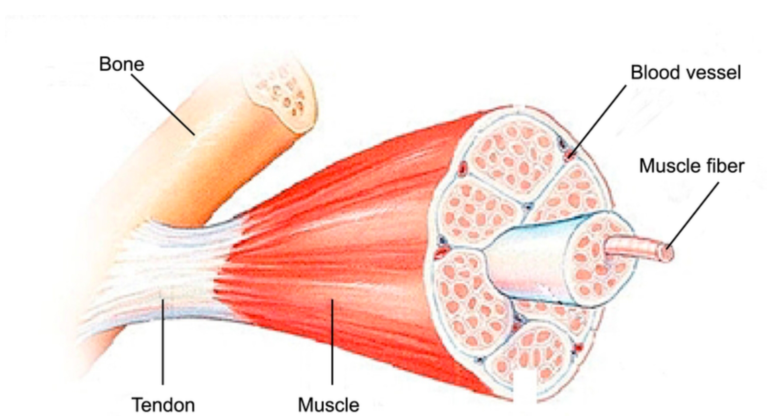


FIGURE 16.19

Skeletal muscles are attached to bones by tendons.

## Skeletal Muscles Work in Pairs

Muscles can only contract. They can't actively lengthen. Therefore, to move bones back and forth at a joint, skeletal muscles must work in pairs. For example, the bicep and triceps muscles of the upper arm work as a pair. You can see how this pair of muscles works in **Figure** 16.20. When the bicep muscle contracts, it bends the arm at the elbow. When the triceps muscle contracts, it straightens the arm.

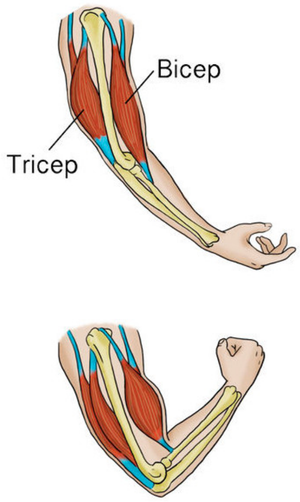


FIGURE 16.20
Bicep and triceps muscles let you bend and straighten your arm at the elbow.

## Keeping Your Muscular System Healthy

Did you ever hear the saying, "Use it or lose it?" That's certainly true when it comes to muscles. If you don't exercise your muscles, they will actually shrink in size. They will also become weaker and more prone to injury.

### Keeping Muscles Strong

Exercising muscles increases their size, and bigger muscles have greater strength. What type of exercises should you do? For all-round muscular health, you should do two basic types of exercise.

- To increase the size and strength of skeletal muscles, you need to make these muscles contract against a resisting force. For example, you can do sit-ups or pushups, where the resisting force is your own body weight. You can see another way to do it in **Figure** 16.21.
- To exercise cardiac muscle and increase muscle endurance, you need to do aerobic exercise. Aerobic exercise increases the size and strength of muscles in the heart and helps all your muscles develop greater endurance. This means they can work longer without getting tired. Aerobic exercise is any exercise such as running, biking, or swimming that causes an increase in your heart rate. You can see another example of aerobic exercise in **Figure** 16.22.

Lifting weights is one way to pit skeletal muscles against a resisting force.

Snowshoeing is a fun way to get aerobic exercise.

### Preventing Muscle Injuries

You are less likely to have a muscle injury if you exercise regularly and have strong muscles. Stretching also helps prevent muscle injuries. Stretching improves the range of motion of muscles and tendons at joints.

You should always warm up before stretching or doing any type of exercise. Warmed-up muscles and tendons are less likely to be injured. One way to warm up is to jog slowly for a few minutes.

FIGURE 16.21
Exercising muscles makes them stronger and increases their endurance.

FIGURE 16.22
Snowshoeing

## Lesson Summary

- Muscles are the main organs of the muscular system. They consist primarily of long, thin cells called muscle fibers.
- A muscle fiber contracts when myosin filaments pull on actin filaments in myofibrils throughout the fiber.
- There are three types of muscle tissues: cardiac, smooth, and skeletal muscle tissues.
- Most muscles are skeletal muscles, which are attached to bones by tendons. Skeletal muscles work in pairs to move bones back and forth at joints.
- Regular resistance exercise and aerobic exercise, preceded by warming up and stretching, can help keep the muscular system strong and healthy.

## Lesson Review Questions

### Recall

1. What are muscles?
2. What role do tendons play in the muscular system?

### Apply Concepts

3. Create a public service announcement to convey the importance of regular exercise for healthy muscles.

### Think Critically

4. Explain how muscles contract.
5. Compare and contrast the three types of muscle tissues.
6. Explain why skeletal muscles must work in pairs to move bones back and forth at joints.

## Points to Consider

You may have heard that eating certain foods causes acne. This may or may not be true. But there's no question that what you eat is important for the health of your skin, bones, muscles.

1. Do you know how to eat for good health?
2. How do you choose healthy foods?

# 16.5 References


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# CHAPTER 17 MS Food and the Digestive System

## Chapter Outline




You've probably heard the saying, "You are what you eat." Actually, it's not just a saying. It's true. What you eat plays an important role in your health. Fried Twinkies may be tasty, but should you eat them? In this chapter you'll find out. You'll learn how to choose foods that promote good health and provide energy for growth and activity.

# 17.1 Food and Nutrients

## Lesson Objectives

- List three reasons why your body needs food.
- Define nutrient, and identify the six major types of nutrients.
- Describe macronutrients, their functions, and foods that contain them.
- Describe micronutrients, their functions, and foods that contain them.

## Lesson Vocabulary

- calorie
- dehydration
- fiber
- macronutrient
- micronutrient
- mineral
- nutrient
- starch
- trans fat
- vitamin

## Introduction

"An apple a day keeps the doctor away." That's another saying about food that you may have heard. Will eating apples really prevent you from getting sick? Probably not, but eating apples and other fresh fruits and vegetables like those in **Figure** 17.1 can help keep you healthy. Why do you need foods like these for good health? What roles does food play in the body? In this lesson, you'll find out. For a good visual introduction to lesson content, watch this video: http://www.youtube.com/watch?v=BnoHbd-9lGY .


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FIGURE 17.1
Fresh fruits and veggies are an important part of a healthy diet.

## Why Your Body Needs Food

Your body needs food for three purposes:

1. Food gives the body energy. You need energy for everything you do. The energy in food is measured in a unit called the Calorie.
2. Food provides building materials for the body. The body needs building materials for growth and repair.
3. Food contains substances that help control body processes. Body processes must be kept in balance for good health.

## What Are Nutrients?

There are a variety of substances in foods that the body needs. Any substance in food that the body needs is called a nutrient. There are six major types of nutrients: carbohydrates, proteins, lipids, water, minerals, and vitamins. Carbohydrates, proteins, and lipids can be used for energy. Proteins also provide building materials. Proteins, minerals, and vitamins help control body processes. Water is needed by all cells just to stay alive.

The six types of nutrients can be divided into two major categories based on how much of them the body needs. The categories are macronutrients and micronutrients.

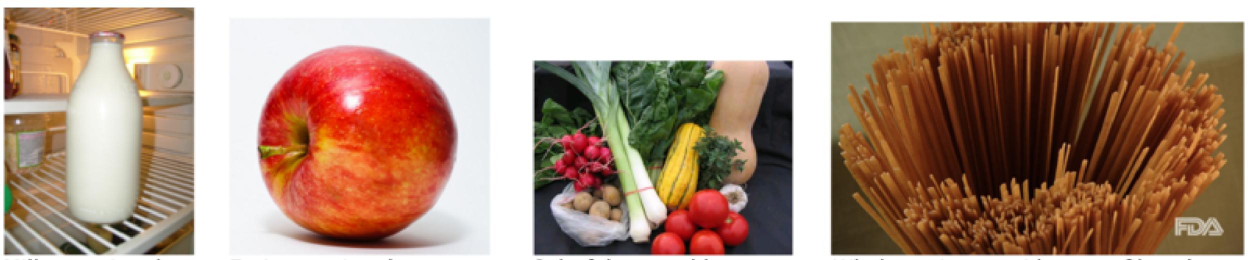
## Macronutrients

Macronutrients are nutrients the body needs in relatively large amounts. They include carbohydrates, proteins, lipids, and water.

### Carbohydrates

Carbohydrates include sugars, starches, and fiber. Sugars and starches are used by the body for energy. One gram of sugar or starch provides 4 Calories of energy. Fiber doesn't provide energy, but it is needed for other uses. At age 13 years, you need about 130 grams of carbohydrates a day. **Figure** 17.2 shows good food sources of each type.

- Sugars are small, simple carbohydrates. They are found in foods such as milk and fruit. Sugars in foods such as these are broken down by your digestive system to glucose, the simplest of all sugars. Glucose is taken up by cells for energy.
- Starches are larger, complex carbohydrates. They are found in foods such as grains and vegetables. Starches are broken down by your digestive system to glucose, which is used for energy.
- Fiber is a complex carbohydrate that consists mainly of cellulose and comes only from plants. High-fiber foods include whole grains and legumes such as beans. Fiber can't be broken down by the digestive system, but it plays important roles in the body. It helps keep sugar and lipids at normal levels in the blood. It also helps keep food waste moist so it can pass easily out of the body.




Milk contains the simple sugar lactose.

Fruit contains the simple sugar fructose.

Colorful vegetables are good sources of starches.

Whole grains provide more fiber than refined grains such as white pasta.

FIGURE 17.2

Good sources of carbohydrates

### Proteins

Proteins are nutrients made up of smaller molecules called amino acids. The digestive system breaks down proteins in food to amino acids, which are used for protein synthesis. Proteins synthesized from the amino acids in food serve many vital functions. They make up muscles, control body processes, fight infections, and carry substances in the blood.

If you eat more protein than you need for these functions, the extra protein is used for energy. One gram of protein provides 4 Calories of energy, the same as carbohydrates. A 13-year-old needs to eat about 34 grams of protein a day. **Figure** 17.3 shows good food sources of protein.

### Lipids

Lipids are nutrients such as fats. They are used for energy and other important purposes. One gram of lipids provides the body with 9 Calories of energy, more than twice as much as carbohydrates or proteins. Lipids also make up cell membranes, protect nerves, control blood pressure, and help blood clot. You must consume some lipids for these purposes. Good food sources of lipids are shown in **Figure** 17.4. Any extra lipids you consume are stored as fat.

FIGURE 17.3
Good sources of protein include whole grains, vegetables, and beans.

A certain amount of stored fat is needed to cushion and protect internal organs and insulate the body. However, too much stored fat can lead to obesity and cause significant health problems.

FIGURE 17.4
Good sources of lipids include fish, nuts, and seeds.

A type of lipid called trans fat is found in many processed foods. Trans fat is rare in nature but is manufactured and added to foods to preserve freshness. Eating foods that contain trans fat increases the risk of heart disease. Trans fat may be found in such foods as cookies, doughnuts, crackers, fried foods, ground beef, and margarine.

### Water

Water is essential to life because chemical reactions within cells take place in water. Most people can survive only a few days without consuming water to replace their water losses. How do you lose water?

- You lose water in your breath each time you exhale.
- You lose water in urine.
- You lose water in sweat, especially if you are active in warm weather.

The boy in **Figure** 17.5 is taking a water break while playing outside on a hot day. If he doesn't take in enough water to replace the water lost in sweat, he may become dehydrated. Symptoms of dehydration include dry mouth, headache, and dizziness. Dehydration can be very serious. It can even cause death.

FIGURE 17.5
When you are active outside on a warm day, it's important to drink plenty of water. You need to replace the water you lose in sweat.

## Micronutrients

Micronutrients are nutrients the body needs in relatively small amounts. They include minerals and vitamins. These nutrients don't provide the body with energy, but they are still essential for good health.

### Minerals

Minerals are chemical elements that don't come from living things or include the element carbon. Many minerals are needed in the diet for normal functioning of the body. Several minerals that are needed in relatively large amounts are listed in **Table** 17.1. As you can see from these examples, minerals have a diversity of important functions. Your body can't produce any of the minerals it needs, so you must get them from the food you eat. The table shows good food sources of the minerals.

TABLE 17.1: Some of the minerals needed by the human body

| Mineral | Function | Good Food Sources |
|---|---|---|
| Calcium | strong bones and teeth | milk, green leafy vegetables |
| Chloride | salt-water balance | table salt, most packaged foods |
| Magnesium | strong bones | whole grains, nuts |
| Phosphorus | strong bones and teeth | poultry, whole grains |
| Potassium | muscle and nerve functions | meat, bananas |
| Sodium | muscle and nerve functions | table salt, most packaged foods |

Not getting enough minerals can cause health problems. For example, not getting enough calcium may cause osteoporosis. This is a disease in which the bones become porous so they break easily. Getting too much of some minerals can also cause health problems. Many people get too much sodium. Sodium is added to most packaged foods. People often add more sodium to their food by using table salt. Too much sodium has been linked to high blood pressure in some people.

### Vitamins

Vitamins are organic compounds that the body needs in small amounts to function properly. Humans need 16 different vitamins. Six of them are listed in **Table** 17.2. Vitamin D is made in the skin when it is exposed to sunlight. Bacteria that normally live in the gut make vitamins B12 and K. All other vitamins must come from food. The table

The vitamins to watch out for are A, D, E, and K. These vitamins are stored by the body, so they can build up to high levels.

## Lesson Summary

- Your body needs food for energy, building materials, and substances that control body processes.
- Nutrients are substances in food that your body needs. There are six types of nutrients: carbohydrates, proteins, lipids, water, minerals, and vitamins.
- Macronutrients are nutrients that are needed in relatively large amounts. They include carbohydrates, proteins, lipids, and water. Except for water, macronutrients can all provide the body with energy.
- Micronutrients are nutrients that are needed in relatively small amounts. They include minerals and vitamins. They do not provide the body with energy but are needed for good health.

## Lesson Review Questions

### Recall

1. What are three general purposes for which the body needs food?
2. Define nutrient, and list types of nutrients that can provide the body with energy.
3. Identify three functions of protein in the diet.

### Apply Concepts

4. An apple contains about 20 grams of carbohydrates. How much energy does it provide?

### Think Critically

5. Compare and contrast macronutrients and micronutrients.
6. Explain why you need fiber in your diet even though you can't digest it.
7. Why is water considered a nutrient?

## Points to Consider

Now you know what nutrients you need and some of the foods that contain them.

1. How can you combine the foods for a healthy diet?
2. What rules or guidelines should you follow?

# 17.2 Choosing Healthy Foods

## Lesson Objectives

- Describe how to use MyPlate to make nutritious food choices.
- Outline how to use food labels to choose healthy foods.
- Explain why you must balance food with exercise to maintain a healthy weight and avoid obesity.

## Lesson Vocabulary

- ingredient
- main ingredient
- MyPlate
- nutrition facts label
- obesity

## Introduction

Foods such whole grains and fresh vegetables provide nutrients you need for good health. You need a range of foods because different foods give you different types of nutrients. You also need different amounts of each nutrient. How can you choose the right mix of foods to get the proper balance of nutrients? Two tools can help you choose foods wisely: MyPlate and food labels.

## MyPlate

MyPlate is a diagram that shows you how to balance foods at each meal. It represents the relative amounts of five food groups that you should put on your plate (and in your cup). You can see MyPlate in **Figure** 17.6. The five food groups in MyPlate are:

1. Grains, such as whole-grain bread, pasta, and cereal.
2. Vegetables, such as spinach, broccoli, and carrots.
3. Fruits, such as oranges, strawberries, and bananas.
4. Dairy, such as milk, yogurt, and cheese.
5. Protein, such as meat, fish, and beans

Follow these guidelines for using MyPlate:

- Enjoy your food, but eat less.
- Avoid oversized portions.

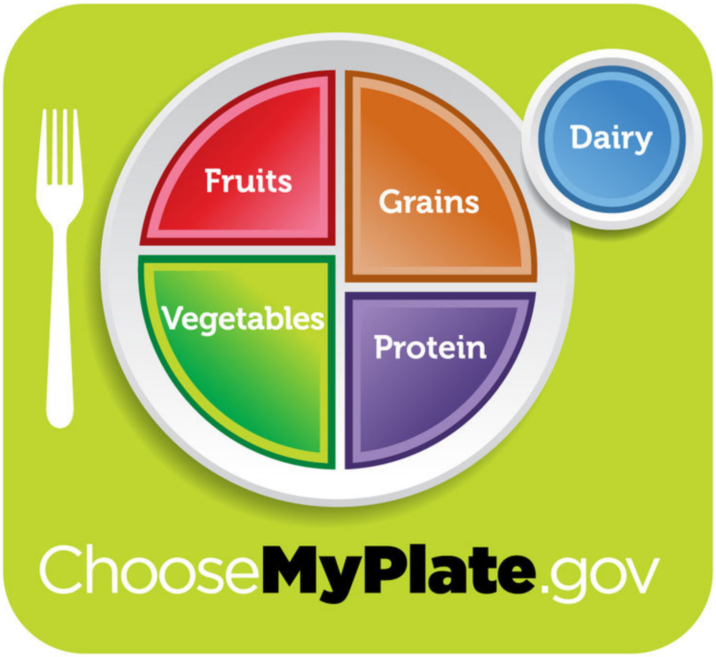



FIGURE 17.6
MyPlate

- Make half your plate fruits and vegetables, including both green and yellow or orange vegetables.
- Make at least half your grains whole grains.
- Choose fat-free or low-fat milk.
- Avoid high-sodium foods.
- Drink water instead of sugary drinks.

You'll notice that there is no food group on MyPlate for foods like ice cream, cookies, and potato chips. These foods have little nutritional value. They may also be high in fats, sugars, or salt. They should be eaten only sparingly if at all.

## Food Labels

How do you know which foods contain whole grain and which are low in fat and sodium? That's where food labels come in. In the U.S., packaged foods must be labeled with nutritional information. A nutrition facts label shows the main nutrients in one serving of the food. Packaged foods must also be labeled with their ingredients. An ingredient is a specific item that a food contains.

### Using Nutrition Facts Labels

Look at the nutrition facts label in **Figure** 17.7. Instructions at the right of the label tell you what to look for.

- At the top of the label, look for the serving size. The serving size tells you how much of the food you should eat to get the nutrients listed on the label. For this food, 1 cup is a serving.
- The Calories in one serving are listed next. In this food, there are 250 Calories per serving.

- Next on the nutrition facts label, look for the percent daily values (% DV) of several nutrients. The percent daily value shows what percent of daily needs for a given nutrient that the food provides (based on a 2000-Calorie-per-day diet). A food is low in a nutrient if the %DV is 5% or less. This particular food is low in fiber, vitamin A, vitamin C, and iron. A food is high in a nutrient if the %DV is 20% or more. This food is high in sodium, potassium, and calcium.

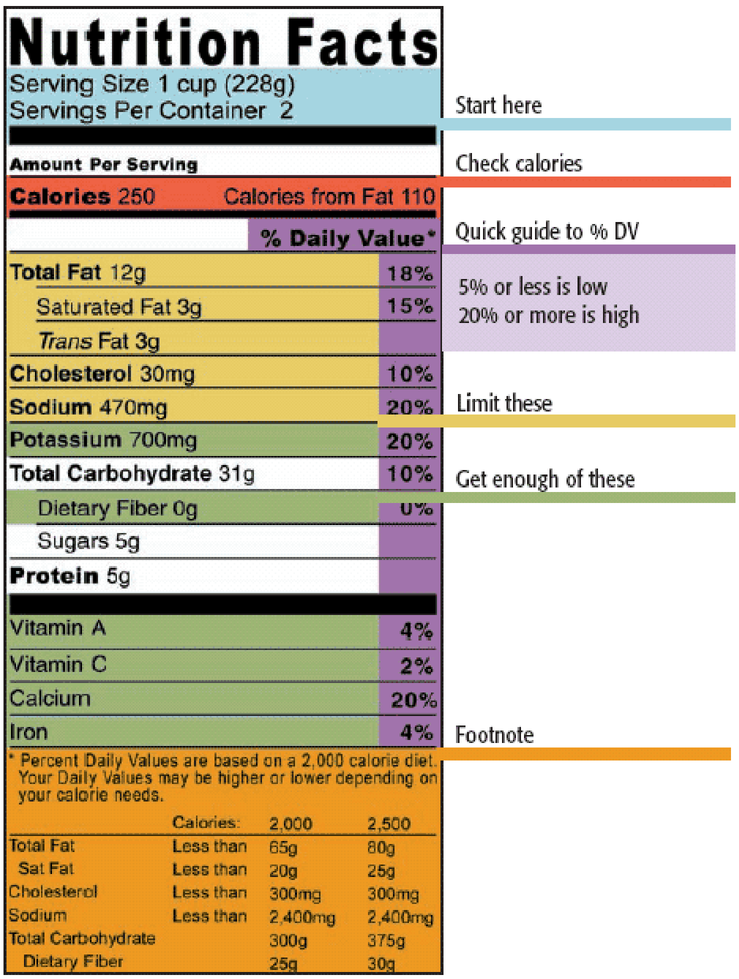



FIGURE 17.7

Reading nutrition facts labels can help you choose healthy foods. Look at the nutrition facts label shown here. Do you think this food is a good choice for a healthy eating plan? Why or why not?

To learn more about nutrition facts labels and how to use them, watch this video: http://www.oprah.com/health/How-to-Read-a-Food-Label-Video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### Using Ingredients Lists

The food label in **Figure** 17.8 represents a different food and includes the list of ingredients. The main ingredient is always listed first. The main ingredient is the ingredient that is present in the food in the greatest amount. As you go down the list, the ingredients are present in smaller and smaller amounts.

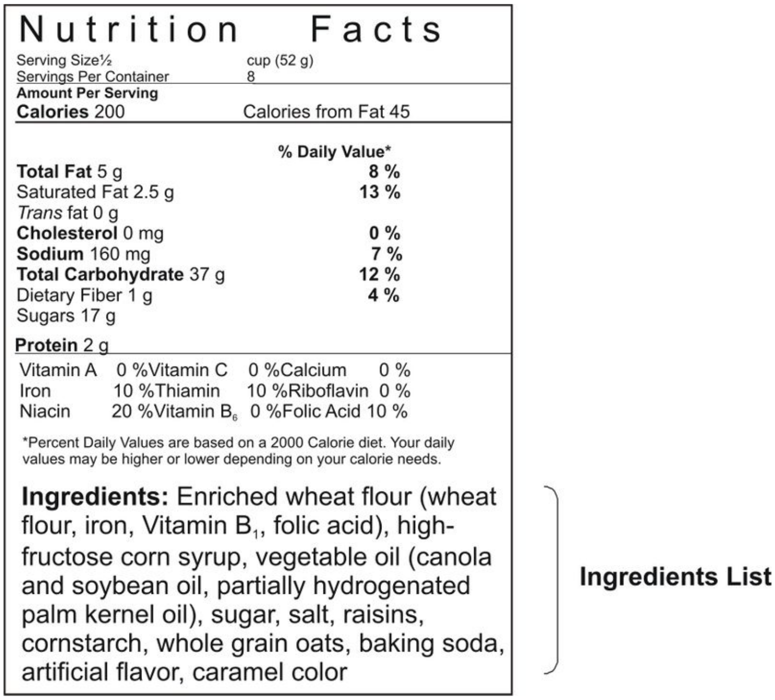


FIGURE 17.8
This food label includes the list of ingredients in the food. The main ingredient is enriched wheat flour, followed by high-fructose corn syrup. Why should you avoid foods with ingredients such as these at the top of the ingredients list?

Reading the ingredients lists on food labels can help you choose the healthiest foods. At the top of the list, look for ingredients such as whole grains, vegetables, fruits, and low-fat milk. Ingredients such as these are needed in the greatest amounts for balanced eating. Avoid foods that list fats, oils, sugar, or salt near the top of the list. For good health, you should avoid getting too much of these ingredients. Be aware that ingredients such as corn syrup are sugars.

You should also use moderation when eating foods that contain ingredients such as white flour or white rice. These ingredients have been processed, and processing removes nutrients. The word “enriched” is a clue that an ingredient has been processed. Ingredients are enriched with added nutrients to replace those lost during processing. Even so, they are still likely to have fewer nutrients than unprocessed ingredients.

## Balancing Food with Exercise

Physical activity is an important part of balanced eating. It helps you use up any extra Calories in the foods you eat. You should try to get at least an hour of exercise just about every day (see **Figure** 17.9). Exercise has many health benefits in addition to balancing the energy in food. For example, it strengthens the bones and muscles and may improve your mood.

FIGURE 17.9
Walking the dog is a good way to add exercise to your daily routine.

### Obesity

What happens if you don't get enough exercise to balance the food you eat? Any unused energy in the food is stored as fat. If you take in more energy than you use day after day, you will store more and more fat and become overweight. Eventually, you may become obese.

Obesity is diagnosed in people who have a high percentage of body fat. A measure called Body Mass Index, or BMI, is often used to diagnose obesity. You can learn more about BMI by watching this video: http://www.youtube.com/watch?v=5UsGqPrZjN8 .

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Obesity is associated with many health problems, including high blood pressure and diabetes. People that remain obese during their entire adulthood usually do not live as long as people that stay within a healthy weight range. The current generation of young people in the U.S. is the first generation in our history that may have a shorter life span than their parents because of obesity and the health problems associated with it.

### Avoiding Obesity

You can avoid gaining too much weight and becoming obese. Choose healthy foods and balance the energy in food with exercise.

- To choose healthy foods, use MyPlate and nutrition facts labels. On food labels, pay attention to Calories as well as nutrients. Keep in mind that the average 11–13 year old needs about 2000 Calories a day.
- To balance energy with exercise, aim to get about an hour of physical activity each day. You can use an online calculator like this one to find the number of Calories you use in a wide range of activities: http://www.myfitnesspal.com/exercise/lookup

## Lesson Summary

- MyPlate is a diagram that shows you how to balance foods at each meal. It represents the relative amounts of five food groups that you should put on your plate (and in your cup). The five food groups are grains,

vegetables, fruits, dairy, and protein.
- A nutrition facts label shows the main nutrients in one serving of the food. Packaged foods must also be labeled with their ingredients. Knowing how to interpret this information can help you choose the healthiest foods.
- Exercise is important for balanced eating. Exercise helps you use up any extra Calories in the foods you eat. You should try to get at least an hour of physical activity just about every day. This will help you avoid obesity and its health problems.

## Lesson Review Questions

### Recall

1. What is MyPlate?
2. List four guidelines for using MyPlate.
3. Identify information included in a nutrition facts label.
4. Define obesity. What causes it and what health problems are associated with it?

### Apply Concepts

5. Look at the nutrition facts label in **Figure** 17.8. Which, if any, nutrients are present at high levels in the food? Which are present at low levels?
6. Describe a weekly plan that would allow you to fit adequate physical activity into your schedule.

### Think Critically

7. Explain how you can use a food label to identify the main ingredient in a food.

## Points to Consider

The food you eat provides your body with nutrients. But first, the food must be broken down by the digestive system.

1. What are some of the organs that make up the digestive system?
2. What processes break down food into nutrients?

# 17.3 The Digestive System

## Lesson Objectives

- Identify the major organs and general functions of the digestive system.
- Explain the role of enzymes and other secretions in digestion.
- Outline the digestive functions of the mouth, esophagus, and stomach.
- Explain how digestion and absorption occur in the small intestine.
- State functions of the large intestine and roles of intestinal bacteria.
- Describe two digestive system problems and how to prevent them.

## Lesson Vocabulary

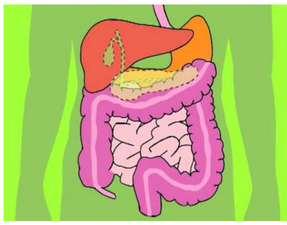
- absorption
- chemical digestion
- digestion
- digestive system
- elimination
- esophagus
- food allergy
- foodborne illness
- gall bladder
- gastrointestinal (GI) tract
- large intestine
- liver
- mechanical digestion
- pancreas
- peristalsis
- small intestine
- stomach
- villi (villus, singular)

## Introduction

Nutrients in the food you eat are needed by the cells of your body. How do they get from your sandwich to your cells? What organs and processes break down the food and make the nutrients available to cells? The organs are those of the digestive system. The processes are digestion and absorption.

## Overview of the Digestive System

The digestive system is the body system that breaks down food and absorbs nutrients. It also eliminates solid food wastes that remain after food is digested. The major organs of the digestive system are shown in **Figure** 17.10. For an entertaining overview of the digestive system and how it works, watch this video: http://www.youtube.com/watch?v=JnzwbipJuAA .



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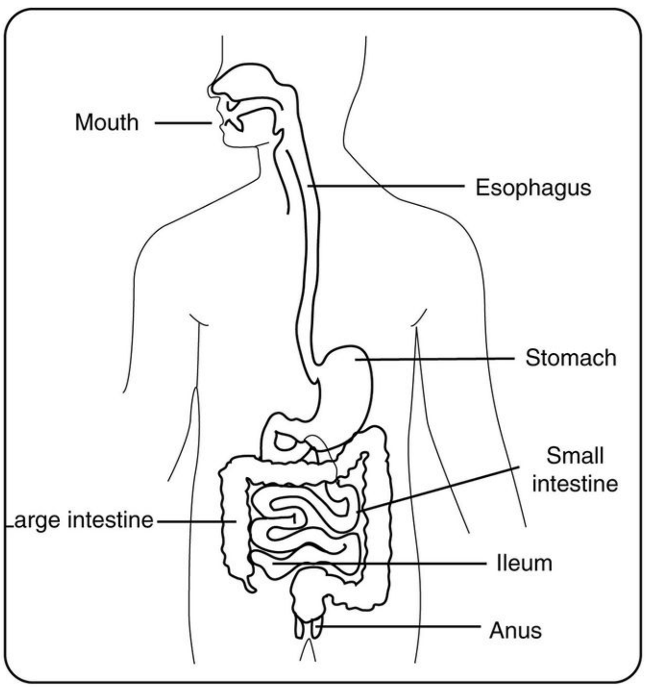


FIGURE 17.10

Major organs of the digestive system make up the GI tract.

### The GI Tract

The organs in **Figure** 17.10 make up the gastrointestinal (GI) tract. This is essentially a long tube that connects the mouth to the anus. Food enters the mouth and then passes through the rest of the GI tract. Food waste leaves the body through the anus. In adults, the GI tract is more than 9 meters (30 feet) long!

Organs of the GI tract are covered by muscles that contract to keep food moving along. A series of involuntary muscle contractions moves rapidly along the tract, like a wave travelling through a spring toy. The muscle contractions are called peristalsis. The diagram in **Figure** 17.11 shows how peristalsis works.

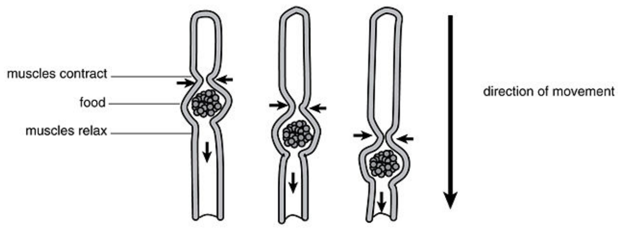


FIGURE 17.11
Peristalsis

### Digestion

As food is pushed through the GI tract by peristalsis, it undergoes digestion. Digestion is the process of breaking down food into nutrients. There are two types of digestion: mechanical digestion and chemical digestion.

- Mechanical digestion occurs when large chunks of food are broken down into smaller pieces. This is a physical process that happens mainly in the mouth and stomach.
- Chemical digestion occurs when large food molecules are broken down into smaller nutrient molecules. This is a chemical process that begins in the mouth and stomach but occurs mainly in the small intestine.

### Absorption

After food is broken down into nutrient molecules, the molecules are absorbed by the blood. Absorption is the process in which nutrients or other molecules are taken up by the blood. Once absorbed by the blood, nutrients can travel in the bloodstream to cells throughout the body.

### Elimination

Some substances in food can't be broken down into nutrients. They remain behind in the digestive system after the nutrients have been absorbed. Any substances in food that can't be digested pass out of the body as solid waste. This process is called elimination.

## Digestive Enzymes and Other Secretions

Chemical digestion could not take place without the help of digestive enzymes and other substances secreted into the GI tract. An enzyme is a protein that speeds up a biochemical reaction. Digestive enzymes speed up the reactions of chemical digestion. **Table** 17.3 lists a few digestive enzymes, the organs that produce them, and their functions in digestion.

TABLE 17.3: Examples of digestive enzymes

| Enzyme | Organ that Produces It | Substance It Helps Digest |
|---|---|---|
| Amylase | mouth | starch |
| Pepsin | stomach | protein |

**TABLE 17.3:** (continued)

| Enzyme | Organ that Produces It | Substance It Helps Digest |
|---|---|---|
| Lipase | pancreas | fat |
| Ribonuclease | pancreas | RNA |

Most digestive enzymes are secreted into the GI tract by organs of the GI tract or from a nearby gland named the pancreas. **Figure** 17.12 shows where the pancreas is located. The figure also shows the locations of the liver and gall bladder. These organs produce or store other digestive secretions.

- The liver secretes bile acids. Bile acids help digest fat. Some liver bile is secreted directly into the small intestine.
- Some liver bile goes to the gall bladder. This sac-like organ stores and concentrates the liver bile before releasing it into the small intestine.

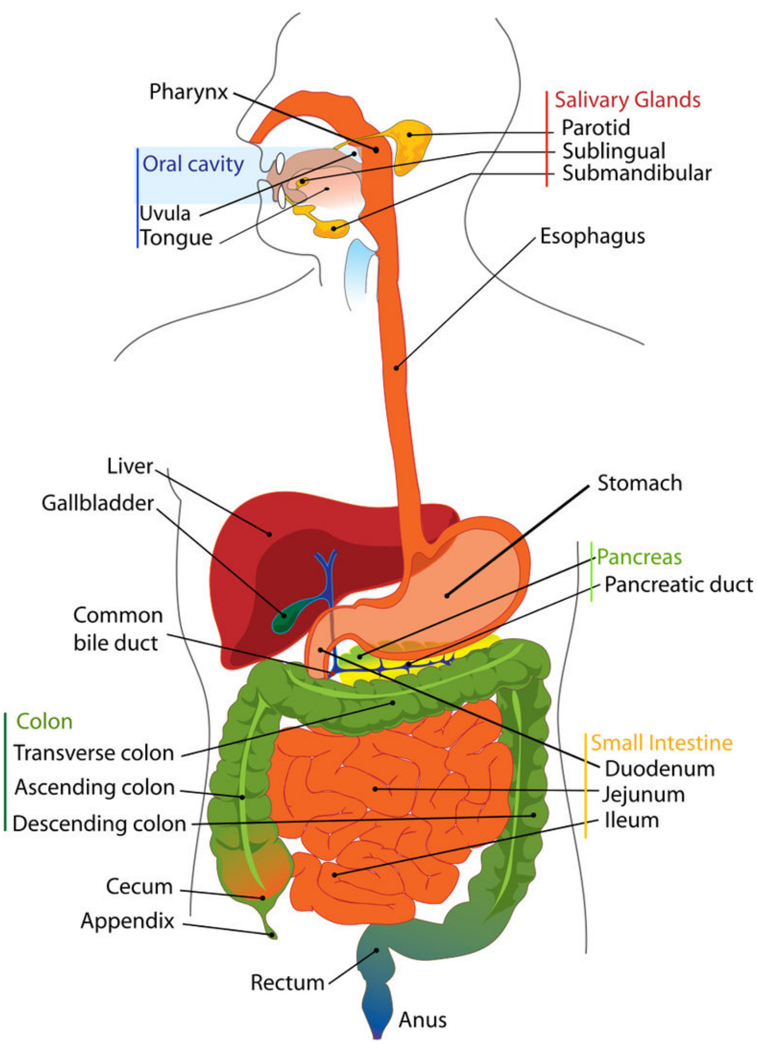


FIGURE 17.12
Digestive system organs and glands

## The Start of Digestion: Mouth to Stomach

Does the sight or smell of your favorite food make your mouth water? When this happens, you are getting ready for digestion.

### Mouth

The mouth is the first digestive organ that food enters. The sight, smell, or taste of food stimulates the release of saliva and digestive enzymes by salivary glands inside the mouth. Saliva wets the food, which makes it easier to break up and swallow. The enzyme amylase in saliva begins the chemical digestion of starches to sugars.

Your teeth help to mechanically digest food. Look at the different types of human teeth in **Figure** 17.13. Sharp teeth in the front of the mouth cut or tear food when you bite into it. Broad teeth in the back of the mouth grind food when you chew. Your tongue helps mix the food with saliva and enzymes and also helps you swallow. When you swallow, a lump of chewed food passes from the mouth into a tube in your throat called the pharynx. From the pharynx, the food passes into the esophagus.

FIGURE 17.13
Teeth are important for mechanical digestion.

### Esophagus

The esophagus is a long, narrow tube that carries food from the pharynx to the stomach. It has no other purpose. Food moves through the esophagus because of peristalsis. At the lower end of the esophagus, a circular muscle, called a sphincter, controls the opening to the stomach. The sphincter relaxes to let food pass into the stomach. Then the sphincter contracts to prevent food from passing back into the esophagus.

### Stomach

The stomach is a sac-like organ at the end of the esophagus. It has thick muscular walls that contract and relax to squeeze and mix food. This helps break the food into smaller pieces. It also helps mix the food with enzymes and other secretions in the stomach. For example, the stomach secretes the enzyme pepsin, which helps digest proteins.

Water, salt, and simple sugars can be absorbed into the blood from the lining of the stomach. However, most substances must undergo further digestion in the small intestine before they can be absorbed. The stomach stores the partly digested food until the small intestine is empty. Then a sphincter between the stomach and small intestine relaxes, allowing food to enter the small intestine.

## Digestion and Absorption: The Small Intestine

The small intestine is a narrow tube that starts at the stomach and ends at the large intestine. In adults, it's about 7 meters (23 feet) long. Most chemical digestion and almost all nutrient absorption take place in the small intestine.

The small intestine is made up of three parts:

1. The duodenum is the first part of the small intestine. It is also the shortest part. This is where most chemical digestion takes place. Many enzymes and other substances involved in digestion are secreted into the duodenum
2. The jejunum is the second part of the small intestine. This is where most nutrients are absorbed into the blood. The inside surface of the jejunum is covered with tiny projections called villi (villus, singular). The villi make the inner surface of the small intestine 1000 times greater than it would be without them. You can read in **Figure** 17.14 how villi are involved in absorption.
3. The ileum is the last part of the small intestine. It is covered with villi like the jejunum. A few remaining nutrients are absorbed in the ileum. From the ileum, any remaining food waste passes into the large intestine.

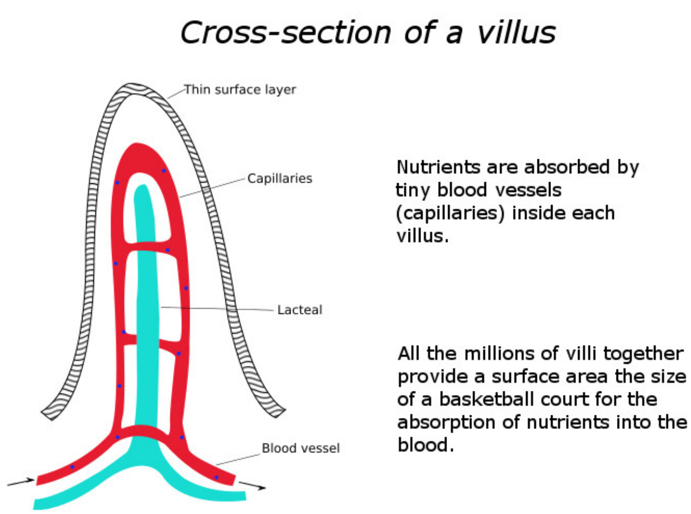


FIGURE 17.14
This diagram shows what's inside each of the millions of villi that line the jejunum and ileum of the small intestine. The villus is drawn greatly enlarged.

## Elimination and Other Functions of the Large Intestine

The large intestine is a wide tube that connects the small intestine with the anus. In adults, the large intestine is about 1.5 meters (5 feet) long. It is larger in width but shorter in length than the small intestine.

### Producing and Eliminating Feces

Food waste enters the large intestine from the small intestine in a liquid state. As the waste moves through the large intestine, excess water is absorbed from it. The remaining solid waste is called feces. After a certain amount of feces have collected, a sphincter relaxes to let the feces pass out of the body through the anus. This is elimination.

### Bacteria in the Large Intestine

Trillions of bacteria normally live in the large intestine. Don't worry—most of them are helpful. They have several important roles. For example, intestinal bacteria:

- produce vitamins B12 and K.
- control the growth of harmful bacteria.
- break down toxins in the large intestine.
- break down fiber and some other substances in food that can't be digested.

## Digestive System Health

Much of the time, you probably aren't aware of your digestive system. It works well without causing any problems. But most people have problems with their digestive system at least once in a while. Did you ever eat something that didn't "agree" with you? Maybe you had a stomachache or felt sick to your stomach. Perhaps you had diarrhea. These can be symptoms of food poisoning.

### Food Poisoning

Food poisoning is the common term for foodborne illness. This type of illness occurs when harmful bacteria enter your digestive system in food and make you sick. The bacteria—or toxins they produce—may cause cramping, vomiting, or other GI tract symptoms.

Following these healthy practices may decrease your risk of foodborne illness:

- Wash your hands after handling raw foods such as meats, poultry, fish, or eggs. These foods often contain bacteria that your hands could transfer to your mouth.
- Cook meats, poultry, fish, or eggs thoroughly before eating them. The heat of cooking kills any bacteria the foods may contain so they can't make you sick.
- Keep hot foods hot and cold foods cold. This is especially important when food is packed for lunch or a picnic (see **Figure** 17.15). Maintaining the proper temperature slows the growth of bacteria in the food.

### Food Allergies

Food allergies occur when the immune system reacts to harmless substances in food as though they were harmful "germs." Food allergies are relatively common. Almost 10 percent of children have them. Some of the foods most likely to cause allergies include milk, shellfish, nuts, grains, and eggs.

If you eat foods to which you are allergic, you may experience vomiting, diarrhea, or a rash. In some people, eating even tiny amounts of certain foods causes them to have serious symptoms, such as difficulty breathing. They need immediate medical attention. The best way to prevent food allergy symptoms is to avoid eating the offending food. This may require careful reading of food labels.

FIGURE 17.15
Picnic food is a potential cause of food-borne illness.

## Lesson Summary

- The digestive system is the body system that digests food mechanically and chemically and absorbs nutrients. The digestive system also eliminates solid food waste. The major organs of the digestive system include the mouth, esophagus, stomach, and small and large intestines. These organs make up the long tube called the gastrointestinal (GI) tract, which goes from the mouth to the anus.
- Chemical digestion depends on the work of digestive enzymes and other substances. These are secreted into the GI tract by organs of the digestive system or by the pancreas, liver, or gall bladder.
- Digestion starts in the mouth. When food is swallowed, it travels through the esophagus to the stomach. In the stomach, digestion continues and a small amount of absorption of nutrients takes place.
- Most chemical digestion and nearly all absorption of nutrients take place in the small intestine. This organ consists of three parts: duodenum, jejunum, and ileum.
- Excess water is absorbed from food waste in the large intestine before it passes out of the body through the anus as feces. Trillions of helpful bacteria also live in the large intestine. They carry out important roles, such as making vitamins.
- Common digestive system problems include foodborne illness and food allergies. Following healthy food-handling practices may decrease your risk of foodborne illness. Food allergy symptoms can be prevented by avoiding the offending foods.

## Lesson Review Questions

### Recall

1. What is the GI tract? What organs does it include?
2. Describe the roles of the mouth, esophagus, and stomach in digestion.
3. Identify two functions of the large intestine.
4. List three foods that commonly cause food allergies.

### Apply Concepts

5. How could you reduce the risk of foodborne illness on a picnic? What materials and methods could you use?

### Think Critically

6. Explain the role of enzymes in digestion, and give two examples.
7. Explain the structure and function of villi in the small intestine.

## Points to Consider

In the digestive system, food is digested and its nutrients are absorbed by the blood for transport around the body. The blood is part of the cardiovascular system.

1. What organs make up the cardiovascular system?
2. Besides nutrients, what other substances are transported by the blood?

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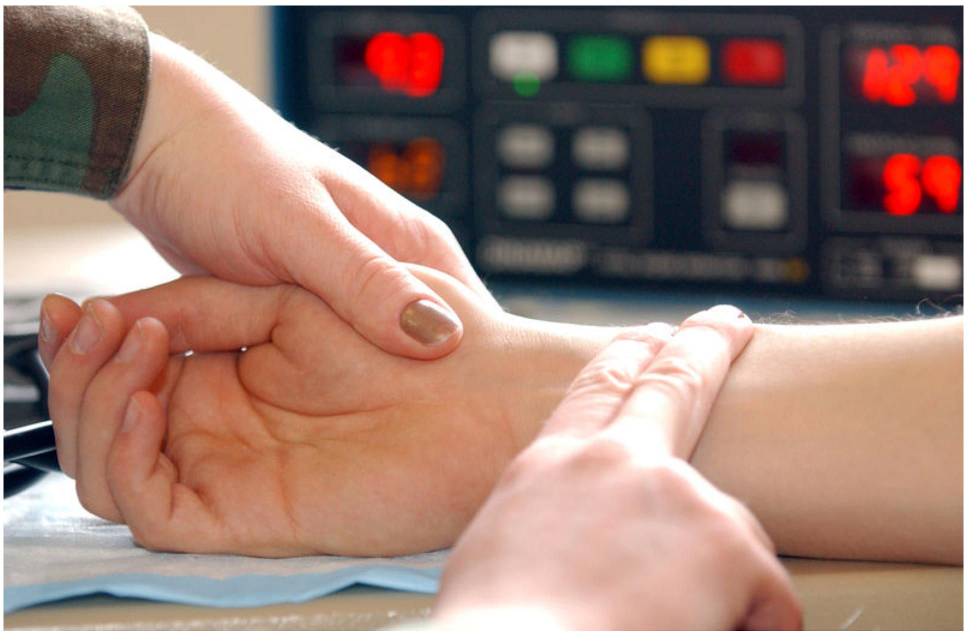
# CHAPTER 18 MS Cardiovascular System

## Chapter Outline





Place two fingers of one hand on the inside of your other wrist, as shown in this photo. You should be able to feel your pulse. What you are actually feeling is the pressure of blood inside a blood vessel in your wrist. Each throb of your pulse represents a beat of your heart. Your heart, blood vessels, and blood are all part of your cardiovascular system.

# 18.1 Overview of the Cardiovascular System

## Lesson Objectives

- Identify parts of the cardiovascular system.
- State functions of the cardiovascular system.
- Compare and contrast the two circulations of the cardiovascular system.

## Lesson Vocabulary

- cardiovascular system
- pulmonary circulation
- systemic circulation

## Introduction

The cardiovascular system is the system of organs that delivers blood to all the cells of the body. It's like the body's lifeline. Without the cardiovascular system circulating your blood, you couldn't survive.

## Parts of the Cardiovascular System

The organs that make up the cardiovascular system are the heart and a network of blood vessels that run throughout the body. The blood in the cardiovascular system is a liquid connective tissue. **Figure** 18.1 shows the heart and major vessels through which blood flows in the system. The heart is basically a pump that keeps blood moving through the blood vessels.

## Functions of the Cardiovascular System

The main function of the cardiovascular system is transporting substances around the body. **Figure** 18.1 shows some of the substances that are transported in the blood. They include hormones, oxygen, nutrients from digested food, and cellular wastes. Transport of all these materials is necessary to maintain homeostasis of the body and life itself.

The cardiovascular system also helps regulate body temperature by controlling where blood moves around the body. Blood is warm, so when more blood flows to the surface of the body, it warms the surface. This allows the body to lose excess heat from the surface. When less blood flows to the surface, it cools the surface. This allows the body

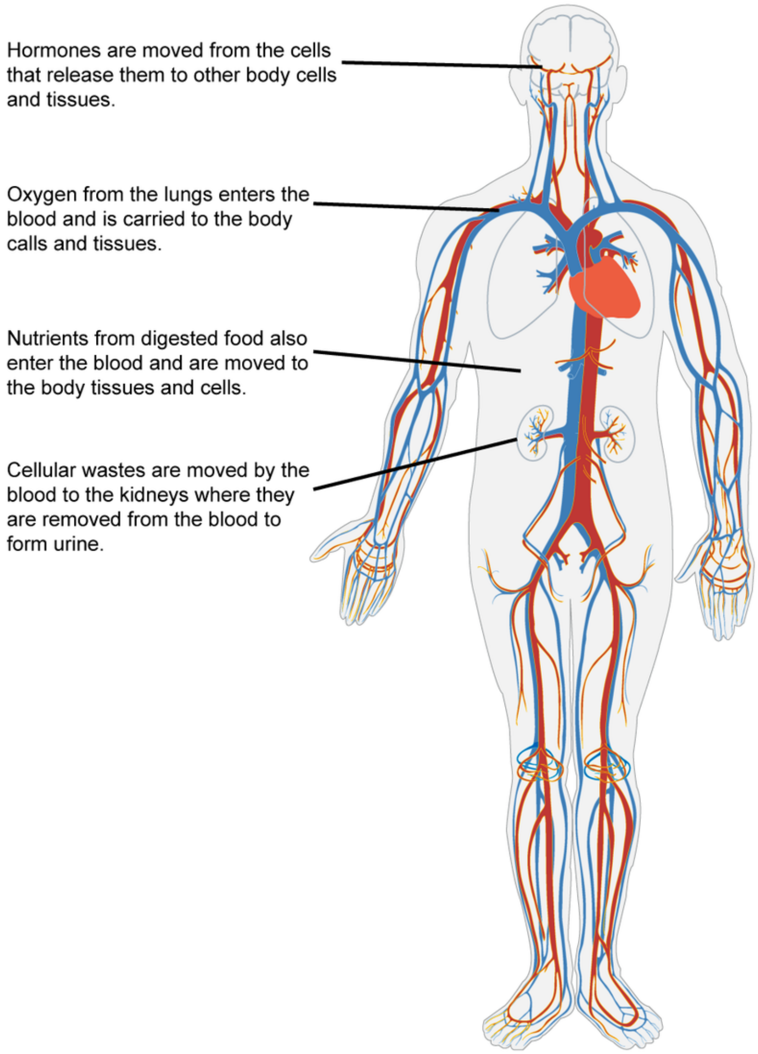



FIGURE 18.1
The cardiovascular system transports many substances to and from cells throughout the body.

to conserve heat and stay warm. You can see the role of blood vessels in the regulation of body temperature in this video: http://www.youtube.com/watch?v=eFhYa9B4pSg .

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## Two Circulations

The heart and blood vessels form a closed system through which blood keeps circulating. However, blood actually circulates in two different loops within this closed system. The two loops are called pulmonary circulation and systemic circulation. In both loops, blood passes through the heart. You can see a simple model of each circulation loop in **Figure** 18.2. As blood circulates through the body, it travels first through one loop and then the other loop, over and over again.

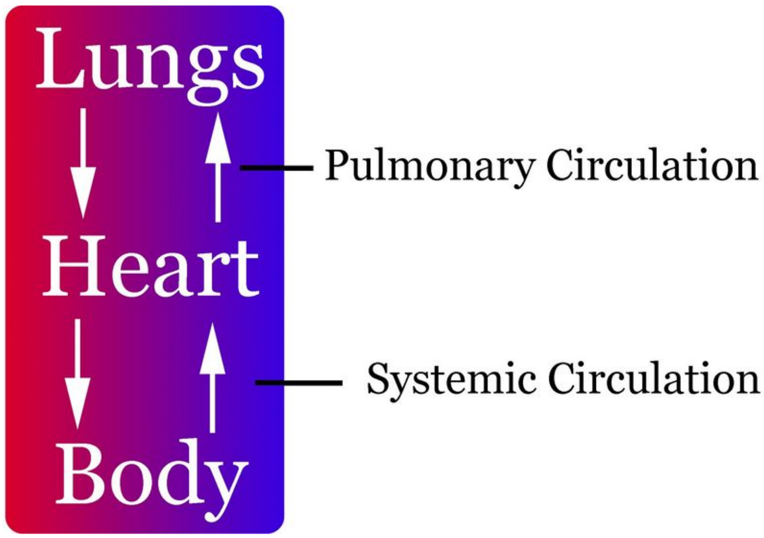



FIGURE 18.2
Pulmonary and systemic circulation

### Pulmonary Circulation

Pulmonary circulation is the shorter loop of the cardiovascular system. It carries blood between the heart and lungs. Oxygen-poor blood flows from the heart to the lungs. In the lungs, the blood absorbs oxygen and releases carbon dioxide. Then the oxygen-rich blood returns to the heart.

### Systemic Circulation

Systemic circulation is the longer loop of the cardiovascular system. It carries blood between the heart and the rest of the body. Oxygen-rich blood flows from the heart to cells throughout the body. As it passes cells, the blood releases oxygen and absorbs carbon dioxide. Then the oxygen-poor blood returns to the heart.

## Lesson Summary

- The cardiovascular system consists of the heart, a network of blood vessels, and blood. Blood is a liquid tissue. The heart is a pump that keeps blood flowing through the vessels of the system.
- The main function of the cardiovascular system is transport. It carries substances such as hormones, oxygen, nutrients, and cellular wastes around the body. The cardiovascular system also helps regulate body temperature by controlling blood flow.
- The cardiovascular system circulates blood through two different loops. Pulmonary circulation is a loop that carries blood between the heart and lungs. Systemic circulation is a loop that carries blood between the heart and the rest of the body.

## Lesson Review Questions

### Recall

1. List the parts of the cardiovascular system.
2. State two general functions of the cardiovascular system.

### Apply Concepts

3. The cardiovascular system has been called the highway system of the body. Do you think this is a good analogy for the cardiovascular system? Why or why not?

### Think Critically

4. Compare and contrast the pulmonary and systemic circulation loops of the cardiovascular system.

## Points to Consider

The main organs of the cardiovascular system are the heart and blood vessels. Both organs contain valves. Valves also are found in plumbing systems. They can be turned on or off to control the flow of water.

1. What is the function of valves in the cardiovascular system?
2. Why are valves needed in the cardiovascular system?

# 18.2 Heart and Blood Vessels

## Lesson Objectives

- Describe the structure and function of the heart.
- Identify types of blood vessels, and explain how blood vessels help maintain homeostasis.
- Describe cardiovascular diseases and ways to keep the cardiovascular system healthy.

## Lesson Vocabulary

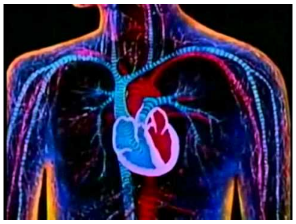
- artery
- atherosclerosis
- atrium (atria, plural)
- blood vessel
- capillary
- cardiovascular disease
- coronary heart disease
- heart
- heart attack
- valve
- vein
- ventricle

## Introduction

You can exercise your skeletal muscles, like the bicep muscles in your upper arms, by lifting weights. In between repetitions of the exercise, you let the muscles relax and rest. Unlike your skeletal muscles, your heart muscle can't rest. It must keep contracting and pumping blood continuously throughout your life. Obviously, the heart is a very special organ.

## The Heart

The heart is a muscular organ in the chest. It consists mainly of cardiac muscle tissue. It pumps blood by repeated, rhythmic contractions. This produces the familiar "lub-dub" sound of each heartbeat. For a good video introduction to the heart and how it works, watch this entertaining Bill Nye video: http://www.youtube.com/watch?v=GbttJ-5do9M .



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## Structure of the Heart

The heart has four chambers, or "rooms," which you can see in **Figure** 18.3. Each chamber is an empty space with muscular walls through which blood can flow.

- The top two chambers of the heart are called the left and right atria (atrium, singular). The atria of the heart receive blood from the body or lungs and pump it into the bottom chambers of the heart.
- The bottom two chambers of the heart are called the left and right ventricles. The ventricles receive blood from the atria and pump it out of the heart, either to the lungs or to the rest of the body.

Flaps of tissue called valves separate the heart's chambers. Valves keep blood flowing in just one direction through the heart. For example, a valve at the bottom of the right atrium opens to let blood flow from the right atrium to the right ventricle. Then the valve closes so the blood can't flow back into the right atrium.

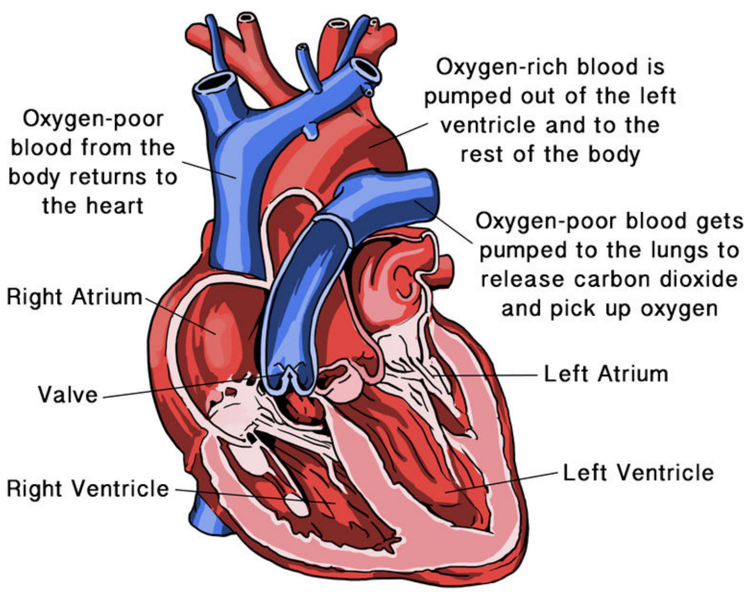
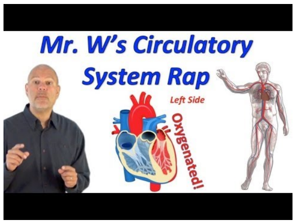



FIGURE 18.3

Parts of the heart

## How Blood Flows Through the Heart

Blood flows through the heart in two paths. Trace these two paths in **Figure** 18.4 as you read about them below. You can also learn about how blood flows through the heart with this rap: http://www.youtube.com/watch?v=KSbbDnbSEyM .

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1. One path of blood in the heart is through the right atrium and right ventricle. The right atrium receives oxygen-poor blood from the body. It pumps the blood into the right ventricle. Then the right ventricle pumps the blood out of the heart to the lungs. This path through the heart is part of the pulmonary circulation.
2. The other path of blood in the heart is through the left atrium and left ventricle. The left atrium receives oxygen-rich blood from the lungs. It pumps the blood into the left ventricle. Then the left ventricle pumps the blood out of the heart to the rest of the body. This path through the heart is part of the systemic circulation.

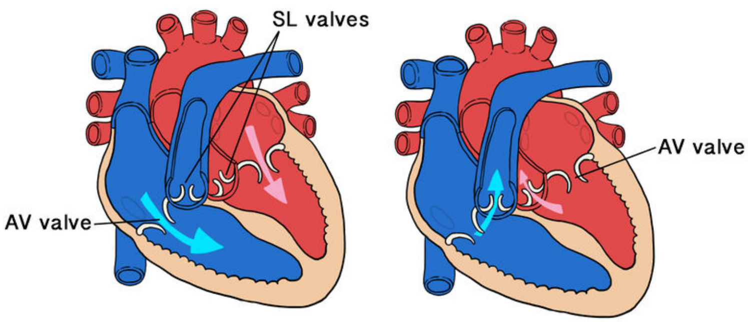



FIGURE 18.4

Blood flows through the heart along two different paths, shown here by blue and red arrows. Notice where valves open and close to keep the blood moving in just one direction along each path.

### How the Heart Beats

To move blood through the heart, cardiac muscles must contract in a certain sequence. First the atria must contract, followed quickly by the ventricles contracting. This series of contractions keeps blood moving continuously through the heart.

Contractions of cardiac muscles aren't under voluntary control. They are controlled by a cluster of special cells within the heart, commonly called the pacemaker. These cells send electrical signals to cardiac muscles so they contract in the correct sequence and with just the right timing.

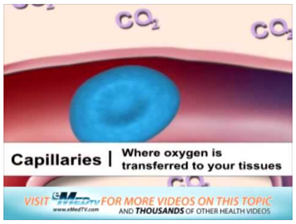
## Blood Vessels

Blood vessels are long, tube-like organs that consist mainly of muscle, connective, and epithelial tissues. They branch to form a complex network of vessels that run throughout the body. This network transports blood to all the body's cells.

### Types of Blood Vessels

There are three major types of blood vessels: arteries, veins, and capillaries. You can see each type in **Figure** 18.5. You can watch a good video introduction to the three types at this link: http://www.youtube.com/watch?v=CjNKb

L_-cwA .

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- Arteries are muscular blood vessels that carry blood away from the heart. They have thick walls that can withstand the pressure of blood pumped by the heart. Arteries generally carry oxygen-rich blood. The largest artery is the aorta, which receives blood directly from the heart. It branches to form smaller and smaller arteries throughout the body. The smallest arteries are called arterioles.
- Veins are blood vessels that carry blood toward the heart. This blood is no longer under pressure, so veins have thinner walls. To keep the blood moving, many veins have valves that prevent the backflow of blood. Veins generally carry oxygen-poor blood. The smallest veins are called venules. They merge to form larger and larger veins. The largest vein is the inferior vena cava, which carries blood from the lower body directly to the heart.
- Capillaries are the smallest type of blood vessels. They connect the smallest arteries (arterioles) and veins (venules). Exchange of substances between cells and the blood takes place across the walls of capillaries, which may be only one cell thick.

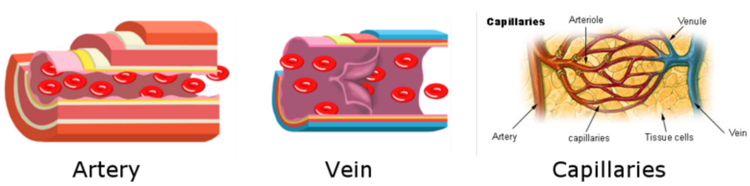



FIGURE 18.5

Arteries, veins and capillaries

### Blood Vessels and Homeostasis

Blood vessels help regulate body processes by either dilating (widening) or constricting (narrowing). This changes the amount of blood flowing to particular organs. For example, dilation of blood vessels in the skin allows more blood to flow to the surface of the body. This helps the body lose excess heat. Constriction of these blood vessels has the opposite effect and helps the body conserve heat.

## Cardiovascular Health

Diseases of the cardiovascular system are common and may be life threatening. A healthy lifestyle can reduce the risk of such diseases developing.

### Diseases of the Cardiovascular System

Diseases of the heart and blood vessels are called cardiovascular diseases. The leading cause of cardiovascular disease is atherosclerosis.

Atherosclerosis is a condition in which a material called plaque builds up inside arteries. Plaque consists of cell debris, cholesterol, and other substances. As plaque builds up in an artery, the artery narrows, as shown in **Figure 18.6**. This reduces blood flow through the artery.

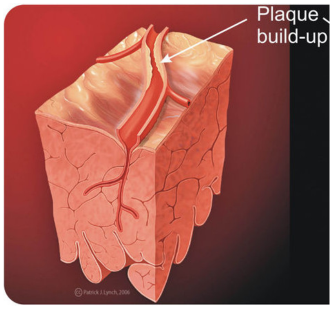



FIGURE 18.6

Plaque buildup in an artery reduces blood flow through the vessel.

If plaque blocks coronary arteries that supply blood to the heart, coronary heart disease results. Poor blood flow to the heart may cause chest pain or a heart attack. A heart attack occurs when the blood supply to part of the heart muscle is completely blocked so that cardiac muscle cells die. Coronary heart disease is the leading cause of death in U.S adults.

### Keeping the Cardiovascular System Healthy

Many factors influence your risk of developing cardiovascular diseases. Some of these factors you can't control. Older age, male gender, and a family history of cardiovascular disease all increase the risk and can't be controlled. However, you can control many other factors. To reduce the risk of cardiovascular disease, you can:

- avoid smoking.
- get regular physical activity.
- maintain a healthy percent of body fat.
- eat a healthy, low-fat diet.
- get regular checkups to detect and manage problems such as high blood pressure and high blood cholesterol.

## Lesson Summary

- The heart is a muscular organ in the chest that consists mainly of cardiac muscle. It pumps blood through blood vessels by repeated, rhythmic contractions. Blood flows through four chambers of the heart when it beats. Heartbeat is controlled by electrical signals from special cells within the heart called the pacemaker.
- Blood vessels are long, tube-like organs that form a complex network throughout the body. They transport blood to all the body's cells. There are three types of blood vessels: arteries, veins, and capillaries. Transfer of substances between the blood and cells takes place across the thin walls of capillaries.
- Diseases of the cardiovascular system are common and may be life threatening. Examples include atherosclerosis and coronary heart disease. A healthy lifestyle can reduce the risk of such diseases developing. This includes avoiding smoking, getting regular physical activity, and maintaining a healthy percent of body fat.

## Lesson Review Questions

### Recall

1. Describe the structure of the heart.
2. Give an example of homeostasis involving blood vessels.
3. Define cardiovascular diseases.

### Apply Concepts

4. Create a poster showing ways to keep the cardiovascular system healthy.

### Think Critically

5. Explain how the heart pumps blood.
6. Compare and contrast the three major types of blood vessels.

## Points to Consider

Transporting blood is the main job of the heart and blood vessels.

1. What is blood? What is it made of?
2. What substances are transported around the body in blood?

# 18.3 Blood

## Lesson Objectives

- Describe blood components, and list functions of the blood.
- Define blood type, and explain its medical significance.
- Identify some diseases of the blood.

## Lesson Vocabulary

- anemia
- antigen
- blood
- blood clot
- blood type
- hemoglobin
- hemophilia
- leukemia
- plasma
- platelet
- red blood cell
- sickle-cell disease
- white blood cell

## Introduction

The young man in **Figure** 18.7 is donating blood. By donating blood, he may well be saving lives. Blood transfusions, in which patients receive blood from a donor, save countless lives each year. That's because blood is such a vital body fluid.

## Structure and Functions of Blood

Blood is a liquid connective tissue. It circulates throughout the body via blood vessels due to the pumping action of the heart. You couldn't survive without the approximately 4.5 to 5 liters of blood that are constantly being pumped through your blood vessels.

FIGURE 18.7
Blood donation

## Blood Components

Blood consists of both liquid and cells. The liquid part of blood is called plasma. Plasma is a watery, golden-yellow fluid that contains many dissolved substances. Substances dissolved in plasma include glucose, proteins, and gases.

Plasma also contains blood cells. There are three types of blood cells: red blood cells, white blood cells, and platelets. You can see all three types in **Figure** 18.8.

1. Red blood cells are shaped like flattened disks. There are trillions of red blood cells in your blood. Each red blood cell has millions of molecules of hemoglobin. Hemoglobin is a protein that contains iron. The iron in hemoglobin gives red blood cells their red color. It also explains how hemoglobin carries oxygen. The iron in hemoglobin binds with oxygen molecules so they can be carried by red blood cells.
2. White blood cells are larger than red blood cells, but there are far fewer of them. Their role is to defend the body in various ways. For example, white blood cells called phagocytes engulf and destroy microorganisms and debris in the blood.
3. Platelets are small, sticky cell fragments that help blood clot. A blood clot is a solid mass of cell fragments and other substances that plugs a leak in a damaged blood vessel. Platelets stick to tears in blood vessels and to each other, helping to form a clot at the site of injury. Platelets also release chemicals that are needed for clotting to occur.

### Functions of Blood

The main function of blood is transport. Blood in arteries carries oxygen and nutrients to all the body's cells. Blood in veins carries carbon dioxide and other wastes away from cells to be excreted. Blood also transports the chemical messengers called hormones to cells throughout the body where they are needed to regulate body functions. Blood has several other functions as well. For example, blood:

- defends the body against infections.
- repairs body tissues.
- controls the body's pH.
- helps regulate body temperature.

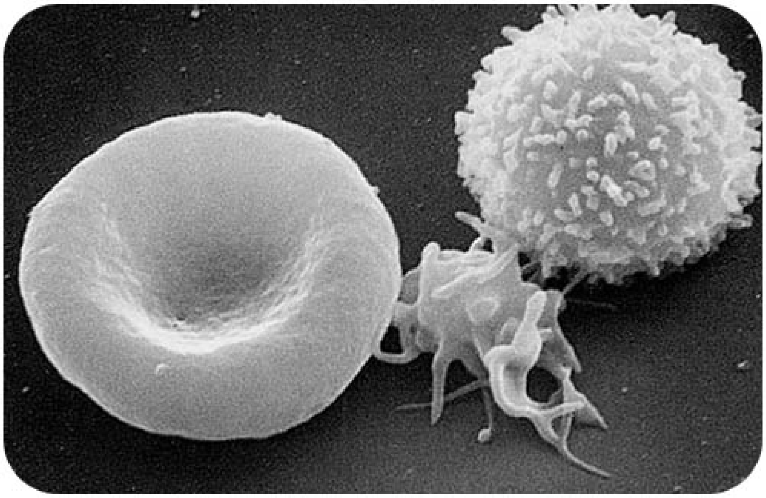


FIGURE 18.8
Blood cells include disk-shaped red blood cells (left), spherical white blood cells (right), and small cell fragments called platelets (center).

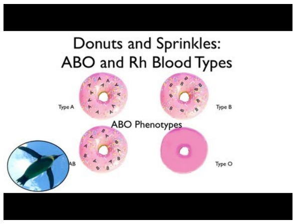
## Blood Type

Red blood cells carry proteins called antigens on their surface. People may vary in the exact antigens their red blood cells carry. The specific proteins are controlled by the genes they inherit from their parents. The particular antigens you inherit determine your blood type.

Why does your blood type matter? Blood type is important for medical reasons. A patient can't safely receive a transfusion of blood containing antigens not found in the patient's own blood. With "foreign" antigens, the transfused blood will be rejected by the person's immune system. This causes a reaction in the patient's bloodstream, called agglutination. The transfused red blood cells clump together, as shown in **Figure** 18.9. The clumped cells block blood vessels and cause other life-threatening problems.

FIGURE 18.9
Normal and agglutinated blood: normal blood smear (left) and agglutinated blood smear (right).

There are many sets of antigens that determine different blood types. Two of the best known are the ABO and Rhesus antigens. Both are described below. You can also learn more about them by watching this video: http://www.youtube.com/watch?v=L06TJTMVkBo .

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### ABO Blood Type

ABO blood type is determined by two common antigens, often called antigen A and antigen B.

- If your red blood cells carry only antigen A, you have blood type A.
- If your red blood cells carry only antigen B, you have blood type B.
- If your red blood cells carry both antigen A and antigen B, you have blood type AB.
- If your red blood cells carry neither antigen A nor antigen B, you have blood type O.

### Rhesus Blood Type

Another red blood cell antigen determines a person's Rhesus blood type. This blood type depends on a single common antigen, typically referred to as the Rhesus (Rh) antigen.

- If your red blood cells carry the Rhesus antigen, you have Rhesus-positive blood, or blood type Rh+.
- If your red blood cells lack the Rhesus antigen, you have Rhesus-negative blood, or blood type Rh-.

## Diseases of the Blood

Some diseases affect mainly the blood or its components. They include anemia, leukemia, hemophilia, and sickle-cell disease.

### Anemia

Anemia is a disease that occurs when there is not enough hemoglobin (or iron) in the blood so it can't carry adequate oxygen to the cells. There are many possible causes of anemia. One possible cause is excessive blood loss due to an injury or surgery. Not getting enough iron in the diet is another possible cause.

### Leukemia

Leukemia is a type of cancer in which bone marrow produces abnormal white blood cells. The abnormal cells can't do their job of fighting infections. Like most cancers, leukemia is thought to be caused by a combination of genetic and environmental factors. It is the most common cancer in children.

### Hemophilia

Hemophilia is a genetic disorder in which blood fails to clot properly because a normal clotting factor in the blood is lacking. In people with hemophilia, even a minor injury can cause a life-threatening loss of blood. Most cases of hemophilia are caused by a recessive gene on the X chromosome. The disorder is expressed much more commonly in males because they have just one X chromosome.

### Sickle-Cell Disease

Sickle-Cell Disease is another genetic disorder of the blood. It is more common in people with African origins because it helps protect against malaria. Sickle-cell disease occurs in people who inherit two copies of the recessive mutant gene for hemoglobin. The abnormal hemoglobin that results causes red blood cells to take on a characteristic sickle shape under certain conditions. You can compare sickle-shaped and normal red blood cells in **Figure** 18.10. The sickle-shaped cells get stuck in tiny capillaries and block blood flow. This causes serious, painful symptoms. Watch this video animation to learn more about the genetic basis of sickle-cell disease: http://www.dnalc.org/resources/3d/17-sickle-cell.html

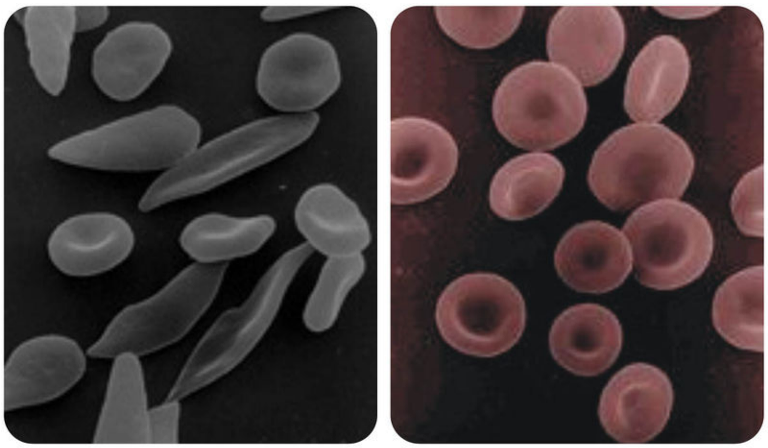

FIGURE 18.10
Comparison of sickle-shaped and normal red blood cells

## Lesson Summary

- Blood consists of liquid plasma, which contains dissolved substances, and three types of cells: red blood cells, white blood cells, and platelets. The main function of blood is transport. Blood also fights infections, repairs tissues, controls pH, and helps regulate body temperature.
- Specific antigens on the surface of red blood cells determine blood type. The best-known blood types are ABO and Rhesus (Rh) blood types. Blood type is important in cases of blood transfusion. A patient must receive blood of his or her own blood type to avoid clumping of red blood cells.
- Many diseases affect the blood or its components. They include anemia, leukemia, hemophilia, and sickle-cell disease.

## Lesson Review Questions

### Recall

1. What is blood?
2. Identify the main function of blood.
3. Describe two diseases of the blood and their causes.

### Apply Concepts

4. Why might it be necessary to determine your ABO blood type?
5. If you have type O blood, which type(s) of blood can you safely receive?

### Think Critically

6. Compare and contrast red blood cells and white blood cells.
7. Relate antigens to blood types.

## Points to Consider

The blood picks up oxygen in the lungs and carries it to cells throughout the body.

1. How does oxygen enter the lungs?
2. How does oxygen get from the lungs into the blood?

# 18.4 References


1. Mariana Ruiz Villarreal (User:LadyofHats/Wikimedia Commons), modified by CK-12 Foundation. http://commons.wikimedia.org/wiki/File:Circulatory_System_no_tags.svg . Public Domain
2. Sam McCabe. CK-12 Foundation . CC BY-NC 3.0
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# CHAPTER 19 MS Respiratory and Excretory Systems

## Chapter Outline



You don't have to be a musician to know that playing a wind instrument like the trumpet takes a lot of air. Having healthy lungs is necessary to play a trumpet or other wind instrument. The lungs are part of the respiratory system.

# 19.1 The Respiratory System

## Lesson Objectives

- Define respiration and distinguish it from cellular respiration.
- Identify structures of the respiratory system.
- Explain how breathing, gas exchange, and gas transport occur.
- Describe respiratory system diseases and how to keep the respiratory system healthy.

## Lesson Vocabulary

- asthma
- emphysema
- lung
- pneumonia
- respiration
- respiratory system
- trachea

## Introduction

All the cells of your body need oxygen, which they get from red blood cells. Red blood cells, in turn, get oxygen in the lungs. The lungs are the main organs of the respiratory system. The respiratory system is the body system that exchanges gases with the outside air. It brings air containing oxygen into the body for the cells. It also releases carbon dioxide from the cells into the air.

## What Is Respiration?

The body's exchange of oxygen and carbon dioxide with the air is called respiration. Respiration actually consists of two stages. In one stage, air is taken into the body and carbon dioxide is released to the outside air. In the other stage, oxygen is delivered to all the cells of the body and carbon dioxide is carried away from the cells.

Another kind of respiration takes place within body cells. This kind of respiration is called cellular respiration. It's the process in which cells obtain energy by "burning" glucose. Both types of respiration are connected. Cellular respiration uses oxygen and produces carbon dioxide. Respiration by the respiratory system supplies the oxygen needed for cellular respiration. It also removes the carbon dioxide produced by cellular respiration.

## Structures of the Respiratory System

You can see the main structures of the respiratory system in **Figure** 19.1. They include the nose, trachea, lungs, and diaphragm. Use the figure to trace how air moves through the respiratory system when you read about it below. You can also use this interactive to explore the respiratory system and see how it functions: http://science.nationalgeographic.com/science/health-and-human-body/human-body/lungs-article/

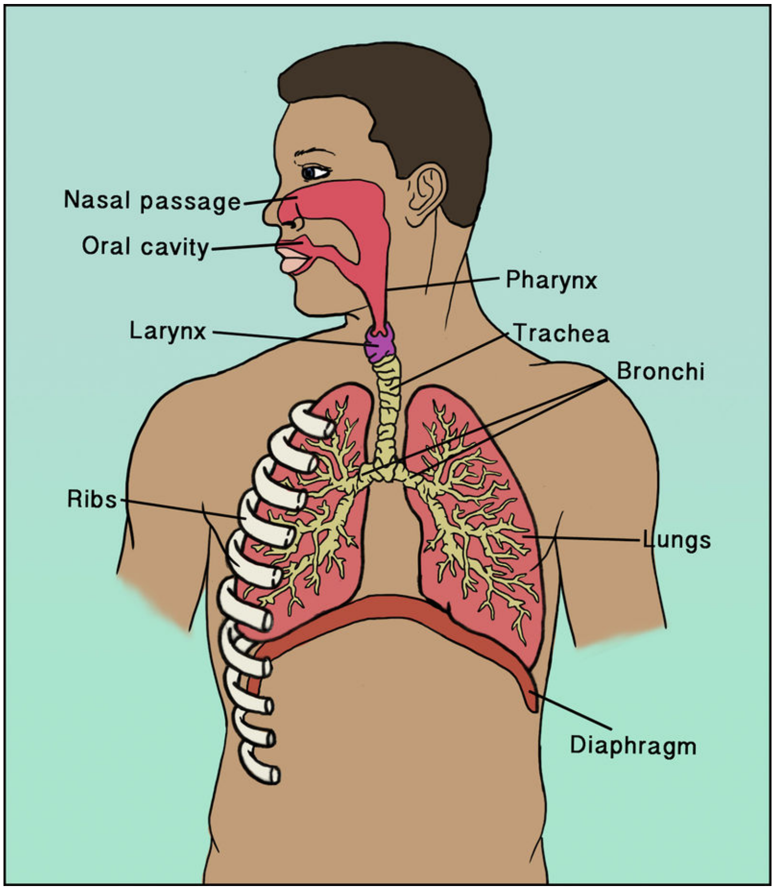



FIGURE 19.1
Structures of the respiratory system

## Steps in Respiration

Take in a big breath of air through your nose. As you breathe in, you may feel the air pass down through your throat and notice your chest expand. Now breathe out and observe the opposite events occurring. Breathing in and out may seem like simple actions, but they are just part of the complex process of respiration. Respiration actually occurs in four steps:

1. breathing (inhaling and exhaling)
2. gas exchange between the air and blood
3. gas transport by the blood
4. gas exchange between the blood and cells

### Breathing

Breathing is the process of moving air into and out of the lungs. The process depends on a muscle called the diaphragm. This is a large, sheet-like muscle below the lungs. You can see it in **Figure** 19.2.

- Inhaling, or breathing in, occurs when the diaphragm contracts. This increases the size of the chest, which decreases air pressure inside the lungs. The difference in air pressure between the lungs and outside air causes air to rush into the lungs.
- Exhaling, or breathing out, occurs when the diaphragm relaxes. This decreases the size of the chest, which increases air pressure inside the lungs. The difference in air pressure between the lungs and outside air causes air to rush out of the lungs.

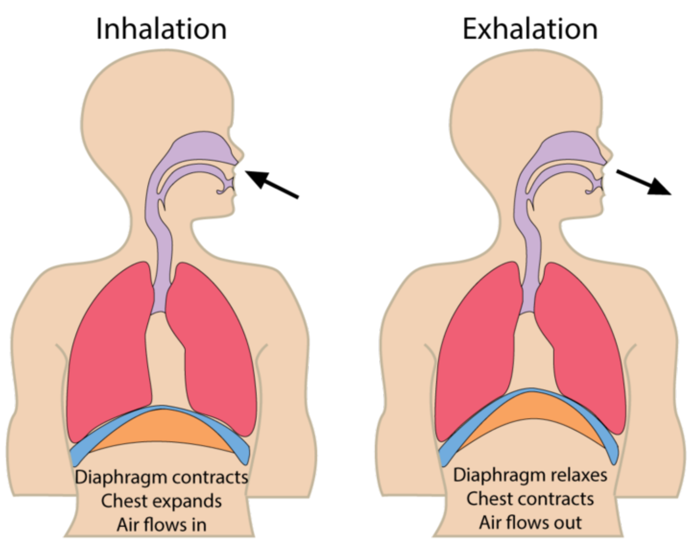



FIGURE 19.2
How the diaphragm controls breathing

When you inhale, air enters the respiratory system through your nose and ends up in your lungs, where gas exchange with the blood takes place. What happens to the air along the way?

- In the nose, mucus and hairs trap any dust or other particles in the air. The air is also warmed and moistened so it won't harm delicate tissues of the lungs.
- Next, air passes through the pharynx, a passageway that is shared with the digestive system. From the pharynx, the air passes next through the larynx, or voice box.
- After the larynx, air moves into the trachea, or wind pipe. This is a long tube that leads down to the lungs in the chest.
- In the chest, the trachea divides as it enters the lungs to form the right and left bronchi (bronchus, singular). These passages are covered with mucus and tiny hairs called cilia. The mucus traps any remaining particles in the air. The cilia move and sweep the particles and mucus toward the throat so they can be expelled from the body.
- Air passes from the bronchi into smaller passages called bronchioles. The bronchioles end in clusters of tiny air sacs called alveoli (alveolus, singular).

### Gas Exchange Between the Air and Blood

The alveoli in the lungs are where gas exchange between the air and blood takes place. Each alveolus is surrounded by a network of capillaries. When you inhale, air in the alveoli has a greater concentration of oxygen than does blood in the capillaries. The difference in oxygen concentration causes oxygen to diffuse from the air into the blood. You can see how this occurs in **Figure** 19.3.

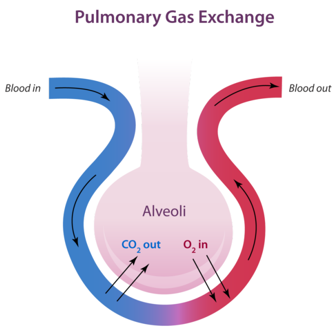



FIGURE 19.3
How gases are exchanged in alveoli

Unlike oxygen, carbon dioxide is more concentrated in the blood in the capillaries surrounding the alveoli than it is in the air inside the alveoli. Therefore, carbon dioxide diffuses in the opposite direction. It moves out of the blood and into the air.

### Gas Transport in the Blood

After the blood in the capillaries in the lungs picks up oxygen, it leaves the lungs and travels to the heart. The heart pumps the oxygen-rich blood into arteries, which carry it throughout the body. The blood passes eventually into capillaries that supply body cells.

### Gas Exchange Between the Blood and Cells

The cells of the body have a lower concentration of oxygen that does blood in the capillaries that supply body cells. Therefore, oxygen diffuses from the blood into the cells. Carbon dioxide, which cells produce in cellular respiration, is more concentrated in the cells. Therefore, carbon dioxide diffuses out of the cells and into the blood. The carbon dioxide travels in capillaries to veins and then to the heart. The heart pumps the blood to the lungs, where the carbon dioxide diffuses into the alveoli. It passes out of the body during exhalation. This brings the process of respiration full circle.

## Respiratory System Health

No doubt you've had the common cold. When you did, you probably had respiratory system symptoms. For example, you may have had a stuffy nose that made it hard to breathe. While you may feel miserable when you have a cold, it is generally a relatively mild disease. Many other respiratory system diseases are more serious.

### Diseases of the Respiratory System

Common diseases of the respiratory system include asthma, pneumonia, and emphysema. All of them are diseases of the lungs. You can see some of the changes in the lungs that occur in each of these diseases in **Figure** 19.4.

- Asthma is a disease in which bronchioles in the lungs periodically swell and fill with mucus. Symptoms of asthma may include difficulty breathing, wheezing, coughing, and chest tightness. An asthma attack may be triggered by allergies, strenuous exercise, stress, or another respiratory illness such as a cold.

- Pneumonia is a disease in which some of the alveoli of the lungs fill with fluid so they can no longer exchange gas. Symptoms of pneumonia typically include coughing, chest pain, difficulty breathing, and fatigue. Pneumonia may be caused by an infection or an injury to the lungs.
- Emphysema is a disease in which the walls of the alveoli break down so less gas can be exchanged by the lungs. The main symptom of emphysema is shortness of breath. The damage to the alveoli is usually caused by smoking and is permanent.

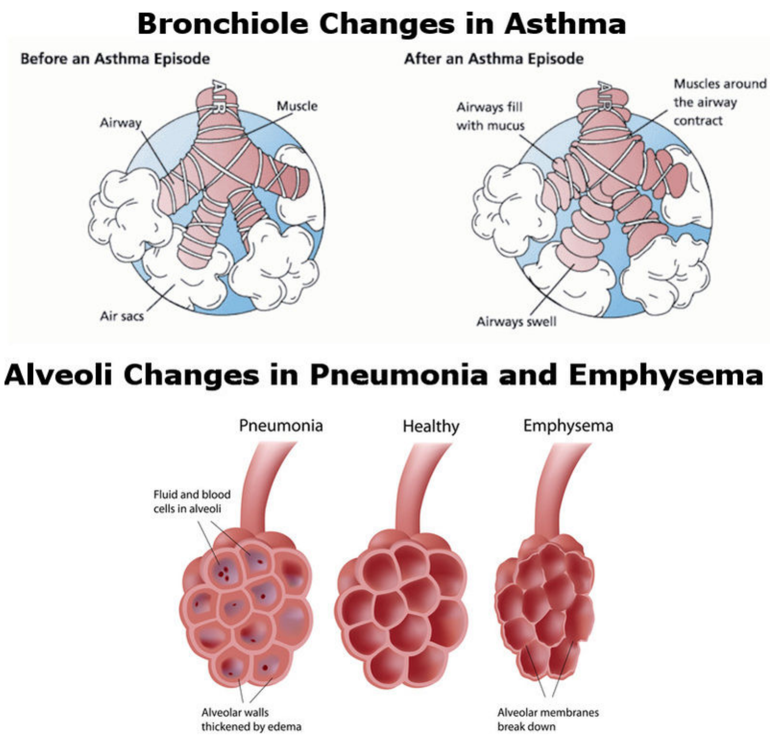



FIGURE 19.4

Changes in the lungs due to asthma (top), pneumonia (bottom left), and emphysema (right)

### Keeping Your Respiratory System Healthy

The main way to keep your respiratory system healthy is to avoid smoking or breathing in the smoke of others. Smoking causes, or makes you more susceptible to, many respiratory diseases, including asthma, bronchitis, emphysema, and lung cancer. Other steps you can take to keep your respiratory system healthy are listed below.

- Eat well, get enough sleep, and be active every day. These healthy lifestyle choices will help keep your immune system healthy so it can fight off respiratory infections and other diseases.
- Wash your hands often. This will reduce your risk of picking up viruses or bacteria that could make you sick with colds or other respiratory infections.
- Avoid contact with other people when they are sick and stay home when you are sick. These steps will help reduce the spread of infectious diseases.

## Lesson Summary

- The respiratory system is the body system that exchanges gases with the outside air. It brings air containing oxygen into the body for the cells. It also releases carbon dioxide from the cells into the air. This exchange of

gases is called respiration.
- Breathing is the process of moving air into and out of the lungs. It depends on the muscle called the diaphragm.
- The lungs are the main organs of the respiratory system. This is where gases are exchanged between the air and the blood. Gases are also transported by the blood and exchanged between the blood and all the cells of the body.
- Common diseases of the respiratory system include asthma, pneumonia, and emphysema. All of them are diseases of the lungs. The main way to keep your respiratory system healthy is to avoid smoking or breathing in the smoke of others.

## Lesson Review Questions

### Recall

1. What is the function of the respiratory system?
2. Define respiration and relate it to cellular respiration.
3. List steps in the process of respiration.
4. Describe asthma, including its symptoms and possible triggers.

### Apply Concepts

5. Make a poster warning teens of the respiratory system dangers of smoking.

### Think Critically

6. Explain how the diaphragm controls breathing.
7. Relate the structure of alveoli to the function of the lungs.

## Points to Consider

The lungs release carbon dioxide into the air. Carbon dioxide is a gaseous waste product of the cells. Wastes are excreted from the body by the excretory system. Therefore, the lungs are organs of the excretory system as well as the respiratory system.

1. What are some other organs of the excretory system?
2. What types of waste products do these organs excrete?

# 19.2 The Excretory System

## Lesson Objectives

- Define excretion, and identify organs of the excretory system.
- Outline the structures and functions of the urinary system.
- Explain how the kidneys filter blood and produce urine.
- Describe how the kidneys help maintain homeostasis.
- Identify kidney diseases and how they are treated.

## Lesson Vocabulary

- excretion
- excretory system
- kidney
- kidney failure
- kidney stone
- nephron
- ureter
- urethra
- urinary bladder
- urinary system
- urinary tract infection
- urination
- urine

## Introduction

The boy in **Figure** 19.5 is working out on a hot day. He's losing a lot of water in sweat. To maintain homeostasis, his body can balance the water lost in sweat by excreting less water in urine. The amount of water lost in urine is controlled by the kidneys. The kidneys are organs of excretion.

## Excretion

Excretion is any process in which excess water or wastes are removed from the body. Excretion is the job of the excretory system. Besides the kidneys, other organs of excretion include the large intestine, liver, skin and lungs.

- The large intestine eliminates food wastes that remain after digestion takes place.
- The liver removes excess amino acids and toxins from the blood.

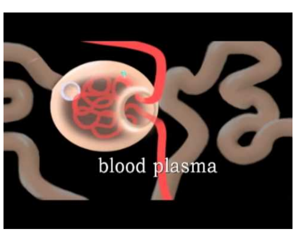
FIGURE 19.5
Water lost in sweat must be balanced in some way for the body to maintain homeostasis.

- Sweat glands in the skin excrete excess water and salts in sweat.
- The lungs exhale carbon dioxide and also excess water as water vapor.

Each of the above organs of excretion is also part of another body system. For example, the large intestine and liver are part of the digestive system, and the lungs are part of the respiratory system. The kidneys are the main organs of excretion. They are part of the urinary system.

## The Urinary System

The urinary system is shown in **Figure** 19.6. It includes two kidneys, two ureters, the urinary bladder, and the urethra. The main function of the urinary system is to filter waste products and excess water from the blood and excrete them from the body as urine. For a visual presentation on the urinary system and how it works, watch this video: http://www.youtube.com/watch?v=OkyFPMXa28c .

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### The Kidneys

The kidneys are a pair of bean-shaped organs at each side of the body just above the waist. You can see a diagram of a kidney in **Figure** 19.7. The function of the kidneys is to filter blood and form urine. Tiny structures in the kidneys, called nephrons, perform this function. Each kidney contains more than a million nephrons.

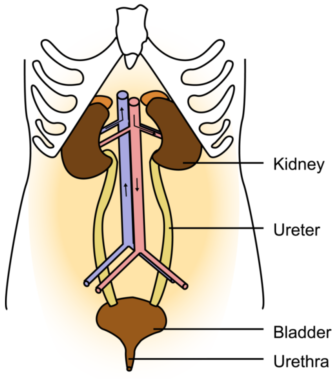



FIGURE 19.6
The kidneys are the main organs of the urinary system.

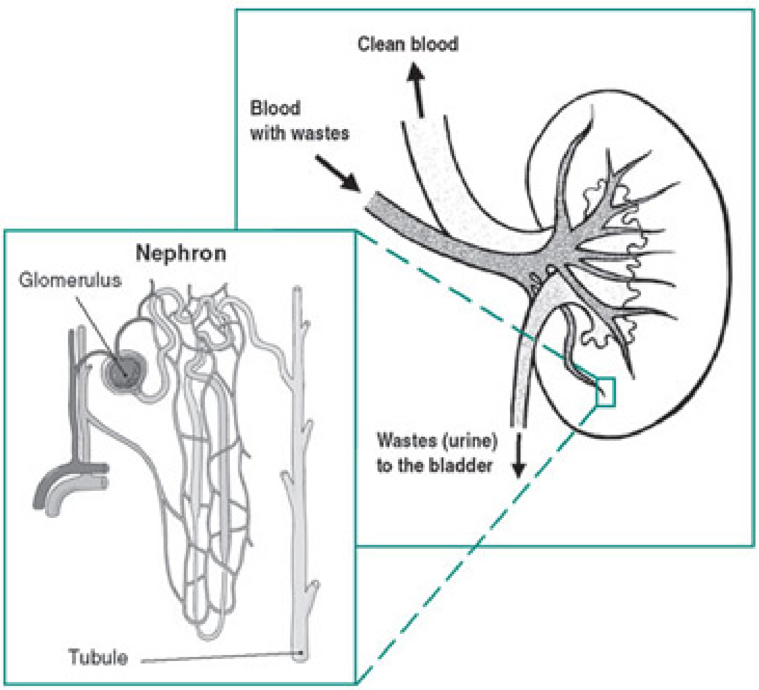



FIGURE 19.7
Structures in the kidney

## Formation of Urine

Blood with wastes enters each kidney through an artery, which branches into many capillaries. After passing through capillaries and being filtered, the clean blood leaves the kidney through a vein.

The part of each nephron called the glomerulus is where blood in the capillaries is filtered. Excess water and wastes are filtered out of the blood. The tubule of the nephron collects these substances. Some of the water is reabsorbed. The remaining fluid is urine.

## Excretion of Urine

From the kidneys, urine enters the ureters. These are two muscular tubes that carry urine to the urinary bladder. Contractions of the muscles of the ureters move the urine along by peristalsis. The urinary bladder is a sac-like organ that stores urine. When the bladder is about half full, a sphincter relaxes to let urine flow out of the bladder and into the urethra. The urethra is a muscular tube that carries urine out of the body through another sphincter. The process of urine leaving the body is called urination. The second sphincter and the process of urination are normally under conscious control.

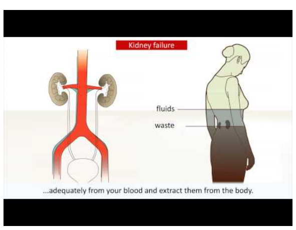
## How the Kidneys Maintain Homeostasis

The kidneys help the body maintain homeostasis in several ways. They filter all the blood in the body many times each day and produce urine. They control the amount of water and dissolved substances in the blood by excreting more or less of them in urine.

The kidneys also secrete hormones that help maintain homeostasis. For example, they produce a hormone that stimulates bone marrow to produce red blood cells when more are needed. They also secrete a hormone that regulates blood pressure and keeps it in a normal range.

## Kidney Health and Disease

You need only one kidney to live a normal, healthy life. A single kidney can do all the work of filtering the blood and maintaining homeostasis. However, at least one kidney must function properly to maintain life. Diseases that threaten the health and functioning of the kidneys include kidney stones, infections, and diabetes. You can learn more about kidney diseases in this video: http://www.youtube.com/watch?v=BodnYcHGtiA .

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Kidney stones are mineral crystals that form in urine inside a kidney, as shown in **Figure** 19.8. The stones may be extremely painful. If a kidney stone blocks a ureter, it must be removed so urine can leave the kidney and be excreted.

Bacterial infections of urinary organs, especially the urinary bladder, are common. They are called urinary tract infections. Generally, they can be cured with antibiotic drugs. However, if they aren't treated, they can lead to more serious infections and damage to the kidneys.

Untreated diabetes may damage capillaries in the kidneys so the nephrons can no longer filter blood. This is called kidney failure. The only cure for kidney failure is to receive a healthy transplanted kidney from a donor. Until that happens, a patient with kidney failure can be kept alive by artificially filtering the blood through a machine. This is called hemodialysis. You can see how it works in **Figure** 19.9.

## Lesson Summary

- Excretion is any process in which excess water or wastes are removed from the body. Excretion is the job of the excretory system. Organs of excretion include the large intestine, liver, skin, lungs, and kidneys.

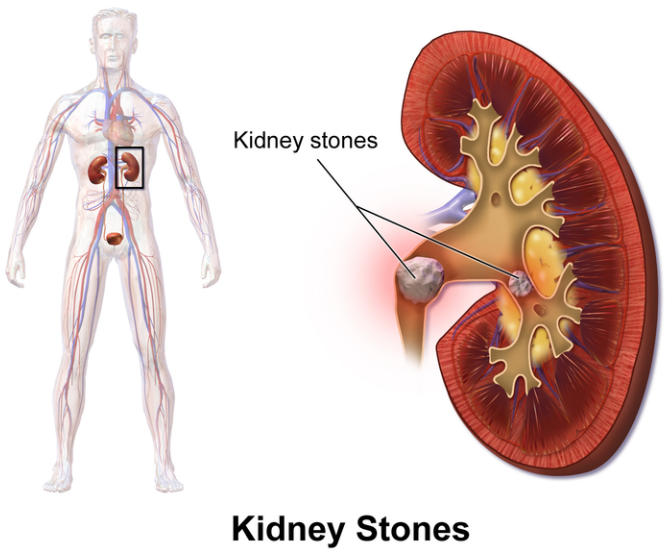


FIGURE 19.8
Kidney stones

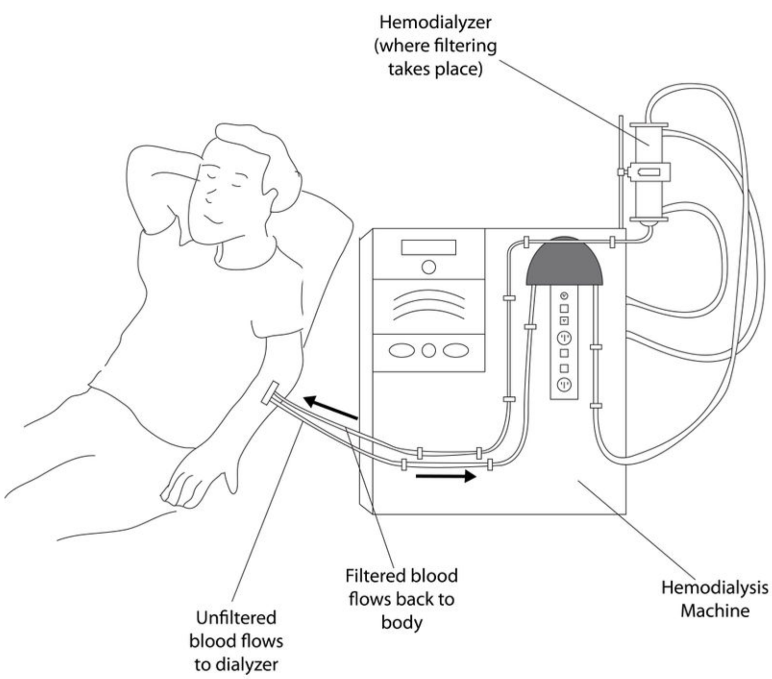


FIGURE 19.9
Hemodialysis filters blood through a machine in patients with kidney failure.

- The urinary system filters wastes and excess water from the blood, forms urine, and excretes urine from the body. It includes two kidneys, two ureters, the urinary bladder, and the urethra. Nephrons are tiny structures in the kidneys that filter blood and form urine.
- Diseases of the urinary system include kidney stones and urinary tract infections. Untreated diabetes may cause kidney failure and the need for hemodialysis or a kidney transplant.

## Lesson Review Questions

### Recall

1. Define excretion.
2. What are the organs of the excretory system?
3. Describe the urinary system.

### Apply Concepts

4. Why does a person with kidney failure need hemodialysis?

### Think Critically

5. Explain how the kidneys filter blood and form urine.
6. Explain two ways that the kidneys maintain homeostasis.

## Points to Consider

Although the process of urination is under conscious control, the other processes of the urinary system are not. You can't control the work of your kidneys, for example, but this doesn't mean that they operate without any control.

1. What organ system controls the kidneys?
2. What organs make up this system?

# 19.3 References


1. Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
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# CHAPTER 20 MS Controlling the Body

## Chapter Outline



Hakeem is a talented skater, but he almost fell off this railing when his feet got tangled together. He thought he would fall, but in the blink of an eye, he used his muscles to shift his weight and keep his balance. His heart was pounding, but at least he didn't fall and get hurt. How was Hakeem able to react so quickly? He can thank his nervous system for that.

# 20.1 The Nervous System

## Lesson Objectives

- Define the nervous system, and state its functions.
- Describe neurons, and explain how nerve impulses travel.
- Give an overview of the central nervous system.
- Outline the divisions of the peripheral nervous system.
- Describe nervous system diseases and injuries.
- Identify how drugs may affect the nervous system.

## Lesson Vocabulary

- brain
- brain stem
- central nervous system
- cerebellum
- cerebrum
- concussion
- drug abuse
- drug addiction
- nerve
- nerve impulse
- nervous system
- neuron
- paralysis
- peripheral nervous system
- nervous system
- spinal cord
- synapse

## Introduction

The nervous system is a complex network of nervous tissue that carries electrical messages. It includes the brain, spinal cord, and many nerves that run throughout the body. You can see these components of the nervous system in **Figure** 20.1. For a short visual introduction to the nervous system, watch this animated video: http://www.youtube.com/watch?v=dah-4mtAnsQ .

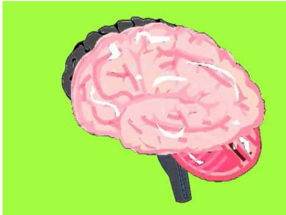

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FIGURE 20.1

The human nervous system

## Functions of the Nervous System

Controlling muscles and maintaining balance are just two of the functions of the human nervous system. What else does the nervous system do?

- It senses the surrounding environment with sense organs that include the eyes and ears.
- It senses the body's own internal environment, including its temperature.
- It controls internal body systems to make sure the body maintains homeostasis.
- It prepares the body to fight or flee in the case of an emergency.
- It allows thinking, learning, memory, and language.

Remember Hakeem the skater from the first page of the chapter? When Hakeem started to fall off the railing, his nervous system sensed that he was losing his balance. It responded by sending messages to his muscles. Some muscles contracted while other relaxed. As a result, Hakeem gained his balance again. How did his nervous system accomplish all of this in just a split second? You need to know how the nervous system transmits messages to answer that question.

## Neurons and Nerve Impulses

The nervous system is made up of nerves. A nerve is a bundle of nerve cells. A nerve cell that carries messages is called a neuron. The messages carried by neurons are called nerve impulses.

A nerve impulse can travel very quickly because it is an electrical signal. Think about flipping on a light switch when you enter a room. When you flip the switch, electricity flows to the light through wires inside the walls. The electricity may have to travel many meters to reach the light. Nonetheless, the light still comes on as soon as you flip the switch. Nerve impulses travel just as quickly through the network of nerves inside the body.

### Structure of a Neuron

The structure of a neuron suits it for its function of transmitting nerve impulses. You can see what a neuron looks like in **Figure** 20.2. It has a special shape that lets it pass electrical signals to and from other cells. A neuron has three main parts: cell body, dendrites, and axon.

1. The cell body contains the nucleus and other organelles.
2. Dendrites receive nerve impulses from other cells. A single neuron may have thousands of dendrites.
3. The axon passes on the nerve impulses to other cells. It branches at the end into multiple nerve endings so it can transmit impulses to many other cells.

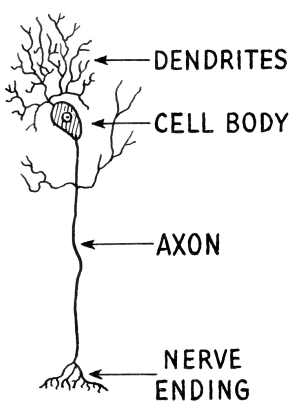


FIGURE 20.2
Parts of a neuron

### Types of Neurons

There are three basic types of neurons: sensory neurons, motor neurons, and interneurons. All three types must work together to receive and respond to information.

1. Sensory neurons transmit nerve impulses from sense organs and internal organs to the brain via the spinal cord. In other words, they carry information about the inside and outside environment to the brain.
2. Motor neurons transmit nerve impulses from the brain via the spinal cord to internal organs, glands, and muscles. In other words, they carry information from the brain to the body, telling the body how to respond.
3. Interneurons carry nerve impulses back and forth between sensory and motor neurons.

### The Synapse

The nerve endings of an axon don't actually touch the dendrites of other neurons. The messages must cross a tiny gap between the two neurons, called the synapse. Chemicals called neurotransmitters carry the message across this gap. When a nerve impulse arrives at the end of an axon, neurotransmitters are released. They travel across the synaptic gap to a dendrite of another neuron. The neurotransmitters bind to the membrane of the dendrite, triggering a nerve impulse in the next neuron. You can see how this works in **Figure** 20.3 and in this animation: http://www.watchknowlearn.org/Video.aspx?VideoID=7385&CategoryID=1505 .

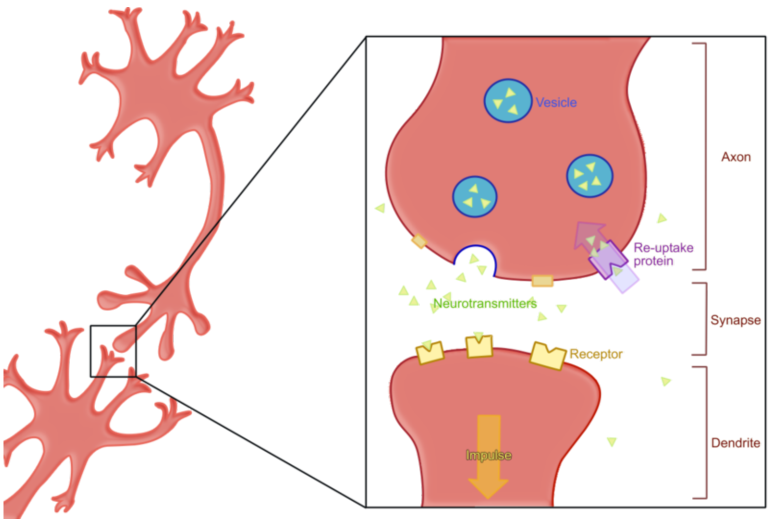


FIGURE 20.3
This diagram shows a synapse between neurons. When a nerve impulse arrives at the end of the axon, neurotransmitters are released and travel to the dendrite of another neuron, carrying the nerve impulse from one neuron to the next.

The transmission of nerve impulses between neurons is like the passing of a baton between runners in a relay race. After the first runner races, she passes the baton to the second runner. Then the second runner takes over. Instead of a baton, a neuron passes neurotransmitters to the next neuron.

## Central Nervous System

The nervous system has two main parts, called the central nervous system and the peripheral nervous system. The peripheral nervous system is described later in this lesson. The central nervous system is shown in **Figure** 20.4. It includes the brain and spinal cord.

### The Amazing Human Brain

The human brain is an amazing organ. It is the most complex organ in the human body. By adulthood, the brain weighs about 3 pounds and consists of billions of neurons. All those cells need a lot of energy. In fact, the adult brain uses almost a quarter of the total energy used by the body!

The brain serves as the control center of the nervous system and the body as a whole. It lets us understand what we see, hear, or sense in other ways. It allows us to learn, think, remember, and use language. It controls all the organs and muscles in our body.

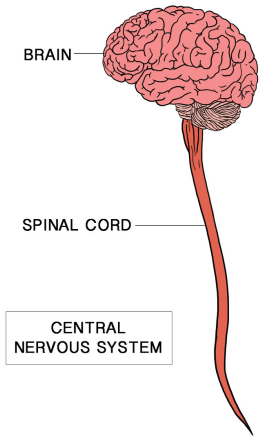


FIGURE 20.4
The brain and spinal cord make up the central nervous system.

## Parts of the Brain

The brain consists of three major parts, called the cerebrum, cerebellum, and brain stem. You can see these three parts of the brain in **Figure** 20.5. You can use this interactive animation to explore these parts of the brain: http://science.nationalgeographic.com/science/health-and-human-body/human-body/brain-article/

1. The cerebrum is the largest part of the brain. It controls conscious functions, such as thinking, sensing, speaking, and voluntary muscle movements. Whether you are chatting with a friend or playing a video game, you are using your cerebrum.
2. The cerebellum is the next largest part of the brain. It controls body position, coordination, and balance. Hakeem's cerebellum kicked in when he started to lose his balance on the railing in the opening photo. It allowed him to regain his balance.
3. The brain stem (also called the medulla) is the smallest part of the brain. It controls involuntary body functions such as breathing, heartbeat, and digestion. It also carries nerve impulses back and forth between the rest of the brain and the spinal cord.

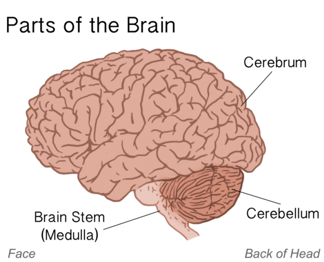


FIGURE 20.5
Three major parts of the brain

## Hemispheres and Lobes of the Cerebrum

The cerebrum is divided down the middle from the front to the back of the head. The two halves of the cerebrum are called the right and left hemispheres. The two hemispheres are very similar but not identical. They are connected to each other by a thick bundle of axons deep within the brain. These axons allow the two hemispheres to communicate with each other. Did you know that the right hemisphere of the cerebrum controls the left side of the body, and vice versa? This can happen because of the connections between the two hemispheres.

Each hemisphere is further divided into four parts, called lobes, as you can see in **Figure** 20.6. Each lobe has different functions. One function of each lobe is listed in the figure.

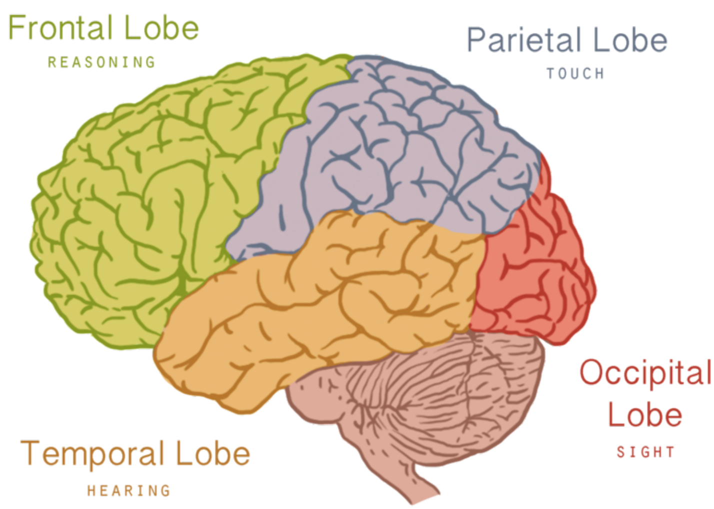


FIGURE 20.6
The four lobes of the left hemisphere are color coded in this illustration.

### The Spinal Cord

The spinal cord is a long, tube-shaped bundle of neurons. It runs from the brain stem to the lower back. The main job of the spinal cord is to carry nerve impulses back and forth between the body and brain. The spinal cord is like a two-way road. Messages about the body, both inside and out, pass through the spinal cord to the brain. Messages from the brain pass in the other direction through the spinal cord to tell the body what to do.

## Peripheral Nervous System

All the other nervous tissues in the body are part of the peripheral nervous system. If you look again at **Figure** 20.1, you can see the major nerves of the peripheral nervous system. They include nerves that run through virtually every part of the body, both inside and out, except for the brain and spinal cord.

The peripheral nervous system has two main divisions: the sensory division and the motor division. The divisions carry messages in opposite directions. **Figure** 20.7 shows these divisions of the peripheral nervous system.

### Sensory Division

The sensory division of the peripheral nervous system carries messages from sense organs and internal organs to the central nervous system. For example, it carries messages about images from the eyes to the brain. Once the messages reach the brain, the brain interprets the information.

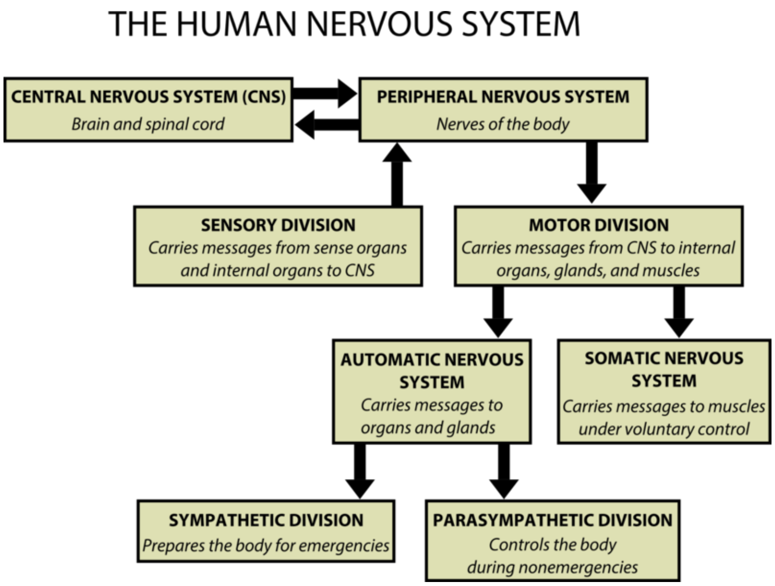


FIGURE 20.7

The central nervous system interprets messages from sense organs and internal organs and the motor division sends messages to internal organs, glands, and muscles.

### Motor Division

The motor division of the peripheral nervous system carries messages from the central nervous system to muscles, internal organs, and glands throughout the body. The brain sends commands to these tissues, telling them how to respond. As you can see in **Figure** 20.7, the motor division is divided into additional parts.

- The autonomic part of the motor division controls involuntary responses. It sends messages to organs and glands. These messages control the body both during emergencies (sympathetic division) and during nonemergencies (parasympathetic division).
- The somatic part of the motor division controls voluntary responses. It sends messages to the skeletal muscles for movements that are under conscious control.

## Nervous System Diseases and Injuries

Nervous system problems include diseases and injuries. Most nervous system diseases can't be prevented. But you can take steps to decrease your risk of nervous system injuries.

### Infections of the Nervous System

Bacteria and viruses can infect the brain or spinal cord. An infection of the brain is called encephalitis. An infection of the membranes that cover the brain and spinal cord is called meningitis. A vaccine is available to prevent meningitis caused by viruses (see **Figure** 20.8).

Encephalitis and meningitis aren't very common, but they can be extremely serious. They may cause swelling of the brain, which can be fatal. That's why it's important to know the symptoms of these diseases. Both encephalitis and meningitis typically cause a severe headache and a fever. Meningitis also causes a stiff neck. Both require emergency medical treatment.

FIGURE 20.8
Children as young as 2 years of age can be vaccinated against viral meningitis.

### Epilepsy

Epilepsy is a disease in which seizures occur. A seizure is a period of lost consciousness that may include violent muscle contractions. It is caused by abnormal electrical activity in the brain. Epilepsy may result from an infection, injury, or tumor. In many cases, however, the cause can't be identified. There is no known cure for epilepsy, but the seizures often can be prevented with medicine. Sometimes children with epilepsy outgrow it by adulthood.

### Stroke

A stroke occurs when a blood clot blocks blood flow to part of the brain. Brain cells die quickly when their oxygen supply is cut off. Therefore, a stroke may cause permanent loss of normal mental functions. Many stroke patients suffer some degree of paralysis, or loss of the ability to feel or move certain parts of the body. If medical treatment is given very soon after a stroke occurs, some of the damage may be reversed. Strokes occur mainly in older adults.

### Alzheimer's Disease

Alzheimer's disease is another disease that occurs mainly in older adults. In Alzheimer's disease, a person gradually loses most normal mental functions. The patient typically suffers from increasing memory loss, confusion, and mood swings. The cause of Alzheimer's isn't known for certain, but it appears to be associated with certain abnormal changes in the brain. There is no known cure for this devastating disease, but medicines may be able to slow its progression.

### Injuries to the Brain and Spinal Cord

The brain and spinal cord are protected within bones of the skeletal system, but injuries to these organs still occur. With mild injuries, there may be no lasting effects. With severe injuries, there may be permanent disability or even death.

Brain and spinal cord injuries most commonly occur because of car crashes or athletic activities. Fortunately, many injuries can be prevented by wearing seat belts and safety helmets (see **Figure** 20.9). Avoiding unnecessary risks, such as doing stunts on a bike or diving into shallow water, can also reduce the chances of brain and spinal cord injuries.

FIGURE 20.9

Wearing the right type of helmet can reduce the risk of a brain injury when riding a bike.

The most common type of brain injury is a concussion. This is a bruise on the surface of the brain. It may cause temporary symptoms such as headache and confusion. Most concussions heal on their own in a few days or weeks. However, repeated concussions can lead to permanent changes in the brain. More serious brain injuries also often cause permanent brain damage.

Spinal cord injuries may cause paralysis. Some people recover from spinal cord injuries. However, many people remain paralyzed for life. This happens when the spinal cord can no longer transmit nerve impulses between the body and brain.

## Drugs and the Nervous System

A drug is any chemical substance that affects the body or brain. Some drugs are medicines. Although these drugs are helpful when used properly, they can be misused like any other drug. Drugs that aren't medicines include both legal and illegal drugs. Both can do harm.

### Psychoactive Drugs

Many drugs affect the brain and influence how a person feels, thinks, or acts. Such drugs are called psychoactive drugs. They include legal drugs such as caffeine and alcohol, as well as illegal drugs such as cocaine and heroin. They also include certain medicines, such as antidepressant drugs and medical marijuana.

Some psychoactive drugs, such as caffeine, stimulate the central nervous system. They may make the user feel more alert. Some psychoactive drugs, such as alcohol, depress the central nervous system. They may make the user feel more relaxed. Still other psychoactive drugs, such as marijuana, are hallucinogenic drugs. They may make the user have altered sensations, perceptions, or thoughts.

### Drug Abuse and Drug Addiction

Psychoactive drugs may bring about changes in mood that users find desirable. These drugs may be abused. Drug abuse is use of a drug without the advice of a medical professional and for reasons not originally intended. Continued use of a psychoactive drug may lead to drug addiction. This occurs when a drug user is unable to stop using the drug. Over time, a drug user may need more of the drug to get the desired effect. This can lead to drug overdose and death.

## Lesson Summary

- The nervous system is a complex network of nervous tissue that carries electrical messages throughout the body. Its functions include controlling muscles, maintaining balance, sensing internal and external environments, controlling body systems to maintain homeostasis, preparing the body for emergencies, and allowing higher mental functions such as thinking.
- The nervous system is made up of bundles of nerve cells called neurons. Messages carried by neurons are called nerve impulses. A nerve impulse can travel very quickly because it is an electrical signal. Neurotransmitters carry nerve impulses between neurons at synapses.
- The central nervous system includes the brain and spinal cord. The brain serves as the control center of the nervous system and the body as a whole. It consists of three major parts: the cerebrum, cerebellum, and brain stem. The spinal cord carries nerve impulses back and forth between the body and brain.
- All other nervous tissue in the body makes up the peripheral nervous system, which has two major divisions. The sensory division carries messages from sense organs and internal organs to the central nervous system. The motor division carries messages from the central nervous system to muscles, internal organs, and glands throughout the body. The motor division is further divided into parts that control involuntary or voluntary responses.
- Diseases of the nervous system include infections, epilepsy, strokes, and Alzheimer's disease. Injuries include concussions and spinal cord damage that may cause paralysis. Most nervous system diseases can't be prevented, but many nervous system injuries can be prevented by following safe practices.
- Psychoactive drugs affect the brain and influence how a person feels, thinks, or acts. They include medicines and other legal drugs as well as illegal drugs. They may stimulate or depress the central nervous system. Abuse of such drugs may lead to drug addiction, overdose, and death.

## Lesson Review Questions

### Recall

1. What is the nervous system?
2. List three functions of the nervous system.
3. Describe neurons and nerve impulses.
4. Describe two nervous system diseases, including causes and symptoms.

### Apply Concepts

5. A brain injury has affected a patient's ability to see. Explain which part of the brain was most likely injured.

### Think Critically

6. Explain the role of synapses and neurotransmitters in the transmission of nerve impulses.
7. Compare and contrast the central nervous system and peripheral nervous system. How are the two systems related?

## Points to Consider

The peripheral nervous system includes several sense organs that gather information from the external environment.

1. Name two sense organs.
2. What information do these two sense organs monitor?

# 20.2 The Senses

## Lesson Objectives

- Describe human vision, explain how the eye works, and identify vision problems.
- Describe other human senses and sensory organs, including hearing and the ears.

## Lesson Vocabulary

- cochlea
- eardrum
- hearing
- hyperopia
- lens
- myopia
- retina
- semicircular canal
- taste bud
- touch
- vision

## Introduction

The girl in **Figure** 20.10 is keeping her eyes on the volleyball in order to hit it at just right moment. Playing volleyball and most other sports depends on the ability to see.

## Human Vision

The ability to see is called vision. It depends on both the eyes and the brain. The eyes sense light and form images. The brain interprets the images formed by the eyes and tells us what we are seeing. For a fascinating account of how the brain helps us see, watch this short video: http://www.youtube.com/watch?v=1KkqlnEljy8 .

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FIGURE 20.10
You have to keep your eyes on the ball to hit a volleyball.

### Seeing in 3-D and Color

Did you ever use 3-D glasses to watch a movie, like the teens in **Figure** 20.11? If you did, then you know that the glasses make images on the flat screen seem more realistic by giving them depth. The images seem to jump right out of the screen toward you.

FIGURE 20.11
3-D glasses make movies look three-dimensional.

Unlike many other animals, human beings and other primates normally see the world around them in three dimensions. That's because we have two eyes that face the same direction but are a few inches apart. Both eyes focus on the same object at the same time but from slightly different angles. The brain uses the different images from the two eyes to determine the distance to the object.

Human beings and other primates also have the ability to see in color. We have special cells inside our eyes that can distinguish different wavelengths of visible light. Visible light is light in the range of wavelengths that the human eye can sense. The exact wavelength of visible light determines its color.

### How the Eye Works

The function of the eye is to focus light and form images. We see some objects, such as stars and light bulbs, because they give off their own light. However, we see most objects because they reflect light from another source such as the sun. We form images of the objects when some of the reflected light enters our eyes.

Look at the parts of the eye in **Figure** 20.12. Follow the path of light through the eye as you read about it below.

1. Light from an object passes first through the cornea. This is a clear, protective covering on the outside of the eye.
2. Then light passes through the pupil, an opening in the center of the eye. The pupil, which looks black, is surrounded by the colored part of the eye, called the iris.
3. Light entering through the pupil next passes through the lens. The lens is a clear, curved structure, like the lens of a magnifying glass. Along with the cornea, the lens focuses the light on the back of the eye.
4. The back of the eye is covered by a thin layer called the retina. This is where the image of the object normally forms. The retina consists of special light-sensing cells called rods and cones. Rods sense dim light. Cones sense different colors of light.
5. Nerve impulses from rods and cones travel to the optic nerve. It carries the nerve impulses to the brain.

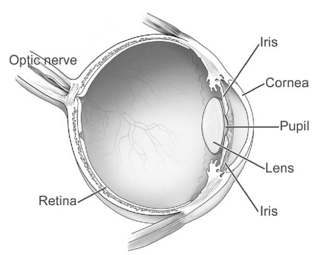
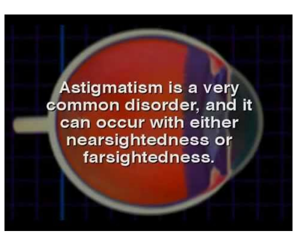



FIGURE 20.12
Parts of the eye

### Vision Problems

You probably know people who need eyeglasses or contact lenses to see clearly. Maybe you need them yourself. Lenses are used to correct vision problems. Two of the most common vision problems in young people are myopia and hyperopia. You can compare myopia and hyperopia in **Figure** 20.13. To learn about astigmatism, another common vision problem, watch this very short video: http://www.youtube.com/watch?v=5ZNZWr5mNpE .

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- Myopia is commonly called nearsightedness. People with myopia can see nearby objects clearly, but distant objects appear blurry. Myopia occurs when images focus in front of the retina because the eyeball is too long. This vision problem can be corrected with concave lenses, which curve inward. The lenses focus images correctly on the retina.

- Hyperopia is commonly called farsightedness. People with hyperopia can see distant objects clearly, but nearby objects appear blurry. Hyperopia occurs when images focus in back of the retina because the eyeball is too short. This vision problem can be corrected with convex lenses, which curve outward. The lenses focus images correctly on the retina.

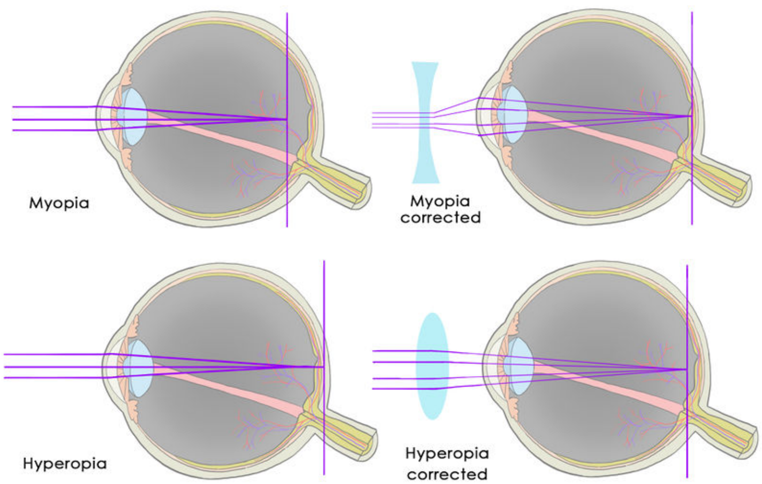


FIGURE 20.13
How eye shape affects vision

## Other Human Senses

Vision is just one of several human senses. Other human senses include hearing, touch, taste, and smell. Imagine shopping at the fruit market in **Figure** 20.14. It would stimulate all of these senses. You would hear the noisy bustle of the market. You could feel the smooth skin of the fruit. If you tried a sample, you could smell the fruity aroma and taste its sweet flavor.

FIGURE 20.14
This outdoor fruit market stimulates all the senses —sight, sound, smell, taste, and touch.

### Hearing and Balance

What do listening to music and riding a bike have in common? Both activities depend on the ears. The ears are organs that sense sound. They also sense the position of the body and help maintain balance.

Hearing is the ability to sense sound. Sound travels through the air in waves. Suppose a car horn blows in the distance. Sound waves spread through the air from the horn. Some of the sound waves enter your ears and cause vibrations. The vibrations trigger nerve impulses that travel to the brain through the auditory nerve. You can learn how this happens in **Figure** 20.15. The brain then interprets the impulses and tells you what you are hearing. To find out how the brain determines where a sound is coming from, watch this amusing video: http://www.youtube.com/watch?v=BaOCuvvX7Xg .

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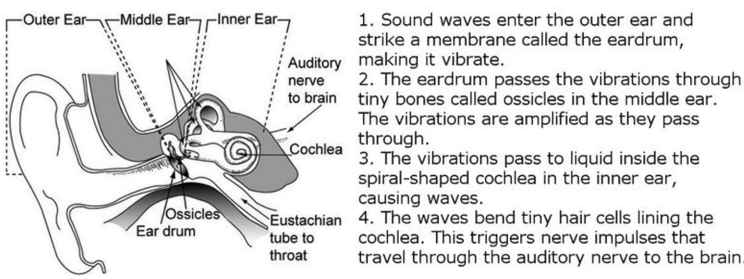



FIGURE 20.15

How the ears sense sounds

The parts of the ears involved in balance are the semicircular canals. These are the curved structures above the cochlea in the inner ear in **Figure** 20.15. Like the cochlea, the semicircular canals contain liquid and are lined with tiny hair cells. As the head changes position, the liquid moves. This causes the hair cells to bend. The bending of the hair cells triggers nerve impulses that travel to the cerebellum in the brain. The cerebellum uses the information to maintain balance.

### Touch

Touch is the ability to sense pain, pressure, or temperature. Nerve cells that sense touch are found mainly in the skin. The skin on the palms, soles, face, and lips has the most neurons. Neurons that sense pain are also found inside the body inside the body in the tongue, joints, muscles, and other organs.

Suppose you wanted to test the temperature of bath water before getting into the tub. You might stick one toe in the water. Neurons in the skin on your toe would sense the temperature of the water and send a message about it to the brain through the spinal cord. The brain would process the information. It might decide that the water is too hot and send a message to your muscles to pull your toe out of the water.

### Taste and Smell

The sense of taste is controlled by sensory neurons on the tongue. They are grouped in bundles called taste buds. You can see taste buds on the tongue in **Figure** 20.16. Taste neurons sense chemicals in food. They can detect five different tastes: sweet, salty, sour, bitter, and umami, which is a meaty taste. When taste neurons sense chemicals, they send messages to the brain about them. The brain then decides what you are tasting.

FIGURE 20.16
The tiny red bumps on this tongue are taste buds.

The sense of smell also involves sensory neurons that sense chemicals. These neurons are found in the nose, and they sense chemicals in the air. Unlike taste neurons, smell neurons can detect thousands of different odors. Your sense of smell plays a big role in your sense of taste. You can use your sense of taste alone to learn that a food is sweet. However, you have to use your sense of smell as well to learn that the food tastes like apple pie.

## Lesson Summary

- Vision is the ability to see. Humans and other primates have 3-D and color vision. The eyes focus light, form images, and send nerve impulses to the brain. The brain interprets the images and tells us what we are seeing. Vision problems include myopia and hyperopia. Both can be corrected with lenses.
- Other human senses include hearing, balance, touch, taste, and smell. The ears sense sound and allow us to hear. They also sense body position to help maintain balance. Touch neurons, mainly in the skin, sense pain, pressure, and temperature. Taste neurons on the tongue sense chemicals in food. Odor neurons in the nose sense chemicals in the air.

## Lesson Review Questions

### Recall

1. Identify five human senses.
2. Summarize how the eye works.
3. Outline how sound waves travel through the ear.

### Apply Concepts

4. Why does food taste bland when your nose is stuffy from a cold?

### Think Critically

5. Explain 3-D vision in human beings.
6. Compare and contrast the human senses of taste and smell.

## Points to Consider

Sensory organs such as the eyes and ears are part of the nervous system. The nervous system controls all other body systems. However, the nervous system doesn't work alone. The endocrine system also helps to regulate the body and its functions.

1. What are the organs of the endocrine system?
2. The nervous system sends electrical messages. What type of messages does the endocrine system send?

# 20.3 The Endocrine System

## Lesson Objectives

- Describe the endocrine system and its hormones.
- Identify several glands of the endocrine system.
- Explain how endocrine hormones work.
- Describe two endocrine system diseases.

## Lesson Vocabulary

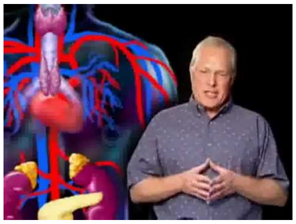
- adrenal gland
- endocrine gland
- endocrine system
- gonad
- hormone
- hypothalamus
- pituitary gland
- target cell
- thyroid gland

## Introduction

The nervous system couldn't control the rest of the body without the help of the endocrine system. How do these two systems work together? Read on to find out.

## What Is the Endocrine System?

The endocrine system is a system of glands that release chemical messenger molecules into the blood stream. The messenger molecules are called hormones. Hormones act slowly compared with the rapid transmission of electrical impulses of the nervous system. Endocrine hormones must travel through the bloodstream to the cells they control, and this takes time. On the other hand, because endocrine hormones are released into the bloodstream, they travel to cells everywhere in the body. For a good visual introduction to the endocrine system, watch this short video: http://www.youtube.com/watch?v=gjmS4_7kvDM .



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## Glands of the Endocrine System

An endocrine gland is a gland that secretes hormones into the bloodstream for transport around the body (instead of secreting hormones locally, like sweat glands in the skin). Major glands of the endocrine system are shown in **Figure** 20.17. The glands are the same in males and females except for the ovaries and testes.

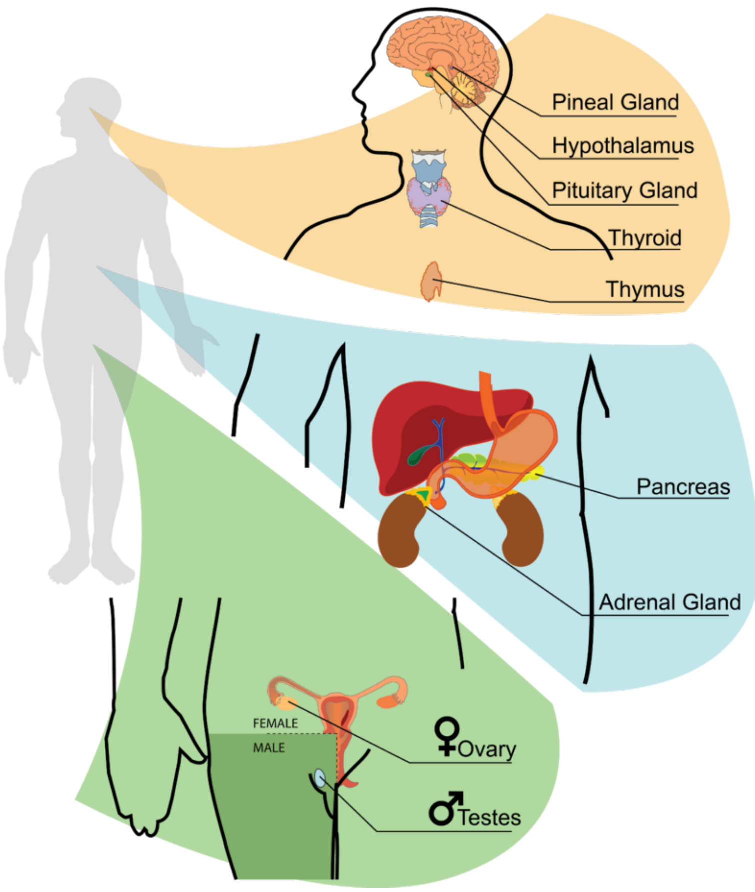



FIGURE 20.17

Endocrine system glands

### Hypothalamus

The hypothalamus is actually part of the brain, but it also secretes hormones. Some of its hormones go directly to the pituitary gland in the endocrine system. These hypothalamus hormones tell the pituitary to either secrete or stop secreting its hormones. In this way, the hypothalamus provides a link between the nervous and endocrine systems.

The hypothalamus also produces hormones that directly regulate body processes. For example, it produces antidiuretic hormone. This hormone travels to the kidneys and stimulates them to conserve water by producing more concentrated urine.

### Pituitary Gland

The pea-sized pituitary gland is just below the hypothalamus and attached directly to it. The pituitary receives hormones from the hypothalamus. It also secretes its own hormones. Most pituitary hormones control other endocrine glands. That's why the pituitary gland is called the "master gland" of the endocrine system. **Table** 20.1 lists several pituitary hormones and what they do.

**TABLE 20.1:** Some pituitary hormones and their effects

| Pituitary Hormone | Target Glands/Cells | Effects(s) |
|---|---|---|
| Adrenocorticotropic hormone (ACTH) | adrenal glands | Stimulates the cortex (outer layer) of the adrenal glands to secrete their hormones |
| Thyroid-stimulating hormone (TSH) | thyroid gland | Stimulates the thyroid gland to secrete its hormones |
| Growth hormone (GH) | body cells | Stimulates body cells to make proteins and grow |
| Follicle-stimulating hormone (FSH) | ovaries or testes | Stimulates the ovaries to develop mature eggs; stimulates the testes to produce sperm |
| Luteinizing hormone (LH) | ovaries or testes | Stimulates the ovaries or testes to secrete sex hormones; stimulates the ovaries to release eggs |
| Prolactin (PRL) | mammary glands | Stimulates the mammary glands to produce milk |

### Other Endocrine Glands

There are several other endocrine glands. Find them in **Figure** 20.17 as you read about them below.

- The thyroid gland is a relatively large gland in the neck. Hormones secreted by the thyroid gland include thyroxin. Thyroxin increases the rate of metabolism in cells throughout the body.
- The pancreas is a large gland located near the stomach. Hormones secreted by the pancreas include insulin. Insulin helps cells absorb glucose from the blood. It also stimulates the liver to take up and store excess glucose.
- The two adrenal glands are glands located just above the kidneys. Each adrenal gland has an outer layer (cortex) and inner layer (medulla) that secrete different hormones. The hormone adrenaline is secreted by the inner layer. It prepares the body to respond to emergencies. For example, it increases the amount of oxygen and glucose going to the muscles.
- The gonads are glands that secrete sex hormones. Male gonads are called testes. They secrete the male sex hormone testosterone. The female gonads are called ovaries. They secrete the female sex hormone estrogen. Sex hormones stimulate the changes of puberty. They also control the production of sperm or eggs by the gonads.

## How Endocrine Hormones Work

Endocrine hormones travel throughout the body in the blood. However, each endocrine hormone affects only certain cells, called target cells.

### Hormones and Target Cells

A target cell is the type of cell on which a given endocrine hormone has an effect. A target cell is affected by a given hormone because it has proteins on its surface to which the hormone can bind. When the hormone binds to target cell proteins, it causes changes inside the cell. For example, binding of the hormone might cause the release of enzymes inside the cell. The enzymes then influence cell processes.

### Feedback Loops

Endocrine hormones control many cell activities, so they are very important for homeostasis. But what controls the hormones? Most endocrine hormones are controlled by feedback loops. In a feedback loop, the hormone produced by a gland feeds back to control its own production by the gland. A feedback loop can be negative or positive. Most endocrine hormones are controlled by negative feedback loops. .Negative feedback occurs when rising levels of a hormone feed back to decrease secretion of the hormone or when falling levels of the hormone feed back to increase its secretion.

You can see an example of a negative feedback loop in **Figure** 20.18. It shows how levels of thyroid hormones regulate the thyroid gland. This loop involves the hypothalamus and pituitary gland as well as the thyroid gland. Low levels of thyroid hormones in the blood cause the release of hormones by the hypothalamus and pituitary gland. These hormones stimulate the thyroid gland to secrete more hormones. The opposite happens with high levels of thyroid hormones in the blood. The hypothalamus and pituitary gland stop releasing hormones that stimulate the thyroid.

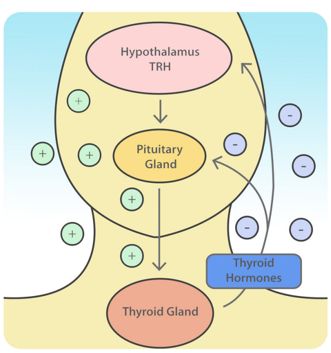
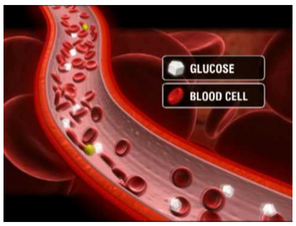



FIGURE 20.18
The thyroid gland is controlled by a negative feedback loop that includes the hypothalamus and pituitary gland.

## Endocrine System Diseases

Diseases of the endocrine system are fairly common. An endocrine disease usually involves the secretion of too much or not enough hormone by an endocrine gland. This may happen because the gland develops an abnormal lump of cells called a tumor. For example, a tumor of the pituitary gland can cause secretion of too much growth hormone. If this occurs in a child, it may result in very rapid growth and unusual tallness by adulthood. This is called gigantism.

Type 1 diabetes is another endocrine system disease. In this disease, the body's own immune system attacks insulin-secreting cells of the pancreas. As a result, not enough insulin is secreted to maintain normal levels of glucose in the blood. Patients with type 1 diabetes must regularly check the level of glucose in their blood. When it gets too high, they must give themselves an injection of insulin to bring it under control. You can learn more about glucose, insulin, and type 1 diabetes by watching this video: http://www.youtube.com/watch?v=_OOWhuC_9Lw .

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## Lesson Summary

- The endocrine system is a system of glands that release chemical messenger molecules called hormones into the blood stream. Endocrine hormones travel more slowly than nerve impulses, but can reach cells anywhere in the body.
- The hypothalamus is part of the brain and also secretes hormones, thus connecting the nervous and endocrine systems. The pituitary gland is the master gland of the endocrine system and controls other endocrine glands. Endocrine glands also include the thyroid gland, adrenal glands, pancreas, and gonads.
- Each endocrine hormone affects only certain cells, called target cells. A target cell has proteins on its surface to which a given hormone can bind. Most endocrine hormones are controlled by negative feedback loops. Negative feedback occurs when low levels of a hormone feed back to increase its secretion—and vice versa.
- Endocrine system diseases are fairly common. An endocrine disease usually involves the secretion of too much or not enough hormone by an endocrine hormone. Examples of endocrine diseases are gigantism and Type 1 diabetes.

## Lesson Review Questions

### Recall

1. What is the endocrine system? How do endocrine hormones differ from the secretions of other glands, such as sweat glands?
2. How are the nervous and endocrine systems connected?
3. Define target cell.

### Apply Concepts

4. Hypothyroidism is an endocrine system disease in which the thyroid gland doesn't secrete enough of its hormones. How do you think this disease might be treated?

### Think Critically

5. Explain why the pituitary gland is considered the master gland of the endocrine system.
6. Use an example to show how negative feedback controls the secretion of endocrine hormones.

## Points to Consider

Type 1 diabetes occurs when the immune system attacks and damages insulin-producing cells of the pancreas.

1. What is the immune system? What is its function?
2. What are some of the parts of the immune system?

# 20.4 References


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# CHAPTER 21 MS Diseases and the Body's Defenses

## Chapter Outline



This worm, called schistosoma, is actually very tiny. It's been greatly enlarged in this photo. It's a human parasite that spreads in contaminated water. It can penetrate pores in the skin of people who wade or swim in the water. Worldwide, infections with the schistosoma parasite are common. This poses a serious problem, because the parasite makes people very sick.

Like this parasitic worm, many other organisms can make us sick if they manage to enter our body. Fortunately for us, the body can defend itself from most such invaders. In this chapter, you'll learn how.

# 21.1 Infectious Diseases

## Lesson Objectives

- Identify pathogens that cause infectious diseases, and explain how pathogens spread.
- List ways to prevent the spread of infectious diseases.

## Lesson Vocabulary

- infectious disease

## Introduction

The student sitting next to you on the bus is coughing and sneezing. He says he has a cold. You feel fine, but a day or two later, you come down with a cold too. Diseases such as the common cold are contagious. You can catch them from someone else. Contagious diseases are also called infectious diseases.

## What Causes Infectious Diseases?

An infectious disease is a disease that is caused by a pathogen. A pathogen is an organism or virus that causes disease in another living thing. Pathogens are commonly called germs. Watch this dramatic video for an historic perspective on infectious diseases and their causes: http://www.youtube.com/watch?v=oUMCKai3xp4 .

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### Types of Pathogens

There are several types of pathogens that cause diseases in human beings. They include bacteria, viruses, fungi, and protozoa. The different types are described in **Table** 21.1. The table also lists several diseases caused by each type of pathogen. Many infectious diseases caused by these pathogens can be cured with medicines. For example, antibiotic drugs can cure most diseases caused by bacteria.

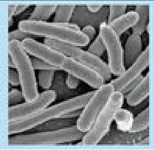
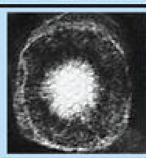
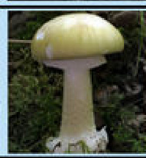
| Type of pathogen | Description | Human diseases caused by pathogens of that type |
|---|---|---|
| **Bacteria** *Escherichia coli*  | Single-celled organisms without a nucleus | Strep throat, staph infections, tuberculosis, food poisoning, tetanus, pneumonia, syphilis |
| **Viruses** *Herpes simplex*  | Thread-like particles that reproduce by taking over living cells | Common cold, flu, genital herpes, cold sores, measles, AIDS, genital warts, chiken pox, small pox |
| **Fungi** *Death cap mushroom*  | Simple organisms, including mushrooms and yeasts, that grow as single cells or thread like filaments | Ringworm, athlete's foot, tinea, candidiasis, histoplasmosis, mushroom poisoning |
| **Protozoa** *Giardia lamblia*  | Single-celled organism with a nucleus | Malaria, "traveler's diarrhea" giardiasis, trypanosomiasis ("sleeping sickness") |

FIGURE 21.1
Types of pathogens that cause human diseases

## How Pathogens Spread

Different pathogens spread in different ways. Some are easy to "catch." Others are much less contagious.

- Some pathogens spread through food or water. When harmful bacteria contaminate food, they cause foodborne illness, commonly called food poisoning. An example of a pathogen that spreads through water is the protozoan named Giardia lamblia, described in **Table** 21.1. It causes a disease called giardiasis.
- Some pathogens spread through sexual contact. In the U.S., the pathogen most commonly spread this way is HPV, or human papillomavirus. It may cause genital warts and certain types of cancer. A vaccine can prevent the spread of this pathogen.
- Many pathogens spread by droplets in the air. Droplets are released when a person coughs or sneezes, as you can see in **Figure** 21.2. The droplets may be loaded with pathogens. Other people may get sick if they breathe in the pathogens on the droplets. Viruses that cause colds and flu can spread this way.
- Other pathogens spread when they are deposited on objects or surfaces. The fungus that causes athlete's food spreads this way. For example, you might pick up the fungus from the floor of a public shower. You can also pick up viruses for colds and flu from doorknobs and other commonly touched surfaces.
- Still other pathogens are spread by vectors. A vector is an organism that carries pathogens from one person or animal to another. Most vectors are insects such as ticks or mosquitoes. They pick up pathogens when they bite an infected animal and then transmit the pathogens to the next animal they bite. Ticks spread the bacteria that cause Lyme disease. Mosquitoes spread the protozoa that cause malaria.

FIGURE 21.2
Sneezing sends thousands of tiny droplets into the air unless the mouth and nose are covered. Each droplet may carry thousands of bacteria or viruses.

## Preventing the Spread of Infectious Diseases

What can you do to avoid infectious diseases? Eating well and getting plenty of sleep are a good start. These habits will help keep your immune system healthy. With a healthy immune system, you will be able to fight off many pathogens.

Vaccines are available for some infectious diseases. For example, there are vaccines to prevent measles, mumps, whooping cough, and chicken pox. These vaccines are recommended for infants and young children.

You can also take the following steps to avoid picking up pathogens or spreading them to others. Watch this video for additional information on preventing the spread of infectious diseases: http://www.youtube.com/watch?v=lEzTBzh4NQg .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- Wash your hands often with soap and water. Spend at least 20 seconds scrubbing with soap. See **Figure** 21.3 for effective hand washing tips.
- Avoid touching your eyes, nose, or mouth with unwashed hands.
- Avoid close contact with people who are sick. This includes kissing, hugging, shaking hands, and sharing cups or eating utensils.
- Cover your coughs and sneezes with a tissue or shirt sleeve, not your hands.
- Disinfect frequently touched surfaces, such as keyboards and doorknobs, especially if someone is sick.
- Stay home when you are sick.

The best way to prevent diseases spread by vectors is to avoid contact with the vectors. For example, you can wear long sleeves and long pants to avoid tick and mosquito bites. Using insect repellent can also reduce your risk of insect bites.


FIGURE 21.3
The proper way to wash your hands

## Lesson Summary

- Infectious diseases are diseases that are caused by pathogens. Human pathogens include bacteria, viruses, fungi, and protozoa. Different pathogens spread in different ways. Pathogens may spread through contaminated food or water, sexual contact, droplets in the air from coughs or sneezes, contaminated objects or surfaces, or vectors.
- To avoid infectious diseases, eat well and get plenty of sleep to keep your immune system healthy. Get recommended vaccinations, and follow good hygiene practices such as frequent hand washing. Also, avoid contact with vectors such as ticks and mosquitoes.

## Lesson Review Questions

### Recall

1. What is an infectious disease?
2. List four types of human pathogens, and give an example of a disease caused by each type.
3. What is a vector? Name a human disease spread by a vector.

### Apply Concepts

4. Create a poster that shows young children ways to reduce their risk of catching a cold.

### Think Critically

5. Explain how you could catch the flu by touching a doorknob.

## Points to Consider

Some diseases are not infectious. They are not caused by pathogens.

1. What are some examples of noninfectious diseases?
2. What causes these diseases?

# 21.2 Noninfectious Diseases

## Lesson Objectives

- Define noninfectious disease.
- List causes and common types of cancer, and state how cancer can be treated and prevented.
- Describe diabetes, and distinguish between type 1 and type 2 diabetes.
- Identify autoimmune diseases, and explain why allergies occur.

## Lesson Vocabulary

- allergen
- allergy
- autoimmune disease
- cancer
- carcinogen
- diabetes
- noninfectious disease
- tumor
- type 1 diabetes
- type 2 diabetes

## Introduction

Not all diseases are contagious. A disease that is not contagious is called a noninfectious disease. These diseases are not caused by pathogens. Instead, they are likely to have causes such as lifestyle factors, environmental toxins, or gene mutations. Common types of noninfectious diseases include cancer, diabetes, and immune system diseases.

## Cancer

Cancer is a disease in which cells divide out of control. Normally, the body has ways to prevent cells from dividing out of control. However, in the case of cancer, these ways fail. The rapidly dividing cells may form a mass of abnormal tissue called a tumor. This is illustrated in **Figure** 21.4. Watch this video for an animated introduction to cancer: http://www.youtube.com/watch?v=LEpTTolebqo .

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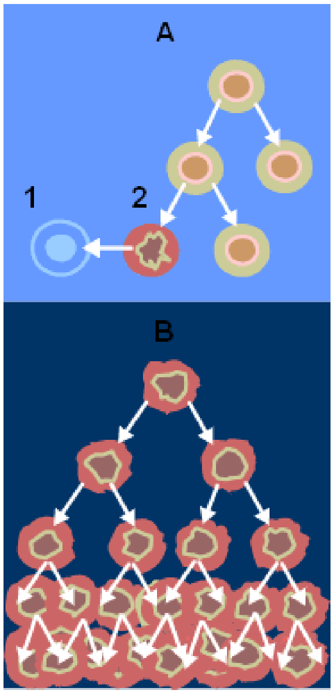



FIGURE 21.4

In panel A, an abnormal cell (2) is prevented from dividing, and the abnormal cell dies (1). In panel B, an abnormal cell is not prevented from dividing. Instead, it divides uncontrollably, leading to the formation of a tumor.

As a tumor increases in size, it may harm normal tissues around it. Sometimes cancer cells break away from a tumor. If they enter the bloodstream, they are carried throughout the body. Then the cells may start growing in other tissues. This is usually how cancer spreads from one part of the body to another. Once this happens, cancer is very hard to stop.

## Causes of Cancer

Most cancers are caused by mutations. Mutations are random errors in genes. Mutations that lead to cancer usually occur in genes that control the cell cycle. Because of the mutations, abnormal cells are allowed to divide.

Some mutations that lead to cancer may be inherited. However, most of the mutations are caused by environmental factors. Anything in the environment that can cause cancer is called a carcinogen. Common carcinogens include certain chemicals and some types of radiation.

- Many different chemicals can cause cancer. For example, tobacco contains dozens of chemicals, including nicotine, that have been shown to cause cancer. **Figure** 21.5 shows some of these chemicals. Smoking tobacco or using smokeless tobacco increases the risk of cancer of the lung, mouth, throat, and urinary bladder.
- Types of radiation that cause cancer include ultraviolet (UV) radiation and radon. UV radiation is part of sunlight. It is the leading cause of skin cancer. Radon is a naturally occurring radioactive gas that escapes from underground rocks. It may seep into the basements of buildings. It can cause lung cancer.


FIGURE 21.5
Chemicals in cigarettes

## Most Common Types of Cancer

Cancer occurs most often in adults, especially adults over the age of 50. The most common types of cancer in adults differ between males and females.

- The most common type of cancer in adult males is cancer of the prostate gland. The prostate gland is part of the male reproductive system. About one third of all cancers in men are prostate cancers.
- The most common type of cancer in adult females is cancer of the breast. About one third of all cancers in women are breast cancers.

In both men and women, the second most common type of cancer is lung cancer. Most cases of lung cancer develop in people who smoke.

Childhood cancer is rare. The main type of cancer in children is leukemia. It makes up about one third of all childhood cancers. It occurs when the body makes abnormal white blood cells.

## Diagnosing and Treating Cancer

Many cases of cancer can be cured if the cancer is diagnosed and treated early. Treatment often involves removing a tumor with surgery. This may be followed by other types of treatments. These treatments may include drugs and radiation, both of which target and kill cancer cells.

It's important to know the warning signs of cancer so it can be diagnosed as early as possible. Having warning signs doesn't mean that you have cancer, but you should check with a doctor to be sure. Warning signs of cancer include:

- a change in bowel or bladder habits.
- a sore that doesn't heal.
- unusual bleeding or discharge.
- a lump in the breast or elsewhere.
- frequent, long-term indigestion.
- difficulty swallowing.
- obvious changes in a wart or mole.
- persistent cough or hoarseness.

### Preventing Cancer

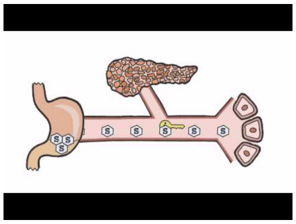
Making healthy lifestyle choices can help prevent some types of cancer. For example, you can reduce your risk of lung cancer by not smoking. You can reduce your risk of skin cancer by using sunscreen (see **Figure** 21.6).

FIGURE 21.6
This young woman is applying sunscreen to reduce her exposure to cancer-causing UV radiation.

## Diabetes

Diabetes is another type of noninfectious disease. Diabetes occurs when the pancreas doesn't make enough insulin or else the body's cells are resistant to the effects of insulin. Insulin is a hormone that helps cells absorb glucose from the blood.

When there is too little insulin or cells do not respond to it, the blood contains too much glucose. High glucose levels in the blood can damage blood vessels and other cells in the body. The kidneys work harder to filter the extra glucose from the blood and excrete it in urine. This leads to frequent urination, which in turn causes excessive thirst. Watch this short video for an animated introduction to diabetes, its causes, and its consequences: http://www.youtube.com/watch?v=MGL6km1NBWE .



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There are two main types of diabetes: type 1 diabetes and type 2 diabetes. The two types of diabetes have different causes.

### Type 1 Diabetes

Type 1 diabetes is caused by the immune system attacking and destroying normal cells of the pancreas. As a result, the cells can no longer produce insulin. Why the immune system acts this way is not known for certain. It's possible that a virus may trigger the attack. This type of diabetes usually develops in childhood or adolescence.

At present, there is no known way to prevent the development of type 1 diabetes. However, it is a treatable disease. Treatment of type 1 diabetes includes:

- taking several insulin injections every day or using an insulin pump (see **Figure** 21.7).
- monitoring blood glucose levels several times a day.
- eating a healthy diet that spreads out carbohydrate intake throughout the day.
- regular physical activity, which helps the body use insulin more efficiently.
- regular medical checkups.

### Type 2 Diabetes

Type 2 diabetes is much more common than type 1 diabetes. Type 2 diabetes occurs when body cells no longer respond normally to insulin. The pancreas still makes insulin, but the cells of the body can't use it. Being overweight and having high blood pressure increase the chances of developing type 2 diabetes. This type of diabetes usually develops in adulthood. However, it is becoming more common in teens and children because more young people are overweight now than ever before.

You can greatly reduce your risk of developing type 2 diabetes by maintaining a healthy body weight. Some cases of type 2 diabetes can be cured with weight loss. However, most people with the disease need to take medicine to control their blood glucose. Regular exercise and balanced eating also help. Like people with type 1 diabetes, people with type 2 diabetes must frequently check their blood glucose.

## Immune System Diseases

The immune system is the body system that normally fights infections and defends against other causes of disease. When the immune system is working well, it usually keeps you from getting sick. But like any other body system,

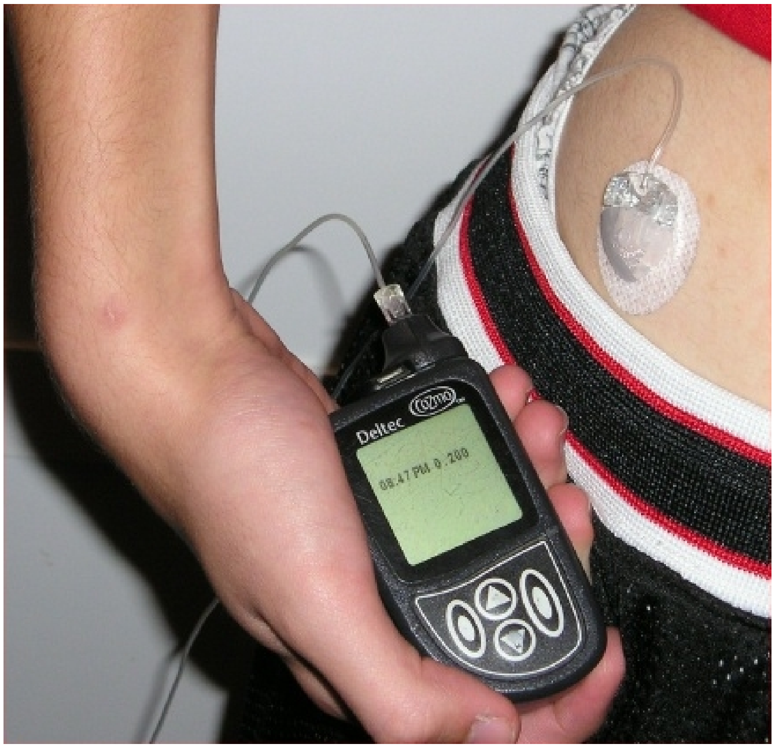


FIGURE 21.7
An insulin pump monitors blood glucose levels and injects the needed amount of insulin to keep glucose levels within the normal range.

the immune system can have problems and develop diseases. Two types of immune system diseases are autoimmune diseases and allergies.

### Autoimmune Diseases

An autoimmune disease is a disease in which the immune system attacks the body's own cells. Why this happens is not known for certain, but a combination of genetic and environmental factors are likely to be responsible. Type 1 diabetes is an example of an autoimmune disease. In this case, the immune system attacks cells of the pancreas. Two other examples are multiple sclerosis and rheumatoid arthritis.

- In multiple sclerosis, the immune system attacks nerve cells. This causes weakness and pain that gradually get worse over time.
- In rheumatoid arthritis, the immune system attacks joints. This causes joint damage and pain.

These diseases can't be prevented and have no known cure. However, they can be treated with medicines that weaken the immune system's attack on normal cells.

### Allergies

An allergy is a disorder in which the immune system responds to a harmless substance as though it was a pathogen. Any substance that causes an allergy is called an allergen. The most common allergens are pollen, dust mites, mold, animal dander, insect stings, latex, and certain foods and medications. To see in greater detail how allergies occur, watch this animated video: http://www.youtube.com/watch?v=UfLAwO4_NTQ .


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Did you ever hear of hay fever? It's not really a fever, and it may have nothing to do with hay. It's actually an allergy to plant pollens. People with this type of allergy generally have seasonal allergies that come back year after year. Symptoms commonly include watery eyes and nasal congestion. Ragweed, shown blooming in **Figure** 21.8, causes more pollen allergies than any other plant.

FIGURE 21.8

Pollen from ragweed blossoms like these cause allergic reactions in many people.

Allergy symptoms can range from mild to severe. Mild symptoms might include itchy eyes, sneezing, and a runny nose. Severe symptoms can cause difficulty breathing, which may be life threatening. Keep in mind that it is the immune system and not the allergen that causes the allergy symptoms. Allergy symptoms can be treated with medications such as antihistamines. Severe allergic reactions may require an injection of the hormone epinephrine. These treatments lessen or counter the immune system's response.

Often, allergy symptoms can be prevented. One way is to avoid exposure to the allergens that cause your symptoms. If you are allergic to pollen, for example, you can reduce your exposure by staying inside when pollen levels are highest. Some people receive allergy shots to help prevent allergic reactions. The shots contain tiny amounts of allergens. After many months or years of shots, the immune system gets used to the allergens and no longer reacts to them.

## Lesson Summary

- Noninfectious diseases are not contagious because they are not caused by pathogens. Instead, they are caused by such factors as lifestyle choices, environmental toxins, or mutations.
- Most cancers are caused by mutations. Anything that causes mutations leading to cancer is called a carcinogen. Examples of carcinogens include chemicals in tobacco smoke and UV radiation.
- Diabetes is a disease in which insulin fails to keep blood glucose levels within a healthy range. In type 1 diabetes, the pancreas doesn't produce insulin. In type 2 diabetes, body cells do not respond normally to

insulin.
- Autoimmune diseases occur when the immune system attacks the body's own cells. Type 1 diabetes is an example. Allergies occur when the immune system attacks a harmless substance such as pollen as though it was a pathogen.

## Lesson Review Questions

### Recall

1. What is a noninfectious disease?
2. Define carcinogen, and give two examples.
3. What causes multiple sclerosis?
4. What is the single best way to reduce your risk of developing lung cancer?

### Apply Concepts

5. Some people have allergies only at certain times of the year. Other people have allergies all year round. Give examples of allergens that might trigger the different types of allergic responses.

### Think Critically

6. Explain how mutations can lead to cancer.
7. Compare and contrast type 1 and type 2 diabetes.

## Points to Consider

Most types of cancer are noninfectious diseases. However, some types of cancer are caused by viruses. Fortunately, your body has ways to protect you from viruses and other pathogens.

1. How does your body protect you from pathogens?
2. What organs and body systems are involved?

# 21.3 First Two Lines of Defense

## Lesson Objectives

- Describe the barriers that keep most pathogens out of the body.
- Explain how inflammation, phagocytosis, and fever help protect you from pathogens.

## Lesson Vocabulary

- fever
- inflammation
- mucus
- phagocyte
- phagocytosis

## Introduction

Your body has many ways to protect you from pathogens. Your body's defenses are like the ancient castle in **Figure** 21.9. In medieval times, the moat and high walls of the castle kept out most enemies. If any enemies made it past these defenses, soldiers inside the castle were ready to fight them. Like a castle, your body has a series of defenses. Only pathogens that get through all of the defenses can harm you.

FIGURE 21.9
Medieval castle

## First Line of Defense

Your body's first line of defense is like a castle's moat and walls. It keeps most pathogens out of your body. The first line of defense includes physical, chemical, and biological barriers.

### Physical Barriers

The skin is a very important barrier to pathogens. It is the body's largest organ and the most important defense against disease. It forms a physical barrier between the body and the outside environment. The outer layer of the skin, called the epidermis, consists of dead cells filled with the protein keratin. These cells form a tough, waterproof covering on the body. It is very difficult for pathogens to get through the epidermis.

The inside of the mouth and nose are lined with mucous membranes. Other organs that are exposed to substances from the environment are also lined with mucous membranes. These include the respiratory and digestive organs. Mucous membranes aren't tough like skin, but they have other ways of keeping out pathogens.

- One way mucous membranes protect the body is by producing mucus. Mucus is a sticky, moist secretion that covers mucous membranes. The mucus traps pathogens and particles so they can't enter the body.
- Many mucous membranes are also covered with cilia. These are tiny, hair-like projections. Cilia move in waves and sweep mucus and trapped pathogens toward body openings. You can see this in the diagram in **Figure** 21.10. When you clear your throat or blow your nose, you remove mucus and pathogens from your body.

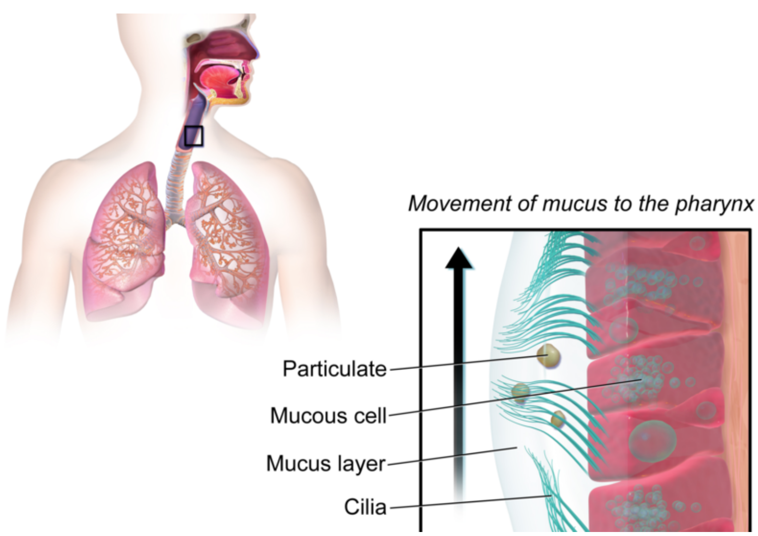



FIGURE 21.10
Cilia lining the respiratory system sweep mucus and trapped pathogens toward the pharynx in the throat.

### Chemical Barriers

In addition to mucus, your body releases a variety of fluids, including tears, saliva, and sweat. These fluids contain enzymes called lysozymes. Lysozymes break down the cell walls of bacteria and kill them.

Your stomach contains a very strong acid, called hydrochloric acid. This acid kills most pathogens that enter the stomach in food or water. Urine is also acidic, so few pathogens are able to grow in it.

### Biological Barriers

Your skin is covered by millions of bacteria. Millions more live inside your body, mainly in your gastrointestinal tract. Most of these bacteria are helpful. For one thing, they help defend your body from pathogens. They do it by competing with harmful bacteria for food and space. They prevent the harmful bacteria from multiplying and making you sick.

## Second Line of Defense

Did you ever get a splinter in your skin, like the one in **Figure** 21.11? It doesn't look like a serious injury, but even a tiny break in the skin may let pathogens enter the body. If bacteria enter through the break, for example, they could cause an infection. These bacteria would then face the body's second line of defense.

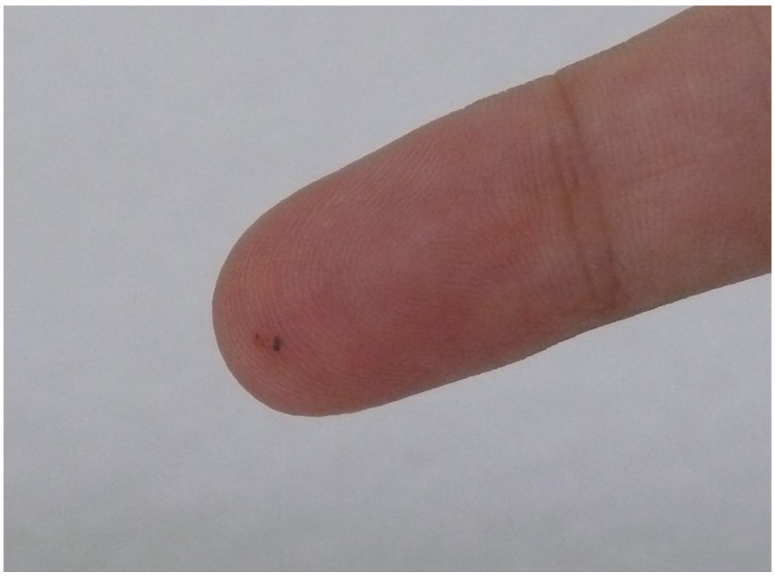
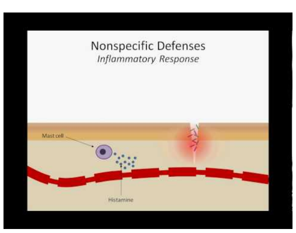


FIGURE 21.11
A splinter in the skin may let bacteria in.

### Inflammation

If bacteria enter the skin through a splinter or other wound, the area may become red, warm, and painful. These are signs of inflammation. Inflammation is one way the body reacts to infections or injuries. It occurs due to chemicals that are released when tissue is damaged. The chemicals cause nearby blood vessels to dilate, increasing blood flow to the area. The chemicals also attract white blood cells to the area. The white blood cells leak out of the blood vessels and into the damaged tissue. You can see an animation of the inflammatory response by watching this video: http://www.youtube.com/watch?v=_bNN95sA6-8 .

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### Phagocytosis

The white blood cells that go to a site of inflammation and leak into damaged tissue are called phagocytes. They start "eating" pathogens and dead cells by engulfing and destroying them. This process is called phagocytosis. You can see how it happens in **Figure ??**. You can see it in action in the animation at this link: http://commons.wikimedia.org/wiki/File:FAGOCITOSI_BY_RAFF.gif .

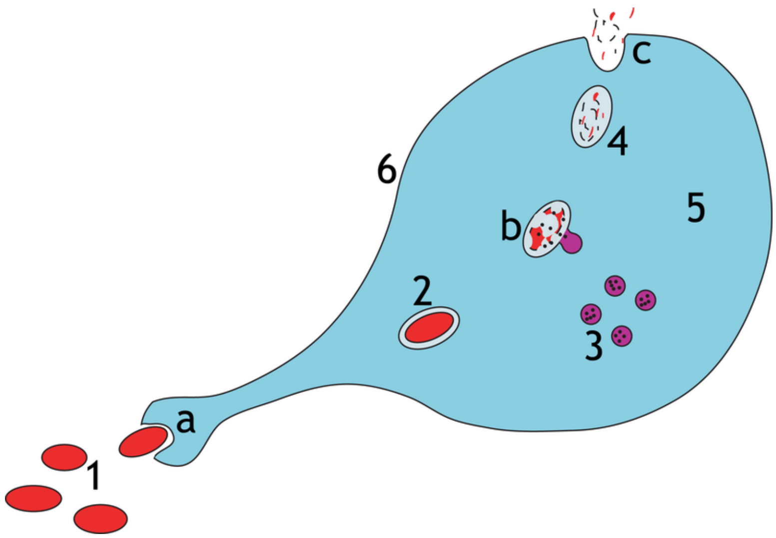


FIGURE 21.12

Phagocytosis occurs when a phagocyte engulfs bacteria, destroys them with chemicals, and excretes the wastes.

### Fever

Phagocytes also release chemicals that cause a fever. A fever is a higher-than-normal body temperature. Normal human body temperature is 98.6° F (37° C). Most bacteria and viruses that infect people reproduce quickly at this temperature. When the temperature rises higher, the pathogens can't reproduce as quickly. Therefore, a fever helps to limit the infection. A fever also causes the immune system to make more white blood cells to fight the infection.

## Lesson Summary

- The body's first line of defense against pathogens includes physical, chemical, and biological barriers. These barriers keep most pathogens out of the body.
- If pathogens do manage to enter the body, the body's second line of defense attacks them. The second line of defense includes inflammation, phagocytosis, and fever.

## Lesson Review Questions

### Recall

1. How does your skin protect you from pathogens?
2. Identify chemical barriers in the body's first line of defense.
3. Define phagocytosis, and describe how it occurs.

### Apply Concepts

4. Assume that you scrape your knee. The next day, the scrape has become red, warm, and painful. Why are these signs that the scrape has become infected?

### Think Critically

5. Explain how a fever helps fight pathogens.

## Points to Consider

The phagocytes that are part of the body's second line of defense attack any pathogens they encounter. They provide a general defense. Some white blood cells attack only certain pathogens. They provide a specific defense.

1. How do you think specific pathogens can be identified by the body?
2. Why do you think the body needs specific defenses as well as general defenses?

# 21.4 Immune System Defenses

## Lesson Objectives

- Identify the parts of the immune system and the roles they play in immune responses.
- Compare and contrast immune responses involving B cell and those involving T cells.
- Define immunity, and explain two ways that immunity may be acquired.

## Lesson Vocabulary

- antibody
- immune response
- immune system
- immunity
- lymph
- lymph node
- lymphocyte
- spleen
- thymus gland
- tonsil
- vaccination

## Introduction

If pathogens get through the body's first two lines of defense, a third line of defense takes over. This third line of defense involves the immune system. For a cartoon introduction to the immune system, watch this video: http://www.youtube.com/watch?v=WJEc2GDEfz8 .

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## What Is the Immune System?

The immune system is the body system that fights to protect the body from specific pathogens. It has a special response for each type of pathogen. The immune system's specific reaction to a pathogen is called an immune response.

The immune system is shown in **Figure** 21.13. It includes several organs and a network of vessels that carry lymph. Lymph is a yellowish liquid that normally leaks out of tiny blood vessels into spaces between cells in tissues. When inflammation occurs, more lymph leaks into tissues, and the lymph is likely to contain pathogens.

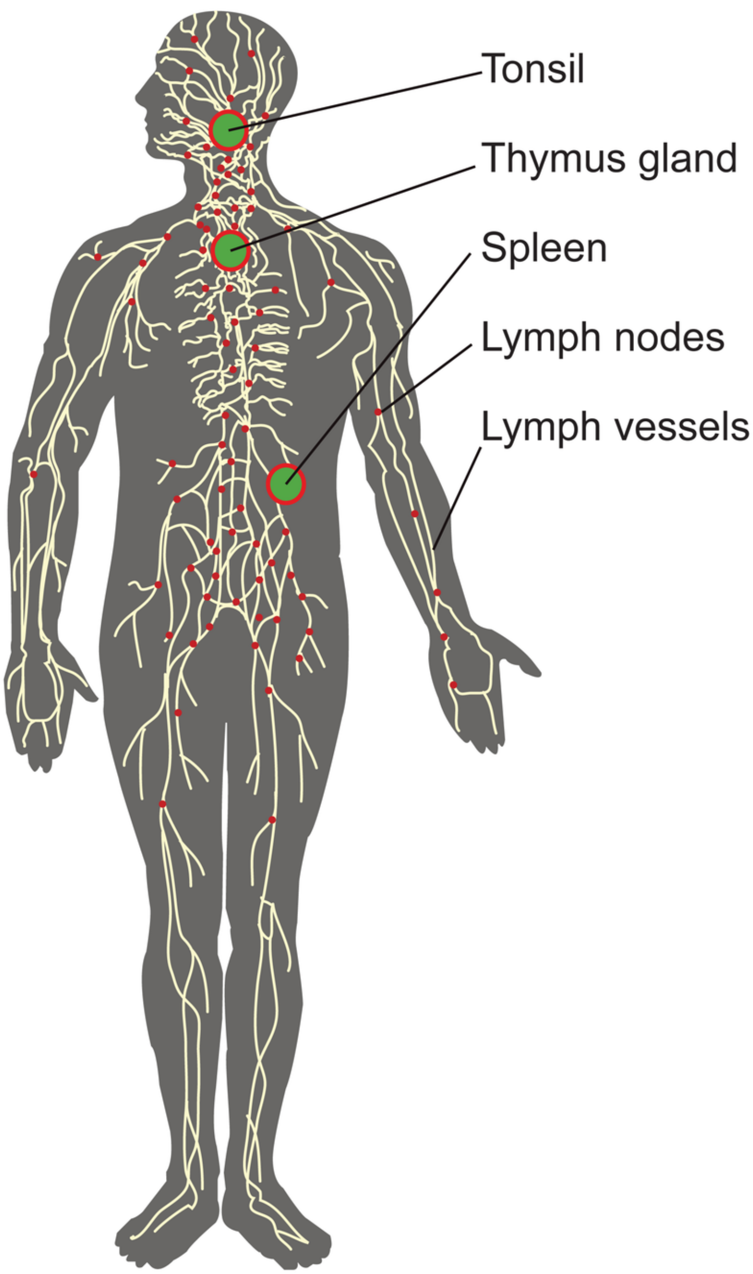



FIGURE 21.13
Parts of the immune system

### Organs of the Immune System

Immune system organs include bone marrow, the thymus gland, the spleen, and the tonsils. Each organ has a different job in the immune system.

- Bone marrow is found inside many bones. Its role in the immune system is to produce white blood cells called lymphocytes.
- The thymus gland is in the chest behind the breast bone. It stores some types of lymphocytes while they mature.
- The spleen is in the abdomen below the lungs. Its job is to filter pathogens out of the blood.
- The two tonsils are located on either side of the throat. They trap pathogens that enter the body through the mouth or nose.

### Circulation of Lymph

Lymph vessels make up a circulatory system that is similar to the blood vessels of the cardiovascular system. However, lymph vessels circulate lymph instead of blood, and the heart does not pump lymph through the vessels.

Lymph that collects in tissues slowly passes into tiny lymph vessels. Lymph then travels from smaller to larger lymph vessels. Muscles around the lymph vessels contract and squeeze the lymph through the vessels. The lymph vessels also contract to help move the lymph along. Eventually, lymph reaches the main lymph vessels, which are located in the chest. From these vessels, lymph drains into two large veins of the cardiovascular system. This is how lymph returns to the blood.

Before lymph reaches the bloodstream, it passes through small oval structures called lymph nodes, which are located along the lymph vessels. **Figure** 21.14 shows where some of the body's many lymph nodes are concentrated. Lymph nodes act like filters and remove pathogens from lymph.

### Lymphocytes

A lymphocyte is the type of white blood cell involved in an immune system response. You can see what a lymphocyte looks like, greatly magnified, in **Figure** 21.15. Lymphocytes make up about one quarter of all white blood cells, but there are trillions of them in the human body. Usually, fewer than half of the body's lymphocytes are in the blood. The majority are in the lymph, lymph nodes, and lymph organs.

There are two main types of lymphocytes, called B cells and T cells. Both types of lymphocytes are produced in bone marrow. They are named for the sites where they grow and mature. The B in B cells stands for bone marrow, where B cells mature. The T in T cells stands for thymus gland, where T cells mature. Both B cells and T cells must be "switched on" in order to fight a specific pathogen. Once this happens, they produce an "army" of cells that are ready to fight that particular pathogen.

How can B and T cells recognize specific pathogens? Pathogens have unique antigens, often located on their cell surface. Antigens are proteins that the body recognizes either as self or nonself. Self antigens include those found on red blood cells that determine a person's blood type. Generally, the immune system doesn't respond to self antigens. Nonself antigens include those found on bacteria, viruses, and other pathogens. Nonself antigens are also found on other cells, such as pollen cells and cancer cells. It is these antigens that trigger an immune response.

## Immune Responses

There are two different types of immune responses. Both types involve lymphocytes. However, one type of response involves B cells. The other type involves T cells.

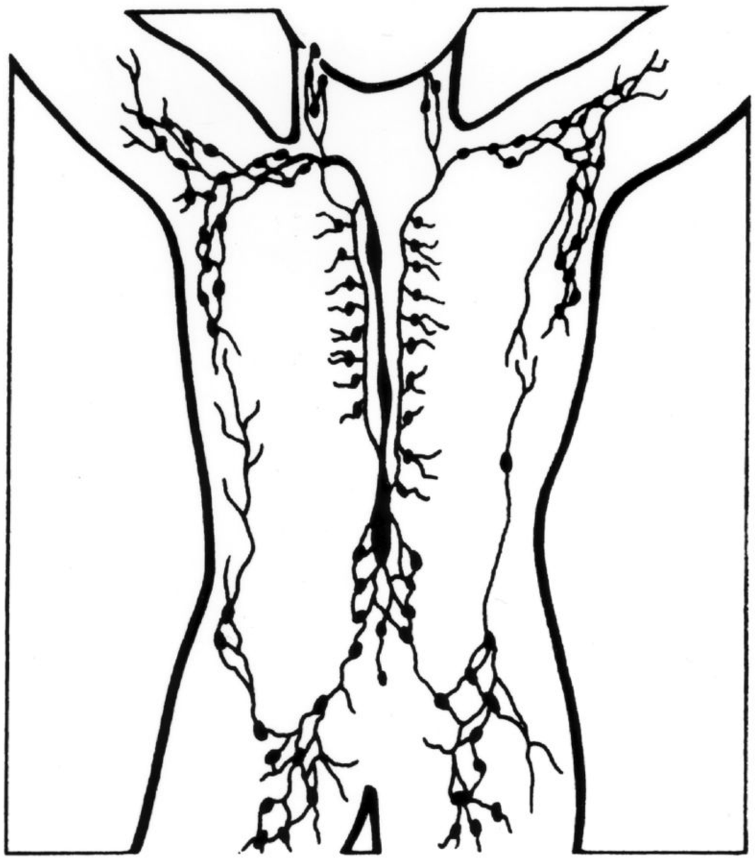


FIGURE 21.14
Lymph nodes are represented by black dots in this drawing.

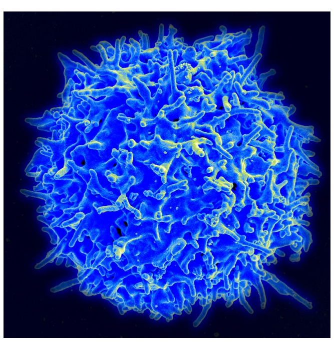
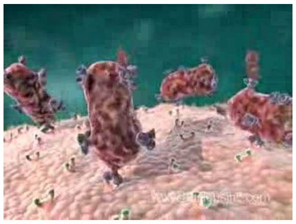


FIGURE 21.15
This image shows a lymphocyte thousands of times its actual size.

### How B Cells Respond

B cells respond to pathogens in the blood and lymph. Most B cells fight infections by making antibodies. An antibody is a large, Y-shaped molecule that binds to an antigen. Each antibody can bind with just one specific type of antigen. The antibody and antigen fit together like a lock and key. You can see how this works in **Figure** 21.16. The antibody in the figure can bind only with the type of antigen that is colored yellow. Once the antibody binds with the antigen, it signals a phagocyte to engulf and destroy them, along with the pathogen that carries the antigen on its surface. You can watch an animation of the antibody-antigen binding process at this link: http://www.youtu be.com/watch?v=lrYlZJiuf18 .



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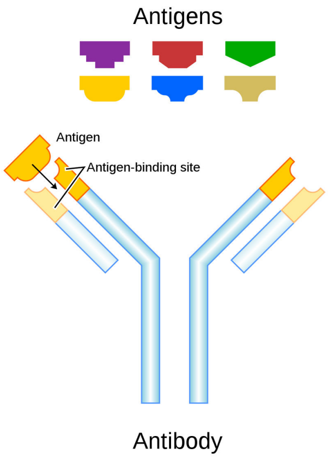


FIGURE 21.16

How an antibody binds to an antigen

### How T Cells Respond

There are different types of T cells, including killer T cells and helper T cells. Killer T cells destroy infected, damaged, or cancerous body cells. **Figure** 21.17 shows how a killer T cells destroys an infected cell. When the killer T cell comes into contact with the infected cell, it releases toxins. The toxins make tiny holes in the infected cell's membrane. This causes the cell to burst open. Both the infected cell and the pathogens inside it are destroyed.

Helper T cells do not destroy infected, damaged, or cancerous body cells. However, they are still needed for an immune response. They help by releasing chemicals that control other lymphocytes. The chemicals released by helper T cells "switch on" B cells and killer T cells so they can recognize and fight specific pathogens.

## Immunity and Vaccination

Most B cells and T cells die after an infection has been brought under control. But some of them survive for many years. They may even survive for a person's lifetime. These long-lasting B and T cells are called memory cells

Memory cells allow the immune system to "remember" a pathogen after the infection is over. If the pathogen invades the body again, the memory cells will start dividing in order to fight it. They will quickly produce a new "army" of B or T cells to fight the pathogen. They will begin a faster, stronger attack than the first time the pathogen invaded the body. As a result, the immune system will be able to destroy the pathogen before it can cause an infection. Being able to fight off and resist a pathogen in this way is called immunity.

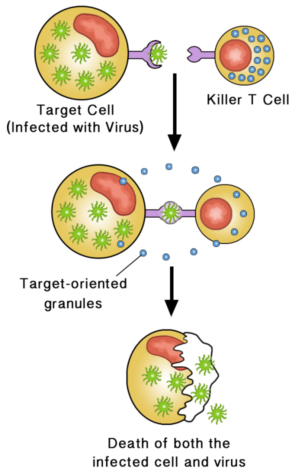


FIGURE 21.17
How a killer T cell destroys a cell infected with viruses

You don't have to suffer through an infection to gain immunity to some diseases. Immunity can also come about by vaccination. Vaccination is the process of exposing a person to pathogens on purpose so the person will develop immunity to them. In vaccination, the pathogens are usually injected under the skin. Only part of the pathogens are injected, or else weakened or dead pathogens are used. This causes an immune response without causing the disease. Diseases you are likely to have been vaccinated against include measles, mumps, and chicken pox.

## Lesson Summary

- The immune system is the body system that fights to protect the body from specific pathogens. The immune system's specific reaction to a pathogen is called an immune response. The immune system includes several organs and a system of vessels that carry lymph.
- White blood cells called lymphocytes are the key cells involved in an immune response. There are two main types of lymphocytes, called B cells and T cells. B cells respond to pathogens in the blood and lymph by making antibodies against them. Killer T cells kill infected, damaged, or cancerous cells. Helper T cells release chemicals that control other lymphocytes.
- Immunity is the ability of the immune system to launch a rapid attack against a particular pathogen because it "remembers" it. Immunity prevents the pathogen from making you sick. It can come about by having a prior infection with the pathogen or by receiving a vaccination for it.

## Lesson Review Questions

### Recall

1. What is an immune response?
2. Identify three immune system organs and their functions.

### Apply Concepts

3. Some diseases are diagnosed by looking for antibodies in the patient's blood. Explain what a positive finding of antibodies means.

### Think Critically

4. Compare and contrast how B cells and T cells respond to pathogens.
5. Explain how vaccinations can protect you from infectious diseases such as measles and chicken pox.

## Points to Consider

Diseases caused by the human papilloma virus (HPV) can be prevented with a vaccination. HPV infects organs of the reproductive system.

1. What are some organs of the reproductive system?
2. What is the function of the reproductive system?

# 21.5 References


1. E coli: Rocky Mountain Laboratories, NIAID, NIH; Herpes simplex: CDC/Dr. Erskine Palmer; Death cap: GLJIVARSKO DRUSTVO NIS; Giarda lamblia: CDC/Janice Carr. E coli: http://commons.wikimedia.org/wiki/File:EscherichiaColi_NIAID.jpg; Herpes simplex: http://commons.wikimedia.org/wiki/File:Herpes_simplex_virus_TEM_B82-0474_lores.jpg; Death cap: http://www.flickr.com/photos/ressaure/6580918185/; Giarda lamblia: http://commons.wikimedia.org/wiki/File:Giardia_lamblia_SEM_8698_lores.jpg . E coli, Herpes simplex, Giarda lamblia: Public Domain; Death cap: CC BY 2.0
2. Courtesy of James Gathany/CDC. http://commons.wikimedia.org/wiki/File:Sneeze.JPG . Public Domain
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4. NIH, National Cancer Institute. http://commons.wikimedia.org/wiki/File:Normal_cancer_cell_division_from_NIH.png . public domain
5. projectandi. http://commons.wikimedia.org/wiki/File:Some_Kills.jpg . public domain
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14. NCI/NIH. http://commons.wikimedia.org/wiki/File:Lymph_nodes_illustration.jpg . public domain
15. NIAID/NIH. http://commons.wikimedia.org/wiki/File:Healthy_Human_T_Cell.jpg . public domain
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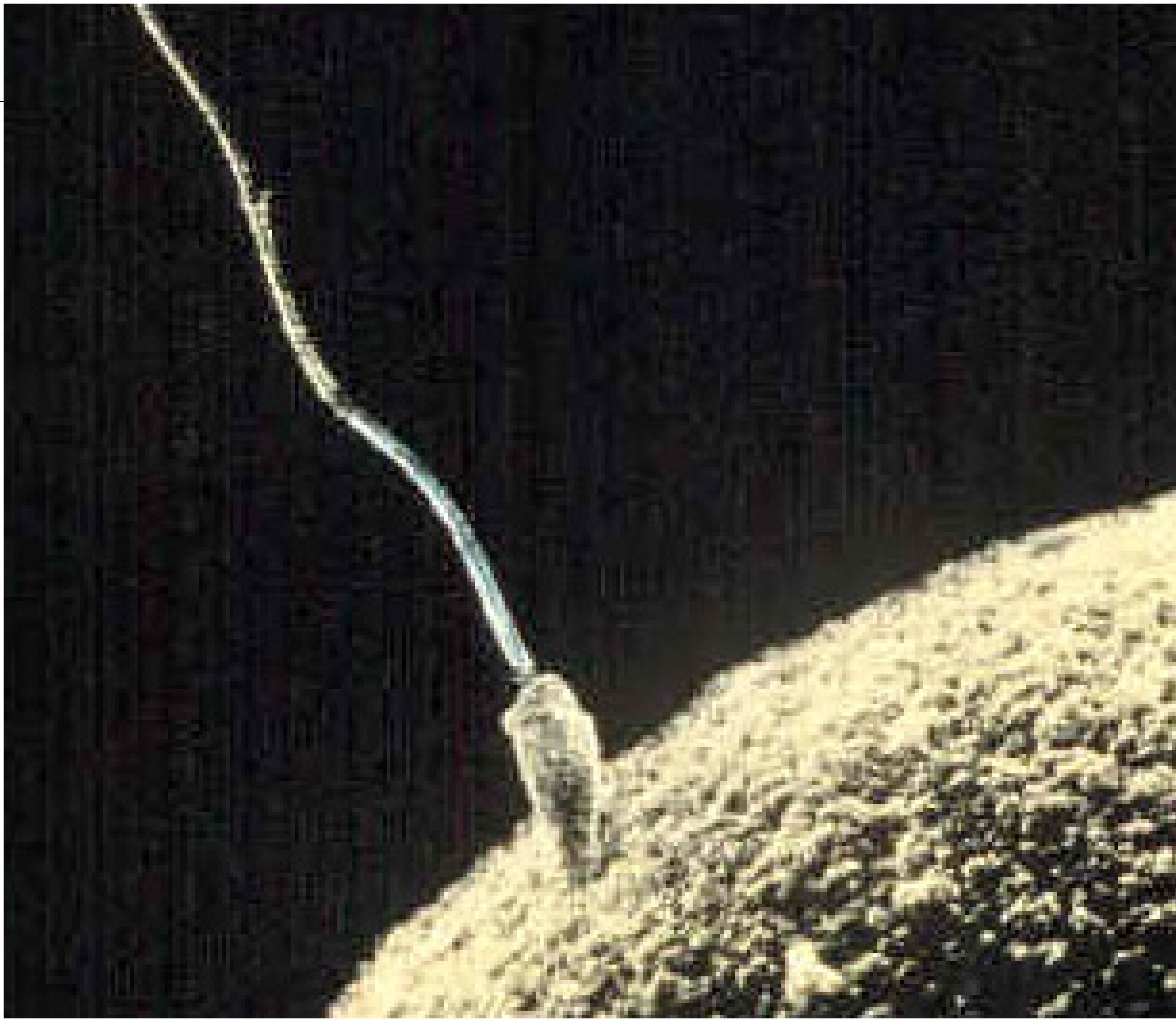
# CHAPTER 22 MS Reproductive Systems and Life Stages

## Chapter Outline





This picture shows the amazing moment when a human sperm and egg unite. The process is called fertilization. If it's successful, it will lead to a brand new human being. Do you know how the sperm and egg are produced? Do you know how a fertilized egg develops into a complete and complex human being? You'll find out when you read this chapter.

# 22.1 Male Reproductive System

## Lesson Objectives

- Identify functions of the male reproductive system.
- Describe organs of the male reproductive system.
- Describe sperm, and explain how they are produced.

## Lesson Vocabulary

- epididymis
- penis
- prostate gland
- reproductive system
- semen
- testis (testes, plural)
- testosterone
- vas deferens

## Introduction

Dogs have puppies. Cats have kittens. All living things reproduce, including human beings. Like other mammals, human beings have a body system that controls reproduction. It's called the reproductive system. It's the only human body system that differs significantly between males and females. The male and female reproductive systems have different organs and different functions.

## Functions of the Male Reproductive System

The male reproductive system has two main functions: producing sperm and releasing testosterone.

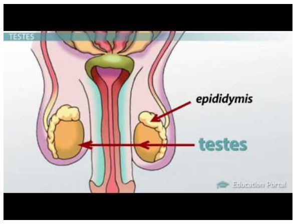
Sperm are male gametes, or reproductive cells. Sperm form when certain cells in the male reproductive system divide by meiosis to form haploid cells. Being haploid means they have half the number of chromosomes of other cells in the body. An adult male may produce millions of sperm each day!

Testosterone is the major sex hormone in males. Testosterone has two primary roles:

1. During adolescence, testosterone causes most of the changes associated with puberty. It causes the reproductive organs to mature. It also causes other adult male traits to develop. For example, it causes the voice to deepen and facial hair to start growing.
2. During adulthood, testosterone is needed for the production of sperm.

## Organs of the Male Reproductive System

The male reproductive organs include the penis, testes, epididymis, vas deferens, and prostate gland. These organs are shown in **Figure** 22.1. The figure also shows some other parts of the male reproductive system. Find each organ in the drawing as you read about it below. For a cartoon about the male reproductive system, watch this video: http://www.youtube.com/watch?v=oFlUqgYqt1A .

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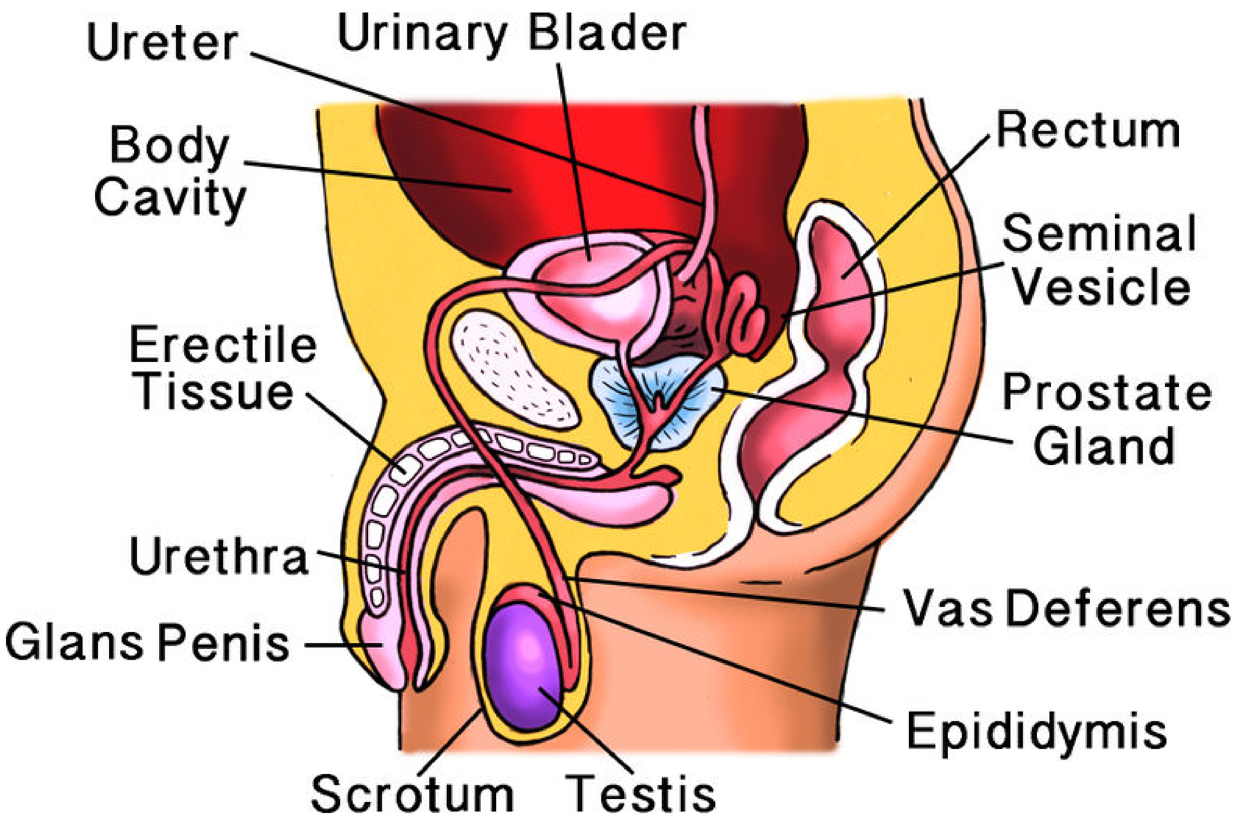


FIGURE 22.1

Male reproductive system as viewed from the side

- The penis is an external, cylinder-shaped organ that contains the urethra. The urethra is the tube that carries urine out of the body. It also carries sperm out of the body.
- The two testes (testis, singular) are oval organs that produce sperm and secrete testosterone. They are located inside a sac called the scrotum that hangs down outside the body. The scrotum also contains the epididymis.

- The epididymis is a tube that is about 6 meters (20 feet) long in adults. It is tightly coiled, so it fits inside the scrotum on top of the testes. The epididymis is where sperm mature. It stores the sperm until they leave the body.
- The vas deferens is a tube that carries sperm from the epididymis to the urethra.
- The prostate gland secretes a fluid that mixes with sperm to help form semen. Semen is a whitish liquid that contains sperm. It passes through the urethra and out of the body.

## Producing Sperm

Sperm are tiny cells. In fact, they are the smallest of all human cells. They have a structure that suits them well to perform their function.

### Structure and Function of Sperm

As you can see in **Figure** 22.2, a sperm has three main parts: the head, connecting piece (or midpiece), and tail.

1. The head of the sperm contains the nucleus. The nucleus holds the chromosomes. In humans, the nucleus of a sperm cell contains 23 chromosomes. The acrosome on the head contains enzymes that help the sperm penetrate an egg.
2. The connecting piece of the sperm is packed with mitochondria. Mitochondria are organelles in cells that produce energy. Sperm use the energy to move.
3. The tail of the sperm moves like a propeller. It spins around and around and pushes the sperm forward. Sperm can travel about 30 inches per hour.

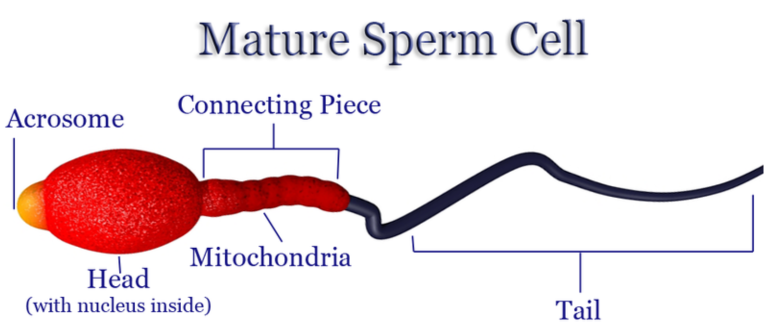


FIGURE 22.2
Structure of sperm

### How Sperm Form

It takes up to two months for mature sperm to form. The process occurs in several steps:

1. Special cells in the testes go through mitosis to make identical copies of themselves.
2. The copies of the original cells divide by meiosis. This results in haploid cells called spermatids. These cells lack tails and cannot yet swim.
3. Spermatids move from the testes to the epididymis, where they slowly mature. For example, they grow a tail and lose some of the cytoplasm from the head.
4. Once sperm are mature, they can swim. The mature sperm remain in the epididymis until it is time for them to leave the body.

Sperm leave the epididymis through the vas deferens. As they travel through the vas deferens, they pass by the prostate and other glands. The sperm mix with secretions from these glands, forming semen. Semen travels through the urethra and leaves the body through the penis. A teaspoon of semen may contain as many as half a billion sperm!

## Lesson Summary

- The male reproductive system has two main functions: producing sperm and secreting testosterone. Sperm are male gametes. Testosterone is the major sex hormone in males.
- The male reproductive organs include the penis, testes, epididymis, vas deferens, and prostate gland.
- Sperm form in the testes and mature in the epididymis. Each sperm has three main parts: head, connecting piece, and tail. Sperm mix with secretions from glands to form semen.

## Lesson Review Questions

### Recall

1. What are the two main roles of the male reproductive system?
2. Name three male reproductive organs, and identify their reproductive functions.
3. What are sperm? What is the function of the tail of a sperm?

### Apply Concepts

4. A man who doesn't want to have any more children may have a procedure in which the vas deferens is cut. Why does this procedure prohibit him from having more children?

### Think Critically

5. Explain how sperm form and mature.

## Points to Consider

The female reproductive system has different functions and organs than the male reproductive system.

1. What are the functions of the female reproductive system?
2. What are some of the organs of the female reproductive system?

# 22.2 Female Reproductive System

## Lesson Objectives

- Identify functions of the female reproductive system.
- Describe organs of the female reproductive system.
- Describe eggs, and explain how they are produced.
- Summarize the monthly cycle of the female reproductive system.

## Lesson Vocabulary

- estrogen
- fallopian tube
- menstrual cycle
- menstruation
- ovary
- ovulation
- uterus
- vagina

## Introduction

Most of the male reproductive organs are outside the body. Female reproductive organs, in contrast, are inside the body. The male and female organs also look very different and have different functions.

## Functions of the Female Reproductive System

Two functions of the female reproductive system are similar to the functions of the male reproductive system: producing gametes and secreting a major sex hormone. In the case of females, however, the gametes are eggs, and they are produced by the ovaries. The hormone is estrogen, which is the main sex hormone in females. Estrogen has two major roles:

- During adolescence, estrogen causes the changes of puberty. It causes the reproductive organs to mature. It also causes other female traits to develop. For example, it causes the breasts to grow and the hips to widen.
- During adulthood, estrogen is needed for a woman to release eggs from the ovaries.

The female reproductive system has another important function, which is not found in males. It supports a baby as it develops before birth. It also gives birth to the baby at the end of pregnancy.

## Organs of the Female Reproductive System

The female reproductive organs include the ovaries, fallopian tubes, uterus, and vagina. These organs are shown in **Figure** 22.3, along with some other structures of the female reproductive system. Find each organ in the drawing as you read about it below. For a cartoon about the female reproductive system, watch this video: http://education-portal.com/academy/lesson/female-reproductive-system-internal-anatomy.html

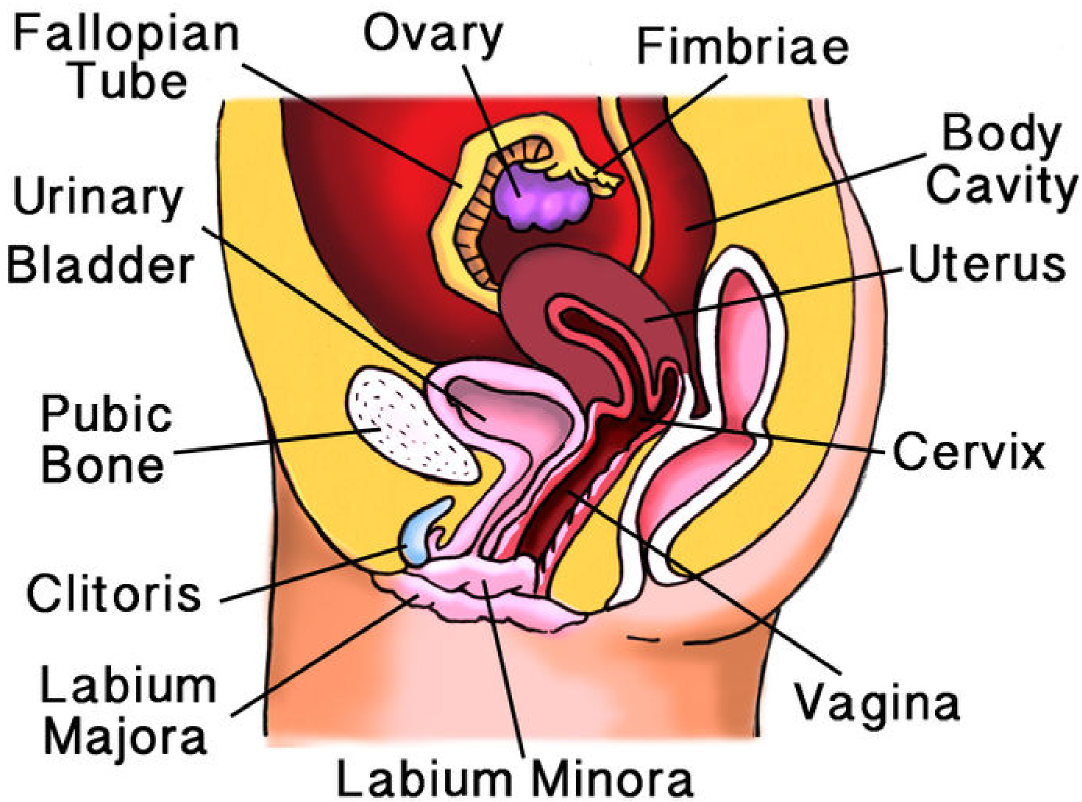


FIGURE 22.3
Female reproductive system as viewed from the side

- The two ovaries are small, oval organs on either side of the abdomen. Each ovary contains thousands of eggs. However, the eggs do not develop fully until a female has gone through puberty. Then, about once a month, an egg is released by one of the ovaries. The ovaries also secrete estrogen.
- The two fallopian tubes are thin tubes that are connected to the uterus and extend almost to the ovaries. The upper end of each fallopian tube has "fingers" (called fimbriae) that sweep an egg into the fallopian tube when it is released by the ovary. The egg then passes through the fallopian tube to the uterus. If an egg is fertilized, this occurs in the fallopian tube.
- The uterus is a hollow organ with muscular walls. The uterus is where a baby develops until birth. The walls of the uterus stretch to accommodate the growing fetus. The muscles in the walls contract to push the baby out during birth. The uterus is connected to the vagina by a small opening called the cervix.
- The vagina is a cylinder-shaped organ that opens to the outside of the body. The other end joins with the uterus. Sperm deposited in the vagina swim up through the cervix, into the uterus, and from there into a

fallopian tube. During birth, a baby passes from the uterus through the vagina to leave the body.

## Producing Eggs

When a baby girl is born, her ovaries contain all of the eggs they will ever produce. But these eggs are not fully developed. They develop only after the female reaches puberty at about age 12 or 13. Then, just one egg develops each month until she reaches her 40s or early 50s.

### Structure and Function of Eggs

Human eggs are very large cells. In fact, they are the largest of all human cells. You can even see an egg without a microscope. It's almost as big as the period at the end of this sentence. Like a sperm cell, an egg cell is a haploid cell with half the number of chromosomes of other cells in the body. Unlike a sperm cell, the egg lacks a tail and contains a lot of cytoplasm.

### How Eggs Form

Egg production takes place in the ovaries. It occurs in several steps:

1. Before birth, special cells in the ovaries go through mitosis to make identical daughter cells.
2. The daughter cells then start to divide by meiosis. However, they go though only the first of the two cell divisions of meiosis at this time. They remain in that stage until the girl goes through puberty.
3. After puberty, an egg develops in an ovary about once a month. As you can see in **Figure** 22.4, the egg rests in a nest of cells called a follicle. The follicle and egg grow larger and go through other changes.
4. After a couple of weeks, the egg bursts out of the follicle and through the wall of the ovary. This is called ovulation.

After ovulation occurs, the moving "fingers" of the nearby fallopian tube sweep the egg into the tube. Fertilization may occur if sperm reach the egg while it is passing through the fallopian tube. If this happens, the egg finally completes meiosis. This results in two daughter cells that differ in size. The smaller cell is called a polar body. It soon breaks down and disappears. The larger cell is the fertilized egg, which will develop into a new human being.

## Menstrual Cycle

Egg production in the ovary is part of the menstrual cycle. The menstrual cycle is a series of changes in the reproductive system of mature females that repeats every month on average. These changes include the development of an egg and follicle in the ovary.

While the egg is developing, other changes are taking place in the uterus. It develops a thick lining that is full of tiny blood vessels. The lining prepares the uterus to receive a fertilized egg if fertilization actually takes place.

If fertilization doesn't occur, the egg passes through the uterus and vagina and out of the body. The lining of the uterus also breaks down. Blood and other tissues from the lining pass through the vagina and leave the body. This is called menstruation. Menstruation is also called a menstrual period. It typically lasts about 4 days. When the menstrual period ends, the cycle begins repeats.

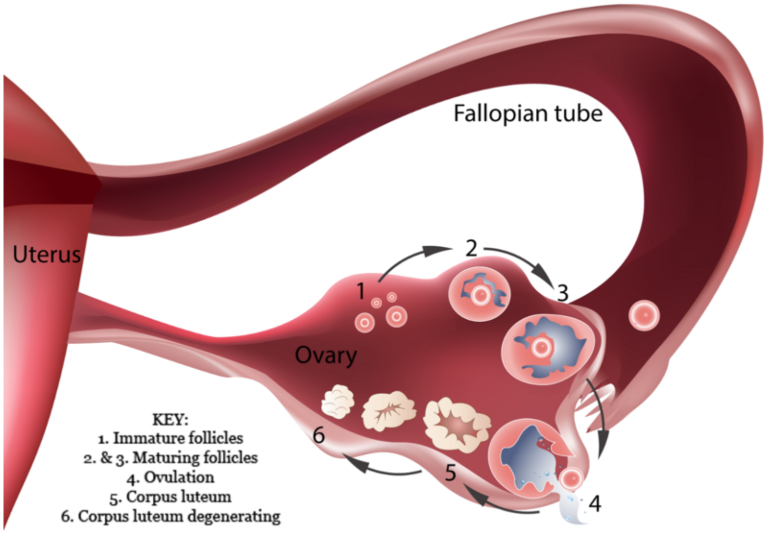


FIGURE 22.4
How an egg and its follicle develop in an ovary: (1) undeveloped eggs; (2) and (3) egg and follicle developing; (4) ovulation; (5) and (6) follicle (now called corpus luteum) breaking down

## Lesson Summary

- Two functions of the female reproductive system are producing eggs and secreting estrogen. Eggs are female gametes. Estrogen is the major sex hormone in females. The female reproductive system also supports a developing fetus and gives birth to an infant.
- The female reproductive organs include the ovaries, fallopian tubes, uterus, and vagina.
- Eggs form in the ovaries. After puberty, an egg is released from an ovary each month in the process of ovulation. The egg passes through the fallopian tube where fertilization may take place.
- The menstrual cycle is a series of changes in the reproductive system of mature females that repeats every month on average. It includes changes in the uterus as well as development of an egg and ovulation. If fertilization does not occur, menstruation occurs and the cycle repeats.

## Lesson Review Questions

### Recall

1. List three functions of the female reproductive system.
2. Identify three organs of the female reproductive system, and state their functions.
3. Describe what happens during ovulation.

### Apply Concepts

4. If a woman's fallopian tubes are blocked, she is unable to become pregnant even if she produces healthy eggs. Explain why.

### Think Critically

5. What is menstruation, and why does it occur?

## Points to Consider

If an egg is fertilized, this event takes place in a fallopian tube.

1. What happens next to the fertilized egg?
2. As an embryo grows into a fetus, the mother must provide nourishment to her offspring. How do nutrients pass from the mother to the fetus?

# 22.3 Reproduction and Life Stages

## Lesson Objectives

- Summarize events from fertilization to birth.
- Describe pregnancy and birth.
- Outline the major changes that occur from birth to adulthood.
- Give an overview of early, middle, and late adulthood.

## Lesson Vocabulary

- adolescence
- amniotic sac
- blastocyst
- childhood
- fetus
- implantation
- infancy
- pregnancy
- puberty
- umbilical cord

## Introduction

A day or two after an ovary releases an egg, the egg may unite with a sperm. Sperm are deposited in the vagina during sexual intercourse. They propel themselves through secretions in the uterus and enter a fallopian tube. This is where fertilization normally takes place.

## From Fertilization to Birth

When a sperm penetrates the cell membrane of an egg, it triggers the egg to complete meiosis. The sperm also undergoes changes. Its tail falls off, and its nucleus fuses with the nucleus of the egg. The resulting cell, called a zygote, contains the diploid number of chromosomes. Half of the chromosomes come from the egg, and half come from the sperm. You can watch the process of fertilization and the development of a baby until birth in this amazing video: http://www.ted.com/talks/alexander_tsiaras_conception_to_birth_visualized


MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/140771

## The Blastocyst

The zygote spends the next few days traveling down the fallopian tube toward the uterus, where it will take up residence. As it travels, it divides many times by mitosis. It soon forms a tiny, fluid-filled ball of cells called a blastocyst.

The blastocyst has an inner and outer layer of cells, as you can see in **Figure** 22.5. The inner layer, called the embryoblast, will develop into the new human being. The outer layer, called the trophoblast, will develop into other structures needed to support the new organism.

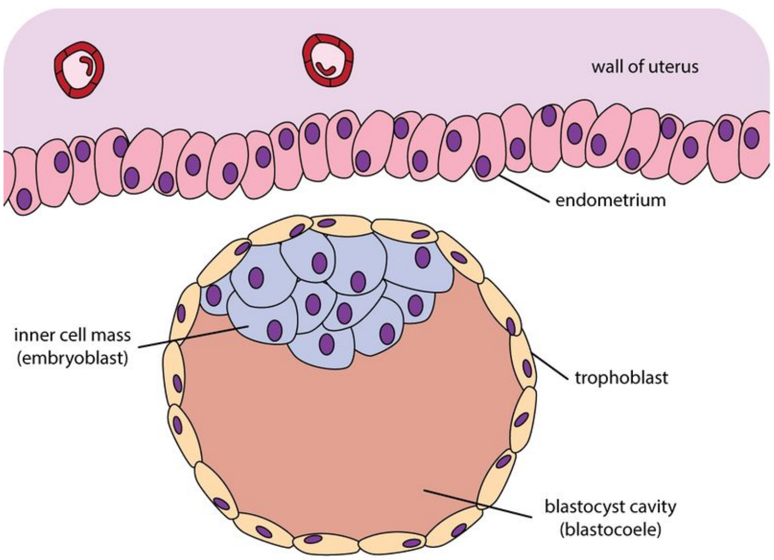


FIGURE 22.5

Blastocyst stage

## Implantation

The blastocyst continues down the fallopian tube until it reaches the uterus, about 4 or 5 days after fertilization. When the outer cells of the blastocyst contact cells lining the uterus (the endometrium in **Figure** 22.5), the blastocyst embeds itself in the uterine lining. This process is called implantation. It generally occurs about a week after fertilization.

## The Embryo

After implantation occurs, the blastocyst is called an embryo. The embryonic stage lasts from the end of the first week following fertilization through the end of the eighth week. During this time, the embryo grows in size and becomes more complex. It develops specialized cells and tissues. Most organs also start to form. You can see some of the specific changes that take place during weeks four to eight of the embryonic period in **Figure** 22.6. By the end of week eight, the embryo is about 30 millimeters (just over 1 inch) in length. It may also have begun to move.

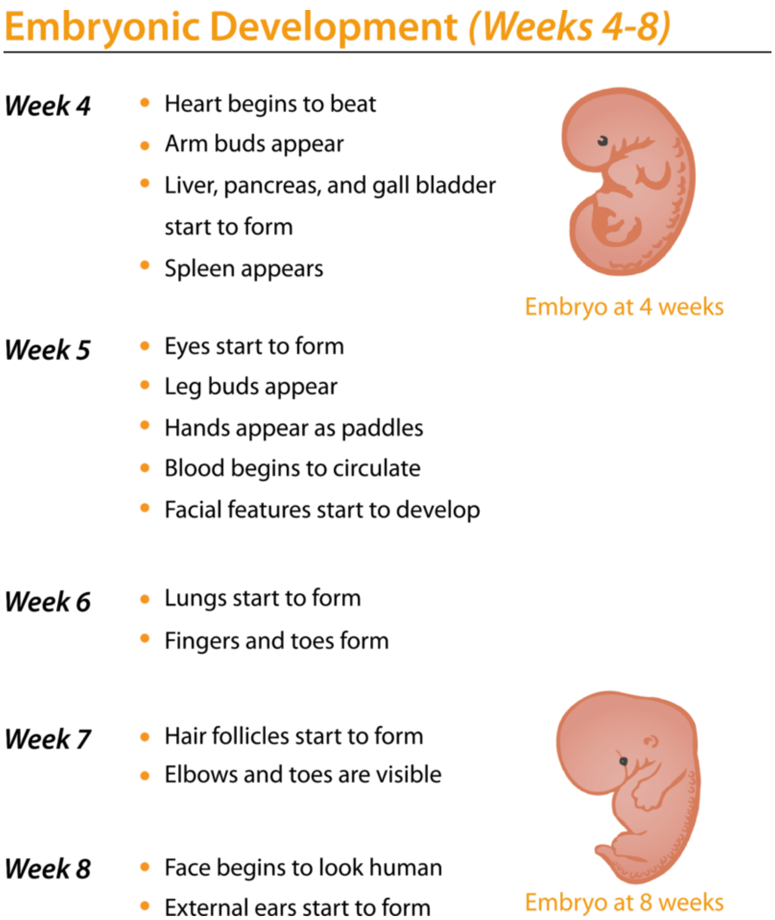


FIGURE 22.6
Embryonic Development (Weeks 4–8). Most organs develop in the embryo during weeks 4 through 8. If the embryo is exposed to toxins during this period, the effects are likely to be very damaging. Can you explain why? (Note: the drawings of the embryos are not to scale.)

### The Fetus

From the eighth week following fertilization until birth, the developing human being is called a fetus. Birth typically occurs at about 38 weeks after fertilization, so the fetal period generally lasts about 30 weeks. During this time, the organs complete their development. The fetus also grows rapidly in length and weight. Some of the specific changes that occur during the fetal stage are listed in **Figure** 22.7.

By the 38th week, the fetus is fully developed and ready to be born. A 38-week fetus normally ranges from about 36 to 51 centimeters (14–20 inches) in length and weighs between 2.7 and 4.6 kilograms (about 6–10 pounds).

### Placenta and Amniotic Sac

The fetus could not grow and develop without oxygen and nutrients from the mother. Wastes from the fetus also must be removed in order for it to survive. The exchange of these substances between the mother and fetus occurs through the placenta.

The placenta is a temporary organ that starts to form shortly after implantation. It forms from the trophoblast layer of cells in the blastocyst and from maternal cells in the uterus. The placenta continues to develop and grow to meet the needs of the growing fetus.

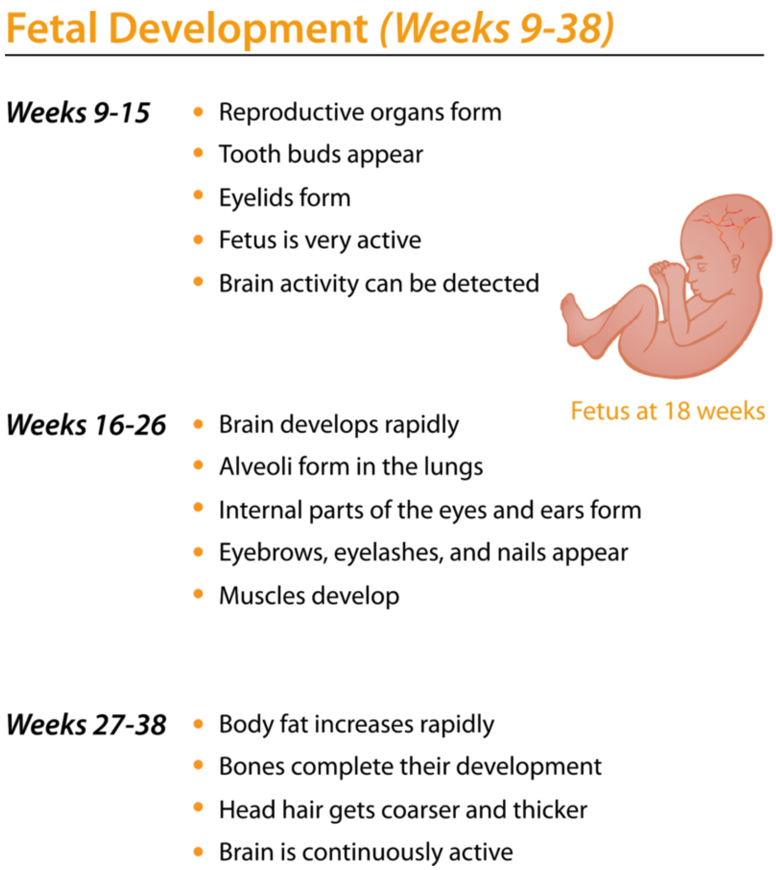


FIGURE 22.7
Developments in the fetus

A fully developed placenta, like the one in **Figure** 22.8, is made up of a large mass of blood vessels from both mother and fetus. The maternal and fetal vessels are close together but separated by tiny spaces. This allows the mother's and fetus's blood to exchange substances across their capillary walls without the blood actually mixing.

The fetus is connected to the placenta through the umbilical cord. This is a long tube that contains two arteries and a vein. Blood from the fetus enters the placenta through the umbilical arteries. It exchanges gases and other substances with the mother's blood. Then it travels back to the fetus through the umbilical vein.

Another structure that supports the fetus is the amniotic sac. This is a membrane that surrounds and protects the fetus. It contains amniotic fluid, which consists of water and dissolved substances. The fluid allows the fetus to move freely until it grows to fill most of the available space. The fluid also cushions the fetus and helps protect it from injury.

## Pregnancy and Birth

Pregnancy is the carrying of one or more offspring from the time of implantation until birth. It is the development of an embryo and fetus from the expectant mother's point of view.

### Role of the Mother

The pregnant mother plays a critical role in the development of the embryo and fetus. She must avoid toxic substances such as alcohol, which can damage the developing offspring. She also must provide all the nutrients

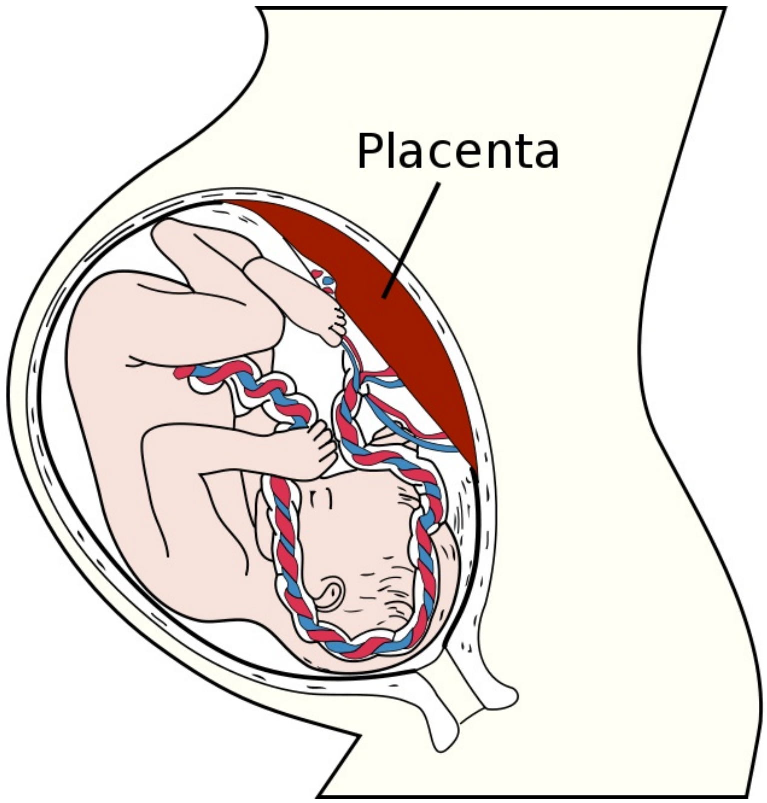


FIGURE 22.8
Placenta and umbilical cord

and other substances needed for normal growth and development. Most nutrients are needed in greater amounts by a pregnant woman because she is literally eating for two people. That's why it's important for a woman to eat plenty of nutritious foods during pregnancy. The pregnant woman in **Figure** 22.9 is eating a variety of fresh fruits, which provide energy, vitamins, and other nutrients.

### Birth

Near the time of birth, the amniotic sac breaks in a gush of liquid. Labor usually begins within a day of this event. Labor involves contractions of the muscular walls of the uterus. With the mother's help, the contractions eventually push the fetus out of the uterus and through the vagina.

Within seconds of birth, the umbilical cord is cut. Without this connection to the placenta, the baby can't exchange gases, so carbon dioxide quickly builds up in the baby's blood. This stimulates the baby's brain to trigger breathing, and the newborn takes her first breath.

## From Birth to Adulthood

For the first year after birth, a baby is referred to as an infant. Childhood begins at the age of two years and continues until puberty. Adolescence begins with puberty and lasts until adulthood.

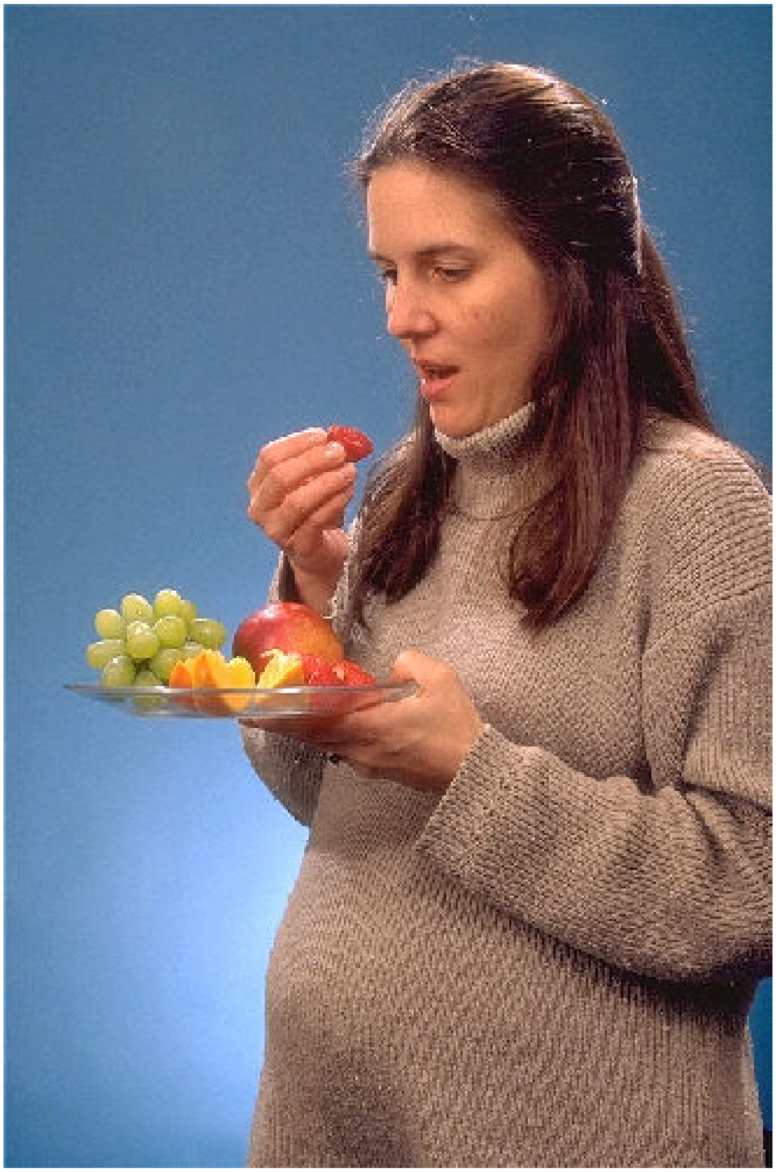

FIGURE 22.9
A pregnant woman needs to pay special attention to her diet and eat a variety of healthy foods.

## Infancy

The first year of life after birth is called infancy. During infancy, a baby grows very quickly. The baby's length typically doubles and her weight triples by her first birthday. Many other important changes also occur during infancy:

- The baby starts smiling, usually by about 6 weeks of age (see **Figure** 22.10).
- The baby starts noticing people and grabbing toys and other objects
- The baby teeth start to come in, usually by 6 months of age.
- The baby begins making babbling sounds. By the end of the first year, the baby may be saying a few words, such as "Mama" and Dada."
- The baby learns to sit, crawl, and stand. By the end of the first year, the baby may be starting to walk.

FIGURE 22.10
Smiling is an early milestone in infant development.

### Childhood

Childhood begins after the baby's first birthday and continues until puberty. Between 1 and 3 years of age, a child is called a toddler. During the toddler stage, growth is still very rapid, but not as rapid as it was during infancy. Toddlers learn many new words and starts putting them together in simple sentences. Motor skills also develop quickly during the toddler stage. By the age of 3 years, most children can run and climb steps. They can hold crayons and scribble with them. They can also feed themselves, and most can use the toilet.

From age 3 until puberty, growth slows down. The body also changes shape. The arms and legs grow longer relative to the trunk. Children continue to develop new motor skills. For example, many young children learn how to ride a tricycle and then a bicycle. Most learn how to play games and sports.

By the age of 6 years, children start losing their baby teeth. Permanent teeth come in to replace them. Most children have started school by this age. They typically start learning to read and write around age 6 or 7 (see **Figure** 22.11). During the later years of childhood, children also start to develop friendships and become less dependent on their parents.

### Puberty

Puberty is the stage of life when a child becomes sexually mature. Puberty lasts from about 10 to 16 years of age in girls and from about 12 to 18 years of age in boys. In both girls and boys, puberty begins when the pituitary gland signals the gonads (ovaries or testes) to start secreting sex hormones (estrogen in girls, testosterone in boys). Sex hormones, in turn, cause many other changes to take place.

In girls, estrogen causes the following changes to occur:

- The uterus and ovaries grow.
- The ovaries start releasing eggs.
- The menstrual cycle begins.
- Pubic hair grows.
- The hips widen and the breasts develop.

In boys, testosterone causes these changes to take place:

- The penis and testes grow.

FIGURE 22.11
Learning how to write is a major accomplishment of childhood.

- The testes start producing sperm.
- Pubic and facial hair grow.
- The shoulders broaden.
- The voice becomes deeper as the larynx in the throat grows larger (see **Figure** 22.12).

Girls and boys of the same age are similar in height during childhood. In both girls and boys, growth in height and weight is very fast during puberty. But boys grow more quickly that girls do, and their period of rapid growth also lasts longer. In addition, boys generally start puberty later than girls, so they have a longer period of childhood growth. For all these reasons, by the end of puberty, the average height of boys is 10 centimeters (about 4 inches) greater than the average height of girls.

### Adolescence

Adolescence is the stage of life between the start of puberty and the beginning of adulthood. Adolescence begins with the physical changes of puberty. It also includes many other changes, including mental, emotional, and social changes. During adolescence:

- Teens develop new thinking abilities. For example, they develop the ability to understand abstract ideas, such as honesty and freedom. Their ability to think logically also improves. They usually get better at problem

FIGURE 22.12
A teenage boy develops a bump in his throat called an Adam's apple because of an increase in the size of the larynx, or voice box.

solving as well.
- Teens try to establish a sense of identity. They typically become increasingly independent from their parents.
- Many teens have emotional ups and downs. This is at least partly due to their changing hormone levels.
- Teens usually start spending more time with their peers, like the girls in **Figure** 22.13. Adolescents usually spend much more time with their friends and classmates than they do with family members.

FIGURE 22.13
Teen friends enjoying card games and each other's company

## Adulthood

Adulthood doesn't have a definite starting point. Teens may become physically mature by the age 16 years, but they are not adults in a legal sense until they are older. For example, in the U.S., you must be 18 years old to vote or serve in the armed forces. You must be 21 years old before you can take on many legal and financial responsibilities. Once adulthood begins, it can be divided into three stages: early, middle, and late adulthood.

### Early Adulthood

Early adulthood refers to the 20s and early 30s. During early adulthood, most people are at their physical peak, and they are usually in good health. Often, they are completing their education and getting established in the workforce. Many people become engaged or marry during this time.

### Middle Adulthood

Middle adulthood is the period from the mid-30s to the mid-60s. During this stage of life, people start showing signs of aging. Their hair may thin and slowly turn gray. Their skin develops wrinkles. The risk of serious health problems increases. For example, cardiovascular diseases, cancer, and type 2 diabetes become more common in people of middle age. This is also the stage when many people raise a family and strive to attain career goals.

### Late Adulthood

Late adulthood begins in the mid-60s and continues until death. This is the stage of life when most people retire from work. This frees up their time for hobbies, grandchildren, or other interests. For example, the man in **Figure** 22.14 enjoys creating music in old age.

FIGURE 22.14
This elderly man not only plays the guitar. He built the guitar that he's playing in the photo.

During late adulthood, the risk of developing diseases such as cardiovascular diseases and cancer continues to rise. Most people also have a decline in strength and stamina. Their senses may start failing, and their reflex time typically increases. Their immune system also doesn't work as well as it used to. As a result, common diseases like the flu may become more serious and even lead to death. The majority of late adults develop arthritis, and as many as one in four develop Alzheimer's disease.

Despite problems such as these, many people remain healthy and active into their 80s and even 90s. Do you want to be one of them? If so, adopt a healthy lifestyle now and follow it for life. Doing so will increase your chances of staying fit and active in old age.

## Lesson Summary

- Fertilization of an egg by a sperm in a fallopian tube produces a zygote. The zygote develops into a blastocyst, which implants in the uterus. The offspring then goes through the embryonic and fetal stages. The placenta supports the needs of the developing embryo and fetus. Birth generally occurs at about 38 months after fertilization.
- An expectant mother must avoid toxins to protect the developing fetus. She also must eat a nutritious diet during pregnancy for the health of her child.
- For the first year after birth, a baby is referred to as an infant. Childhood begins at the age of two years and continues until puberty, when sexual maturation takes place. Adolescence is the last stage of life before adulthood. It starts with puberty and ends around age 20.
- Stages of adulthood include early, middle, and late adulthood. Each stage is associated with different physical abilities, health concerns, and social roles.

## Lesson Review Questions

### Recall

1. What happens during fertilization? Where does it normally take place?
2. Describe the blastocyst stage.
3. What is implantation? When does it occur?
4. Identify the three stages of adulthood.

### Apply Concepts

5. Why do you think an embryo would be more susceptible than a fetus to damage by toxins?
6. Create a timeline showing a few of the important changes that occur from birth to adulthood.

### Think Critically

7. Explain the role of the placenta during fetal development.
8. Compare and contrast puberty and adolescence.

## Points to Consider

Many diseases become more common as people grow older. However, sexually transmitted infections (STIs) are more common in teens and young adults.

1. What are some examples of STIs?
2. How can STIs be prevented?

# 22.4 Reproductive System Health

## Lesson Objectives

- Identify myths about STIs, and distinguish between bacterial and viral STIs.
- Describe other male and female reproductive system disorders.
- List ways to keep the reproductive system healthy.

## Lesson Vocabulary

- acquired immunodeficiency syndrome (AIDS)
- chlamydia
- genital herpes
- genital warts
- gonorrhea
- human immunodeficiency virus (HIV)
- human papilloma virus (HPV)
- sexually transmitted infection (STI)
- syphilis

## Introduction

A healthy reproductive system is important for two reasons. It's important for overall good health. It's also important for reproduction. If the reproductive system isn't healthy, a person may be unable to have children.

Many health problems can affect the reproductive system. They include sexually transmitted infections and cancers. The good news is that many reproductive health problems can be prevented or cured.

## Sexually Transmitted Infections

A sexually transmitted infection (STI) is a disease that spreads mainly through sexual contact. STIs are caused by pathogens that enter the body through the reproductive organs. Many STIs also spread through body fluids such as blood. For example, a shared tattoo needle is one way that some STIs can spread. Some STIs can also spread from a mother to her infant during birth.

### STI Myths and Facts

STIs are more common in teens and young adults than in older people. One reason is that young people are more likely to engage in risky behaviors. They also may not know how STIs spread. Instead, they may believe myths about STIs, like those in **Table** 22.1. Knowing the facts is important to prevent the spread of STIs.

**TABLE 22.1:** Myths and facts about sexually transmitted infections

| Myth | Fact |
|---|---|
| If you are sexually active with just one person, then you can't get STIs. | The only sure way to avoid getting STIs is to practice abstinence from sexual activity. |
| If you don't have any symptoms, then you don't have an STI. | Many STIs do not cause symptoms, especially in females. |
| Getting STIs is no big deal, because they can be cured with medicines. | Only some STIs can be cured with medicines; others cannot be cured. |

### Bacterial STIs

A number of STIs are caused by bacteria. Bacterial STIs can usually be cured with antibiotics. However, some people with bacterial STIs may not have symptoms so they fail to get treatment. Left untreated, these infections may damage reproductive organs and lead to an inability to have children.

Three bacterial STIs are chlamydia, gonorrhea, and syphilis.

- Chlamydia is the most common bacterial STI in the U.S. Females are more likely to develop it than males. Symptoms may include burning during urination and a discharge from the vagina or penis.
- Gonorrhea is another common bacterial STI. Symptoms may include painful urination and a discharge from the vagina or penis.
- Syphilis is a very serious STI but somewhat less common than chlamydia or gonorrhea. It usually begins with a small sore on the genitals. This is followed a few months later by a rash and flu-like symptoms. If syphilis isn't treated, it can eventually damage the heart, brain, and other organs and even cause death.

### Viral STIs

Several STIs are caused by viruses. Viral STIs can't be cured with antibiotics. Other drugs may help control the symptoms of viral STIs, but the infections usually last for life.

Three viral STIs are genital warts, genital herpes, and AIDS.

- Genital herpes is a common STI caused by a herpes virus. The virus causes painful blisters on the penis or near the vaginal opening. The blisters generally go away on their own, but they may return repeatedly throughout life. There is no cure for genital herpes, but medicines can help prevent or shorten outbreaks.
- Acquired Immunodeficiency Syndrome (AIDS) is caused by human immunodeficiency virus (HIV). HIV destroys lymphocytes that normally fight infections. AIDS develops if the number of lymphocytes drops to a very low level. People with AIDS come down with diseases—such as certain rare cancers—that almost never occur in people with a healthy immune system. Medicines can delay the progression of an HIV infection and may prevent AIDS from developing.
- Genital warts is an STI caused by human papilloma virus (HPV), which is pictured in **Figure** 22.15. This is one of the most common STIs in U.S. teens. Genital warts can't be cured, but a vaccine can prevent most HPV infections. The vaccine is recommended for boys and girls starting at 11 or 12 years of age. It's important to prevent HPV infections because they may lead to cancer later in life.

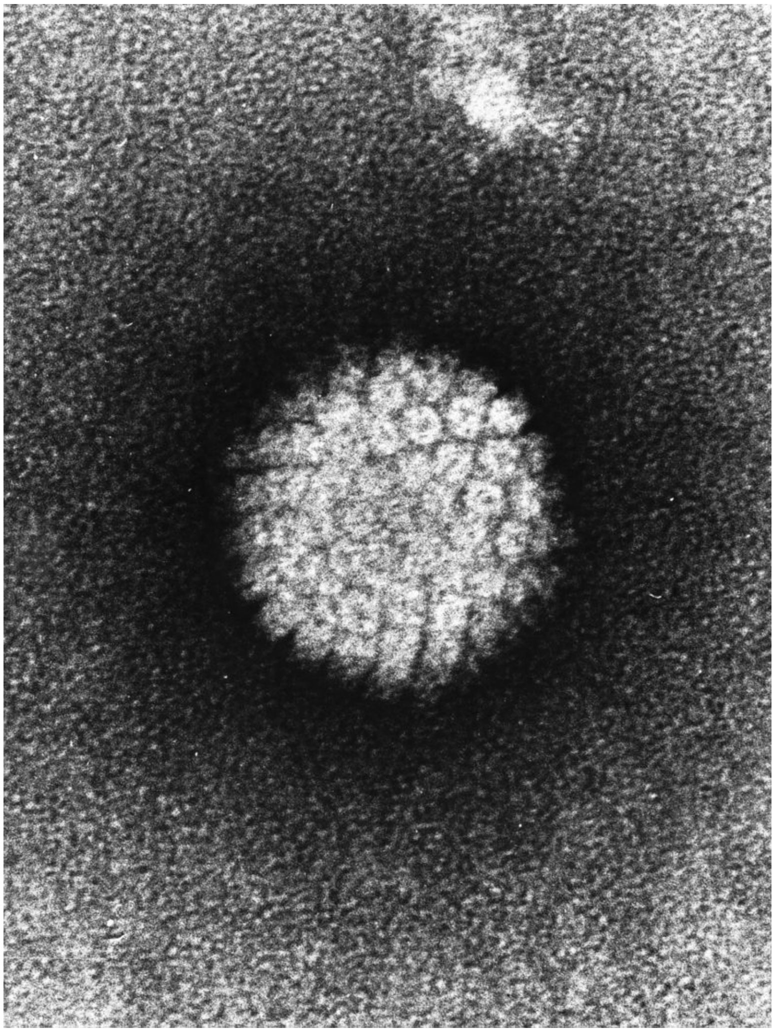

FIGURE 22.15
HPV, the virus that causes genital warts, may also cause cancer.

## Other Disorders of the Reproductive System

Other reproductive system disorders include injuries and noninfectious diseases. These are different in males and females.

### Male Reproductive System Disorders

Most common disorders of the male reproductive system involve the testes. They include injuries and cancer.

- Injuries to the testes are very common. In teens, such injuries occur most often while playing sports. Injuries to the testes are likely to be very painful and cause bruising and swelling. However, they generally subside fairly quickly.
- Cancer of the testes is most common in males aged 15 to 35. It occurs when cells in the testes grow out of control and form a tumor. If found early, cancer of the testes usually can be cured with surgery.

### Female Reproductive System Disorders

Disorders of the female reproductive system may involve the vagina, uterus, or ovaries. They may also affect the breasts.

- Vaginitis is a very common disorder. Symptoms include redness and itching of the vagina. It may be caused by soap or bubble bath. Another possible cause is a yeast infection. Yeast normally grow in the vagina. If they multiple too quickly, they may cause irritation. A yeast infection can be treated with medication.
- Cysts may develop in the ovaries. A cyst is a sac filled with fluid or other material. Ovarian cysts are usually harmless and often disappear on their own. However, some cysts may be painful and require surgery.
- Many females experience abdominal cramps during menstruation. This is usually normal and not a cause for concern. Exercise, heat, or medication may help relieve the pain. In severe cases, prescription medicine may be needed.
- Breast cancer is the most common type of cancer in females. It occurs when cells in the breast grow out of control and form a tumor. Breast cancer is rare in teens but becomes more common as females get older. Regular screening is recommended for most women starting around age 40. If found early, breast cancer usually can be cured with surgery.

## Keeping Your Reproductive System Healthy

Maintaining overall good health will help keep your reproductive system healthy. You should eat right, get regular exercise, and follow other healthy lifestyle behaviors. In addition, the following practices will help keep the reproductive system healthy:

- Keep the genitals clean. A daily shower or bath is all that's needed. Avoid harsh soaps or other personal hygiene products that may be irritating.
- Avoid risky behaviors. This includes contact with blood or dirty needles as well as sexual activity.
- If you are a girl and use tampons, be sure to change them every 4 to 6 hours. This will reduce your risk of toxic shock syndrome. This is a very dangerous condition that may occur if tampons are left in too long.
- If you are a boy, wear a protective cup if you play a contact sport. This will help protect the testes from injury. You should also learn how to check yourself for testicular cancer (see **Figure** 22.16). You can learn how by watching this video: http://www.today.com/video/today/53552792#53552792


MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/140772

## Lesson Summary

- A sexually transmitted infection (STI) is a disease that spreads mainly through sexual contact. STIs are more common in teens and young adults than in older people. Bacterial STIs include chlamydia, gonorrhea, and syphilis. Viral STIs include genital warts, genital herpes, and AIDS.

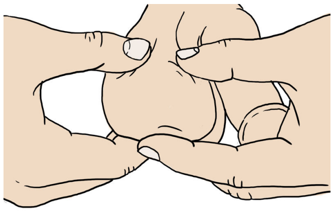

FIGURE 22.16

Teen boys should learn how to examine their testes for lumps that could be a sign of cancer.

- Other reproductive system disorders include injuries and noninfectious diseases such as cancer. These disorders are different in males and females.
- Maintaining overall good health, keeping the genitals clean, and avoiding risky behaviors are ways to keep the reproductive system healthy.

## Lesson Review Questions

### Recall

1. What is a sexually transmitted infection?
2. Identify some noninfectious reproductive system disorders.
3. List ways to keep the reproductive system healthy.

### Apply Concepts

4. How do you think myths about STIs contribute to their spread?

### Think Critically

5. Compare and contrast bacterial and viral STIs. Include examples of each type of STI.

## Points to Consider

Reproduction is important not only to families but also to planet Earth. Human reproduction has led to rapid growth of the human population.

1. How big is the human population?
2. Do you think that Earth is overpopulated when it comes to human beings?

# 22.5 References


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# Chapter 23 MS Introduction to Ecology

## Chapter Outline



The lake in this photo looks as though it might be completely lacking in life. Even its name—the Dead Sea—adds to that impression. Located far below sea level, the Dead Sea is much saltier than the ocean. It's too salty for fish, frogs, or other animals to survive. Yet even here, living things thrive. The bottom of the Dead Sea, for example, is carpeted with mats of microorganisms. How do they manage to live in these unusual conditions? How have they adapted to their extreme environment?

All organisms must adapt to their environment in order to survive. This is true whether they live in the highly salty water of the Dead Sea or in a lush tropical rainforest that is bursting with life. Most environments are not as extreme as the Dead Sea. But they all have conditions that require adaptations. In this chapter, you'll read about a wide variety of environments and the organisms that live in them.

# 23.1 What Is Ecology?

## Lesson Objectives

- Define ecology.
- Distinguish between biotic and abiotic factors in the environment.
- Outline levels of organization in ecology.

## Lesson Vocabulary

- abiotic factor
- biosphere
- biotic factor
- ecology

## Introduction

The science of how living things interact with each other and their environment is called ecology. Ecology is a major branch of life science, but it overlaps with many other fields. For example, it shares data and theories with geography, biology, climatology, and other sciences. In this lesson, you'll learn some of the basic concepts of ecology.

## Organisms and Environmental Factors

Organisms are individual living things. They range from microscopic bacteria to gigantic blue whales (see **Figure** 23.1). Despite their great diversity, all organisms have the same basic needs: energy and matter. Energy and matter must be obtained from the environment.

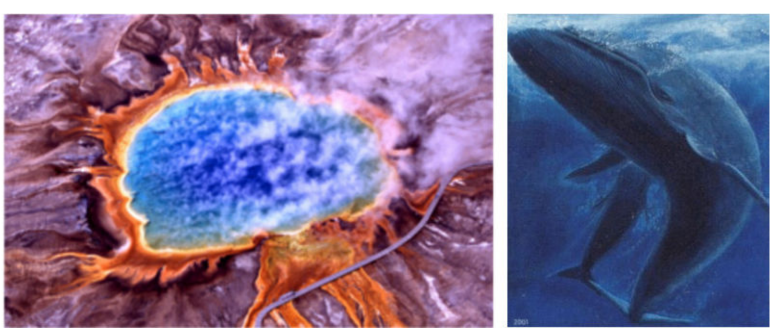


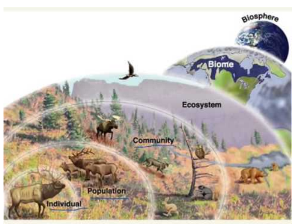
FIGURE 23.1
Organisms show tremendous diversity. Some of the smallest and largest living organisms are pictured here: billions of microorganisms that thrive in this hot spring give it its striking colors (left); blue whales are the largest living organisms (right).

Organisms depend on their environment to meet their needs, so they are greatly influenced by it. There are many factors in the environment that affect organisms. The factors can be classified as either biotic or abiotic.

- Biotic factors are all of the living or once-living aspects of the environment. They include all the organisms that live there as well as the remains of dead organisms.
- Abiotic factors are all of the aspects of the environment that have never been alive. They include factors such as sunlight, minerals in soil, temperature, and moisture.

## Levels of Organization in Ecology

Ecologists study organisms and environments at several different levels, from the individual to the biosphere. The levels are depicted in **Figure** 23.2 and described below. For a video introduction to the levels of organization in ecology, click on this link: http://www.youtube.com/watch?v=5FtlqU1DDK0 .

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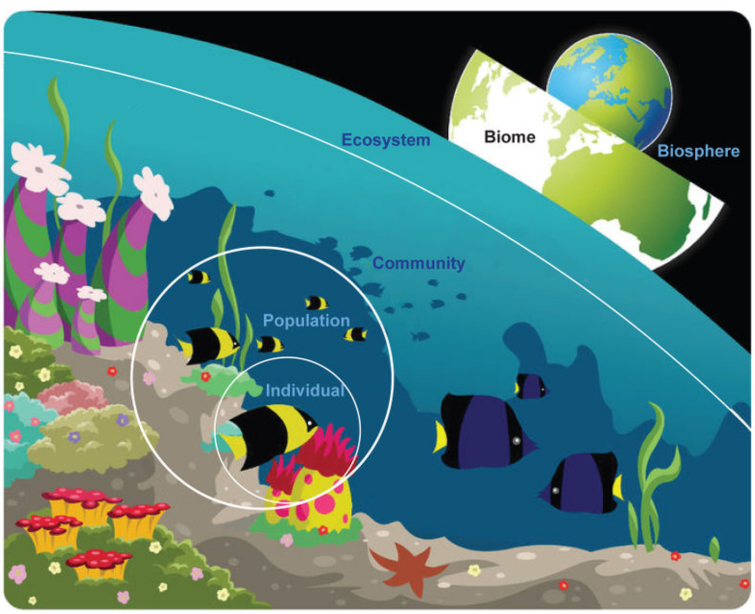



FIGURE 23.2
From individuals to the biosphere, ecology can be studied at several different levels.

- An individual is an organism, or single living thing.
- A population is a group of individuals of the same species that live in the same area. Members of the same population generally interact with each other.
- A community is made up of all the populations of all the species that live in the same area. Populations in a community also generally interact with each other.

- An ecosystem consists of all the biotic and abiotic factors in an area. It includes a community, the abiotic factors in the environment, and all their interactions.
- A biome is a group of similar ecosystems with the same general abiotic factors and primary producers. Biomes may be terrestrial (land-based) or aquatic (water-based).
- The biosphere consists of all the parts of Earth where life can be found. This is the highest level of organization in ecology. It includes all of the other levels below it. The biosphere consists of all the world's biomes, both terrestrial and aquatic.

## Lesson Summary

- Ecology is the science of how living things interact with each other and their environment.
- All organisms depend on their environment for energy and matter and are influenced by their environment. Factors in the environment that can affect organisms include biotic factors and abiotic factors.
- Ecologists study organisms and environments at several different levels. From smallest to largest, they include the individual, population, community, ecosystem, biome, and biosphere.

## Lesson Review Questions

### Recall

1. What is ecology?
2. Define the biosphere.

### Apply Concepts

3. Make an illustrated chart to show the different levels of organization in ecology.

### Think Critically

4. Explain why organisms depend on their environment.
5. Compare and contrast biotic and abiotic factors in the environment.

## Points to Consider

The population is an important level of organization in ecology. It is also the unit of microevolution.

1. What is a population?
2. How can a population grow?

# 23.2 Populations

## Lesson Objectives

- Define population.
- Identify measures of population size, growth, and structure.
- Describe how the human population grew in the past and is predicted to grow in the future.

## Lesson Vocabulary

- age-sex structure
- carrying capacity
- demographic transition
- exponential growth
- logistic growth
- population density
- population distribution
- population growth rate
- population pyramid

## Introduction

A population is a group of individuals of the same species that live in the same area. The population is the unit of natural selection, adaptation, and microevolution. In ecology, how large a population is and how quickly it is growing are often used as measures of a species' health.

## Population Size, Growth, and Structure

Population size is the number of individuals in a population. Population size influences the chances of a species surviving or going extinct. If a species' populations become very small, the species may be at risk of going extinct.

### Population Density and Distribution

Another sign of a species' state of health is the density of its populations. Population density is the average number of individuals in a population for a given area. Density is a measure of how crowded or spread out the individuals in a population are on average. For example, a population of 100 deer that live in an area of 10 square kilometers has a population density of 10 deer per square kilometer.

Population density is an average measure. Often, individuals in a population are not spread out evenly. Instead, they may live in clumps or some other pattern. How individuals in a population are distributed, or spread throughout their area, is called population distribution. You can see different patterns of population distribution in **Figure** 23.3. Different patterns characterize different species and types of environments, as you can read in the figure.

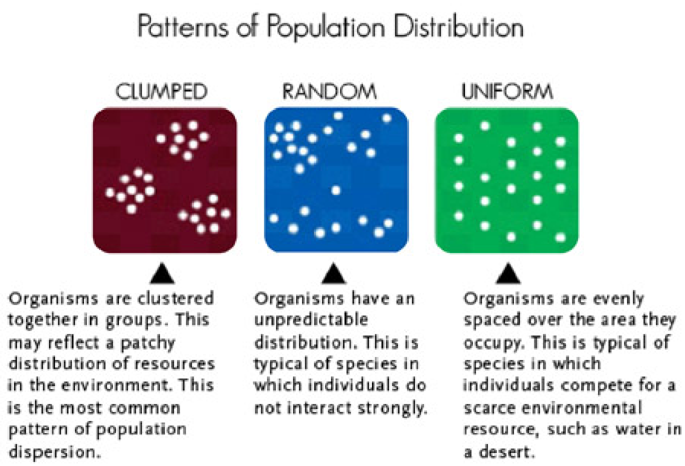



FIGURE 23.3

Patterns of population distribution include clumped, random, and uniform distributions. Each pattern is associated with different types of species or environments.

### Population Growth

Whether its populations are growing or shrinking in size may be another indicator of a species' health. Individuals may be added to a population through births and the migration of individuals into the population. Individuals may be lost from a population through deaths and the migration of individuals out of the population.

The population growth rate is how quickly a population changes in size over time. The rate of growth of a population may be positive or negative. A positive growth rate means that the population is increasing in size because more people are being added than lost. A negative growth rate means that the population is decreasing in size because more people are being lost than added.

Populations may show different patterns of growth. The growth pattern depends partly on the conditions under which a population lives. Two common growth patterns are exponential growth and logistic growth. Both are represented in **Figure** 23.4.

- With exponential growth, the population starts out growing slowly. As population size increases, the growth rate also increases. The larger the population becomes, the more quickly it grows. This type of growth generally occurs only when a population is living under ideal conditions. However, it can't continue for very long.
- With logistic growth, the population starts out growing slowly, and then the rate of growth increases—but only to a point. The rate of growth tapers off as the population size approaches its carrying capacity. Carrying capacity is the largest population size that can be supported in an area without harming the environment. This type of growth characterizes many populations.

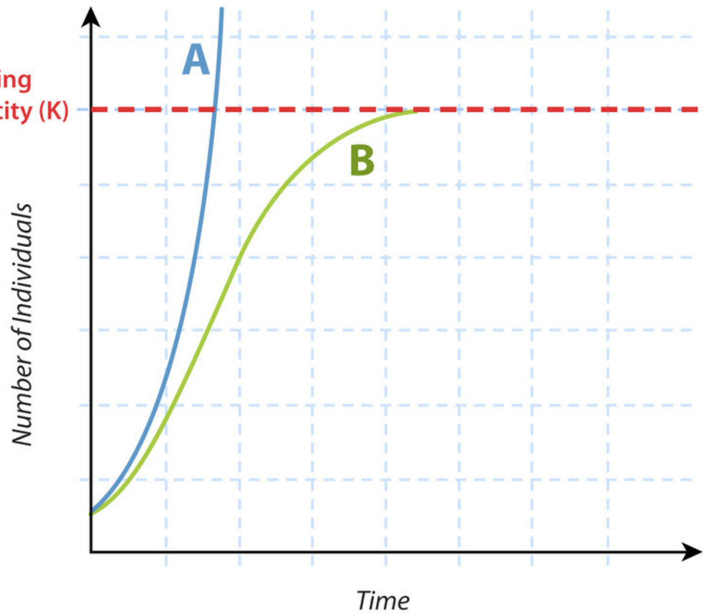
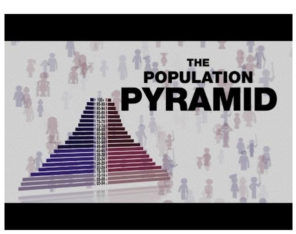



FIGURE 23.4
Curve A represents exponential population growth. Curve B represents logistic population growth.

### Population Age and Sex Structure

Another way of describing a population is its age-sex structure. This refers to the numbers of individuals of each sex and age in the population. The age-sex structure of a population may influence the population growth rate. This is because only individuals of certain ages are able to reproduce, and because individuals of certain ages may be more likely to die. For example, if there are many individuals of reproductive age, there are likely to be many births, causing the population to grow rapidly.

The age-sex structure of a population is often represented with a special bar graph called a population pyramid. You can see an example of a population pyramid in **Figure** 23.5. The graph in the figure actually has a pyramid shape because the bars become narrower from younger to older ages. However, this is not always the case. In some populations, for example, there may be more people at older than younger ages, resulting in a top-heavy population pyramid. Learn more about population pyramids and what you can learn from them, watch this TED video: http://www.youtube.com/watch?v=RLmKfXwWQtE .

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## The Human Population

Human beings have been called the most successful weed species on Earth. Like garden weeds, populations of human beings grow quickly and disperse rapidly. Human beings have colonized almost every terrestrial part of the planet. Overall, the human population has had a pattern of exponential growth, as you can see in **Figure** 23.6. The early human population grew very slowly. However, as the population grew larger, it started to grow more rapidly.

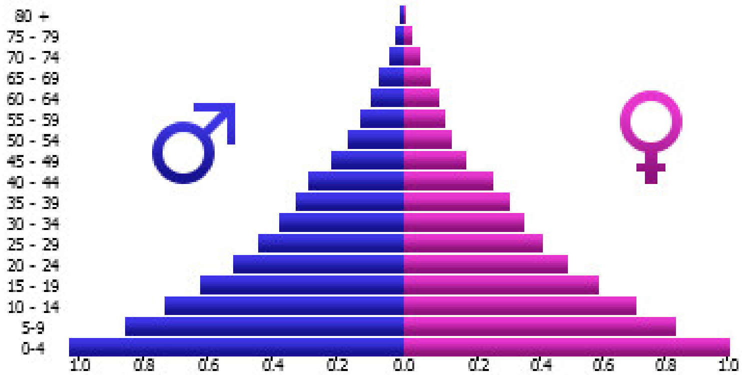


FIGURE 23.5
A population pyramid shows the age-sex structure of a population. This population pyramid represents the human population of the African country of Angola in 2005.

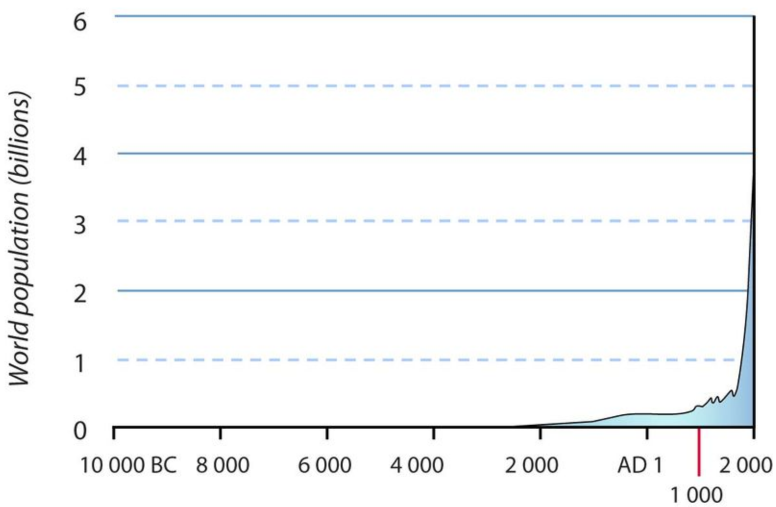


FIGURE 23.6
Growth of the Human Population.

## Early Population Growth

The earliest members of the human species evolved around 200,000 years ago in Africa. Early humans lived in small populations of nomadic hunters and gatherers. Human beings remained in Africa until about 40,000 years ago. After that, they spread throughout Europe, Asia, and Australia. By 10,000 years ago, the first human beings colonized the Americas. During this long period of time, the total number of human beings increased very slowly. Birth rates were fairly high but so were death rates, producing low rates of population growth.

Human beings invented agriculture about 10,000 years ago. This provided a bigger, more dependable food supply. It also allowed people to settle down in villages and cities for the first time. Birth rates went up because there was more food and settled life had other advantages. Death rates also rose because of crowded living conditions and diseases that spread from domestic animals. Because the higher birth rates were matched by higher death rates, the human population continued to grow very slowly.

## Demographic Transition

Major changes in the human population first began in the 1700s. These changes occurred mainly in Europe, North America, and a few other places that became industrialized. First death rates fell. Then, somewhat later, birth rates also fell. These changes in death and birth rates affected the rate of population growth and are referred to as the demographic transition. The graph in **Figure** 23.7 shows the stages in which the demographic transition occurred. You can learn more about the stages by watching this video: http://education-portal.com/academy/lesson/what-is-demographic-transition-definition-stages.html

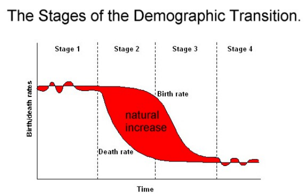


FIGURE 23.7
The demographic transition occurred in the stages shown in this graph.

In Stage 1, both birth and death rates were high so population growth was slow. In Stage 2, death rates fell while birth rates remained high. Why did death rates fall? There were several reasons, including new scientific knowledge of the causes of disease. Water supplies were cleaned up and sewage was disposed of more safely. Better farming techniques and machines increased the food supply and the distribution of food. For all these reasons, death rates fell, especially in children. Birth rates, on the other hand, remained high. This resulted in faster population growth.

Before long, birth rates also started to fall. People started having fewer children because large families became too expensive. For example, with better farming machines, farm families no longer needed as many children to work in the fields. Laws were also passed that required children to go to school. They could no longer work and help support the family. Having many children became too costly. Eventually, birth rates fell to match death rates (Stage 4). As a result, population growth slowed down.

### Recent Population Growth

Just as they did in Europe and North America, death rates have fallen throughout the world. No country today remains in Stage 1 of the demographic transition. However, birth rates are still high in many of the poorest countries of the world. These populations seem to be stuck in Stage 2 or 3 of the demographic transition. They have high population growth rates because low death rates are not matched by equally low birth rates. Whether these populations will ever enter Stage 4 and attain very low rates of population growth is uncertain.

### Future Population Growth

As of 2014, there were more than 7 billion human beings on planet Earth. That number is increasing rapidly. More than 200,000 people are added to the human population each day! At this rate, the human population will pass 9 billion by 2050.

Many experts think that the human population has reached its carrying capacity. It has already harmed the environment. An even larger human population may cause severe environmental problems. It could also lead to devastating outbreaks of disease, starvation, and war. To solve these problems, two approaches may be needed:

- Slow down human population growth so there are fewer people.
- Distribute Earth's resources more fairly so that everyone has enough.

Hopefully, we will act before it's too late. Otherwise, the planet may be ruined for future generations of human beings and other species.

## Lesson Summary

- A population is a group of individuals of the same species that live in the same area.
- Populations can be described in terms of size, density, and distribution. Population growth may be exponential or logistic. The age-sex structure of a population affects the rate of population growth.
- The world's human population has shown exponential growth. It grew very slowly for tens of thousands of years. Then it started growing very rapidly as many populations reached and remained in Stage 2 or 3 of the demographic transition. At the current rate of growth, the human population is predicted to pass 9 billion by 2050.

## Lesson Review Questions

### Recall

1. Define population.
2. What is a population pyramid?
3. What are some changes that caused the original demographic transition?

### Apply Concepts

4. Describe the growth of a population that in a given year has 10 births, 8 deaths, and no migration.
5. If the human population reaches predicted levels by 2050, how do you think this may affect the environment?

### Think Critically

6. Compare and contrast the concepts of population density and population distribution.
7. Relate carrying capacity to logistic growth of a population.

## Points to Consider

A population doesn't exist alone. It is part of a community.

1. What is a community?
2. How might populations in a community interact?

# 23.3 Communities

## Lesson Objectives

- Define community.
- Explain how predation affects predator and prey populations.
- Describe outcomes of intraspecific and interspecific competition.
- Identify three types of symbiotic relationships.

## Lesson Vocabulary

- commensalism
- community
- competition
- host
- keystone species
- mutualism
- parasite
- parasitism
- predation
- predator
- prey
- symbiosis

## Introduction

A community is the biotic component of an ecosystem. It consists of the populations of all the species that live in the same area. Populations in communities often interact with each other. Community interactions are important factors in natural selection. They help shape the evolution of the interacting species. Types of community interactions include predation, competition, and symbiosis. You'll read about each type of interaction in this lesson.

## Predation

Predation is a relationship in which members of one species consume members of another species. The consuming species is called the predator. The species that is consumed is called the prey. In **Figure** 23.8, the wolves are predators, and the moose is their prey.

FIGURE 23.8
Pack of wolves preying on a moose

### Predator and Prey Populations

A predator-prey relationship tends to keep the populations of both species in balance. Look at the graph in **Figure** 23.9. As the prey population increases, there is more food for the predators. So after a slight lag time, the predator population also increases. As the number of predators increases, more prey are captured. This causes the prey population to decrease, followed by the predator population decreasing again.

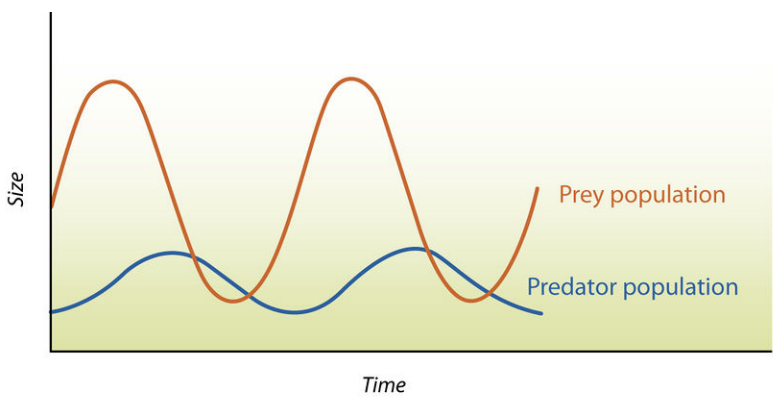


FIGURE 23.9
Predator-Prey populations.

### Keystone Species

Some predator species play a special role in their community. They are called keystone species. When the population size of a keystone species changes, the populations of many other species are affected. Prairie dogs, pictured in **Figure** 23.10, are an example of a keystone species. Their numbers affect most of the other species in their community. Prairie dog actions improve the quality of soil and water for plants, upon which most other species in the community depend.

### Adaptations to Predation

Both predators and prey have adaptations to predation that evolve through natural selection. Predator adaptations help them capture prey. Prey adaptations help them avoid predators. A common adaptation in both predator and prey species is camouflage. You can see an example in **Figure** 23.11. You can also see some amazing examples in

FIGURE 23.10
Prairie dogs are a keystone species in their community.

this video: http://www.ted.com/talks/david_gallo_shows_underwater_astonishments?language=en


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FIGURE 23.11
There is a well-camouflaged frog in this photo. Do you see it?

## Competition

Competition is a relationship between organisms that depend on the same resources. The resources might be food, water, or space. Competition can occur between organisms of the same species or between organisms of different species.

- Competition within a species is called intraspecific competition. It leads to natural selection within the species, so the species becomes better adapted to its environment.

- Competition between different species is called interspecific competition. It might lead to the less well-adapted species going extinct. Or it might lead to one or both species evolving specialized adaptations. For example, competing species might evolve adaptations that allow them to use different food sources. You can see an example in **Figure** 23.12.

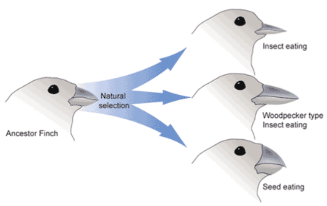



FIGURE 23.12
These species of birds have evolved different types of beaks to exploit different food sources. This allows them to live in the same area without competing for food.

## Symbiosis

Symbiosis is a close relationship between two species in which at least one species benefits. For the other species, the relationship may be beneficial, harmful, or neutral. There are three types of symbiosis: mutualism, parasitism, and commensalism.

### Mutualism

Mutualism is a symbiotic relationship in which both species benefit. An example of mutualism is pictured in **Figure** 23.13. The clownfish in the photo is hiding among the tentacles of a sea anemone. The tentacles have stingers that can inject poison in the anemone's prey. The clownfish is protected from the stingers by mucus that covers its body.

How do the two species benefit from their close relationship? The anemone provides the clownfish with a safe place to live by keeping away predatory fish. The clownfish also feeds on the remains of the anemone's prey. In return, the clownfish helps the anemone catch food by attracting prey with its bright colors. Its feces also provide nutrients to the anemone.

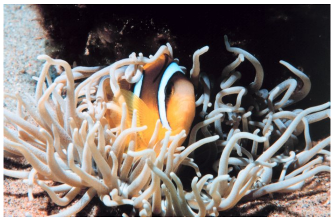


FIGURE 23.13
A clownfish takes refuge among the tentacles of a sea anemone.

### Parasitism

Parasitism is a symbiotic relationship in which one species benefits and the other species is harmed. The species that benefits is called the parasite. The species that is harmed is called the host. Many species of animals are parasites, at least during some stage of their life cycle. Most animal species are also hosts to one or more parasites.

A parasite generally lives in or on its host. An example of a parasite that lives in its host is the hookworm. **Figure** 23.14 shows two hookworms living inside a human host's intestines. The hookworms obtain nutrients and shelter from their host, which is harmed by the loss of nutrients and blood.

Some parasites kill their host, but most do not. It's easy to see why. If a parasite kills its host, the parasite may also die. Instead, parasites usually cause relatively minor damage to their host.

FIGURE 23.14
Hookworm parasites inside their human host's intestines

### Commensalism

Commensalism is a symbiotic relationship in which one species benefits while the other species is not affected. An example is the relationship between birds called cattle egrets and cattle (see **Figure** 23.15). Cattle egrets feed on insects. They follow cattle herds around to take advantage of the insects stirred up by the feet of the cattle. The egrets get ready access to food from the relationship, whereas the cattle are not affected.

FIGURE 23.15
A cattle egret "hangs out" near cattle to catch insects stirred up by the cattle's feet.

## Lesson Summary

- A community is the biotic component of an ecosystem. It consists of the populations of all the species that live in the same area.
- Predation is a relationship in which members of one species, called the predator, consume members of another species, called the prey.
- Competition is a relationship between organisms that depend on the same resources. Competition can occur between members of the same species or between members of different species.
- Symbiosis is a close relationship between two species in which at least one species benefits. Types of symbiosis include mutualism, parasitism, and commensalism.

## Lesson Review Questions

### Recall

1. Define community.
2. Describe two potential outcomes of interspecific competition.
3. Identify three types of symbiosis.

### Apply Concepts

4. After a rainy summer and excessive weed growth, a population of mice has doubled in size because of a greater food supply. The main predators of the mice are owls. Predict how the owl population in the same community is likely to change.

### Think Critically

5. Explain how camouflage could benefit both predator and prey species.
6. Why do parasites usually not kill their host?

## Points to Consider

A community is the biotic component of an ecosystem.

1. What is an ecosystem?
2. What are some examples of ecosystems?

# 23.4 Ecosystems

## Lesson Objectives

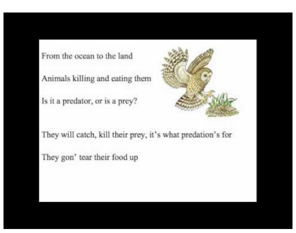
- Define ecosystem.
- Describe the role of energy and matter in ecosystems.
- Define niche and habitat, and explain the competitive exclusion principle.

## Lesson Vocabulary

- competitive exclusion principle
- ecosystem
- habitat
- niche

## Introduction

The focus of study in ecology is often the ecosystem. Ecosystems are units of nature. Each ecosystem consists of all the biotic and abiotic factors in an area and all the ways in which the factors interact. A forest could be an ecosystem, but so could a dead log on the forest floor. Both the forest and the log contain a community of species that interact with each other and with abiotic factors. For an entertaining introduction to ecosystems, watch this great music video: http://www.youtube.com/watch?v=GUY_-LK_lOc .

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## Energy and Matter in Ecosystems

Ecosystems need a constant input of energy to supply the needs of their organisms. Most ecosystems get energy from sunlight. A few ecosystems get energy from chemical compounds.

Unlike energy, matter doesn't need to be constantly added to ecosystems. Instead, matter is recycled through ecosystems. Water and elements such as carbon and nitrogen that living things need are used over and over again.

## Key Ecosystem Concepts

Two important concepts associated with the ecosystem are niche and habitat.

### Niche

Niche is the role that a particular species plays in its ecosystem. This role includes all the ways that the species interacts with the biotic and abiotic factors in the ecosystem.

A major aspect of any niche is how the species obtains energy and matter. Look at **Figure** 23.16. The grass in the figure obtains energy from sunlight and uses it to convert carbon dioxide and water to sugar by photosynthesis. The deer in the figure gets matter and energy by consuming and digesting the grass. Each species has a different and distinctive niche.

FIGURE 23.16
The grass and deer fill two different niches in an ecosystem.

### Habitat

Another important aspect of a species' niche is its habitat. Habitat is the physical environment in which a species lives and to which it has adapted. Features of a habitat depend mainly on abiotic factors, such as temperature and rainfall. These factors influence the traits of the organisms that live there.

### Just One Species Please!

A given habitat may contain many different species. However, each species in the same habitat must have a different niche. Two different species cannot occupy the same niche in the same habitat at the same time. This is called the competitive exclusion principle.

What do you think would happen if two species were to occupy the same niche in the same habitat? The two species would compete for everything they needed in the environment. One species might outcompete and replace the other. Or, both species might evolve different specializations so they can fill slightly different niches.

## Lesson Summary

- An ecosystem is a unit of nature. It consists of all the biotic and abiotic factors in an area and all the ways in which they interact.
- Ecosystems need a constant input of energy for their organisms, but matter is recycled through ecosystems.

- Niche is the role that a particular species plays in its ecosystem. Habitat is the physical environment in which a species lives and to which it has adapted. According to the competitive exclusion principle, two different species cannot occupy the same niche in the same habitat at the same time.

## Lesson Review Questions

### Recall

1. What is an ecosystem?
2. Define niche.

### Apply Concepts

3. Two different species of birds live in the same habitat and eat the same foods. What can you conclude about the niches of the two species?

### Think Critically

4. Relate the competitive exclusion principle to the concepts of niche, habitat, and competition.

## Points to Consider

Similar ecosystems are found in different parts of the world. For example, forests and deserts are found on almost all of Earth's continents.

1. What factors do you think determine where a particular terrestrial ecosystem is found?
2. Think about your own ecosystem. Where else in the world might a similar ecosystem be found?

# 23.5 Biomes

## Lesson Objectives

- Define biome.
- Explain how climate affects terrestrial biomes, and give examples of terrestrial biomes.
- Identify freshwater and marine biomes and relate them to sunlight and nutrients.

## Lesson Vocabulary

- aphotic zone
- aquatic biome
- biome
- climate
- freshwater biome
- marine biome
- photic zone
- terrestrial biome

## Introduction

Look at the two photos in **Figure** 23.17. The left photo shows a forest in South Carolina. The right photo shows Death Valley, a desert in California. Both places are found at about the same latitude, or distance from the equator. However, in many other ways, the two places could hardly be more different. What explains the differences? The South Carolina forest is near an ocean, giving it a wet climate. Death Valley is the rain shadow of mountains, giving it a very dry climate.

FIGURE 23.17
Two locations in the US at about 35 degrees North latitude: South Carolina forest (left) and California desert (right).

The two photos in **Figure** 23.17 represent two different biomes. A biome is a group of similar ecosystems with the same general abiotic factors and primary producers. Producers are organisms that produce food for themselves and other organisms. Biomes may be terrestrial or aquatic.

## Terrestrial Biomes

Terrestrial biomes are land-based biomes. They range from arctic tundra to tropical rainforests. **Figure** 23.18 shows the locations of the world's major terrestrial biomes.

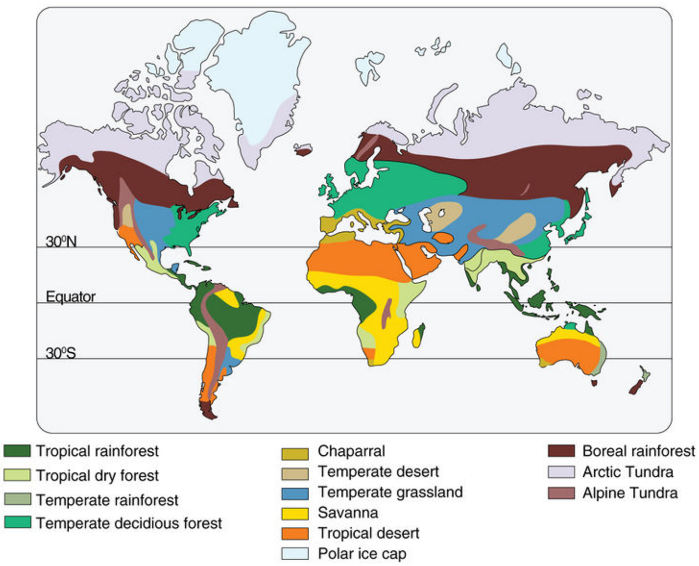


FIGURE 23.18
Major terrestrial biomes

### Terrestrial Biomes and Climate

Plants are the primary producers in terrestrial biomes. They make food for themselves and other organisms by photosynthesis. The major plants in a given biome, in turn, help determine the types of animals and other organisms that can live there.

Which plants grow in a given biome depends mainly on climate. Climate is the average weather in a place over a long period of time. The major climatic factors affecting plant growth are temperature and moisture.

### Examples of Terrestrial Biomes

You can read about three different terrestrial biomes in **Figure** 23.19: tropical rainforest, temperate grassland, and tundra. You can learn more about these and other terrestrial biomes by watching this video: http://www.youtube.com/watch?v=dTaWsFct32g .

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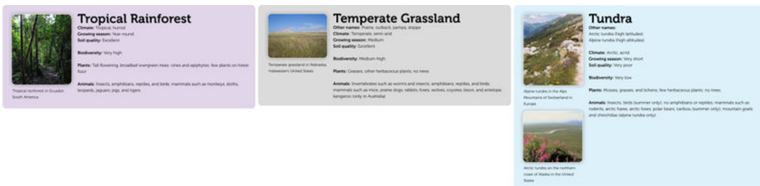


FIGURE 23.19

Terrestrial biomes include tropical rainforest, temperate grassland, and tundra.

## Aquatic Biomes

Aquatic biomes are water-based biomes. They include both freshwater biomes, such as rivers and lakes, and marine biomes, which are salt-water biomes in the ocean. The primary producers in most aquatic biomes are phytoplankton. Phytoplankton consist of microscopic bacteria and tiny algae that make food by photosynthesis. Unlike terrestrial biomes, which are determined mainly by temperature and moisture, aquatic biomes are determined mainly by sunlight and dissolved substances in the water. These factors, in turn, depend mainly on depth of water and distance from shore.

### Aquatic Biomes and Sunlight

Only the top 200 meters or so of water receive enough sunlight for photosynthesis. This part of the water is called the photic zone. Below 200 meters, there is too little sunlight for photosynthesis to take place. This part of the water is called the aphotic zone. In this zone, food must come from other sources. It may be made by chemosynthesis, in which microorganisms use energy in chemicals instead of sunlight to make food. Or, food may drift down from the water above.

### Aquatic Biomes and Dissolved Substances

In addition to sunlight, aquatic producers also need dissolved oxygen and nutrients. Water near the surface generally contains more dissolved oxygen than deeper water. Many nutrients enter the water from the land. Therefore, water nearer shore usually contains more dissolved nutrients than water farther from shore.

### Freshwater Zones

A lake is an example of a freshwater biome. Water in a lake generally forms three different zones based on water depth and distance from shore.

- The shallow water near the shore is called the littoral zone. It has diverse community of organisms. There is adequate light for photosynthesis and plenty of dissolved oxygen and nutrients. Producers include algae and aquatic plants (see **Figure** 23.20). Animals in this zone may include insects, crustaceans, fish, and turtles.

- The top layer of water farther from shore is called the limnetic zone. There is enough light for photosynthesis and plenty of dissolved oxygen. However, dissolved nutrients tend not to be as plentiful as they are in the littoral zone. Producers here are mainly phytoplankton. A variety of zooplankton and fish also occupy this zone.
- The deeper water of a lake makes up the profundal zone. There isn't enough light for photosynthesis in this zone, so most organisms here eat dead organisms that drift down from the water above. Organisms in the profundal zone may include clams, snails, and some species of fish.

FIGURE 23.20
Plants and algae are producers in the littoral zone along the shore of this lake in Iceland.

### Ocean Zones

Zones in the oceans include the intertidal, pelagic, and benthic zones. The types of organisms found in these ocean zones are also determined by such factors as depth of water and distance from shore, among other factors.

One of the most familiar ocean zones is the intertidal zone. This is the narrow strip along a coastline that is covered by water at high tide and exposed to air at low tide. You can see an example of an intertidal zone in **Figure** 23.21. There are plenty of nutrients and sunlight in the intertidal zone. Producers here include phytoplankton and algae. Other organisms include barnacles, snails, crabs, and mussels. They must have adaptations for the constantly changing conditions in this zone.

FIGURE 23.21
Intertidal zone along the North Sea in the Netherlands

Other ocean zones are farther from shore in the open ocean. All the water in the open ocean is called the pelagic zone. It is further divided by depth:

- The top 200 meters of water is the photic zone. Producers here include seaweeds and phytoplankton. Other organisms are plentiful. They include zooplankton and animals such as fish, whales, and dolphins.

- Below 200 meters is the aphotic zone. There are no primary producers here because there isn't enough sunlight for photosynthesis. However, the water may be rich in nutrients because of dead organisms drifting down from above. Organisms that live here may include bacteria, sponges, sea anemones, worms, sea stars, and fish.
- The bottom of the ocean is called the benthic zone. It includes the sediments on the bottom of the ocean and the water just above it. Organisms living in this zone include clams and crabs. They may be few in number due to relatively scarce nutrients in this zone.
- There are many more organisms around deep-sea vents. Microorganisms use chemicals that pour out of the vents to make food by chemosynthesis. These producers support large numbers of other organisms, including crustaceans and red tubeworms like those pictured in **Figure** 23.22.

FIGURE 23.22
Ocean vent biome

## Lesson Summary

- A biome is a group of similar ecosystems with the same general abiotic factors and primary producers.
- Terrestrial biomes are determined mainly by temperature and moisture. Plants are the primary producers. Examples of terrestrial biomes include tropical rainforests, temperate grasslands, and tundra.
- Aquatic biomes are determined mainly by depth of water and distance from shore. They include freshwater and marine biomes.

## Lesson Review Questions

### Recall

1. What is a biome?
2. Identify three terrestrial biomes.
3. Describe the intertidal zone.

### Apply Concepts

4. Randomly choose a location on the map in **Figure** 23.18. Identify its biome and then research that biome to find out what plants and animals you might find there.

### Think Critically

5. Explain the relationship between climate and terrestrial biomes.
6. Compare and contrast the photic and aphotic zones of a body of water.

## Points to Consider

In all biomes, ecosystems need a constant input of energy. Matter, on the other hand, is constantly recycled in ecosystems.

1. Where do most ecosystems get energy?
2. What are some examples of cycles of matter?

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# Chapter 24 MS Ecosystem Dynamics

## Chapter Outline



Sunlight strikes the leaves of this plant. The leaves are like tiny factories. They use the energy in sunlight to manufacture food. Light from the sun is the driving force behind photosynthesis and most of the planet's ecosystems.

# 24.1 Flow of Energy

## Lesson Objectives

- Explain how living things are classified based on the way they obtain energy.
- Show how food chains and food webs model the flow of energy through ecosystems.
- Identify trophic levels, and state how they are related to energy and biomass.

## Lesson Vocabulary

- biomass
- chemoautotroph
- chemosynthesis
- consumer
- decomposer
- detritivore
- food chain
- food web
- photoautotroph
- producer
- saprotroph
- scavenger
- trophic level

## Introduction

Energy is the ability to change or move matter. All living things need energy. They need energy for everything they do, whether it is to move long distances or simply to carry out basic biochemical processes inside cells. Energy enters most ecosystems in the form of sunlight. In a few ecosystems, energy enters in the form of chemical compounds. All ecosystems need a constant input of energy in one of these two forms.

## Types of Organisms and Energy

Living things can be classified based on how they obtain energy. Some use the energy in sunlight or chemical compounds directly to make food. Some get energy indirectly by consuming other organisms, either living or dead.

### Producers

Producers are living things that produce food for themselves and other organisms. They use energy and simple inorganic molecules to make organic compounds. Producers are vital to all ecosystems because all organisms need organic compounds for energy.

Producers are also called autotrophs. There are two basic types of autotrophs: photoautotrophs and chemoautotrophs.

- Photoautotrophs use energy in sunlight to make organic compounds by photosynthesis. They include plants, algae, and some bacteria (see **Figure** 24.1).
- Chemoautotrophs use energy in chemical compounds to make organic compounds. This process is called chemosynthesis. Chemoautotrophs include certain bacteria and archaea.

FIGURE 24.1
The green streaks in this brilliant blue Guatemalan lake are billions of photosynthetic bacteria.

### Consumers

Consumers are organisms that depend on other living things for food. They take in organic compounds by eating or absorbing other living things. Consumers include all animals and fungi. They also include some bacteria and protists.

Consumers are also called heterotrophs. There are several different types of heterotrophs depending on exactly what they consume. They may be herbivores, carnivores, or omnivores.

- Herbivores are heterotrophs that consume producers such as plants or algae. Examples include rabbits and snails.
- Carnivores are heterotrophs that consume animals. Examples include lions and frogs.
- Omnivores are heterotrophs that consume both plants and animals. They include crows and human beings. The grizzly bears pictured in **Figure** 24.2 are also omnivores.

### Decomposers

Decomposers are heterotrophs that break down the wastes of other organisms or the remains of dead organisms. When they do, they release simple inorganic molecules back into the environment. Producers can then use the

FIGURE 24.2
Grizzly bears eat both plant and animal foods, including grasses, berries, fish, and clams.

inorganic molecules to make new organic compounds. For this reason, decomposers are essential to every ecosystem. Imagine what would happen if there were no decomposers. Organic wastes and dead organisms would pile up everywhere, and their nutrients would no longer be recycled.

Decomposers are classified by the type of organic matter they break down. They may be scavengers, detritivores, or saprotrophs.

- Scavengers are decomposers that consume the soft tissues of dead animals. Examples of scavengers include hyenas and cockroaches.
- Detritivores are decomposers that consume dead leaves, animal feces, and other organic debris that collects on the ground or at the bottom of a body of water. Examples of detritivores include earthworms and catfish. You can see another example in **Figure** 24.3.
- Saprotrophs are decomposers that feed on any remaining organic matter that is left after other decomposers do their work. Examples of saprotrophs include fungi and protozoa.

FIGURE 24.3
These dung beetles are detritivores. They are feasting on a pile of horse dung (feces).

## Modeling the Flow of Energy

Energy flows through ecosystems from producers, to consumers, to decomposers. Food chains and food webs are diagrams that model this flow of energy. They represent feeding relationships by showing who eats whom.

## Food Chains

A food chain is a diagram that represents a single pathway through which energy flows through an ecosystem. Food chains are generally simpler than what really happens in nature. That's because most organisms consume and are consumed by more than one species. You can see examples of terrestrial and aquatic food chains in **Figure** 24.4. See if you can construct a food chain of each type by playing the animation at this link: http://www.ecokids.ca/pub/eco_info/topics/frogs/chain_reaction/play_chainreaction.cfm

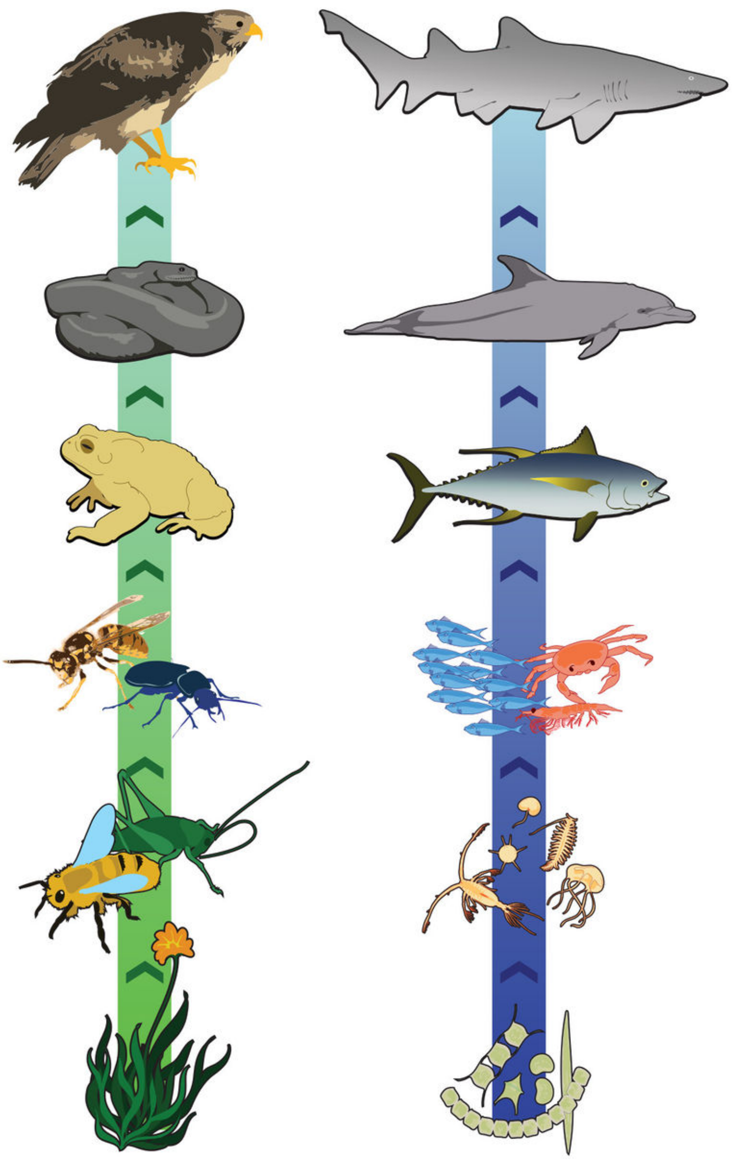


FIGURE 24.4
Terrestrial (left) and aquatic (right) food chains

## Food Webs

A food web is a diagram that represents many pathways through which energy flows through an ecosystem. It includes a number of intersecting food chains. Food webs are generally more similar to what really happens in nature. They show that most organisms consume and are consumed by multiple species. You can see an example of a food web in **Figure** 24.5.

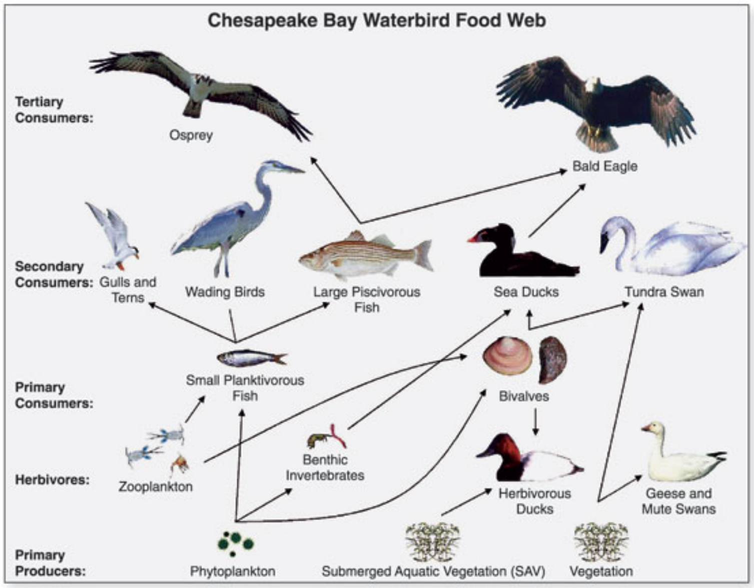



FIGURE 24.5
Food web showing trophic levels

## Trophic Levels

Each food chain or food web has organisms at different trophic levels. A trophic level is a feeding position in a food chain or web. The trophic levels are identified in the food web in **Figure** 24.5. All food chains and webs have at least two or three trophic levels, but they rarely have more than four trophic levels. The trophic levels are:

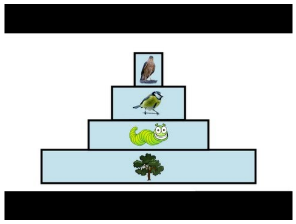
1. Trophic level 1 = producers that make their own food
2. Trophic level 2 = primary consumers that eat producers
3. Trophic level 3 = secondary consumers that eat primary consumers
4. Trophic level 4 = tertiary consumers that eat secondary consumers

Many consumers feed at more than one trophic level. For example, the bivalves in **Figure** 24.5 eat both producers and primary consumers. Therefore, they feed at trophic levels 2 and 3.

### Trophic Levels and Energy

Energy is passed up a food chain or web from lower to higher trophic levels. However, only about 10 percent of the energy at one level is passed up the next level. This is represented by the ecological pyramid in **Figure** 24.6. The other 90 percent of energy at each trophic level is used for metabolic processes or given off to the environment as heat. This loss of energy explains why there are rarely more than four trophic levels in a food chain or web. There isn't enough energy left to support additional levels. It also explains why ecosystems need a constant input of energy.

You can learn more about ecological pyramids in this video: http://www.youtube.com/watch?v=wGfOoRrICto .



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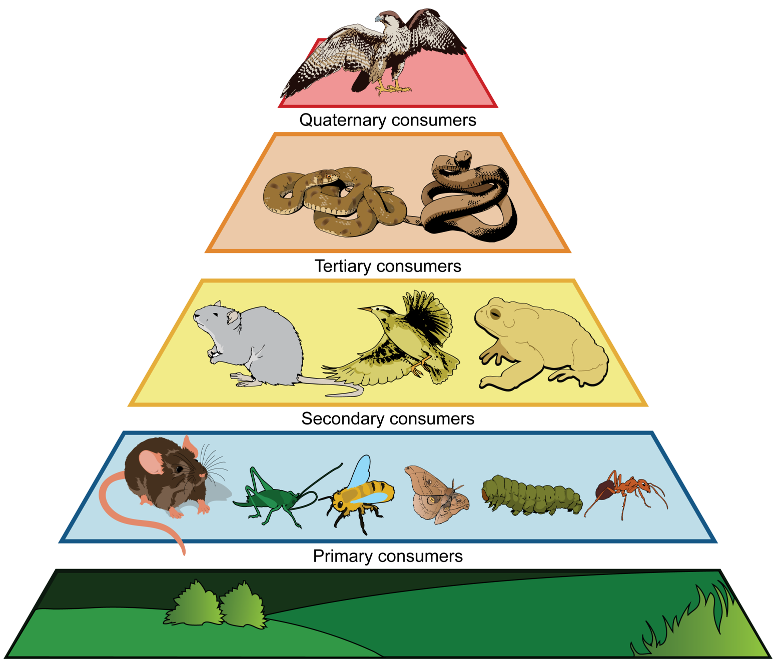


FIGURE 24.6

This ecological pyramid shows how energy and biomass decrease from lower to higher trophic levels.

### Trophic Levels and Biomass

Biomass is the total mass of organisms at a trophic level. With less energy at higher trophic levels, there are usually fewer organisms as well. This is also represented in the pyramid in **Figure** 24.6. Organisms tend to be larger in size at higher trophic levels. However, their smaller numbers result in less biomass.

## Lesson Summary

- All ecosystems need a constant input of energy in the form of sunlight or chemical compounds. Living things can be classified based on how they obtain energy as producers, consumers, or decomposers.
- Food chains and food webs are diagrams that model the flow of energy through ecosystems. They show who eats whom.
- A trophic level is a feeding position in a food chain or food web. Most food chains and webs have a maximum of four trophic levels. There is less energy and biomass at higher trophic levels.

## Lesson Review Questions

### Recall

1. Identify three major categories of living things based on how they obtain energy.
2. What is a food chain? Why are food chains simpler than actual feeding relationships in nature?
3. Define trophic level. How does an organism at trophic level 2 obtain energy?
4. At which trophic levels are you consuming when you eat a cheeseburger and French fries?

### Think Critically

5. Compare and contrast three types of decomposers.
6. Explain why food chains and webs rarely have more than four trophic levels.

## Points to Consider

Energy must constantly be added to an ecosystem for use by organisms. Matter, on the other hand, is continuously recycled through ecosystems.

1. Give an example of a cycle of matter.
2. What role do living things play in this cycle?

# 24.2 Cycles of Matter

## Lesson Objectives

- Define biogeochemical cycle.
- Describe the processes of the water cycle.
- Summarize the carbon cycle.
- Outline the nitrogen cycle.

## Lesson Vocabulary

- biogeochemical cycle
- carbon cycle
- condensation
- evaporation
- groundwater
- nitrogen cycle
- precipitation
- runoff
- sublimation
- water cycle

## Introduction

Where does the water come from that is needed by your cells? What is the source of the carbon and nitrogen that are needed to make your organic molecules? These forms of matter are recycled in an ecosystem. Unlike energy, matter is not lost as it passes through an ecosystem. It just keeps cycling.

## Biogeochemical Cycles

The chemical elements and water that are needed by living things keep recycling on Earth. They pass back and forth through biotic and abiotic components of ecosystems. That's why their cycles are called biogeochemical cycles. For example, a chemical element or water might move from organisms (bio) to the atmosphere or ocean (geo) and back to organisms again.

Elements or water may be held for various periods of time in different parts of a biogeochemical cycle.

- An exchange pool is part of a cycle that holds a substance for a short period of time. For example, the atmosphere is an exchange pool for water. It usually holds water (as water vapor) for just a few days.

- A reservoir is part of a cycle that holds a substance for a long period of time. For example, the ocean is a reservoir for water. It may hold water for thousands of years.

The rest of this lesson describes three biogeochemical cycles: water cycle, carbon cycle, and nitrogen cycle.

## Water Cycle

Water is an extremely important aspect of every ecosystem. Life can't exist without water. Most organisms contain a large amount of water, and many live in water. Therefore, the water cycle is essential to life on Earth.

Water on Earth is billions of years old. However, individual water molecules keep moving through the water cycle. The water cycle is a global cycle. It takes place on, above, and below Earth's surface, as shown in **Figure** 24.7. During the water cycle, water occurs in three different states: gas (water vapor), liquid (water), and solid (ice). Many processes are involved as water changes state to move through the cycle. Watch this video for an excellent visual introduction to the water cycle: http://www.youtube.com/watch?v=al-do-HGuIk .

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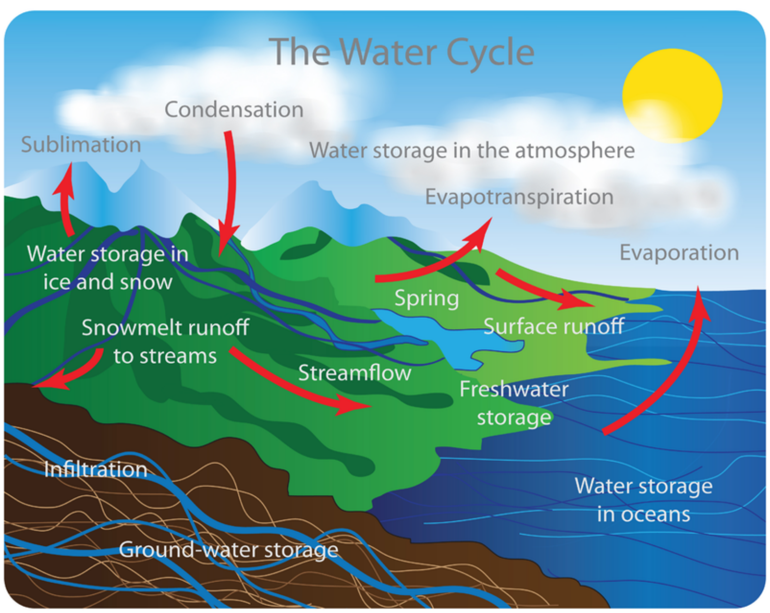


FIGURE 24.7

The water cycle has no beginning or end. It just keeps repeating.

### Evaporation, Sublimation, and Transpiration

Water changes to a gas by three different processes called evaporation, sublimation, and transpiration.

- Evaporation takes place when water on Earth's surface changes to water vapor. The sun heats the water and gives water molecules enough energy to escape into the atmosphere. Most evaporation occurs from the surface of the ocean.
- Sublimation takes place when snow and ice on Earth's surface change directly to water vapor without first melting to form liquid water. This also happens because of heat from the sun.
- Transpiration takes place when plants release water vapor through pores in their leaves called stomata.

### Condensation and Precipitation

Rising air currents carry water vapor into the atmosphere. As the water vapor rises in the atmosphere, it cools and condenses. Condensation is the process in which water vapor changes to tiny droplets of liquid water. The water droplets may form clouds. If the droplets get big enough, they fall as precipitation.

Precipitation is any form of water that falls from the atmosphere. It includes rain, snow, sleet, hail, and freezing rain. Most precipitation falls into the ocean. Eventually, this water evaporates again and repeats the water cycle. Some frozen precipitation becomes part of ice caps and glaciers. These masses of ice can store frozen water for hundreds of years or even longer.

Condensation may also form fog or dew. Some living things, like the lizard in **Figure** 24.8, depend directly on these sources of liquid water.

FIGURE 24.8

The thorny devil lizard lives in such a dry environment in Australia that it has a unique specialization for obtaining water. The scales on its body collect dew and channel it to the corners of the mouth, so the lizard can drink it.

### Runoff and Groundwater

Precipitation that falls on land may flow over the surface of the ground. This water is called runoff. It may eventually flow into a body of water.

Some precipitation that falls on land soaks into the ground. This water becomes groundwater. Groundwater may seep out of the ground at a spring or into a body of water such as the ocean. Some groundwater is taken up by plant roots. Some may flow deeper underground to an aquifer. An aquifer is an underground layer of rock that stores water. Water may be stored in an aquifer for thousands of years.

## Carbon Cycle

The element carbon is the basis of all life on Earth. Biochemical compounds consist of chains of carbon atoms and just a few other elements. Like water, carbon is constantly recycled through the biotic and abiotic factors of ecosystems.

The carbon cycle includes carbon in sedimentary rocks and fossil fuels under the ground, the ocean, the atmosphere, and living things. The diagram in **Figure** 24.9 represents the carbon cycle. It shows some of the ways that carbon moves between the different parts of the cycle. You can see an animated carbon cycle at this link: http://commons.wikimedia.org/wiki/Category:Carbon_cycle#mediaviewer/File:Carbon_Cycle-animated_forest.gif

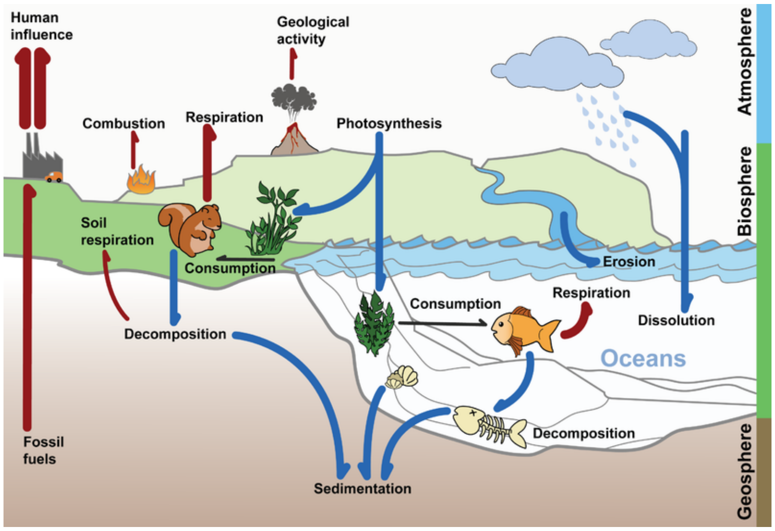


FIGURE 24.9
The Carbon Cycle.

## Carbon Reservoirs

Major reservoirs of carbon include sedimentary rocks, fossil fuels, and the ocean. Sediments from dead organisms may form carbon-containing sedimentary rocks. Alternatively, the sediments may form carbon-rich fossil fuels, which include oil, natural gas, and coal. Carbon can be stored in these reservoirs for millions of years. However, if fossil fuels are extracted and burned, the stored carbon enters the atmosphere as carbon dioxide. Natural processes, such as volcanic eruptions, can also release underground carbon from rocks into the atmosphere.

Water erosion by runoff, rivers, and streams dissolves carbon in rocks and carries it to the ocean. Ocean water near the surface dissolves carbon dioxide from the atmosphere. Dissolved carbon may be stored in the deep ocean for thousands of years.

### Carbon Exchange Pools

Major exchange pools of carbon include organisms and the atmosphere. Carbon cycles more quickly between these components of the carbon cycle.

- Photosynthesis by plants and other producers removes carbon dioxide from the atmosphere to make organic compounds for living things.
- Cellular respiration by living things releases carbon into the atmosphere or ocean as carbon dioxide.
- Decomposition of dead organisms and organic wastes releases carbon back to the atmosphere, soil, or ocean.

## Nitrogen Cycle

Nitrogen is another common element found in living things. It is needed to form both proteins and nucleic acids such as DNA. Nitrogen gas makes up 78 percent of Earth's atmosphere. In the nitrogen cycle, nitrogen flows back and forth between the atmosphere and living things. You can see how it happens in **Figure** 24.10. Several different types of bacteria play major roles in the cycle.

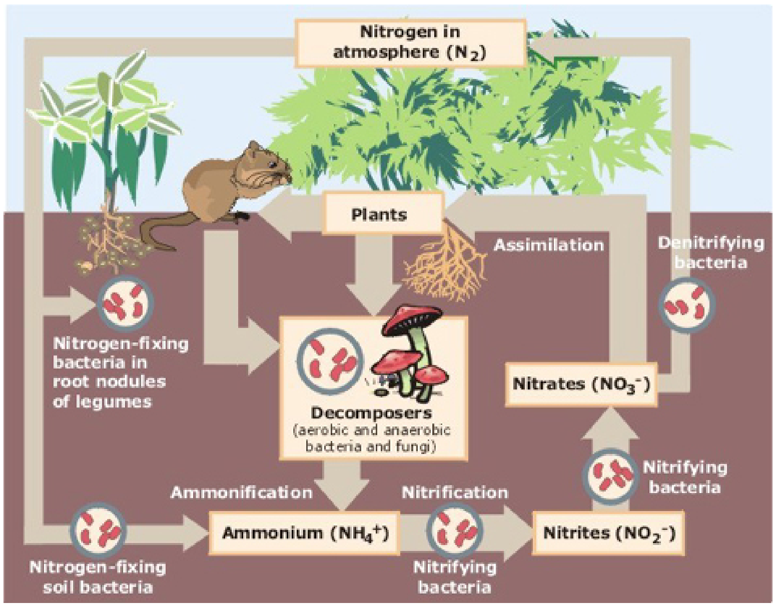


FIGURE 24.10
The nitrogen cycle

Animals get nitrogen by eating plants or other organisms that eat plants. Where do plants get nitrogen? They can't use nitrogen gas in the air. The only form of nitrogen that plants can use is in chemical compounds called nitrates. Plants absorb nitrates through their roots. This is called assimilation. Most of the nitrates are produced by bacteria that live in soil or in the roots of plants called legumes.

- Nitrogen-fixing bacteria change nitrogen gas from the atmosphere to nitrates in soil.
- When organisms die and decompose, their nitrogen is returned to the soil as ammonium ions. Nitrifying bacteria change some of the ammonium ions into nitrates.
- The other ammonium ions are changed into nitrogen gas by denitrifying bacteria.

## Lesson Summary

- Water and chemical elements that organisms need keep recycling through biogeochemical cycles. These cycles include biotic and abiotic components of ecosystems.
- The water cycle includes the ocean, atmosphere, ground, and living things. During the water cycle, water keeps changing state by processes such as evaporation, transpiration, condensation, and precipitation.
- The carbon cycle includes photosynthesis, in which plants change carbon dioxide to organic compounds. It also includes cellular respiration, in which living things "burn" organic compounds and release carbon dioxide. Rocks, fossil fuels, and the ocean are also part of the carbon cycle.
- Bacteria play important roles in the nitrogen cycle. They change nitrogen gas and products of decomposition

into nitrates, which plants can assimilate. Animals obtain nitrogen by eating plants or other organisms. Still other bacteria return nitrogen gas to the atmosphere.

## Lesson Review Questions

### Recall

1. What is a biogeochemical cycle?
2. Identify three ways in which water vapor enters the atmosphere in the water cycle.
3. Describe three ways that carbon can enter the ocean in the carbon cycle.
4. What roles do bacteria play in the nitrogen cycle?

### Apply Concepts

5. A farmer may plant a field with a legume crop to improve the soil. How does this work?

### Think Critically

6. Compare and contrast exchange pools and reservoirs in biogeochemical cycles. Give an example of each from the water and carbon cycles.
7. Explain the role of decomposers in the nitrogen cycle.

## Points to Consider

Ecosystem dynamics include more than the flow of energy and recycling of matter. Ecosystems are also dynamic because they change through time.

1. What are some ways ecosystems might change through time?
2. Do you think there are any ecosystems that do not change through time?

# 24.3 Ecosystem Change

## Lesson Objectives

- Define ecological succession.
- Explain how primary succession occurs.
- Explain why secondary succession occurs more rapidly than primary succession.
- Discuss the concept of climax community.

## Lesson Vocabulary

- climax community
- ecological succession
- pioneer species
- primary succession
- secondary succession

## Introduction

Imagine walking in the forest in **Figure** 24.11. The towering trees have been growing here for hundreds of years. It may seem as though the forest has been there forever. But no ecosystem is truly static. The numbers and types of species in most ecosystems change to some degree through time. This is called ecological succession. Important cases of ecological succession are primary succession and secondary succession.

FIGURE 24.11
An old redwood forest seems unchanging, but even here change happens.

## Primary Succession

Primary succession occurs in an area that has never before been colonized by living things. Generally, the area is nothing but bare rock.

### Where It Happens

This type of environment could come about when:

- a landslide uncovers bare rock
- a glacier retreats and leaves behind bare rock
- lava flows from a volcano and hardens into bare rock (see **Figure** 24.12)

### How It Happens

The first few species to colonize a disturbed area are called pioneer species. In primary succession, pioneer species must be organisms that can live on bare rock. They usually include bacteria and lichens (see **Figure** 24.12). Along with wind and water, the pioneer species help weather the rock and form soil. Once soil begins to form, plants can move in. The first plants are usually grasses and other small plants that can grow in thin, poor soil. As more plants grow and die, organic matter is added to the soil. This improves the soil and helps it hold water. The improved soil allows shrubs and trees to move into the area.

FIGURE 24.12
Lichen growing on bare lava rocks

## Secondary Succession

Secondary succession occurs in a formerly inhabited area that was disturbed.

### Where It Happens

Secondary succession could result from a fire, flood, or human action such as farming. For example, a forest fire might kill all the trees and other plants in a forest, leaving behind only charred wood and soil.

### How It Happens

Secondary succession is faster than primary succession. The soil is already in place. After a forest fire, for example, the pioneer species are plants such as grasses and fireweed. You can see a forest in this stage of recovery in **Figure** 24.13. As organic matter from the pioneer species improves the soil, trees and other forest plants will move into the area. You can see the amazing real-world story of secondary succession on Mount St. Helens by watching this short video: http://www.youtube.com/watch?v=4RsMyVavT2Q .

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FIGURE 24.13
Just a few months after a forest fire, fireweed and other pioneer plants are already growing among the charred tree trunks.

## Climax Community

Does a changing ecosystem ever stop changing? Does its community of organisms ever reach some final, stable state? Scientists used to think that ecological succession always ended at a stable state, called a climax community. Now their thinking has changed. Theoretically, a climax community is possible. But continued change is probably more likely for real-world ecosystems. Most ecosystems are disturbed too often to ever develop a climax community.

## Lesson Summary

- Ecological succession is the process in which the numbers and types of species in an ecosystem change over time.
- Primary succession occurs in an area that has never before been colonized. Pioneer species include bacteria and lichens that can grow on bare rock and help make soil.
- Secondary succession occurs in a formerly inhabited area that was disturbed. Soil is already in place, so pioneer species include small plants such as grasses.
- Most ecosystems are disturbed too often to attain a final, stable climax community.

## Lesson Review Questions

### Recall

1. What is ecological succession?
2. Define climax community, and state why climax communities are unlikely.

### Apply Concepts

3. Assume that a flood washed out all of the plants in a large area along the bank of a river. It left behind nothing but soil. How will ecological succession occur in this area?

### Think Critically

1. Compare and contrast primary and secondary succession.

## Points to Consider

Many ecosystems have changed because of human actions. The human species is responsible for a range of environmental problems.

1. What environmental problems have human actions caused?
2. How have these environmental problems affected living things?

# 24.4 References


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# CHAPTER 25 MS Environmental Problems

## Chapter Outline

It was a sunny afternoon when this picture was taken, but you'd never know it. Noxious smoke from a steel plant filled the air and obscured the sun. The picture was taken in Houston, Texas, in 1972. Since then, laws have been passed in the U.S. to reduce air pollution. However, air pollution is still a major environmental problem.

# 25.1 Air Pollution

## Lesson Objectives

- Define air pollution
- Identify causes and effects of outdoor air pollution.
- Describe sources and ways of controlling indoor air pollution.

## Lesson Vocabulary

- acid rain
- air pollution
- global climate change
- greenhouse effect

## Introduction

The air we breathe plays an important role in maintaining all life on Earth. For example, the atmosphere is a major part of the water cycle. It refills rivers and lakes with fresh water from precipitation. In addition, the atmosphere provides organisms with the gases needed for life. It contains oxygen needed for cellular respiration and carbon dioxide needed for photosynthesis. It also contains nitrogen needed for proteins and nucleic acids.

Earth's atmosphere is vast. However, it has been seriously polluted. Air pollution consists of chemical substances and particles released into the atmosphere, mainly by human actions. Before reading more about the causes of air pollution, watch this video to see some of its devastating effects: http://www.youtube.com/watch?v=UcWpkWBX04E .


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## Outdoor Air Pollution

The major cause of outdoor air pollution is the burning of fossil fuels. Fossil fuels are burned in power plants, factories, motor vehicles, and home heating systems. Ranching and using chemicals such as fertilizers also cause outdoor air pollution. Erosion of soil in farm fields, mining activities, and construction sites adds dust particles to the air as well. Some specific outdoor air pollutants are described in **Table** 25.1.

**TABLE 25.1:** Pollutants in outdoor air

| Air Pollutant | Source | Problem |
|---|---|---|
| Sulfur oxides | coal burning | acid rain |
| Nitrogen oxides | motor vehicle exhaust | acid rain |
| Carbon monoxide | motor vehicle exhaust | poisoning |
| Carbon dioxide | all fossil fuel burning | global climate change |
| Particles (dust, smoke) | wood and coal burning | respiratory problems |
| Mercury | coal burning | nerve poisoning |
| Smog | coal burning | respiratory problems |
| Ground-level ozone | motor vehicle exhaust | respiratory problems |

### Heath Effects of Outdoor Air Pollution

Outdoor air pollution causes serious human health problems. For example, pollutants in the air are major contributors to respiratory and cardiovascular diseases. Air pollution may trigger asthma attacks and heart attacks in people with underlying health problems. In fact, more people die each year from air pollution than automobile accidents.

### Acid Rain

Air pollution may also cause acid rain. This is rain that is more acidic (has a lower pH) than normal rain. Acids form in the atmosphere when nitrogen and sulfur oxides mix with water in air. Nitrogen and sulfur oxides come mainly from motor vehicle exhaust and coal burning.

If acid rain falls into lakes, it lowers the pH of the water and may kill aquatic organisms. If it falls on the ground, it may damage soil and soil organisms. If it falls on plants, it may make them sick or even kill them. Acid rain also damages stone buildings, bridges, and statues, like the one in **Figure** 25.1.

FIGURE 25.1
This stone statue has been dissolved by acid rain.

### Global Climate Change

Another major problem caused by air pollution is global climate change. Gases such as carbon dioxide from the burning of fossil fuels increase the greenhouse effect and raise Earth's temperature.

The greenhouse effect is a natural feature of Earth's atmosphere. It occurs when certain gases in the atmosphere, including carbon dioxide, radiate the sun's heat back down to Earth's surface. **Figure** 25.2 shows how this happens. Without greenhouse gases in the atmosphere, the heat would escape into space. The natural greenhouse effect of Earth's atmosphere keeps the planet's temperature within a range that can support life.

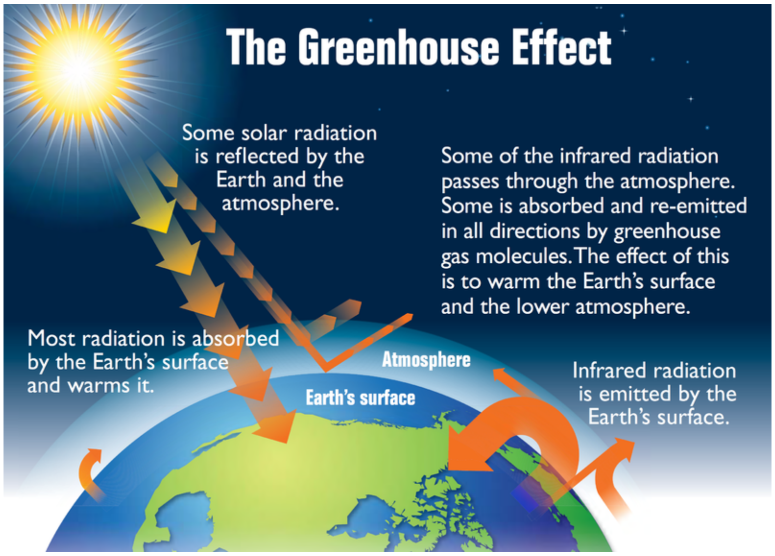


FIGURE 25.2
Earth's atmosphere creates a natural greenhouse effect that moderates Earth's temperature.

The rise in greenhouse gases due to human actions is too much of a good thing. It increases the greenhouse effect and causes Earth's average temperature to rise. Rising global temperatures, in turn, are melting polar ice caps and glaciers. **Figure** 25.3 shows how much smaller the Arctic ice cap was in 2012 than it was in 1984. With more liquid water on Earth's surface, sea levels are rising.

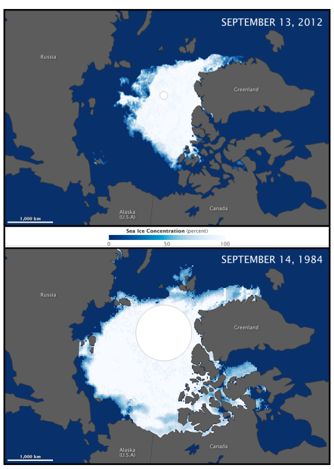


FIGURE 25.3
Shrinking of the Arctic ice cap due to global warming contributes to rising sea levels.

Adding more heat energy to Earth's atmosphere also causes more extreme weather and changes in precipitation patterns. Global warming is already causing food and water shortages and species extinctions. These problems will only grow worse unless steps are taken to curb greenhouse gases and global climate change.

## Indoor Air Pollution

You may be able to avoid some of the health effects of outdoor air pollution by staying indoors on high-pollution days. However, some indoor air is just as polluted as outdoor air.

### Sources of Indoor Air Pollution

One source of indoor air pollution is radon gas. Radon is a radioactive gas that may seep into buildings from rocks underground. Exposure to radon gas may cause lung cancer. Another potential poison in indoor air is carbon monoxide. It may be released by faulty or poorly vented furnaces or other fuel-burning appliances. Indoor furniture, carpets, and paints may release toxic compounds into the air as well. Other possible sources of indoor air pollution include dust, mold, and pet dander.

### Controlling Indoor Air Pollution

It's easier to control the quality of indoor air than outdoor air. Steps home owners can take to improve indoor air quality include:

- keeping the home clean so it is as free as possible from dust, mold, and pet dander.
- choosing indoor furniture, flooring, and paints that are low in toxic compounds such as VOCs (volatile organic compounds).
- making sure that fuel-burning appliances are working correctly and venting properly.
- installing carbon monoxide alarms like the one in **Figure** 25.4 at every level of the home.


FIGURE 25.4
Carbon monoxide alarm

## Lesson Summary

- Air pollution consists of chemical substances and particles released into the atmosphere, mainly by human actions. Both outdoor and indoor air may be polluted, but indoor air pollution is easier to control.
- The main cause of outdoor air pollution is the burning of fossil fuels. Outdoor air pollution causes human health problems, acid rain, and global climate change.
- There are many possible sources of indoor air pollution, including radon gas, fuel-burning appliances, and mold. Home owners can take several steps to improve the quality of indoor air.

## Lesson Review Questions

### Recall

1. Identify causes of outdoor air pollution.
2. What is acid rain? What causes it, and what are its effects?
3. Describe the natural greenhouse effect.

### Apply Concepts

4. Create a public service announcement about indoor air pollution. Focus on practical tips for improving the quality of indoor air.

### Think Critically

5. Explain how human actions contribute to the greenhouse effect and global climate change.

## Points to Consider

Acid rain from air pollution can pollute bodies of water.

1. What are some other causes of water pollution?
2. How does water pollution affect living things?

# 25.2 Water Pollution

## Lesson Objectives

- Define water pollution.
- Explain how fertilizer in runoff leads to algal blooms and dead zones.
- Give examples of point-source pollution, and define thermal pollution.
- Describe how the ocean is being polluted with trash and why ocean water is becoming more acidic.

## Lesson Vocabulary

- algal bloom
- dead zone
- nonpoint-source pollution
- ocean acidification
- point-source pollution
- thermal pollution
- waterborne disease
- water pollution
- wetland

## Introduction

All living things need water. For most human uses, water must be fresh. Of all the water on Earth, only 1 percent is fresh, liquid water. Most of the rest of Earth's water is either salt water in the ocean or ice in glaciers and ice caps.

Although water is constantly recycled through the water cycle, Earth's water is in danger. Water pollution is an increasing problem. It occurs when chemicals, sewage, trash, or heat enter water resources. Water pollution is threatening the limited supply of water that human beings and other living things depend on. Already, more than 1 billion people worldwide do not have enough clean, fresh water. With the rapidly growing human population and global climate change, the water shortage is likely to get worse.

## Algal Blooms and Dead Zones

Water pollution has many causes. One of the biggest causes is fertilizer in runoff. Runoff dissolves fertilizer as it flows over farm fields, lawns, and golf courses. It carries the dissolved fertilizer into bodies of water. More dissolved fertilizer may enter a body of water at the mouth of a river, but there is generally no single point where this type of pollution enters the water. That's why this type of water pollution is called nonpoint-source pollution.

### Algal Blooms

When fertilizer ends up in bodies of water, the added nutrients cause excessive growth of algae. This is called an algal bloom. You can see one in **Figure** 25.5. The algae out-compete other water organisms. They may make the water unfit for human consumption or recreation.

FIGURE 25.5
Algal bloom

### Dead Zones

Eventually, the algae in an algal bloom die and decompose. Their decomposition uses up oxygen in the water so that the water becomes hypoxic ("without oxygen"). This has occurred in many bodies of fresh water and large areas of the ocean, creating dead zones. Dead zones are areas where the hypoxic water can't support life. A very large dead zone exists in the Gulf of Mexico (see **Figure** 25.6). Nutrients carried into the Gulf by the Mississippi River caused this dead zone.

Cutting down on the use of chemical fertilizers is one way to prevent dead zones in bodies of water. Preserving wetlands is also important. Wetlands are habitats such as swamps, marshes, and bogs where the ground is soggy or covered with water much of the year. Wetlands slow down and filter runoff before it reaches bodies of water. Wetlands also provide breeding grounds for many different species of organisms.


FIGURE 25.6
Hypoxic dead zone in the Gulf of Mexico

## Point-Source Pollution

Unlike runoff, which enters bodies of water everywhere, some sources of pollution enter the water at a single point. This type of water pollution is called point-source pollution.

### Sewage and Other Waste

An example of point-source pollution is the release of pollution into a body of water through a pipe from a factory or sewage treatment plant. Waste water from a factory might contain dangerous chemicals such as strong acids, mercury, or lead. Water from a sewage treatment plant might contain untreated or partially treated sewage. Such pollution can make water dangerous for drinking or other uses. You can learn more about the problem of sewage contaminating the water in U.S. coastal communities by watching this video: http://www.youtube.com/watch?v=rreBKDko6OY .

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In poor nations, many people have no choice but to drink water from polluted sources. Drinking sewage-contaminated water causes waterborne diseases, due to pathogens such as protozoa, viruses, or bacteria. Most waterborne diseases cause diarrhea.

### Thermal Pollution

If heated water is released into a body of water, it may cause thermal pollution. Thermal pollution is a reduction in the quality of water because of an increase in water temperature. A common cause of thermal pollution is the use of water as a coolant by power plants and factories. This water is heated and then returned to the natural environment at a higher temperature.

Warm water can't hold as much dissolved oxygen as cool water, so an increase in the temperature of water decreases the amount of oxygen it contains. Fish and other organisms adapted to a particular temperature range and oxygen concentration may be killed by the change in water temperature.

## Ocean Pollution

The ocean is huge but even this body of water is becoming seriously polluted. Climate change also affects the quality of ocean water for living things.

### Plastic Waste

One way that the ocean is becoming polluted is with trash, mainly plastics. The waste comes from shipping accidents, landfill erosion, and the dumping of trash. Plastics may take hundreds or even thousands of years to break down. In the meantime, the waste can be very dangerous to aquatic organisms. Some organisms may swallow plastic bags, for example, and others may be strangled by plastic six-pack rings. You can see some of the trash that routinely washes up on coastlines in **Figure** 25.7. There are five massive garbage patches floating on the Pacific Ocean. Watch this video to learn more about them: http://www.youtube.com/watch?v=1qT-rOXB6NI .

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FIGURE 25.7

Plastic debris in the ocean washes up on shore in the Hawaiian Islands

### Ocean Acidification

Ocean water normally dissolves some of the carbon dioxide in the atmosphere. The burning of fossil fuels has increased the amount of carbon dioxide in the atmosphere. As a result, ocean water is also dissolving more carbon dioxide. When carbon dioxide dissolves in water, it forms a weak acid. With higher levels of dissolved carbon dioxide in ocean water, the water becomes more acidic. This process is called ocean acidification.

Ocean acidification can kill some aquatic organisms, including corals and shellfish. It may make it more difficult for other aquatic organisms to reproduce. Both effects of acidification interfere with marine food webs, threatening the survival of many aquatic organisms.

## Lesson Summary

- Water pollution occurs when chemicals, sewage, trash, or heat enter water resources. Water pollution is threatening the limited supply of clean, fresh water that human beings and other living things depend on.
- Fertilizer in runoff leads to algal blooms and dead zones in bodies of water. This type of pollution is called nonpoint-source pollution. Point-source pollution includes waste water from factories and sewage treatment plants. Hot water discharge causes thermal pollution.
- The ocean is becoming increasingly polluted with trash. Ocean acidification is also occurring because ocean water dissolves some of the excess carbon dioxide in the atmosphere. The more acidic water harms aquatic organisms.

## Lesson Review Questions

### Recall

1. What is a dead zone? How does it develop?
2. What are wetlands? How do they reduce water pollution?
3. Define thermal pollution, and state when it occurs.

### Apply Concepts

4. After a month of heavy rain, a formerly clear pond on a golf course is covered with slimy green algae. What do you think happened?

### Think Critically

5. Compare and contrast point-source and nonpoint-source water pollution. Which type of pollution do you think would be easier to control?
6. Explain the process of ocean acidification. Why does it threaten the survival of many aquatic organisms?

## Points to Consider

Water is one of our most important natural resources.

1. What is a natural resource? Besides water, what are some other examples of natural resources?
2. What is the difference between renewable and nonrenewable natural resources?

# 25.3 Natural Resources

## Lesson Objectives

- Define natural resource.
- Distinguish between renewable and nonrenewable natural resources.
- Identify pros and cons of different types of energy resources.
- Explain how to conserve natural resources by reducing, reusing, and recycling.

## Lesson Vocabulary

- biomass energy
- fossil fuel
- natural resource
- nonrenewable resource
- recycling
- renewable resource
- soil
- solar energy
- sustainable use
- wind energy

## Introduction

A natural resource is something supplied by nature that helps support life. When you think of natural resources, you may think of fossil fuels, like the coal in the coal field pictured in **Figure** 25.8. However, sunlight, wind, soil, and living things are also important natural resources.

## Renewable and Nonrenewable Resources

From a human point of view, natural resources can be classified as either renewable or nonrenewable.

### Renewable Resources

Renewable resources are natural resources that are remade by natural processes as quickly as people use them. Examples of renewable resources include sunlight and wind. They are in no danger of being used up. Metals and some other minerals are considered renewable as well because they are not destroyed when they are used. Instead, they can be recycled and used over and over again.

FIGURE 25.8

This photo shows a huge coal field in the Philippines as it appears from space. Coal is a fossil fuel and a nonrenewable natural resource.

Living things are also renewable resources. They can reproduce to replace themselves. However, living things can be over-used or misused to the point of extinction. For example, over-fishing has caused some of the best fishing spots in the ocean to be nearly depleted, threatening entire fish species with extinction. To be truly renewable, living things must be used wisely. They must be used in a way that meets the needs of the present generation but also preserves them for future generations. Using resources in this way is called sustainable use.

### Nonrenewable Resources

Nonrenewable resources are natural resources that can't be remade or else take too long to remake to keep up with human use. Examples of nonrenewable resources are coal, oil, and natural gas, all of which are fossil fuels. Fossil fuels form from the remains of plants and animals over hundreds of millions of years. We are using them up far faster than they can be replaced. At current rates of use, oil and natural gas will be used up in just a few decades, and coal will be used up in a couple of centuries.

Uranium is another nonrenewable resource. It is used to produce nuclear power. Uranium is a naturally occurring chemical element that can't be remade. It will run out sooner or later if nuclear energy continues to be used.

Soil is a very important natural resource. Plants need soil to grow, and plants are the basis of terrestrial ecosystems. Theoretically, soil can be remade. However, it takes millions of years for soil to form, so from a human point of view, it is a nonrenewable resource. Soil can be misused and eroded (see **Figure** 25.9). It must be used wisely to preserve it for the future. This means taking steps to avoid soil erosion and contamination of soil by toxins such as oil spills.

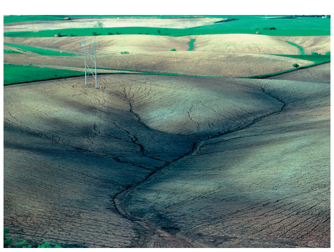

FIGURE 25.9

Bare soil is easily washed away by heavy rains or winds, but it takes millions of years to replace. Ruts in soil washed away by runoff are evident in this photo.

## Energy Resources

Some of the resources we depend on the most are energy resources. Whether it's powering our lights and computers, heating our homes, or providing energy for cars and other vehicles, it's hard to imagine what our lives would be like without a constant supply of energy.

### Fossil Fuels and Nuclear Energy

Fossil fuels and nuclear energy are nonrenewable energy resources. People worldwide depend far more on these energy sources than any others. **Figure** 25.10 shows the worldwide consumption of energy sources by type in 2010. Nonrenewable energy sources accounted for 83 percent of the total energy used. Fossil fuels and the uranium needed for nuclear power will soon be used up if we continue to consume them at these rates.

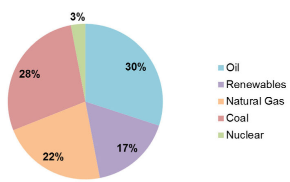


FIGURE 25.10
Worldwide energy use in 2010

Using fossil fuels and nuclear energy creates other problems as well. The burning of fossil fuels releases carbon dioxide into the atmosphere. This is one of the major greenhouse gases causing global climate change. Nuclear power creates another set of problems, including the disposal of radioactive waste.

### Alternative Energy Resources

Switching to renewable energy sources solves many of the problems associated with nonrenewable energy. While it may be expensive to develop renewable energy sources, they are clearly the way of the future. **Figure** 25.11 represents three different renewable energy sources: solar, wind, and biomass energy. The three types are described below. You can watch Bill Nye's introduction to renewable energy resources in this video: http://www.youtube.com/watch?v=grI3BDSGEC4 .

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- Solar energy is energy provided by sunlight. Solar cells can turn sunlight into electricity. The energy in sunlight is virtually limitless and free and creates no pollution to use.
- Wind energy is energy provided by the blowing wind. Wind turbines, like those in **Figure** 25.11, can turn wind energy into electricity. The wind blows because of differences in heating of Earth's atmosphere by the sun. There will never be a shortage of wind.

FIGURE 25.11
Sunlight, wind, and living things can all be used as energy resources.

- Biomass energy is energy provided by burning or decomposing organic matter. For example, when garbage decomposes in a landfill, it releases methane gas. This gas can be captured and burned to produce electricity. Crops such as corn can also be converted into a liquid fuel and added to gasoline. Although biomass is renewable, burning it produces carbon dioxide, similar to fossil fuels.

## Conserving Natural Resources

Especially when it comes to nonrenewable resources, conserving natural resources is important. Using less of them means that they will last longer. It also means they will impact the environment less. Everyone can help make a difference. There are three basic ways that all of us can conserve natural resources. They are referred to as the three R's: reduce, reuse, and recycle.

### Reduce

Reducing the amount of natural resources you use is the best way to conserve resources. It takes energy to make new items, and even reusing or recycling items takes energy. You can reduce the amount of natural resources you use by not using the resources in the first place. Often, this involves just being less wasteful. Follow these tips to reduce your use of natural resources:

- Walk, bike, or use public transit instead of driving. If you must drive, a fuel-efficient vehicle will reduce energy use. Plan ahead to avoid making extra trips.
- Don't buy more than you need. For example, don't buy more fresh food than you can use without it going to waste. You will not only reduce your use of food. You will also reduce your use of energy resources. It takes a lot of energy to grow, process, and ship many of the foods we buy.
- When you shop, keep packaging in mind. "Precycle" by buying items with the least amount of wasted packaging.
- Use energy-efficient appliances and LED light bulbs. Also, turn off appliances and lights when you aren't using them. Both steps will reduce the amount of energy resources you use.
- Keep the thermostat set low in the winter and high in the summer (see **Figure** 25.12). Instead of turning up the heat in cold weather, put on an extra layer of clothes to save energy resources. Open windows and use fans in hot weather rather than turning on the air conditioning.


FIGURE 25.12
If you use air conditioning in hot weather, set the thermostat above normal room temperature to save energy resources.

### Reuse

Reusing means to use an item again rather than throwing it away and replacing it. Items can be reused for the same purpose or for a different purpose. Generally, it takes less energy to reuse an item than to recycle it, so choose this option over recycling when you can. Here are some specific tips for reusing natural resources:

- Consider mending or repairing worn or broken items rather than throwing them out and replacing them.
- Shop with reuse in mind. You can find great buys at flea markets and resale shops. You may be able to get free items online at free-cycle sites. You'll save money as well as natural resources. You can also sell (or give away) your own reusable items.
- Reuse cloth shopping bags. Instead of getting new plastic or paper bags for your purchases each time you shop, take your own reusable bag to the store each time.
- Even little steps can add up and help save natural resources. For example, unwrap gifts carefully and you'll be able to reuse the gift wrap on a package for someone else. You can also reuse writing paper that has only been used on one side. It's great for notes and shopping lists.

### Recycle

If an item can no longer be used or reused, try to recycle it. Recycling means taking a used item, breaking it down, and reusing the components. It generally takes less energy to recycle materials than obtain new ones. Recycling also keeps waste out of landfills. Some of the items that can be recycled include: glass, paper, cardboard, plastic, aluminum, iron, steel, batteries, electronics, tires, and concrete. You can learn how some of these materials are recycled by watching this video: http://www.youtube.com/watch?v=7nZXyjrBraY .

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Even kitchen scraps and garden wastes can be recycled. They can be tossed into a compost bin, like the one in **Figure** 25.13. The recycled compost gradually breaks down to form rich humus that can be added to lawns and gardens to improve the soil.

Encourage your family to recycle if they don't already. Even if you don't have curbside recycling where you live, there are likely to be recycling drop boxes or centers available for recycling many items. If you have recycling bins at school, be sure to use them. If not, raise the issue with your teacher or principal. You can also write a letter to the editor of your local newspaper encouraging everyone in your community to recycle.

FIGURE 25.13
Kitchen and garden wastes can be recycled by composting them.

## Lesson Summary

- A natural resource is something supplied by nature that helps support life.
- From a human point of view, natural resources can be classified as either renewable or nonrenewable. Renewable resources, such as sunlight and living things, can be remade quickly by natural processes. Nonrenewable resources, such as fossil fuels and soil, cannot be remade or else take millions of years to remake.
- Nonrenewable energy resources (fossil fuels and nuclear energy) provide most of the energy used today. They may run out, and their use creates environmental problems. Renewable energy resources (such as solar, wind, and biomass energy) will always be available and are generally better for the environment.
- There are three basic ways to conserve natural resources: reduce, reuse, and recycle.

## Lesson Review Questions

### Recall

1. What is a natural resource?
2. List two cons of using fossil fuels for energy.
3. Describe three renewable energy resources.

### Apply Concepts

4. Identify ways you could conserve natural resources in your own life.

### Think Critically

5. New soil is always being formed, yet soil is considered to be a nonrenewable resource. Explain why.
6. Compare and contrast renewable and nonrenewable natural resources.

## Points to Consider

Biodiversity is another important natural resource.

1. What is biodiversity?
2. Why is biodiversity considered to be a natural resource?

# 25.4 Biodiversity and Extinction

## Lesson Objectives

- Define biodiversity.
- List benefits of biodiversity to people and ecosystems.
- Describe the sixth mass extinction, and identify its chief causes.
- Identify ways individuals can protect biodiversity.

## Lesson Vocabulary

- biodiversity
- exotic species
- habitat loss
- sixth mass extinction

## Introduction

It's obvious that living things are important natural resources needed by human beings. After all, other species provide us with all of the food we eat. We couldn't survive without them. But that's far from the only reason that other species are important for human survival. Biodiversity is an important natural resource in and of itself.

## Biodiversity

Biodiversity refers to the variety of life and its processes. It includes the variation in living organisms, the genetic differences among them, and the range of communities and ecosystems in which they live. Scientists have identified about 1.9 million species alive today, but they are discovering new species all the time.

How many species actually exist in the world? No one knows for sure because only a small percentage of them have already been discovered. Estimates range from 5 to 30 million total species currently in existence. Many of them live on coral reefs and in tropical rainforests (see **Figure** 25.14). These two ecosystems have some of the greatest biodiversity on the planet.

### Importance of Biodiversity

Biodiversity is important to human beings for many reasons. For one thing, biodiversity has direct economic benefits. Here are a few of the economic benefits of biodiversity:

FIGURE 25.14
This coral reef (top) and tropical rainforest (bottom) have a tremendous variety of different species.

- Besides food, diverse living things provide us with many different products. Some examples include dyes, rubber, fibers, paper, adhesives, and timber.
- Living things are an invaluable source of medical drugs. More than half of the most important prescription drugs come from wild species. However, only a fraction of species have yet been studied for their medical potential.
- Certain species may warn us of toxins in the environment. Amphibians are particularly sensitive to toxins because of their permeable skin. Their current high rates of extinction serve as an early warning of environmental damage and danger to us all.
- Wild organisms maintain a valuable pool of genetic variation. This is important because most domestic species have been bred to be genetically uniform. This puts domestic crops and animals at great risk of dying out due to disease.
- Some living things provide inspiration for technology. For example, water strider insects like the one in **Figure** 25.15 have helped engineers develop tiny robots that can walk on water. The robots could be used to monitor water quality, among other useful purposes.

FIGURE 25.15
Water strider insect

### Ecosystem Services

Biodiversity is important for healthy ecosystems. It generally increases ecosystem productivity and stability. It helps ensure that at least some species will survive environmental change. Biodiversity also provides many other ecosystem services. For example:

- Plants and algae maintain Earth's atmosphere. They add oxygen to the air and remove carbon dioxide when they undertake photosynthesis.
- Plants help protect the soil. Their roots grip the soil and keep it from washing or blowing away. When plants die, their organic matter improves the soil as it decomposes.

- Microorganisms purify water in rivers and lakes. They also decompose organic matter and return nutrients to the soil. Certain bacteria fix nitrogen and make it available to plants.
- Predator species such as birds and spiders control insect pests. They reduce the need for chemical pesticides, which are expensive and may be harmful to human beings and other organisms.
- Animals, like the bee in **Figure** below, pollinate flowering plants. Many crop plants depend on pollination by wild animals.

FIGURE 25.16
A bee pollinates a flowering plant.

## Extinction

Extinction is the complete dying out of a species. Once a species goes extinct, it can never return. More than 99 percent of all the species that ever lived on Earth have gone extinct. Five mass extinctions have occurred in Earth's history. They were caused by major geologic and climatic events. The fifth mass extinction wiped out the dinosaurs 65 million years ago.

### The Sixth Mass Extinction

Evidence shows that a sixth mass extinction is happening right now. Species are currently going extinct at the fastest rate since the dinosaurs died out. Dozens of species are going extinct every day. If this rate continues, as many as half of all remaining species could go extinct by 2050.

Why are so many species going extinct today? Unlike previous mass extinctions, the sixth mass extinction is due mainly to human actions.

### Habitat Loss

The single biggest cause of the sixth mass extinction is habitat loss. A habitat is the area where a species lives and to which it has become adapted. When a habitat is disturbed or destroyed, it threatens all the species that live there with extinction.

More than half of Earth's land area has been disturbed or destroyed by farming, mining, forestry, or the development of cities, suburbs, and golf courses. Habitats that are rapidly being destroyed include tropical rainforests. They are being cut and burned, mainly to clear the land for farming. Half of Earth's mature tropical forests have already been destroyed. At current rates of destruction, they will all be gone by 2090. In the U.S., half of the wetlands and almost all of the tall-grass prairies (see **Figure** 25.17) have already been destroyed for farming.

### Other Causes of Extinction

There are several other causes of the sixth mass extinction. Most of them contribute to habitat destruction.

FIGURE 25.17
Bison graze on grasses in a tall-grass prairie nature preserve in Oklahoma.

- The burning of fossil fuels has increased the greenhouse effect and caused global climate change. Increasing temperatures are changing basic climate factors of habitats, and rising sea levels are covering them with water. These changes threaten many species.
- Pollution of air, water, and soil makes habitats toxic to many organisms. A well-known example is the near extinction of the peregrine falcon in the mid-1900s due to the pesticide DDT.
- Humans have over-harvested trees, fish, and other wild species. This threatens not only their survival but the survival of all the other species that depend on them.
- Humans have introduced exotic species into new habitats. These are species that are not native to the habitat where they are introduced. They may lack predators in the new habitat so they can out-compete native species and drive them extinct. Exotic species may also carry new diseases, prey on native species, and disrupt local food webs. You can read about an example of an exotic species in **Figure** 25.18.

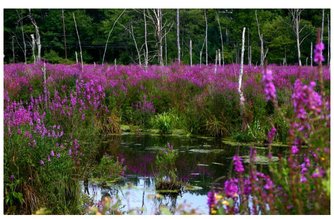

FIGURE 25.18
Purple loosestrife is a European wildflower that was introduced to North America in the early 1800s. It soon spread to take over wetland habitats throughout the U.S. and Canada. Purple loosestrife replaces native wetland plants and threatens native wildlife by eliminating natural foods and cover. It also blocks irrigation systems.

## Protecting Biodiversity

Government policies and laws are needed to protect biodiversity. Such actions have been shown to work in the past. For example, peregrine falcons made an incredible recovery after laws were passed banning the use of DDT.

Individuals can also play a role in protecting biodiversity. What can you do? Here are a few suggestions:

- Start a compost pile to recycle organic wastes. Use the compost to enrich yard and garden soil. It will reduce the need for chemical fertilizers and added water.
- Make your backyard welcoming to native wildlife. Plant native plants that will provide food and shelter for native animals such as birds and amphibians. Add a water source, such as a fountain or bird bath.
- Avoid the introduction of exotic species to local habitats.
- Avoid the use of herbicides and pesticides. In addition to killing garden weeds and pests, they may harm native organisms, such as wildflowers, honey bees, and song birds.
- Conserve natural resources, including energy resources. Always reduce, reuse, or recycle.
- Learn more about biodiversity and how to protect it. Then pass on what you learn to others.

## Lesson Summary

- Biodiversity refers to the variety of life and its processes. Biodiversity has direct economic benefits. It also increases ecosystem productivity and stability and provides vital ecosystem services.
- Extinction is the complete dying out of a species. Five mass extinctions have occurred in Earth's history, caused by major geologic and climatic events. A sixth mass extinction is happening right now. The single biggest cause of the current mass extinction is habitat loss due to human actions.
- Government policies and laws are needed to protect biodiversity, but individuals can also play a role.

## Lesson Review Questions

### Recall

1. What is biodiversity?
2. Identify some of the direct benefits of biodiversity to human beings.
3. Describe two ecosystem services provided by biodiversity.

### Apply Concepts

4. Describe one specific change you could make in your life to help protect biodiversity.

### Think Critically

5. Explain causes and effects of habitat loss.

## Points to Consider

The human species has been incredibly successful. In a relatively short period of time, it has colonized almost all of Earth's terrestrial habitats. Unfortunately, human beings have also impacted Earth, its climate, and its environment. Human actions threaten Earth's valuable biodiversity.

1. What do you think Earth's future may hold?
2. Do you think people will take steps to save Earth for future generations before it's too late?

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# Chapter 26 MS Life Science Glossary

## Chapter Outline

# 26.1 A

**abiotic factor**
aspect of the environment that has never been alive, such as sunlight, minerals, temperature, or moisture

**absolute dating**
any method of dating fossils or rocks, such as carbon-14 dating, that gives the specimen an approximate age in years

**absorption**
process in which nutrients or other molecules are taken up by the blood

**acid rain**
rain that is more acidic (has a lower pH) than normal rain because certain pollutants in the air form acids when they mix with water in the air

**acne**
common skin disorder characterized by the formation of pimples on the skin, which are caused by a bacterial infection

**acquired immunodeficiency syndrome (AIDS)**
disease characterized by rare infections due to a very low number of lymphocytes; caused by human immunodeficiency virus (HIV)

**active transport**
passage of a substance through the cell membrane that requires energy because the substance is moving from a lower to higher concentration or has very large molecules

**adolescence**
stage of life between the start of puberty and the beginning of adulthood that includes physical, mental, emotional, and social changes

**adrenal gland**
one of a pair of endocrine system glands located just above the kidneys that secrete hormones including adrenaline into the blood

**aerobic**
relating to any organism or process that requires oxygen

**age-sex structure**
numbers of individuals of each sex and age (or age group) in a population

**air pollution**
chemical substances and particles released into the atmosphere, mainly by human actions

**alga (algae, plural)**
common name of a plant-like protist, which contains chloroplasts and makes food by photosynthesis

**algal bloom**
excessive growth of algae in a body of water because of pollution with fertilizer in runoff

**allele**
one of the alternate versions of a particular gene

**allele frequency**
number of copies of an allele divided by the total number of alleles for the gene in a gene pool

**allergen**
any substance that causes an allergy

**allergy**
disorder in which the immune system responds to a harmless substance as though it was a pathogen

**alternation of generations**
type of life cycle characteristic of plants (and some protists), in which the organism alternates between haploid

and diploid generations

**alveolus (alveoli, plural)**
one of millions of tiny air sacs in the lungs of mammals where gas exchange takes place

**amniote**
animal such as a reptile or bird that produces eggs with waterproof membranes

**amniotic sac**
membrane that surrounds a fetus and contains amniotic fluid, which cushions the fetus and helps protect it from injury

**amphibian**
ectothermic vertebrate with smooth, moist skin that lives on land as an adult but lays eggs and spends the larval stage in water

**anaerobic**
relating to any organism or process that does not require oxygen

**anaphase**
third phase of mitosis in which spindle fibers shorten and pull sister chromatids to opposite poles of the cell

**anemia**
disease that occurs when there is not enough hemoglobin (or iron) in the blood to transport adequate oxygen to the cells

**angiosperm**
type of modern seed plant that produces seeds in the ovaries of flowers

**animal**
multicellular, heterotrophic eukaryote with specialized cells; member of the Animal Kingdom

**animal behavior**
any way that an animal interacts with other animals or the environment

**Animal Kingdom**
kingdom in the Eukarya Domain that consists of multicellular heterotrophs with specialized cells

**annelid**
segmented worm, such as an earthworm, in Phylum Annelida

**antibiotic drug**
drug developed to kill bacteria and cure bacterial diseases or infections

**antibiotic resistance**
ability of bacteria to resist the effects of one or more antibiotic drugs, which evolves through natural selection

**antibody**
large, Y-shaped molecule that binds to an antigen and marks it for destruction by a phagocyte

**antigen**
protein that may be recognized by the immune system as self or nonself, such as a red blood cell antigen that determines blood type (self) or an antigen on a bacterial cell (nonself)

**aphotic zone**
part of a body of water that is deeper than 200 meters where not enough sunlight penetrates to allow photosynthesis to take place

**applied science**
science that is undertaken to find solutions to practical problems

**aquatic**
of or relating to the water, such as an organism that lives in water rather than on land

**aquatic biome**
water-based biome, or group of similar water-based ecosystems; any freshwater or marine biome

**aquatic plant**
type of plant that lives in the water, such as a water lily or cattail

**Archaea Domain**
one of two domains of prokaryotes, which are single-celled organisms that lack a nucleus and other membrane-bound organelles

**archaean**
single-celled prokaryotic organism that is a member of the Archaea Domain

**artery**
thick-walled blood vessel that generally carries oxygen-rich blood away from the heart

**atherosclerosis**
condition in which plaques build up inside arteries, reduce blood flow, and often cause cardiovascular disease

**arthropod**
invertebrate in Phylum Arthropoda, which includes insects, spiders, centipedes, and lobsters

**asexual reproduction**
production of genetically identical offspring by a single parent through a method such as binary fission, fragmentation, or budding

**asthma**
respiratory disease in which the bronchioles in the lungs periodically narrow, making breathing difficult

**atom**
smallest particle of an element that still has the properties of that element

**ATP (adenosine triphosphate)**
small molecule that cells use for energy

**atrium (atria, plural)**
either of the two upper chambers of the heart; right atrium or left atrium

**autoimmune disease**
disease caused by the immune system attacking the body's own cells as though they were pathogens

**autosome**
any chromosome that is not a sex chromosome

**autotroph**
organism that makes glucose ("self feeder")

# 26.2 B

**bacteria (bacterium, singular)**
single-celled prokaryotic organism that is a member of the Bacteria Domain

**Bacteria Domain**
one of two domains of prokaryotes, which are single-celled organisms that lack a nucleus and other membrane-bound organelles

**basic science**
science that is undertaken to discover new knowledge and gain a better understanding of the natural world, regardless of whether it has any practical use

**binary fission**
method of asexual reproduction in prokaryotes and some single-celled eukaryotes in which DNA replicates and the parent cell splits into two daughter cells

**binomial nomenclature**
method of naming species introduced by Linnaeus in which each species is given a unique two-word name consisting of its genus and species names

**biochemical compound**
any carbon-based compound that is found in living organisms; classes of biochemical compounds include carbohydrates, proteins, lipids, and nucleic acids

**biochemical reaction**
any chemical reaction that takes place inside living things

**biodiversity**
variation in living things, often measured by the number of different species

**biofilm**
colony of prokaryotes that is stuck to a surface

**biogeochemical cycle**
cycle in which a chemical element or water is passed back and forth through biotic and abiotic components of ecosystems

**biological clock**
tiny structure in the brain of many animal species that controls behaviors occurring in daily cycles

**bioluminescence**
production of light by a living organism through biochemical means

**biomass**
total mass of organisms at a given trophic level in a food chain or food web

**biomass energy**
energy obtained by burning or decomposing organic matter

**biome**
group of similar ecosystems with the same general abiotic factors and primary producers, such as the littoral zone in water or the tropical rainforest on land

**biosphere**
highest level of organization in ecology that includes all the parts of Earth where life can be found and consists of all the world's biomes, both terrestrial and aquatic

**biotechnology**
use of technology to change the genetic makeup of living things for human purposes

**biotic factor**
living or once-living aspect of the environment, such as a living organism or the remains of a dead organism

**bipedal**

of or relating to an animal that walks on two legs

**bird**
: four-limbed, endothermic vertebrate that lays amniotic eggs and has wings and feathers

**blastocyst**
: fluid-filled ball of cells that forms within a few days of fertilization from a human zygote

**blood**
: liquid connective tissue that circulates throughout the body via blood vessels due to the pumping action of the heart

**blood clot**
: solid mass of platelets and other substances that plugs a leak in a damaged blood vessel and stops bleeding

**blood type**
: classification of an individual's blood based on the particular antigens found on the individual's red blood cells, such as blood type A in the ABO antigen system, in which red blood cells carry A antigens

**blood vessel**
: long, tube-like organ that forms part of the complex network of vessels that run through the body and transport blood to all the body's cells

**bone**
: hard tissue consisting of the protein collagen and minerals such as calcium that generally makes up most of the vertebrate endoskeleton

**bone fracture**
: crack or break in bone

**bone marrow**
: soft connective tissue inside pores and cavities in spongy bone tissue at the center of a bone

**brachiation**
: moving through trees by using the arms and hands to swing from branch to branch

**brain**
: main organ of the central nervous system that serves as the control center of the nervous system and of the body as a whole

**brain stem**
: smallest part of the human brain that controls unconscious body functions and carries nerve impulses between the rest of the brain and the spinal cord

# 26.3 C

**Calorie**
unit used to measure the energy in food

**Calvin cycle**
second stage of photosynthesis that takes place in the stroma of a chloroplast and in which carbon dioxide is used to produce glucose using energy in ATP and NADPH

**cancer**
disease in which cells grow out of control, usually because of mutations in genes that control the cell cycle

**capillary**
smallest type of blood vessel that connects an arteriole and venule and exchanges substances between cells and the blood

**carbohydrates**
class of biochemical compounds that includes sugar, starch, glycogen, and cellulose

**carbon cycle**
biogeochemical cycle in which carbon passes back and forth between sedimentary rocks, fossil fuels, the atmosphere, the ocean, and organisms

**carcinogen**
anything in the environment that can cause cancer, such as nicotine in tobacco or ultraviolet radiation in sunlight

**cardiac muscle**
type of striated muscle tissue that is found only in the walls of the heart, causes the heart to beat, and is not under voluntary control

**cardiovascular disease**
disease of the heart or blood vessels, such as coronary heart disease

**cardiovascular system**
human body system that consists of the heart, blood vessels, and blood and transports materials throughout the body

**carnivore**
heterotroph that eats only or mainly animals

**carnivorous plant**
type of plant that gets some or most of its nutrients from insects, other small animals, or animal-like protists by trapping and digesting them

**carrying capacity**
largest population size of a species that can be supported in an area without harming the environment

**cartilage**
tough, flexible tissue containing the protein collagen that makes up some or all of the endoskeleton of a vertebrate

**cell**
unit of structure and function of all living things

**cell cycle**
series of stages that a cell goes through during its lifetime, including growth, DNA replication, and cell division

**cell division**
process in which a cell divides to form daughter cells

**cell membrane**
thin coat of phospholipids that surrounds a cell and controls what enters and leaves the cell

**cell theory**

theory that all organisms consist of one or more cells; that cells are alive and the site of all life processes; and that all cells come from pre-existing cells

**cellular respiration**
process in which cells break down glucose, release the stored energy, and use the energy to make ATP

**cellulose**
complex carbohydrate that is a polymer of glucose and that makes up the cell wall of plants

**cell wall**
rigid layer that surrounds the cell membrane of a plant cell or fungal cell and that supports and protects the cell

**Cenozoic Era**
last era of the geologic time scale that began 65 million years ago and continues to the present and is called the age of mammals

**central nervous system**
one of two main parts of the human nervous system that includes the brain and spinal cord

**central vacuole**
large storage sac found in the cells of plants

**centriole**
organelle in animal cells that is located near the nucleus and organizes the DNA prior to cell division, ensuring that the DNA divides correctly when the nucleus divides

**cerebellum**
second largest part of the human brain that is located beneath the cerebrum and controls body position, coordination, and balance

**cerebrum**
largest part of the human brain that controls conscious functions such as thinking, sensing, speaking, and voluntary muscle movements

**chemical bond**
sharing of electrons between two atoms that holds the atoms together

**chemical digestion**
chemical process in which large food molecules are broken down into smaller nutrient molecules in the digestive system

**chemical reaction**
process in which some substances, called reactants, change chemically into different substances, called products

**chemoautotroph**
type of producer that uses chemical energy to make organic compounds by the process of chemosynthesis

**chemosynthesis**
process of using chemical energy to make organic compounds

**childhood**
stage of human life that occurs between the age of 1 year and the start of puberty

**chitin**
tough carbohydrate that makes up the cell walls of fungi and the exoskeleton of insects

**chlamydia**
most common sexually transmitted bacterial infection in the U.S.

**chlorophyll**
green pigment in the chloroplasts of plants and plant-like protists that gives them their green color and absorbs light energy during the process of photosynthesis

**chloroplast**
type of plastid, or plant organelle, that contains chlorophyll and is the site of photosynthesis

**chordate**
animal with a notochord, post-anal tail, dorsal hollow nerve cord, and pharyngeal slits; animal in Phylum Chordata

**chromosome**
structure present in cells during cell division in which the cell's DNA and protein molecules coil into a definite shape visible with a light microscope

**cilium (cilia, plural)**
short, hair-like projections on a cell

**circadian rhythm**
daily cycle of behavior that occurs in an animal, such as the daily sleep-wake cycle

**class**
taxon below the phylum in biological classification that consists of one or more orders

**climate**
average weather in a place over a long period of time

**climax community**
final, stable community resulting from ecological succession that is theoretically possible but unlikely in most real-world ecosystems

**cloaca**
body cavity in most vertebrates that has an external opening to pass wastes and gametes or fertilized eggs out of the body

**cnidarian**
aquatic invertebrate such as a jellyfish or coral in Phylum Cnidaria

**cochlea**
fluid-filled, spiral-shaped structure in the inner ear, lined with tiny hair cells that translate sound waves to nerve impulses

**cocoon**
special container built by an arthropod inside of which the pupa stage of the animal undergoes metamorphosis to change into the adult form

**codon**
group of three nitrogen bases in RNA or DNA that is the genetic code word for a single amino acid or for a start or stop signal

**coelom**
fluid-filled body cavity found in many invertebrates and all vertebrates that is completely enclosed by mesoderm

**coevolution**
evolution of two interacting species in which the evolution of traits in one of the species results in the other species evolving matching traits

**commensalism**
type of symbiotic relationship in which one species benefits while the other species is not affected

**communication**
any way in which animals share information

**community**
biotic component of an ecosystem that consists of all the populations of all the species that live in the same area

**compact bone**
very dense, hard bone tissue that lies between periosteum and spongy bone and that gives bone its strength

**competition**
relationship between organisms that depend on the same resources; may be intraspecific (between members of the same species) or interspecific (between members of different species)

**competitive exclusion principle**
law that two different species cannot occupy the same niche in the same habitat at the same time

**compound**
unique type of matter in which two or more elements are combined chemically in a certain ratio

**concentration**

number of particles of a substance in a given volume

**concussion**
bruise on the surface of the brain that is caused by an injury to the head and that may cause temporary symptoms such as headache and confusion

**condensation**
process in which a gas such as water vapor changes from the gaseous to liquid state

**conditioning**
way of learning that involves a reward or punishment, such as teaching a dog commands by giving it food treats

**connective tissue**
type of tissue that forms the body's structure; includes bone, cartilage, and blood

**cone**
reproductive structure in gymnosperms that is made of overlapping scales and where pollen or eggs form and naked seeds develop

**consumer**
type of organism that obtains food by eating or absorbing other organisms

**control**
factor that might affect a dependent variable so it is held constant in an experiment

**convergent evolution**
independent evolution of the same traits in species that live in similar habitats

**cooperation**
working together with others toward the same overall goal, such as bees working together to feed and protect the colony

**coral**
aquatic invertebrate in Phylum Cnidaria that lives in a large colony in shallow ocean water and may builds a reef

**coral reef**
hard, mineralized underwater structure that is built by coral animals as an exoskeleton and provides a habitat for many other ocean organisms

**coronary heart disease**
cardiovascular disease in which there is poor blood flow to the heart because plaques block coronary arteries that normally supply blood to the heart

**courtship**
special behavior, such as a unique song or visual display, performed by an animal to attract a mate

**cranium**
bony skull that encloses and protects the brain of a vertebrate

**crocodilian**
reptile in the Crocodilia Order, such as a crocodile or an alligator

**cyanobacteria**
type of bacteria that carry out photosynthesis and are important producers in aquatic ecosystems

**cytokinesis**
last event in cell division, when the cell membrane grows into the middle of the cell, the cytoplasm divides, and daughter cells form

**cytoplasm**
material inside the cell membrane, including the watery cytosol and other cell structures except the nucleus if one is present

**cytoskeleton**
structure in a cell consisting of filaments and tubules that crisscross the cytoplasm and help maintain the cell's shape

# 26.4 D

**Darwin**
19th century scientist who is best known for his theory of evolution by natural selection

**dead zone**
area in a body of water where there is too little oxygen to support living things

**decomposer**
type organism that obtains food by breaking down the remains of dead organisms or other organic wastes

**dehydration**
condition in which the water content of the body is too low

**demographic transition**
shift that occurred in some human populations, starting as early as the 1700s, which included a decrease in death rates, followed somewhat later by a decrease in birth rates, so that population growth changed from slow to rapid to slow again

**dependent variable**
variable in an experiment that is affected by another variable, called the independent variable

**dermal tissue**
type of tissue in plants that covers the outside of the plant like skin and secretes waxy cuticle, which helps prevent water loss and damage to the plant

**dermis**
inner layer of skin that is made of tough connective tissue and contains blood vessels, nerve endings, hair follicles, and sweat and sebaceous glands

**detritivore**
type of decomposer that obtains energy and matter by breaking down dead leaves and other organic debris that collects on the ground or at the bottom of a body of water

**diabetes**
noninfectious disease that occurs when the pancreas does not make enough insulin or body cells are resistant to insulin so there is too much glucose in the blood

**diaphragm**
large, flat muscle that lies below the lungs in reptiles and mammals and helps move air into and out of the lungs

**diffusion**
natural movement of a substance from an area of higher to lower concentration without the need for added energy

**digestion**
process of breaking down food into nutrients that takes place in the digestive system; includes mechanical digestion and chemical digestion

**digestive system**
body system that breaks down food, absorbs nutrients, and eliminates any remaining solid food waste

**diploid**
referring to the total number of chromosomes in a sexually reproducing species, which is twice the haploid number of chromosomes

**diurnal**
of or relating to being active during the day, such as a diurnal animal

**DNA (deoxyribonucleic acid)**
double-stranded nucleic acid that stores genetic information in its sequence of nitrogen bases

**DNA replication**

process occurring before cell division in which DNA is copied

**domain**

broadest taxon in modern biological classification that consists of one or more kingdoms

**dominant**

referring to an allele that masks the presence of another allele (called recessive) for the same gene when both are present in a heterozygote; or referring to a trait controlled by such an allele

**drug abuse**

use of a drug, either legal or illegal, without the advice of a medical professional and for reasons not originally intended

**drug addiction**

condition in which a drug user is unable to stop using a psychoactive drug

# 26.5 E

**eardrum**
membrane between the outer and middle ear that vibrates when sound waves strike it and passes the vibrations to the middle ear

**echinoderm**
ocean-dwelling invertebrate in Phylum Echinodermata, such as the sea star, sea urchin, or sand dollar

**ecological succession**
change in the numbers and types of species in an ecosystem over time

**ecology**
science of how living things interact with each other and their environment

**ecosystem**
unit of nature that consists of all the biotic and abiotic factors in an area and all the ways in which they interact

**ectothermy**
controlling body temperatures to a limited extent from outside the body by changing behavior

**egg**
gamete produced by a female parent

**electron microscope**
type of microscope that can make images of extremely tiny objects by passing beams of electrons through or across them

**electron transport**
third stage of cellular respiration, which occurs on the inner membrane of mitochondria, requires oxygen, and produces up to 34 molecules of ATP

**element**
one of more than 100 pure substances that cannot be broken down into other substances

**elimination**
process in which feces pass out of the body through the anus

**embryo**
very early stage in the development of an organism following the zygote stage and during which initial growth and development take place

**emphysema**
respiratory system disease in which the walls of alveoli break down, reducing gas exchange in the lungs and causing shortness of breath

**endocrine gland**
organ of the endocrine system that secretes hormones into the bloodstream for transport around the body

**endocrine system**
system of glands that secrete chemical messenger molecules called hormones into the blood

**endoplasmic reticulum (ER)**
organelle in eukaryotic cells that consists of folded membrane and that helps make and transport proteins and lipids; types include rough ER and smooth ER

**endoskeleton**
internal skeleton of cartilage and bone that supports and protects the body of vertebrates

**endothermy**
controlling body temperature within a narrow range from inside the body through biological means

**energy**
ability to change or move matter

**enzyme**

protein that increases the rate of a biochemical reaction

**epidermis**
: outer layer of skin that consists almost entirely of epithelial cells and contains no skin structures except melanocytes

**epididymis**
: male reproductive organ on top of the testes where sperm mature

**epiphyte**
: type of plant that is adapted to grow on other plants for support and to obtain moisture from the air instead of the soil

**epithelial tissue**
: type of tissue that covers inner and outer body surfaces and secretes and absorbs substances; includes skin and linings of internal organs

**esophagus**
: tube-like organ of the digestive system that carries food from the pharynx in the throat to the stomach

**estrogen**
: main female sex hormone that causes most of the changes of puberty and is needed by an adult female to mature and release eggs from the ovaries

**eukaryote**
: organism that has cells with a nucleus; organisms in the Eukarya Domain

**eukaryotic cell**
: cell in which most of the cell's DNA is enclosed in a nucleus and which has other membrane-bound organelles

**evaporation**
: process in which a liquid such as water changes from the liquid to gaseous state

**evolution**
: change in the inherited traits of organisms over time

**excretion**
: process in which excess water or waste is removed from the body

**excretory system**
: organ system that removes excess water and waste from the body; includes the large intestine, liver, skin, lungs, and kidneys

**exoskeleton**
: non-bony skeleton that forms on the outside of the body of many invertebrates including insects and other arthropods

**exotic species**
: non-native species introduced into a new habitat where it may become invasive and threaten native species

**experiment**
: controlled scientific test of a hypothesis that often takes place in a lab and investigates the effects of an independent variable on a dependent variable

**exponential growth**
: pattern of population growth in which a population starts out growing slowly and grows at an increasing rate as population size increases, so that the larger the population becomes, the more quickly it grows

**extinction**
: complete dying out of a species

**extremophile**
: organism that lives in extreme conditions, such as very hot, salty, acidic, or basic conditions

# 26.6 F

**facilitated diffusion**
passive transport of a substance through a membrane with the help of transport proteins

**fallopian tube**
one of a pair of female reproductive organs consisting of a long, thin tube where fertilization normally takes place

**family**
taxon below the order in biological classification that consists of one or more genera

**fermentation**
form of respiration that takes place without oxygen in bacteria, yeast, and some other cells; types include lactic acid and alcoholic fermentation

**fertilization**
union of two gametes during sexual reproduction

**fetus**
stage of a developing human being from the eighth week following fertilization until birth

**fever**
higher-than-normal body temperature (above 98.6° F or 37° C) that may occur during illness

**fiber**
complex carbohydrate that consists mainly of cellulose, comes only from plants, and is needed for good health although it cannot be digested

**fieldwork**
scientific research that takes place in a natural setting rather than in a lab

**fin**
projection from the body of a fish that helps it swim by acting as a paddle or rudder

**fish**
aquatic, ectothermic vertebrate that is covered with scales and has gills to absorb oxygen from water

**flagellum (flagella, plural)**
whip-like extension on the surface of a cell that helps the cell move

**flatworm**
invertebrate in Phylum Platyhelminthes, such as a tapeworm, which has three embryonic cell layers and bilateral symmetry but lacks a pseudocoelom

**flower**
plant structure in angiosperms that contains male and/or female reproductive organs

**food allergy**
reaction that occurs when the immune system responds to substances in food as though they were pathogens

**foodborne illness**
illness that occurs when harmful bacteria enter the digestive system in food; commonly called food poisoning

**food chain**
diagram that represents a single pathway by which energy flows through an ecosystem

**food web**
diagram that represents several intersecting pathways by which energy flows through an ecosystem

**fossil**
preserved remains or traces of an organism that lived during an earlier age

**fossil fuel**
nonrenewable natural resource that forms over hundreds of millions of years from dead organisms and is burned for energy; coal, oil, or natural gas

**freshwater biome**
: group of similar ecosystems that are based in fresh water, such as the littoral zone near the shore of a lake or the profundal zone at the bottom of the water

**frugivore**
: heterotrophic animal that eats only or mainly fruit

**fruit**
: structure containing seeds that forms from the ovary of a flower in an angiosperm

**fungus**
: eukaryotic organism in the Fungus Kingdom

**Fungus Kingdom**
: kingdom in the Eukarya Domain that consists of both single-celled and multicellular organisms and includes mushrooms and yeasts

# 26.7 G

**Galápagos Islands**
group of 16 islands lying off the west coast of South America that Darwin visited during his voyage on the Beagle and that are home to giant tortoises and Darwin's finches

**gall bladder**
sac-like organ of the digestive system that stores and concentrates liver bile before releasing it into the small intestine

**gamete**
special reproductive cell with the haploid number of chromosomes that is produced by meiosis during sexual reproduction

**gametophyte**
plant in the haploid generation that forms from a haploid spore and reproduces sexually by producing haploid gametes by mitosis

**gastrointestinal (GI) tract**
long tube that connects the mouth to the anus and through which food passes as it is digested, its nutrients are absorbed, and food waste is eliminated; consists of the mouth, esophagus, stomach, small intestine, and large intestine

**gene**
section of a chromosome that contains the genetic code for a particular protein

**gene flow**
change in allele frequencies in a gene pool that occurs when genes move into or out of the gene pool because individuals migrate into or out of the population

**gene pool**
all the genes in all of the members of a population

**gene therapy**
treatment of a genetic disorder by inserting a normal gene into a patient with a defective gene

**generalist**
organism that has general (nonspecialized) traits for exploiting a variety of foods or other resources in the environment

**genetically modified organism (GMO)**
organism that has been given one or more new genes so it will have traits that make it more useful to people

**genetic code**
code of nitrogen bases in DNA that contains the information for making proteins in cells

**genetic disorder**
disease caused by a mutation

**genetic drift**
change in allele frequencies in a gene pool that occurs by chance in a small population

**genetics**
science of heredity, or how traits are passed from parents to offspring

**genetic transfer**
exchange of plasmid DNA between prokaryotic cells that increases genetic variation in asexually reproducing cells

**genital herpes**
common sexually transmitted infection that is caused by a herpes virus and that may cause repeated outbreaks of painful genital blisters throughout life

**genital warts**

common sexually transmitted infection that is caused by the human papilloma virus (HPV) and that causes warts on the genitals and may cause cancer later in life

**genome**

all the genetic information of a species

**genotype**

combination of alleles that an individual inherits for a given gene

**genus (genera, plural)**

taxon below the family in biological classification that consists of one or more species

**geologic time scale**

tool for understanding the history of Earth and its life that divides Earth's history into eons, eras, and periods on the basis of major changes in geology, climate, and the evolution of life

**germination**

early growth and development of a plant embryo inside a seed

**gill**

organ in fish and some other aquatic organisms that absorbs oxygen from water

**global climate change**

worldwide increase in Earth's temperature caused by the addition of greenhouse gases to the atmosphere due to human actions

**glucose**

simple sugar that all living things use to store and transport energy

**glycolysis**

first stage of cellular respiration, which occurs in the cytoplasm, requires no oxygen, and produces two molecules of ATP

**Golgi apparatus**

organelle in eukaryotic cells that receives, labels, and sends proteins and lipids where they are needed

**gonad**

one of a pair of glands in the endocrine system that secretes sex hormones; ovary in females or testis in males

**gonorrhea**

common sexually transmitted bacterial infection that may cause painful urination and a discharge from the vagina or penis

**gravitropism**

growing downward in response to gravity by the roots of a plant

**greenhouse effect**

natural retention of heat on Earth by gases in the atmosphere, which keeps Earth's temperature within a range that allows life

**ground tissue**

type of tissue in plants that makes up much of the inside of a plant, where most biochemical reactions take place, and where food or water may be stored

**groundwater**

water that soaks into the ground and is stored in underground rocks

**gymnosperm**

type of modern seed plant that produces naked seeds in cones rather than flowers

# 26.8 H

**habitat**
: physical environment in which a species lives and to which it has adapted

**habitat loss**
: disturbance or destruction of natural habitats, usually due to human actions such as clearing land for farming

**habituation**
: way of learning that occurs when an animal is exposed repeatedly to a stimulus that is annoying or frightening but not harmful, such as a crow learning to ignore a scarecrow

**hair follicle**
: structure in the dermis, or lower layer of the skin, where a hair originates

**haploid**
: referring to the number of different chromosomes in a sexually reproducing species or to the number of chromosomes in a gamete

**hearing**
: ability to sense sound

**heart**
: muscular organ in the chest that pumps blood through blood vessels in the cardiovascular system

**heart attack**
: death of cardiac muscle cells that occurs when the blood supply to part of the heart muscle is blocked

**hemoglobin**
: protein containing iron that is found in red blood cells and that binds with oxygen so it can be carried by the blood to cells throughout the body

**hemophilia**
: genetic disorder controlled by a gene on the X chromosome in which blood fails to clot properly, leading to excessive bleeding

**herbivore**
: heterotroph that eats only or mainly plants

**heterotroph**
: living thing that obtains glucose by eating other organisms ("other feeder")

**heterozygote**
: type of genotype in which an individual has two different alleles for a gene

**hibernation**
: state in which an animal's body processes slow down and its body temperature falls so it can sleep deeply through a time of year when food is scarce

**homeostasis**
: condition in which an organism maintains a stable internal environment

**homologous chromosomes**
: two members of a given pair of chromosomes, which have the same genes in the same locations

**homozygote**
: type of genotype in which an individual has two of the same allele for a gene

**hookworm**
: type of parasitic roundworm in Phylum Nematoda that infects the intestines of human beings or other vertebrate hosts

**hormone**
: chemical messenger molecule

**host**

species that is harmed by a parasite in a parasitic relationship

**Human Genome Project**
: international effort to sequence all 3 billion bases in human DNA, which began in 1990 and achieved its goal by 2003

**human immunodeficiency virus (HIV)**
: virus that is transmitted sexually or through contact with infected body fluids and that destroys lymphocytes and may cause acquired immunodeficiency syndrome (AIDS)

**human papilloma virus (HPV)**
: virus that is transmitted sexually and that causes genital warts and may cause cancer later in life

**hyperopia**
: vision problem in which distant objects can be seen clearly but nearby objects appear blurry; commonly called farsightedness

**hypha (hyphae, plural)**
: multicellular, thread-like structure in a fungus that resembles the root of a plant

**hypothalamus**
: structure in the brain that secretes hormones and provides a link between the nervous and endocrine systems

**hypothesis**
: potential, testable answer to a scientific question

# 26.9 I

**immune response**
immune system's reaction to a specific pathogen
**immune system**
body system that fights to protect the body from specific pathogens
**immunity**
ability of the immune system to launch a rapid attack against a specific pathogen and prevent disease because the immune system "remembers" the pathogen from a previous exposure
**implantation**
process in which a blastocyst implants in the lining of the uterus about one week after fertilization
**incomplete metamorphosis**
type of life cycle in arthropods in which newly hatched offspring look like small adults and do not go through distinct larval stages before adulthood
**incubation**
keeping eggs warm until they hatch
**independent variable**
variable that is tested in an experiment to see whether it affects another variable, called the dependent variable
**infancy**
stage of human life between birth and the first birthday
**infectious disease**
disease that is contagious because it is caused by a pathogen
**inflammation**
nonspecific reaction to infection or injury that includes redness, warmth, and pain at the site of infection or injury
**ingredient**
specific item that a food contains
**innate behavior**
instinctive behavior that does not need to be learned, or any behavior that occurs naturally and in exactly the same way in all the individuals of a given species
**insect**
arthropod in Class Insecta that has three body segments, six jointed legs, and multiple head appendages
**insectivore**
heterotrophic animal that eats only or mainly insects
**insight learning**
way of learning that is based on past experiences and reasoning and that generally involves coming up with a new way to solve a problem
**instinct**
innate behavior that does not need to be learned but that occurs naturally and in exactly the same way in all the individuals of a given species
**integumentary system**
human body system that includes the skin, hair, and nails
**interphase**
major phase of the eukaryotic cell cycle that incorporates all phases of the cell except cell division and includes growth phase 1 (G1), synthesis phase (S), and growth phase 2 (G2)
**invertebrate**
animal that lacks a vertebral column, or backbone

## 26.10 J

**jellyfish**
aquatic invertebrate in Phylum Cnidaria that lives virtually anywhere in the ocean and is typically a predator

**joint**
place where two or more bones of the skeleton meet

# 26.11 K

**keratin**
tough protein in the skin, scales, feather, fur, or hair of vertebrates

**keystone species**
predator species that plays a special role in its community because changes in its population affect the populations of many other species in the community

**kidney**
one of a pair of urinary system organs that filter blood, form urine, and help maintain homeostasis

**kidney failure**
condition in which the kidneys can no longer filter blood and maintain homeostasis

**kidney stone**
mineral crystal that forms in urine inside a kidney, often causing pain and possibly blocking the ureter

**kingdom**
taxon below the domain in modern biological classification that consists of one or more phyla

**Krebs cycle**
second stage of cellular respiration, which occurs in the matrix of mitochondria, requires oxygen, and produces two molecules of ATP

# 26.12 L

**lactation**
production of milk from mammary glands by a female mammal to feed her offspring

**lancelet**
aquatic invertebrate in Phylum Chordata that retains the four defining traits of chordates into adulthood

**language**
use of symbols such as words to communicate

**large intestine**
wide, tube-like organ of the digestive system that connects the small intestine and anus, eliminates feces from food wastes, and provides a home for helpful bacteria

**larva (larvae, plural)**
distinct juvenile form that many animals go through before becoming an adult

**Last Universal Common Ancestor (LUCA)**
cell that have existed around 3.5 billion years ago and that gave rise to all of the following life on Earth

**law of independent assortment**
Mendel's second law of inheritance that states that factors (alleles) controlling different traits go to gametes independently of each other

**law of segregation**
Mendel's first law of inheritance that states that the two factors (alleles) that control a given trait separate and go to different gametes

**leaf**
plant organ with the primary role of collecting sunlight and making food by photosynthesis

**learned behavior**
any behavior that occurs only after experience or practice

**lens**
clear, curved structure near the front of the eye that helps focus light and form images on the retina

**leukemia**
type of cancer in which bone marrow produces abnormal white blood cells that cannot fight infections

**lichen**
symbiotic relationship between a fungus and cyanobacteria or green algae

**life cycle**
cycle of phases that an organism goes through until it returns to the starting phase and that may include one or more generations

**life science**
study of life and living things

**ligament**
band of fibrous connective tissue that connects bones and holds them together

**light microscope**
type of microscope that uses lenses to refract visible light and make magnified images of small objects

**light reactions**
first stage of photosynthesis in which energy from sunlight is absorbed by chlorophyll and temporarily transferred to ATP and NADPH

**Linnaeus**
"father of taxonomy" who introduced the system of classification that is the basis of modern biological classification and who also developed the method of naming species called binomial nomenclature

**lipids**

class of biochemical compounds that includes fats, oils, and phospholipids

**liver**
: organ of digestion and elimination that makes and secretes bile acids into the small intestine and gall bladder to help digest fats

**logistic growth**
: pattern of population growth in which a population starts out growing slowly, increases its rate of growth, grows more rapidly, and then grows more slowly as the population size approaches the carrying capacity

**lung**
: one of a pair of organs in the respiratory system where gas exchange between the air and blood takes place

**lymph**
: yellowish liquid that leaks out of capillaries into spaces between cells and circulates through lymph vessels before returning to the blood

**lymph node**
: one of many small oval structures located along lymph vessels that filter pathogens out of lymph

**lymphocyte**
: type of white blood cell involved in an immune system response; B cell or T cell

**lysosome**
: organelle in eukaryotic cells that uses enzymes to break down molecules so their components can be recycled

## 26.13 M

**macroevolution**
change in inherited traits of organisms that occurs over a long period of time above the level of the species

**macronutrient**
type of nutrient the body needs in relatively large amounts; carbohydrate, protein, lipid, or water

**main ingredient**
item a food contains in the greatest amount; item listed first on a food's ingredient list

**mammal**
four-limbed, endothermic vertebrate that has hair or fur and mammary glands in females

**mammary gland**
gland in female mammals that produces milk to feed offspring

**marine biome**
group of similar, salt-water based ecosystems in the ocean, such as the intertidal zone along a coast or the benthic zone at the bottom of the ocean

**marsupial**
member of the subclass of mammals that give birth to an embryo, which continues to grow and develop in a pouch on its mother's body

**mass extinction**
one of six similar events in the history of life on Earth during which the majority of species died out

**mating**
pairing of an adult male and an adult female for the purpose of reproduction

**matter**
anything that has mass and takes up space

**mechanical digestion**
physical process in which large chunks of food are broken down into smaller pieces in the digestive system

**medusa (medusae, plural)**
one of two cnidarian body forms (the other is the polyp), in which the animal is bell shaped and typically able to move

**meiosis**
special type of cell division in which a cell divides twice and produces four haploid daughter cells

**melanin**
brown pigment produced by melanocytes in the epidermis that gives skin much of its color and helps protect the dermis from exposure to ultraviolet light

**melanocyte**
special cell in the epidermis of the skin that produces the brown pigment called melanin

**Mendel**
Austrian monk who lived in the 1800s and discovered the laws of inheritance by careful, repeated experiments with pea plants; called the "father of genetics"

**menstrual cycle**
series of changes in the reproductive system of sexually mature females that repeats every month on average; includes ovulation and, if pregnancy does not occur, also includes menstruation

**menstruation**
passage of blood from the uterus during a menstrual cycle; commonly called menstrual period

**Mesozoic Era**
era of the geologic time scale that lasted from 245 to 65 million years ago and is called the age of dinosaurs

**metabolism**

sum of all the biochemical reactions that take place in a living organism, including reactions that build up molecules and reactions that break down molecules

**metamorphosis**
process in which arthropods and many other animals change from a distinct larval form into the adult form

**metaphase**
second phase of mitosis when spindle fibers attach to centromeres of sister chromatids, which line up at the center of the cell

**methanogen**
type of archaean prokaryote that produces methane gas as a waste product of anaerobic respiration

**microevolution**
change in inherited traits of an organism that occurs over a relatively short period of time at the level of the population

**micronutrient**
type of nutrient the body needs in relatively small amounts; vitamin or mineral

**microscope**
device that makes magnified images of small objects so they are visible to the human eye

**migration**
movement of animals from one place to another to find more plentiful resources, or the movement of individuals into or out of a population

**mineral**
inorganic chemical element, such as calcium, that is needed in the diet in small amounts for normal body functioning

**mitochondrion (mitochondria, plural)**
organelle in eukaryotic cells that uses energy in glucose to make ATP, which cells can use for energy

**mitosis**
division of the nucleus in a eukaryotic cell, which occurs in four phases: prophase, metaphase, anaphase, and telophase

**mold**
type of fungus that grows in the form of multicellular filaments called hyphae

**molecular clock**
molecule such as protein or DNA that is compared in different species to gauge how recently they shared a common ancestor

**molecule**
smallest particle of a compound that still has that compound's properties

**mollusk**
invertebrate, such as a snail, in Phylum Mollusca that generally has a shell, head, and foot

**molting**
process in which an animal such as an insect sheds its outgrown exoskeleton

**monotreme**
member of the subclass of mammals that lay eggs, such as the platypus or echidna

**mucus**
sticky, moist secretion of mucous membranes that traps pathogens and particles, preventing them from entering the body

**muscle**
organ of the muscular system that is composed primarily of cells called muscle fibers, which have the ability to contract

**muscle fiber**
long, thin cell in muscle tissue that contains multiple nuclei, mitochondria, and organelles called myofibrils that allow the cell to contract

**muscle tissue**
type of tissue that consists of cells that can contract; includes skeletal, cardiac, and smooth muscle tissues

**muscular system**
human body system that includes muscles and tendons

**mutagen**
any factor in the environment, such as radiation or a chemical, that causes mutations

**mutation**
random change in the nitrogen base sequence of DNA or RNA

**mutualism**
type of symbiotic relationship in which both species benefit from the relationship

**mycelium (mycelia, plural)**
mass of hyphae that make up the body of a fungus, which may range in size from microscopic to enormous

**mycorrhiza**
symbiotic relationship between a fungus and a plant

**myofibril**
organelle in muscle fibers that allows muscles to contract

**myopia**
vision problem in which nearby objects can be seen clearly but distant objects appear blurry because images focus in front of the retina due to the eyeball being too long; also called nearsightedness

**MyPlate**
diagram that shows the relative amounts of five food groups you should eat at each meal for balanced eating

# 26.14 N

**natural resource**
something supplied by nature that helps support life, such as water, oxygen, or soil

**natural selection**
process in which living things with beneficial traits survive longer and produce more offspring so their traits increase in a population over time

**nephron**
one of the millions of identical functional units of the kidneys that filter blood and form urine

**nerve**
bundle of nerve cells through which electrical impulses travel in the nervous system

**nerve impulse**
electrical message that is carried by neurons and nerves of the nervous system

**nervous system**
organ system that consists of the brain, spinal cord, and a complex network of nerves running throughout the body and that functions as the control system of the body

**nervous tissue**
type of tissue that consists of cells that can send and receive electrical messages; includes tissues of the brain, spinal cord, and nerves that run throughout the body

**neuron**
cell that transmits electrical impulses in the nervous system; commonly called nerve cell

**niche**
role that a particular species plays in its ecosystem, including all the ways that the species interacts with the biotic and abiotic factors in the ecosystem

**nitrogen cycle**
biogeochemical cycle in which nitrogen passes back and forth between the atmosphere and organisms, including specialized bacteria in soil

**nocturnal**
of or relating to being active during the night, such as a nocturnal animal

**noninfectious disease**
disease that is not contagious because it is not caused by pathogens

**nonpoint-source pollution**
pollution that enters the environment from many different places, such as fertilizer in runoff that flows from land into a body of water

**nonrenewable resource**
any natural resource that cannot be remade or that takes too long to remake to keep up with human use

**notochord**
rigid rod that runs along the length of the body and is a defining trait of animals in Phylum Chordata

**nucleic acids**
class of biochemical compounds that includes DNA and RNA

**nucleus**
organelle in a eukaryotic cell that contains most of the cell's DNA

**nutrient**
any substance in food that the body needs

**nutrition facts label**
label on packaged food that shows the size, Calories, and major nutrients per serving

# 26.15 O

**obesity**
disorder in which a person has a high percentage of body fat, which increases the risk of diabetes, high blood pressure, and other health problems

**observation**
anything detected with the senses, which include sight, hearing, touch, smell, and taste

**observational learning**
way of learning by watching and copying the behavior of another individual

**ocean acidification**
increasing acidity of ocean water because it is dissolving more carbon dioxide from the atmosphere

**omnivore**
heterotroph that eats a variety of foods, including both plants and animals

**opposable thumb**
thumb that can be brought into opposition with the other fingers of the same hand so the hand can grasp and hold things

**order**
taxon below the class in biological classification that consists of one or more families

**organ**
structure composed of two or more types of tissues that work together to do a specific task

**organelle**
any structure inside a eukaryotic cell that is enclosed by a membrane and does a special job inside the cell

**organ system**
group of organs that work together to do the same overall job

**organism**
life form, or living thing

**osmosis**
diffusion of water

**ossification**
process in which mineral deposits replace cartilage in bone

**osteoporosis**
disease in which the bones become porous and weak because they do not contain enough calcium

**ovary**
one of a pair of female reproductive organs that produce eggs and secrete the hormone estrogen

**ovipary**
development of an embryo within an egg outside the mother's body

**ovovivipary**
development of an embryo within an egg inside the mother's body but without the embryo receiving any nourishment from the mother

**ovulation**
event in which an egg bursts out of its follicle and through the wall of an ovary

# 26.16 P

**paleontologist**
scientist who studies fossils to learn about the evolution of living things

**Paleozoic Era**
era of the geologic time scale that lasted from 544 to 245 million years ago and during which most major groups of multicellular organisms evolved

**pancreas**
gland in the digestive and endocrine systems that secretes digestive enzymes into the small intestine and secretes the hormone insulin into the bloodstream

**paralysis**
inability to feel or move certain parts of the body, usually due to a stroke or spinal cord injury

**parasite**
species that benefits and harms a host in a parasitic relationship

**parasitism**
type of symbiotic relationship in which one species benefits and the other species is harmed

**passive transport**
passage of a substance through the cell membrane that requires no energy because the substance is moving from a higher to lower concentration

**pathogen**
any organism or virus that causes disease in another living thing

**penis**
external, cylinder-shaped male organ containing the urethra through which urine and semen pass out of the body

**periosteum**
tough, fibrous membrane that covers and protects the outer surface of bone

**peripheral nervous system**
one of two main parts of the human nervous system that includes nerves that run throughout the body and consists of all the body's nervous tissue except for the brain and spinal cord

**peristalsis**
waves of muscle contractions in the organs of the gastrointestinal tract that keep food moving through the tract

**petal**
part of a flower that may be large, showy, and brightly colored to attract pollinators

**phagocyte**
type of white blood cell that consumes and destroys pathogens and dead cells by the process of phagocytosis

**phagocytosis**
process in which pathogens and dead cells are consumed and destroyed by a phagocyte

**phenotype**
expression of an organism's genotype as a trait in the organism

**photic zone**
top 200 meters of a body of water where enough sunlight penetrates to allow photosynthesis to take place

**photoautotroph**
type of producer that uses light energy to produce organic compounds by the process of photosynthesis

**photosynthesis**
process in which glucose is made from carbon dioxide and water using the energy in light

**phototropism**
growing toward light by the stems and leaves of a plant

**phylum**
taxon below the kingdom in biological classification that consists of one or more classes

**pioneer species**
first species that colonize an ecosystem after it has been disturbed

**pistil**
female reproductive organ in a flower that consists of a stigma, a style, and an ovary where eggs form and seeds develop

**pituitary gland**
pea-sized structure at the base of the brain that is called the master gland of the endocrine system because it secretes hormones that control most other endocrine glands

**placenta**
temporary, spongy organ that develops from both fetal and maternal tissues to nourish the fetus of a placental mammal

**placental mammal**
member of the largest subclass of mammals that give birth to a relatively large fetus after a long pregnancy during which a placenta develops to sustain the fetus

**plant**
multicellular, autotrophic eukaryote with cell walls of cellulose and chloroplasts for photosynthesis; any member of the Plant Kingdom

**Plant Kingdom**
kingdom in the Eukarya Domain that consists of multicellular organisms with cell walls of cellulose and chloroplasts for photosynthesis

**plasma**
golden-yellow liquid part of the blood that contains dissolved substances such as glucose, proteins, and gases

**plasmid**
small loop of DNA found inside most prokaryotic cells and exchanged between cells during genetic transfer

**platelet**
small, sticky cell fragment in blood that helps blood clot

**pneumonia**
respiratory disease in which some of the alveoli in the lungs fill with fluid so they can no longer exchange gas, causing coughing and other symptoms

**point-source pollution**
pollution that enters the environment from a single place, such as waste water from a factory discharged into a body of water through a pipe

**pollen**
tiny male gametophyte in seed plants that is enclosed in a tough capsule and that carries sperm to an ovule containing eggs or the stigma of a flower

**pollination**
process by which pollen is transferred from a male reproductive structure of a plant to a female reproductive structure of the same plant or a different plant of the same species so fertilization can occur

**pollinator**
animal such as an insect or bat that picks up pollen on its body and carries it to another flower of the same species for pollination

**polyp**
one of two cnidarian body forms (the other is the medusa), in which the animal is tubular and usually attached to a surface and unable to move

**population**
group of individuals of the same species that live in the same area; unit of microevolution

**population density**
average number of individuals in a population per unit of area, such as the average number of individuals per square kilometer

**population distribution**
: measure of how individuals in a population are spread out over the area they occupy

**population growth rate**
: measure of how quickly a population changes in size over time

**population pyramid**
: special bar graph that represents the numbers of individuals of each sex and age (or age group) in a population

**Precambrian**
: supereon at the beginning of the geologic time scale that lasted from 4.6 billion years ago when Earth formed to 544 million years ago and during which life first evolved on Earth

**precipitation**
: process in which moisture falls from clouds to the ground; may include rain, snow, sleet, hail, or freezing rain

**predation**
: relationship between species in a community in which members of one species consume members of another species

**predator**
: species that consumes the prey species in a predator-prey relationship

**pregnancy**
: carrying of one or more offspring by an expectant mother from the time of implantation in the uterus until birth

**prey**
: species that is consumed by a predator species in a predator-prey relationship

**primary succession**
: type of ecological succession that occurs in an area that has never before been colonized by living things and lacks soil

**primate**
: placental mammal in the Primate Order, which has five digits on each hand or foot and opposable thumbs

**producer**
: type of organism that uses light or chemical energy to produce organic compounds for itself and other living things

**prokaryote**
: single-celled organism that lacks a nucleus and other membrane-bound organelles; organism in the Archaea or Bacteria Domain

**prokaryotic cell**
: cell in which the cell's DNA is not enclosed within a nucleus and which lacks other membrane-bound organelles

**prophase**
: first phase of mitosis in which chromosomes form, the nuclear membrane breaks down, centrioles move to opposite poles of the cell (in an animal cell), and spindles form between centrioles

**prosimian**
: small primate such as a lemur or loris that is similar to the earliest primates

**prostate gland**
: male reproductive organ that secretes a fluid to help form semen

**proteins**
: class of biochemical compounds that consist of chains of amino acids

**protein synthesis**
: process in which a protein is made, consisting of transcription of DNA to RNA in the nucleus and translation of RNA to a protein at a ribosome in the cytoplasm

**protist**
: eukaryotic organism in the Protist Kingdom

**Protist Kingdom**
: kingdom in the Eukarya Domain that includes mainly single-celled organisms, including animal-like, plant-

like, and fungus-like protists

**protozoan (protozoa, plural)**
animal-like, usually single-celled organism in the eukaryotic Protist Kingdom

**pseudocoelom**
partial, fluid-filled body cavity not enclosed by mesoderm that is found in some invertebrates such as roundworms

**pseudopod**
temporary extension of the cytoplasm of a protozoan that is used for movement

**puberty**
stage of life when a child becomes sexually mature and grows rapidly; occurs from about 10 to 16 years in girls and 12 to 18 years in boys

**pulmonary circulation**
shorter of two loops of the cardiovascular system that carries blood between the heart and lungs

**Punnett square**
chart for determining the possible genotypes and their likely ratios in offspring of two parents of given genotypes

**pupa**
life stage of an arthropod when it is undergoing metamorphosis and changing from the larval to the adult form, often inside a cocoon

# 26.17 R

**recessive**
referring to an allele that is masked by the presence of another allele (called dominant) for the same gene when both are present in a heterozygote; or referring to a trait controlled by such an allele

**recycling**
breaking down and processing a used item so its components can be reused

**red blood cell**
type of blood cell that carries oxygen in the blood

**reflex behavior**
simple response that always occurs when a certain stimulus is present, such as the grasp reflex in human infants

**relative dating**
method of dating fossils based on their position in rock layers that determines only which fossils are older or younger but not their age in years

**renewable resource**
any natural resource that exists in limitless amounts or can be remade or recycled quickly enough to keep up with human use

**replication**
repeating a scientific investigation and getting the same results

**reproduction**
production of offspring

**reproductive system**
body system that controls reproduction

**reptile**
four-limbed, ectothermic vertebrate that produces amniotic eggs and has scaly skin

**respiration**
exchange of oxygen and carbon dioxide between the body and the outside air

**respiratory system**
organ system that exchanges gases with the outside air and includes the nose, trachea, and lungs

**response**
reaction to a stimulus by a living organism

**retina**
thin layer of light-sensing cells that covers the back of the human eye and is the location where images normally focus in the eye

**ribosome**
structure found in the cytoplasm of all cells that consists of RNA and proteins and is the site of protein synthesis

**RNA (ribonucleic acid)**
single-stranded nucleic acid that transcribes and translates the genetic code in DNA to make proteins, among other functions

**root**
plant organ that generally grows down into the soil to absorb water and nutrients from the soil

**roundworm**
invertebrate in Phylum Nematoda, such as a hookworm, which has a pseudocoelom and a complete digestive system

**runoff**

water that flows over the land from precipitation or melting snow or ice

# 26.18 S

**saprotroph**
type of decomposer that feeds on any remaining organic matter that is left after other decomposers do their work

**scavenger**
type of decomposer that consumes the soft tissues of dead animals

**science**
way of learning about the natural world that depends on evidence, reasoning, and repeated testing

**scientific law**
description of what always occurs under certain conditions in nature

**scientific method**
series of logical steps that scientists use to guide their research, which generally include making observations, asking a question, forming a hypothesis, testing the hypothesis, drawing a conclusion, and the communicating results

**scientific theory**
broad explanation that is widely accepted because it is supported by a great deal of evidence

**sebaceous gland**
gland in the dermis of the skin that produces an oily substance called sebum, which it secretes into a hair follicle

**sebum**
oily substance produced in the dermis by a sebaceous gland that waterproofs the hair and skin

**secondary succession**
type of ecological succession that occurs in a formerly inhabited area that was disturbed but already has soil

**seed**
reproductive structure produced by a seed plant that contains an embryo and food supply enclosed within a hull

**segmentation**
division of an animal's body into multiple parts, or segments

**semen**
whitish liquid containing sperm and secretions from the prostate gland that leaves the male body through the urethra in the penis

**semicircular canal**
fluid-filled, curved structure in the inner ear that senses head position and helps maintain balance

**sex chromosome**
one of two chromosomes (in humans, X or Y chromosome) that determine the sex of an individual in a sexually reproducing species

**sex-linked trait**
trait controlled by a gene on a sex chromosome

**sexually transmitted infection (STI)**
disease that spreads mainly through sexual contact and is caused by pathogens that enter the body through the reproductive organs or in some cases through contact with infected body fluids such as blood

**sexual reproduction**
production of offspring by two parents through the production and fertilization of gametes

**sickle-cell disease**
genetic disorder of the blood in which abnormal hemoglobin causes red blood cells to take on a characteristic sickle shape under certain conditions

**simple diffusion**
passive transport of a substance through a membrane without the help of transport proteins

**sixth mass extinction**
current rapid rate of species extinctions that is due mainly to human destruction of habitats

**skeletal muscle**
type of striated muscle tissue that is attached to bone and under conscious control

**skeletal system**
human body system that includes bones, cartilage, and ligaments

**small intestine**
long, narrow, tube-like organ of the digestive system between the stomach and large intestine that carries out most chemical digestion and nutrient absorption

**smooth muscle**
type of nonstriated muscle tissue that is found in the walls of internal organs and is not under conscious control

**social animal**
any species of animal in which individuals live together in groups and different animals within a group have different jobs so group members must work together for the good of all

**soil**
naturally occurring substance that consists of tiny pieces of rock, minerals, and decaying organic matter and is needed for the growth of most plants

**solar energy**
form of energy in sunlight

**spawning**
gathering of adult fish in the same place at the same time to release gametes into the water for reproduction

**specialist**
organism that has specialized traits for exploiting a specific food or other specific resource in the environment

**speciation**
evolution of a new species

**species**
narrowest taxon in biological classification that consists only of organisms that can breed and produce fertile offspring with each other but not with members of other such groups

**sperm**
gamete produced by a male parent

**spinal cord**
long, tube-shaped bundle of neurons that runs from the brain stem to the lower back and has the main function of carrying nerve impulses back and forth between the body and brain

**spleen**
organ of the immune system located in the abdomen that filters pathogens out of the blood

**sponge**
simple aquatic invertebrate in Phylum Porifera, which lives attached to surfaces and filters food from the water

**spongy bone**
type of bone tissue that lies below compact bone at the center of bone and contains many pores for blood vessels and bone marrow

**spore**
reproductive cell produced by fungi or plants

**sporophyte**
plant in the diploid generation that forms from the fertilization of gametes and reproduces asexually by producing haploid spores by meiosis

**sprain**
strain or tear in a ligament that has been twisted or stretched too far

**stamen**
male reproductive organ in a flower that has a stalk-like filament and ends in an anther where pollen forms

**starch**
: large, complex carbohydrate found in foods such as grains and vegetables that the body uses for energy

**stem**
: organ of a plant that holds the plant upright to get light and air and may also bears leaves, flowers, and/or cones

**stimulus**
: something in the environment that causes a reaction in an organism

**stoma (stomata, plural)**
: tiny pore in the leaf of a plant that can open and close to control the movement of gases between the leaf and the air

**stomach**
: sac-like organ of the digestive system between the esophagus and small intestine that carries out both mechanical and chemical digestion

**stroma**
: fluid-filled space inside a chloroplast where the second stage of photosynthesis (Calvin cycle) occurs

**sublimation**
: process in which snow or ice changes directly to water vapor without first changing to liquid water

**sustainable use**
: use of natural resources in a way that meets present human needs and also conserves resources for future generations

**sweat**
: salty fluid produced by glands in the skin of mammals that helps cool the body when it evaporates

**sweat gland**
: gland in the dermis of the skin that produces the salty fluid called sweat

**swim bladder**
: balloon-like organ in many fish that can be inflated or deflated so the fish can rise or sink in the water

**symbiosis**
: close relationship between two species in a community in which at least one species benefits, while the other species may benefit, be harmed, or be unaffected; types of symbiosis include mutualism, parasitism, and commensalism

**symmetry**
: trait of an organism that can be divided into two identical halves; may be radial or bilateral

**synapse**
: tiny gap between two adjacent neurons across which electrical messages are carried by chemicals called neurotransmitters

**syphilis**
: sexually transmitted infection caused by bacteria that starts out as a sore on the genitals and that can eventually cause death if it goes untreated

**systemic circulation**
: longer of two loops of the cardiovascular system that carries blood between the heart and rest of the body except the lungs

# 26.19 T

**tadpole**
aquatic, legless larval stage of a frog

**tapeworm**
flatworm in Phylum Platyhelminthes that infects the intestines of a human or other vertebrate host

**target cell**
type of cell on which a given hormone has an effect because it has surface proteins to which the hormone can bind

**taste bud**
bundle of sensory neurons on the tongue that sense the taste of chemicals in food

**taxon**
category in a biological classification system, such as the kingdom or species

**taxonomy**
science of classifying living things

**telophase**
final phase of mitosis in which chromosomes uncoil, spindle fibers break down, and new nuclear membranes form

**tendon**
tough connective tissue that anchors a skeletal muscle to a bone

**terrestrial**
of or relating to the land, such as an organism that lives on land rather than in water

**terrestrial biome**
group of similar, land-based ecosystems, such as tropical rainforests, temperate grasslands, or tundras

**territorial**
of or relating to an animal that defends a given area, or territory, typically including its nest and enough space to feed itself and its young

**testis (testes, plural)**
one of a pair of oval male reproductive organs that produce sperm and secrete the hormone testosterone

**testosterone**
main male sex hormone that causes most of the changes of puberty and is needed by an adult male for the production of sperm

**theory of evolution by natural selection**
theory first proposed by Charles Darwin stating that inherited traits of organisms change over time because organisms with beneficial traits survive longer and produce more offspring so their traits increase in frequency

**thermal pollution**
reduction in the quality of water because of an increase in water temperature

**thylakoid**
flattened sac of membrane inside a chloroplast where the first stage of photosynthesis (light reactions) occurs

**thymus gland**
organ of the immune system located in the chest that stores lymphocytes called T cells while they mature

**thyroid gland**
relatively large endocrine gland in the neck that secretes hormones such as thyroxin, which increases the rate of metabolism in cells throughout the body

**tissue**
group of specialized cells of the same kind that perform the same function

**tonsil**

one of a pair of immune system organs located on either side of the throat that trap pathogens entering the body through the mouth or nose

**touch**
: ability to sense pain, pressure, or temperature

**trachea**
: respiratory system organ that consists of a long tube through which air passes from the throat to the lungs; commonly called the wind pipe

**transcription**
: first of two steps of protein synthesis in which RNA makes a copy of the genetic code in DNA in the nucleus of a cell

**trans fat**
: harmful, artificial lipid that is added to some processed foods to preserve freshness

**translation**
: second of two steps of protein synthesis in which the genetic code in RNA is read and amino acids are joined together to form a protein at a ribosome in the cytoplasm

**transpiration**
: release of water vapor into the atmosphere from stomata in the leaves of plants

**transport**
: passage of a substance through a cell membrane

**transport protein**
: protein in a cell membrane that helps molecules pass through the membrane, by either forming a channel for the molecules or carrying the molecules through the membrane

**trophic level**
: feeding position in a food chain or food web

**tropism**
: turning toward, or away from, a stimulus in the environment

**tumor**
: mass of abnormal tissue that may form when cancerous cells divide out of control

**tunicate**
: aquatic invertebrate in Phylum Chordata that loses some of the four defining chordate traits by adulthood; commonly called a sea squirt

**type 1 diabetes**
: type of diabetes that usually develops in childhood or adolescence and is caused by the immune system attacking insulin-producing cells of the pancreas

**type 2 diabetes**
: type of diabetes that usually develops in adulthood and is caused by body cells no longer responding normally to insulin

# 26.20 U

**umbilical cord**
long tube containing two arteries and a vein that connects a fetus to the placenta

**ureter**
one of a pair of muscular tubes in the urinary system that carries urine between a kidney and the urinary bladder

**urethra**
muscular tube in the urinary system that carries urine from the urinary bladder out of the body

**urinary bladder**
sac-like organ in the urinary system that stores urine from the kidneys until it exits the body

**urinary system**
organ system that filters blood, forms urine, and excretes urine from the body; includes the kidneys, ureters, urinary bladder, and urethra

**urinary tract infection**
infection in the urinary system, most commonly in the urinary bladder

**urination**
process of urine leaving the body through the urethra

**urine**
liquid containing excess water and waste that forms in the kidneys and is excreted from the body

**uterus**
hollow female reproductive organ with muscular walls where a baby develops until birth

# 26.21 V

**vaccination**
process of deliberately exposing a person to a pathogen, usually by injection, so the person will develop immunity to it

**vacuole**
sac-like organelle in a cell that stores materials in the cell

**vagina**
cylinder-shaped female reproductive organ where sperm are deposited and through which a baby passes during birth

**valve**
flap in the heart or a blood vessel that opens to allow blood to flow through in one direction and then closes to prevent blood from flowing back in the opposite direction

**vascular tissue**
type of tissue in plants that transports fluid throughout the plant; consists of xylem, which carries fluid from the roots to the leaves, and phloem, which carries fluid from the leaves to the rest of the plant

**vas deferens**
tube-like male reproductive organ that carries sperm from the epididymis to the urethra

**vector**
organism, commonly an insect, that spreads bacteria or other pathogens

**vein**
thin-walled blood vessel that generally carries oxygen-poor blood toward the heart

**ventricle**
either of the two lower chambers of the heart; right ventricle or left ventricle

**vertebra (vertebrae, plural)**
one of the repeating units of bone that make up the vertebral column (backbone) of a vertebrate

**vertebral column**
backbone; defining characteristic of the subphylum of animals called vertebrates

**vertebrate**
animal in Phylum Chordata that has a vertebral column, or backbone

**vesicle**
sac-like organelle smaller than a vacuole that may have a variety of functions, such as storing and transporting substances or providing a chamber for biochemical reactions

**vesicle transport**
use of a vesicle to actively transport a substance across a cell membrane

**vestigial structure**
inherited structure that is no longer used but is still present in a modern organism who inherited it from an ancestor that used the structure

**villi (villus, singular)**
tiny projections covering the inner surface of the jejunum and ileum of the small intestine that greatly increase the surface area for absorption of nutrients

**virus**
DNA or RNA surrounded by a coat of proteins that uses living cells to reproduce and can evolve but which many scientists do not consider to be a living thing

**vision**
ability to sense light, form images, and see

**vitamin**

organic compound, such as vitamin C, that the body needs in small amounts to function properly

**vivipary**

development and nourishment of an embryo within the mother's body and not inside an egg

# 26.22 W

**waterborne disease**
: disease caused by drinking water that contains pathogens

**water cycle**
: biogeochemical cycle in which water passes back and forth between the ocean, ground, atmosphere, and organisms

**water pollution**
: addition of chemicals, sewage, trash, or heat to water resources

**wetland**
: habitat such as a swamp, marsh, or bog where the ground is soggy or covered with water much of the year

**white blood cell**
: type of blood cell that helps defend the body

**wind energy**
: form of energy in blowing wind

# 26.23 X

**xerophyte**

type of plant that is adapted to a very dry environment

# 26.24 Y

**yeast**
type of fungus that exists as a single-celled organism

## 26.25 Z

**zygote**
cell with the diploid number of chromosomes that forms when two gametes unite during fertilization