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CK-12 Biology

Biology

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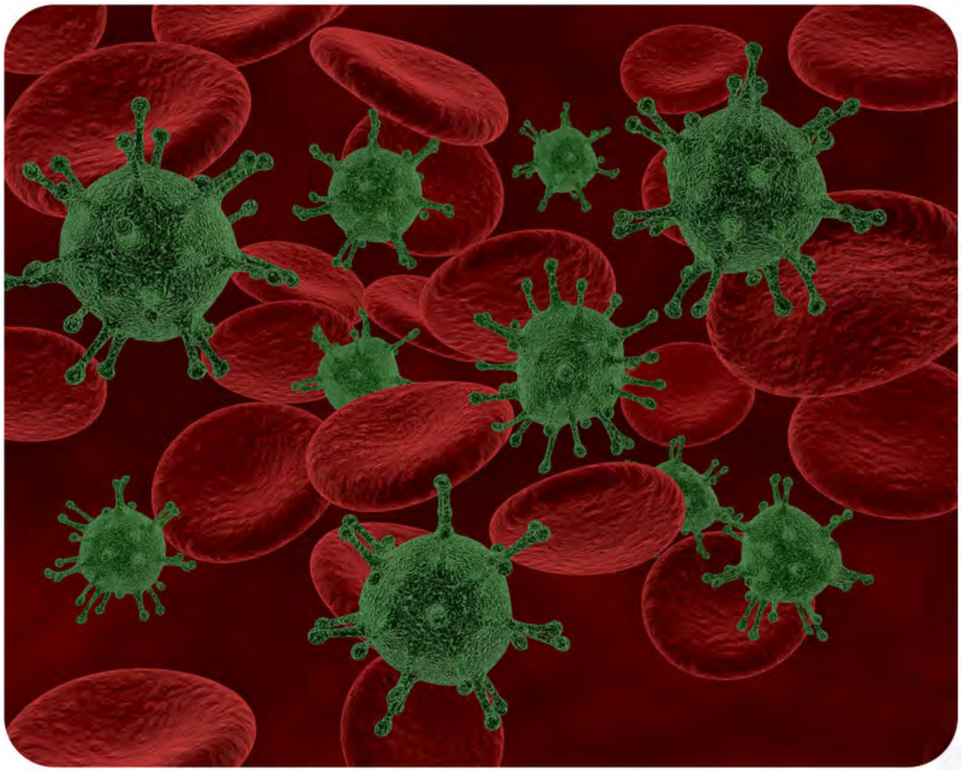
CHAPTER 1 What is Biology?

CHAPTER OUTLINE



Is this picture a colorful work of abstract art, or is it something else? Imagine shrinking down to a tiny size, so small you could enter a blood vessel. The picture shows what you might see rushing toward you. Do you know what the red objects are? If you guessed red blood cells, you are right. What about the knobby green objects? Watch out for these! They are viruses that have invaded the blood. When you read this book, you will take an exciting journey into the realm of blood cells, viruses, and just about everything else that is related to life. You will learn how your own body works, what makes living things unique, and what you and viruses have in common. This first chapter explains how scientists learn about the natural world and introduces you to biology, the science of life.

1.1 Science and the Natural World

Lesson Objectives

- Identify the goal of science.
- Describe how scientists study the natural world.
- Explain how and why scientists do experiments.
- Describe types of scientific investigations.
- Explain what a scientific theory is.

Vocabulary

dependent variable variable in a scientific experiment that is affected by another variable, called the independent variable

evidence any type of data that may be used to test a hypothesis

experiment special type of scientific investigation that is performed under controlled conditions

hypothesis possible answer to a scientific question; must be falsifiable

independent variable variable in a scientific experiment that is manipulated by the researcher to investigate its affect on another variable, called the dependent variable

model representation of part of the real world

observation anything that is detected with the senses

prediction statement that tells what will happen under certain conditions

science distinctive way of gaining knowledge about the natural world that tries to answer questions with evidence and logic

scientific investigation plan for asking questions and testing possible answers

scientific law statement describing what always happens under certain conditions in nature

scientific method the process of a scientific investigation

scientific theory broad explanation that is widely accepted as true because it is supported by a great deal of evidence

Introduction

Did you ever wonder why giraffes have such long necks or how birds learn to sing their special songs? If you ever asked questions such as these about the natural world, then you were thinking like a scientist. The word *science* comes from a Latin word that means "knowledge." **Science** is a distinctive way of gaining knowledge about the natural world that starts with a question and then tries to answer the question with evidence and logic. Science is an exciting exploration of all the whys and hows that any curious person might have about the world. You can be part of that exploration. Besides your curiosity, all you need is a basic understanding of how scientists think and how science is done, starting with the goal of science.

The Goal of Science

The goal of science is to understand the natural world. To achieve this goal, scientists make certain assumptions. They assume that:

- Nature can be understood through systematic study.
- Scientific ideas are open to revision.
- Sound scientific ideas withstand the test of time.
- Science cannot provide answers to all questions.

Nature Can Be Understood

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

An example of a scientific law is the law of gravity, which was discovered by Sir Isaac Newton (see **Figure** 1.1). The law of gravity states that objects always fall towards Earth because of the pull of gravity. Based on this law, Newton could explain many natural events. He could explain not only why objects such as apples always fall to the ground, but he could also explain why the moon orbits Earth. Isaac Newton discovered laws of motion as well as the law of gravity. His laws of motion allowed him to explain why objects move as they do.

Scientific Ideas Can Change

Science is more of a process than a set body of knowledge. Scientists are always testing and revising their ideas, and as new observations are made, existing ideas may be challenged. Ideas may be replaced with new ideas that better fit the facts, but more often existing ideas are simply revised. For example, when Albert Einstein developed his theory of relativity, he didn't throw out Newton's laws of motion. Instead, he showed that Newton's laws are a part of a bigger picture. In this way, scientists gradually build an increasingly accurate and detailed understanding of the natural world.

Scientific Knowledge Can Withstand the Test of Time

Many scientific ideas have withstood the test of time. For example, about 200 years ago, the scientist John Dalton proposed atomic theory—the theory that all matter is made of tiny particles called atoms. This theory is still valid today. There are many other examples of basic science ideas that have been tested repeatedly and found to be true. You will learn about many of them as you study biology.

FIGURE 1.1
Did Newton discover the law of gravity when an apple fell from a tree and hit him on the head Probably not but observations of nature are often the starting point for new ideas about the natural world.

Science Cannot Answer All Questions

Science rests on evidence and logic, so it deals only with things that can be observed. An **observation** is anything that is detected either through human senses or with instruments and measuring devices that extend human senses. Things that cannot be observed or measured by current means—such as supernatural beings or events—are outside the bounds of science. Consider these two questions about life on Earth:

- Did life on Earth evolve over time?
- Was life on Earth created through another method?

The first question can be answered by science on the basis of scientific evidence and logic. The second question could be a matter of belief. Therefore, it is outside the realm of science.

The Scientific Method

"We also discovered that science is cool and fun because you get to do stuff that no one has ever done before." In the article *Blackawton bees,* published by eight to ten year old students: Biology Letters (2010) http://rsbl.royalsocietypublishing.org/content/early/2010/12/18/rsbl.2010.1056.abstract.

There are basic methods of gaining knowledge that are common to all of science. At the heart of science is the scientific investigation, which is done by following the **scientific method**. A **scientific investigation** is a plan for asking questions and testing possible answers. It generally follows the steps listed in **Figure** 1.2 . See http://www.youtube.com/watch?v=KZaCy5Z87FA for an overview of the scientific method.

- See *Multimedia Resources* for a video complementing this information.

Making Observations

A scientific investigation typically begins with observations. You make observations all the time. Let's say you take a walk in the woods and observe a moth, like the one in **Figure** 1.3 , resting on a tree trunk. You notice that the moth

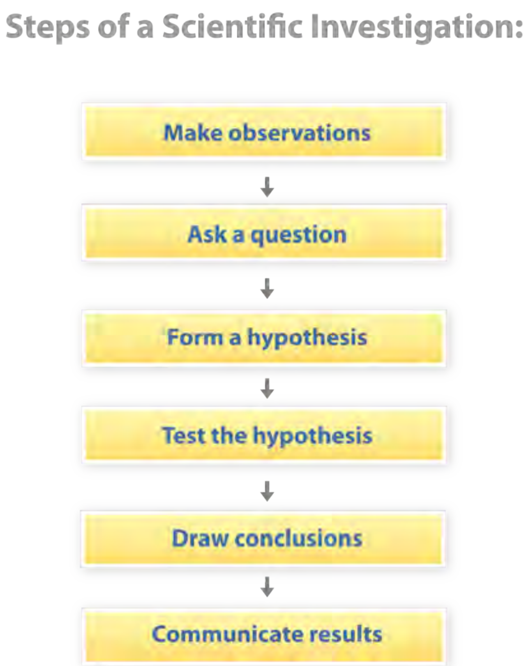


FIGURE 1.2
Steps of a Scientific Investigation. A scientific investigation typically has these steps.

has spots on its wings that look like eyes. You think the eye spots make the moth look like the face of an owl.

FIGURE 1.3
Does this moth remind you of an owl

Asking a Question

Observations often lead to questions. For example, you might ask yourself why the moth has eye spots that make it look like an owl's face. What reason might there be for this observation?

Forming a Hypothesis

The next step in a scientific investigation is forming a hypothesis. A **hypothesis** is a possible answer to a scientific question, but it isn't just any answer. A hypothesis must be based on scientific knowledge, and it must be logical. A hypothesis also must be falsifiable. In other words, it must be possible to make observations that would disprove the hypothesis if it really is false. Assume you know that some birds eat moths and that owls prey on other birds. From this knowledge, you reason that eye spots scare away birds that might eat the moth. This is your hypothesis.

Testing the Hypothesis

To test a hypothesis, you first need to make a prediction based on the hypothesis. A **prediction** is a statement that tells what will happen under certain conditions. It can be expressed in the form: If A occurs, then B will happen. Based on your hypothesis, you might make this prediction: If a moth has eye spots on its wings, then birds will avoid eating it.

Next, you must gather evidence to test your prediction. **Evidence** is any type of data that may either agree or disagree with a prediction, so it may either support or disprove a hypothesis. Assume that you gather evidence by making more observations of moths with eye spots. Perhaps you observe that birds really do avoid eating the moths. This evidence agrees with your prediction.

Drawing Conclusions

Evidence that agrees with your prediction supports your hypothesis. Does such evidence prove that your hypothesis is true? No; a hypothesis cannot be proven conclusively to be true. This is because you can never examine all of the possible evidence, and someday evidence might be found that disproves the hypothesis. Nonetheless, the more evidence that supports a hypothesis, the more likely the hypothesis is to be true.

Communicating Results

The last step in a scientific investigation is communicating what you have learned with others. This is a very important step because it allows others to test your hypothesis. If other researchers get the same results as yours, they add support to the hypothesis. However, if they get different results, they may disprove the hypothesis. When scientists share their results, they should describe their methods and point out any possible problems with the investigation. For example, while you were observing moths, perhaps your presence scared birds away. This introduces an error into your investigation. You got the results you predicted (the birds avoided the moths while you were observing them), but not for the reason you hypothesized. Other researchers might be able to think of ways to avoid this error in future studies.

Experiments

Figure 1.4 shows a laboratory experiment involving plants. An **experiment** is a special type of scientific investigation that is performed under controlled conditions, usually in a laboratory. Some experiments can be very simple, but even the simplest contributed important evidence that helped scientists better understand the natural world. An example experiment can be seen here http://www.youtube.com/watch?v=dVRBDRAsP6U or here http://www.youtube.com/watch?v=F10EyGwd57M#38;feature=related.

KQED: Medicine From the Ocean Floor

Some experiments are much more sophisticated than those shown above. For example, scientists at the University of California, Santa Cruz are using robots to sort through thousands of marine chemicals in search of cures for diseases like cholera, breast cancer, and malaria. These experiments are described in the following links:

http://www.kqed.org/quest/blog/2009/03/20/reporters-notes-medicine-from-the-ocean-floor/

http://www.kqed.org/quest/radio/medicine-from-the-ocean-floor

http://www.kqed.org/quest/slideshow/medicine-from-the-ocean-floor-slideshow

FIGURE 1.4
A laboratory experiment studying plant growth. What might this experiment involve

Variables

An experiment generally tests how one variable is affected by another. The affected variable is called the **dependent variable**. In the plant experiment shown above, the dependent variable is plant growth. The variable that affects the dependent variable is called the **independent variable**. In the plant experiment, the independent variable is fertilizer—some plants will get fertilizer, others will not. In any experiment, other factors that might affect the dependent variable must be controlled. In the plant experiment, what factors do you think should be controlled? (*Hint:* What other factors might affect plant growth?)

Sample Size and Repetition

The sample in an experiment or other investigation consists of the individuals or events that are studied. Typically, the sample is much smaller than all such individuals or events that exist in the world. Whether the results based on the sample are true in general cannot be known for certain. However, the larger the sample is, the more likely it is that the results are generally true. Similarly, the more times that an experiment is repeated and the same results obtained, the more likely the results are valid. This is why scientific experiments should always be repeated.

Other Types of Scientific Investigations

Experiments are sometimes hard or even impossible to do. For example, a scientist who is studying an extinct animal cannot experiment with the animal because it no longer exists. The scientist must rely instead on evidence in the natural world, such as fossils that the extinct animal left behind.

Natural Studies

When scientists do studies in nature, they usually cannot control factors that might affect the variables they are investigating. This is a drawback, because it may make the observations difficult to interpret. Without controls, it may not be possible to determine which of many factors explain the observations. For example, assume you are studying how plants grow in a forest or field. You cannot control the amount of sunlight or rain water the plants receive, so it will be difficult to determine which factors most influence plant growth. On the other hand, a natural study shows what actually occurs in nature. Therefore, it may provide a truer picture of what happens in the real world than an experiment does.

Modeling

Another way to gain scientific knowledge without experiments is by making and manipulating models. A **model** is a representation of part of the real world. Did you ever build a model car? Scientific models are something like model cars; they represent the real world but are simpler than the real world. This is one reason that models are especially useful for investigating complex systems. By using a model, scientists can better understand how the real system works. An example of a scientific model is shown in **Figure** 1.5 . Do you know what systems these two models represent?

FIGURE 1.5

Food Chains. These two food chains represent complex systems in nature. They make the systems easier to understand. These are simple conceptual models. Models of very complex systems are often based on mathematical equations or computer simulations.

Like a hypothesis, a model must be evaluated. It is assessed by criteria such as how well it represents the real world, what limitations it has, and how useful it is. The usefulness of a model depends on how well its predictions match observations of the real world. Even when a model's predictions match real-world observations, however, it doesn't prove that the model is true or that it is the only model that works.

Scientific Theories

With repeated testing, some hypotheses may eventually become scientific theories. A **scientific theory** is a broad explanation for events that is widely accepted as true. To become a theory, a hypothesis must be tested over and over again, and it must be supported by a great deal of evidence. People commonly use the word *theory* to describe a guess about how or why something happens. For example, you might say, "I think a woodchuck dug this hole in the ground, but it's just a theory." Using the word *theory* in this way is different from the way it is used in science. A scientific theory is more like a fact than a guess because it is so well-supported. There are several well-known theories in biology, including the theory of evolution, cell theory, and germ theory. You will read about all three of these theories in the next lesson. A video explaining scientific theories can be seen at http://www.youtube.com/watch?v=S5YGhprR6KE.

- See *Multimedia Resources* for a video complementing this information.

KQED: Bio-Inspiration: Nature as Muse

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

MEDIA

Click image to the left for more content.

Lesson Summary

- The goal of science is to understand the natural world through systematic study. Scientific knowledge is based on evidence and logic.
- Scientists gain knowledge through scientific investigations. A scientific investigation is a plan for asking questions and testing possible answers.
- Scientists use experiments to test hypotheses under controlled conditions. Experiments are often done in a lab.
- Other types of scientific investigations include natural studies and modeling. They can be used when experiments are difficult to do.
- Scientific theories are broad explanations that are widely accepted as true. This is because they are supported by a great deal of evidence.

Lesson Review Questions

Recall

1. What is science? What is the goal of science?

2. Outline the steps of a scientific investigation.

3. What is a scientific hypothesis? What characteristics must a hypothesis have to be useful in science?

4. Give an example of a scientific question that could be investigated with an experiment. Then give an example of scientific question that could not be investigated in this way.

5. What might be an advantage of collecting evidence in a natural setting rather than in a lab?

Apply Concepts

6. Identify the independent and dependent variables in the following experiment:
   A scientist grew bacteria on gel in her lab. She wanted to find out if the bacteria would grow faster on gel A or gel B. She placed a few bacteria on gel A and a few on gel B. After 24 hours, she observed how many bacteria were present on each type of gel.

Think Critically

7. Explain why science cannot provide answers to all questions.
8. Contrast how the term *theory* is used in science and in everyday language.
9. Explain how a hypothesis could become a theory.

Points to Consider

The Points to Consider at the end of each lesson in this book will help you relate what you just learned to what is coming next. The questions will help guide you to the next lesson or chapter. Before reading the next lesson of this chapter, consider these points:

- Remember the opening photo of red blood cells and green viruses? The blood cells are cells of a living thing. Do you think that the viruses are living things? Why or why not?
- Lab experiments are the main method of gathering evidence in some branches of science. Why might lab experiments not be the best way to study living things, such as wild animals?

1.2 Biology: The Study of Life

Lesson Objectives

- List the characteristics of all living things.
- State four unifying principles of biology.
- Describe how living things interact.
- Explain how life on Earth evolves.

Vocabulary

adaptation characteristic that helps living things survive and reproduce in a given environment

biodiversity the variety of life and its processes; including the variety of living organisms, the genetic differences among them, and the communities and ecosystems in which they occur

biology science of life, study of life

biome group of similar ecosystems with the same general type of physical environment

biosphere part of Earth where all life exists, including land, water, and air

cell basic unit of structure and function of living things

cell theory theory that all living things are made up of cells, all life functions occur within cells, and all cells come from already existing cells

community all of the populations of different species that live in the same area

competition relationship between living things that depend on the same resources in the same place and at the same time

ecosystem all the living things in a given area together with the physical factors of the nonliving environment

evolution change in the characteristics of living things over time, the change in species over time

gene theory theory that the characteristics of living things are controlled by genes that are passed from parents to offspring

homeostasis process of maintaining a stable environment inside a cell or an entire organism

natural selection evolutionary process in which some living things produce more offspring than others so the characteristics of organisms change over time

organ structure composed of more than one type of tissue that performs a particular function

organ system group of organs that work together to do a certain job

organism an individual living thing

population all the organisms of the same species that live in the same area

reproduction process by which living things give rise to offspring

symbiosis close relationship between organisms of different species in which at least one of the organisms benefits from the relationship

tissue group of cells of the same kind that perform a particular function in an organism

Introduction

In this book, you will learn about one particular branch of science, the branch called biology. **Biology** is the science of life. Do you know what life is? Can you define it? Watch http://vimeo.com/14142144 or http://vimeo.com/16794275 to begin your journey into the study of life.

Characteristics of Life

Look at the duck decoy in **Figure** 1.6 . It looks very similar to a real duck. Of course, real ducks are living things. What about the decoy duck? It looks like a duck, but it is actually made of wood. The decoy duck doesn't have all the characteristics of a living thing. What characteristics set the real ducks apart from the decoy duck? What are the characteristics of living things?

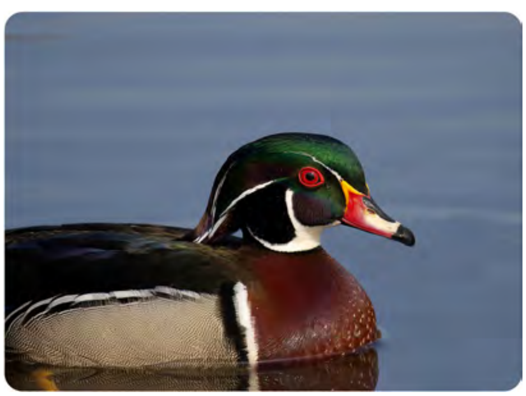


FIGURE 1.6
This duck decoy looks like it&#8217 s alive. It even fools real ducks. Why isn&#8217 t it a living thing

To be classified as a living thing, an object must have all six of the following characteristics:

a. It responds to the environment.
b. It grows and develops.
c. It produces offspring.
d. It maintains homeostasis.
e. It has complex chemistry.
f. It consists of cells.

Response to the Environment

All living things detect changes in their environment and respond to them. What happens if you step on a rock? Nothing; the rock doesn't respond because it isn't alive. But what if you think you are stepping on a rock and actually step on a turtle shell? The turtle is likely to respond by moving—it may even snap at you!

Growth and Development

All living things grow and develop. For example, a plant seed may look like a lifeless pebble, but under the right conditions it will grow and develop into a plant. Animals also grow and develop. Look at the animals in **Figure** 1.7 . How will the tadpoles change as they grow and develop into adult frogs?

FIGURE 1.7
Tadpoles go through many changes to become adult frogs.

Reproduction

All living things are capable of reproduction. **Reproduction** is the process by which living things give rise to offspring. Reproducing may be as simple as a single cell dividing to form two daughter cells. Generally, however, it is much more complicated. Nonetheless, whether a living thing is a huge whale or a microscopic bacterium, it is capable of reproduction.

Keeping Things Constant

All living things are able to maintain a more-or-less constant internal environment. They keep things relatively stable on the inside regardless of the conditions around them. The process of maintaining a stable internal environment is called **homeostasis**. Human beings, for example, maintain a stable internal body temperature. If you go outside when the air temperature is below freezing, your body doesn't freeze. Instead, by shivering and other means, it maintains a stable internal temperature.

Complex Chemistry

All living things—even the simplest life forms—have complex chemistry. Living things consist of large, complex molecules, and they also undergo many complicated chemical changes to stay alive. Complex chemistry is needed to carry out all the functions of life.

Cells

All forms of life are built of cells. A **cell** is the basic unit of the structure and function of living things. Living things may appear very different from one another on the outside, but their cells are very similar. Compare the human cells in **Figure** 1.8 and onion cells in **Figure** 1.9 . How are they similar? If you click on the animation titled *Inside a Cell* at the link below, you can look inside a cell and see its internal structures. http://bio-alive.com/animations/cell-biology.htm

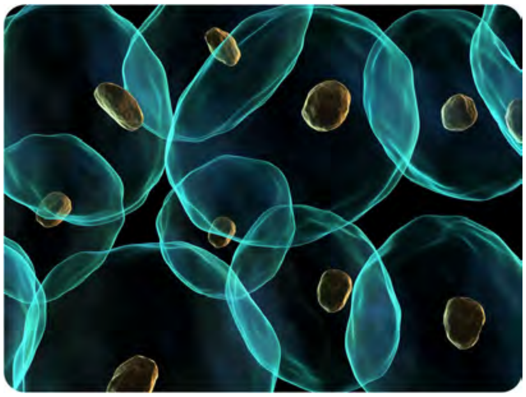


FIGURE 1.8
Human Cells. If you looked at human cells under a microscope this is what you might see.

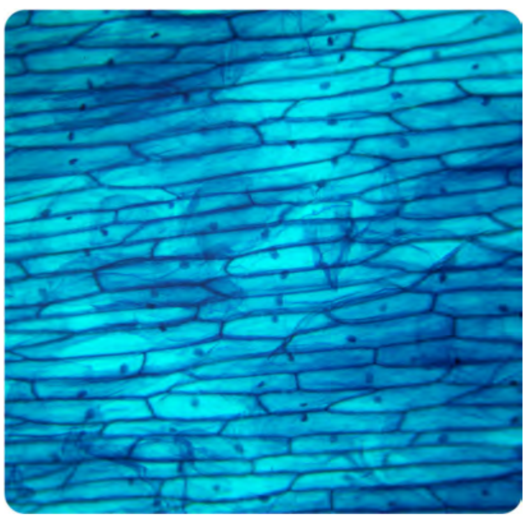


FIGURE 1.9
Onion Cells. If you looked at onion cells under a microscope this is what you might see.

Unifying Principles of Biology

Four unifying principles form the basis of biology. Whether biologists are interested in ancient life, the life of bacteria, or how humans could live on the moon, they base their overall understanding of biology on these four principles:

a. cell theory

b. gene theory
c. homeostasis
d. evolution

The Cell Theory

According to the **cell theory**, all living things are made up of cells, and living cells always come from other living cells. In fact, each living thing begins life as a single cell. Some living things, such as bacteria, remain single-celled. Other living things, including plants and animals, grow and develop into many cells. Your own body is made up of an amazing 100 trillion cells! But even you—like all other living things—began life as a single cell. More of the cell theory will be discussed in a later chapter.

The Gene Theory

The **gene theory** is the idea that the characteristics of living things are controlled by genes, which are passed from parents to their offspring. Genes are located on larger structures, called chromosomes, that are found inside every cell. Chromosomes, in turn, contain large molecules known as DNA (deoxyribonucleic acid). Molecules of DNA are encoded with instructions that tell cells what to do. To see how this happens, click on the animation titled *Journey into DNA* at the link below. http://www.pbs.org/wgbh/nova/genome/dna.html

Homeostasis

Homeostasis, or keeping things constant, is not just a characteristic of living things. It also applies to nature as a whole. Consider the concentration of oxygen in Earth's atmosphere. Oxygen makes up 21% of the atmosphere, and this concentration is fairly constant. What keeps the concentration of oxygen constant? The answer is living things. Most living things need oxygen to survive, and when they breathe, they remove oxygen from the atmosphere. On the other hand, many living things, including plants, give off oxygen when they make food, and this adds oxygen to the atmosphere. The concentration of oxygen in the atmosphere is maintained mainly by the balance between these two processes. A quick overview of homeostasis can be viewed at http://www.youtube.com/watch?v=DFyt7FJn-UM.

Evolution

Evolution is a change in the characteristics of living things over time. Evolution occurs by a process called natural selection. In **natural selection**, some living things produce more offspring than others, so they pass more genes to the next generation than others do. Over many generations, this can lead to major changes in the characteristics of living things. Evolution explains how living things are changing today and how modern living things have descended from ancient life forms that no longer exist on Earth. As living things evolve, they generally become better suited for their environment. This is because they evolve adaptations. An **adaptation** is a characteristic that helps a living thing survive and reproduce in a given environment. Look at the mole in **Figure** 1.10 . It has tentacles around its nose that it uses to sense things by touch. The mole lives underground in the soil where it is always dark. However, by using its touch organ, it can detect even tiny food items in the soil in total darkness. The touch organ is an adaptation because it helps the mole survive in its dark, underground environment.

A cartoon depicting the evolution of Homer (Simpson) can be viewed at http://www.youtube.com/watch?v=faRlFsYmkeY.

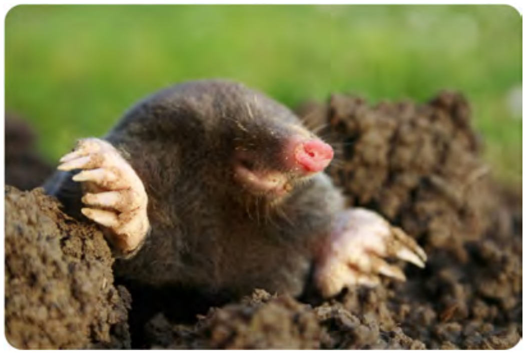


FIGURE 1.10
This mole uses its star-shaped nose organ to sense food by touch in the dark. The mole&#8217 s very large front claws are also an adaptation for its life in the soil. Can you explain why

Interdependence of Living Things

All living things depend on their environment to supply them with what they need, including food, water, and shelter. Their environment consists of physical factors—such as soil, air, and temperature—and also of other organisms. An **organism** is an individual living thing. Many living things interact with other organisms in their environment. In fact, they may need other organisms in order to survive. For example, living things that cannot make their own food must eat other organisms for food. Other interactions between living things include symbiosis and competition.

Symbiosis

Symbiosis is a close relationship between organisms of different species in which at least one of the organisms benefits. The other organism may also benefit, or it may be unaffected or harmed by the relationship. **Figure** 1.11 shows an example of symbiosis. The birds in the picture are able to pick out food from the fur of the deer. The deer won't eat the birds. In fact, the deer knowingly lets the birds rest on it. What, if anything, do you think the deer gets out of the relationship?

FIGURE 1.11
A flock of starlings looks out before searching for parasites on a red deer stag.

Competition

Competition is a relationship between living things that depend on the same resources. The resources may be food, water, or anything else they both need. Competition occurs whenever they both try to get the same resources in the same place and at the same time. The two organisms are likely to come into conflict, and the organism with better adaptations may win out over the other organism.

Levels of Organization

The living world can be organized into different levels. For example, many individual organisms can be organized into the following levels:

- Cell: basic unit of all living things
- **Tissue**: group of cells of the same kind
- **Organ**: structure composed of one or more types of tissues
- **Organ system**: group of organs that work together to do a certain job
- Organism: individual living thing that may be made up of one or more organ systems

Examples of these levels of organization are shown in **Figure** 1.12 .

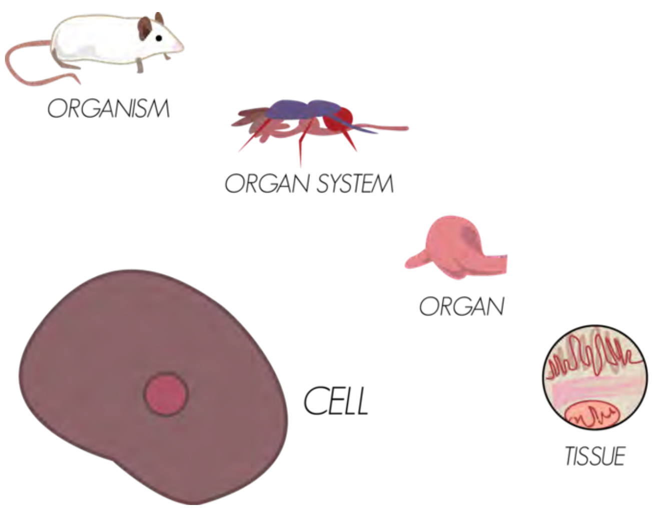


FIGURE 1.12
An individual mouse is made up of several organ systems. The system shown here is the digestive system which breaks down food to a form that cells can use. One of the organs of the digestive system is the stomach. The stomach in turn consists of different types of tissues. Each type of tissue is made up of cells of the same type.

There are also levels of organization above the individual organism. These levels are illustrated in **Figure** 1.13 .

- Organisms of the same species that live in the same area make up a **population**. For example, all of the goldfish living in the same area make up a goldfish population.
- All of the populations that live in the same area make up a **community**. The community that includes the goldfish population also includes the populations of other fish, coral and other organisms.
- An **ecosystem** consists of all the living things in a given area, together with the nonliving environment. The nonliving environment includes water, sunlight, and other physical factors.
- A group of similar ecosystems with the same general type of physical environment is called a **biome**.
- The **biosphere** is the part of Earth where all life exists, including all the land, water, and air where living things can be found. The biosphere consists of many different biomes.

Diversity of Life

Life on Earth is very diverse. The diversity of living things is called **biodiversity**. A measure of Earth's biodiversity is the number of different species of organisms that live on Earth. At least 10 million different species live on Earth

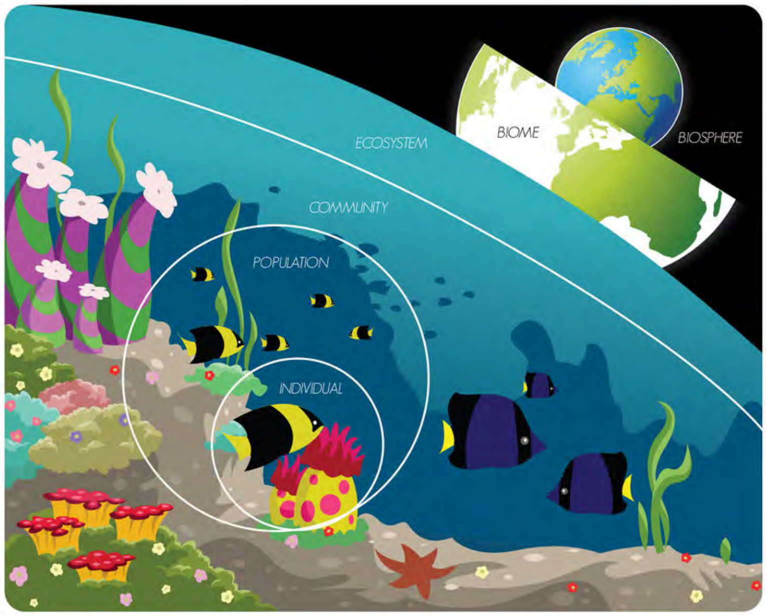


FIGURE 1.13
This picture shows the levels of organization in nature from the individual organism to the biosphere.

today. They are commonly grouped into six different kingdoms. Examples of organisms within each kingdom are shown in **Figure** 1.14 .

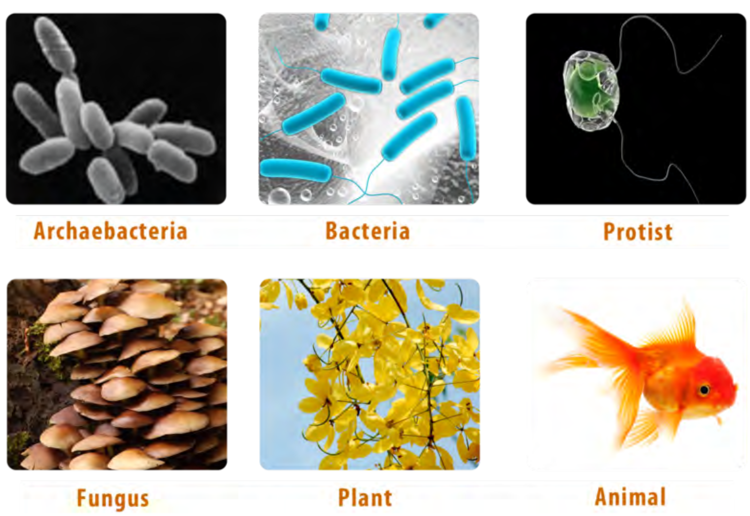


FIGURE 1.14
Diversity of life from Archaebacteria to Plants and Animals.

Evolution of Life

The diversity of life on Earth today is the result of evolution. Life began on Earth at least 4 billion years ago, and it has been evolving ever since. At first, all living things on Earth were simple, single-celled organisms. Much later, the first multicellular organisms evolved, and after that, Earth's biodiversity greatly increased. **Figure** 1.15 shows a timeline of the history of life on Earth. You can also find an interactive timeline of the history of life at the link below. http://www.johnkyrk.com/evolution.html

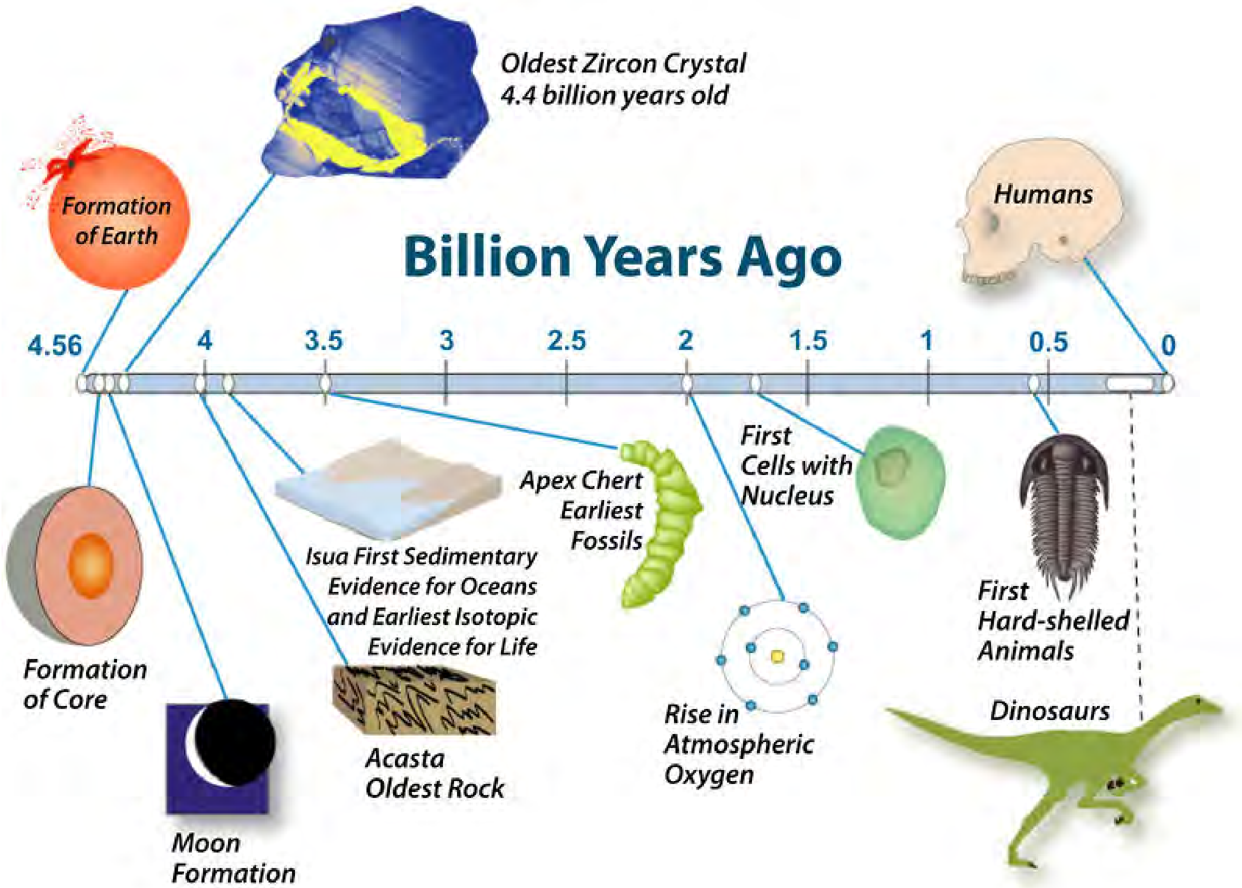


FIGURE 1.15

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

Today, scientists accept the evolution of life on Earth as a fact. There is too much evidence supporting evolution to doubt it. However, that wasn't always the case. An introduction to evolution and natural selection can be viewed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/0/GcjgWov7mTM.

MEDIA

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Darwin and the Theory of Evolution

The idea of evolution has been around for centuries. In fact, it goes all the way back to the ancient Greek philosopher Aristotle. However, evolution is most often associated with Charles Darwin. Darwin published a book on evolution in 1869 titled *On the Origin of Species*. In the book, Darwin stated the theory of evolution by natural selection. He also presented a great deal of evidence that evolution occurs. Despite all the evidence Darwin presented, his theory was not well-received at first. Many people found it hard to accept the idea that humans had evolved from an ape-like ancestor, and they saw evolution as a challenge to their religious beliefs. Look at the cartoon in **Figure** 1.16 . Drawn in 1871, it depicts Darwin himself as an ape. The cartoon reflects how many people felt about Darwin and his theory during his own time. Darwin had actually expected this type of reaction to his theory and had waited a long time before publishing his book for this reason. It was only when another scientist, named Alfred Wallace, developed essentially the same theory of evolution that Darwin put his book into print.

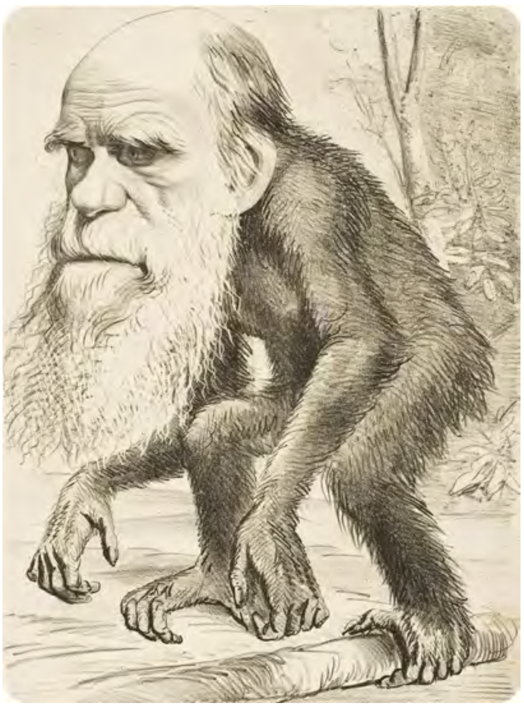


FIGURE 1.16
Charles Darwin&#8217 s name is linked with the theory of evolution. This cartoon from the 1870s makes fun of both Darwin and his theory.

Although Darwin presented a great deal of evidence for evolution in his book, he was unable to explain how evolution occurs. That's because he knew nothing about genes. As a result, he didn't know how characteristics are passed from parents to offspring, let alone how they could change over time.

Evolutionary Theory After Darwin

Since Darwin's time, scientists have gathered even more evidence to support the theory of evolution. Some of the evidence comes from fossils, and some comes from studies that show how similar living things are to one another. By the 1930s, scientists had also learned about genes. As a result, they could finally explain how characteristics of organisms could pass from one generation to the next and change over time.

Using modern technology, scientists can now directly compare the genes of living species. The more genes different species share in common, the more closely related the species are presumed to be. Consider humans and chimpanzees. They share about 98% of their genes. This means that they shared a common ancestor in the not-too-distant past. This is just one of many pieces of evidence that show we are part of the evolution of life on Earth.

Misconceptions About Evolution

Today, evolution is still questioned by some people. Often, people who disagree with the theory of evolution do not really understand it. For example, some people think that the theory of evolution explains how life on Earth first began. In fact, the theory explains only how life changed after it first appeared. Some people think the theory of evolution means that humans evolved from modern apes. In fact, humans and modern apes have a common ancestor that lived several million years ago. These and other misconceptions about evolution contribute to the controversy that still surrounds this fundamental principle of biology.

Lesson Summary

- Living things are distinguished from nonliving things on the basis of six characteristics: response to the environment, growth and development, reproduction, homeostasis, complex chemistry, and cells.
- Four underlying principles form the basis of biology. They are cell theory, gene theory, homeostasis, and evolution.
- Many living things interact with one another in some way. The interactions are often necessary for their survival.
- The great diversity of life on Earth today is the result of 4 billion years of evolution. During that time, living things evolved from simple, single-celled organisms to complex, multicellular life forms.

Lesson Review Questions

Recall

1. List the six characteristics of all living things.

2. Identify four unifying principles of modern biology.

3. Outline the levels of organization of a complex, multicellular organism such as a mouse, starting with the cell.

4. What is homeostasis? Give an example.

Apply Concepts

5. Describe examples of ways that you depend on other living things.

6. Assume that you found an object that looks like a dead twig. You wonder if it might be a stick insect. How could you determine if it is a living thing?

Think Critically

7. Compare and contrast symbiosis and competition.

8. Explain how a population differs from a community.

9. How is gene theory related to the theory of evolution?

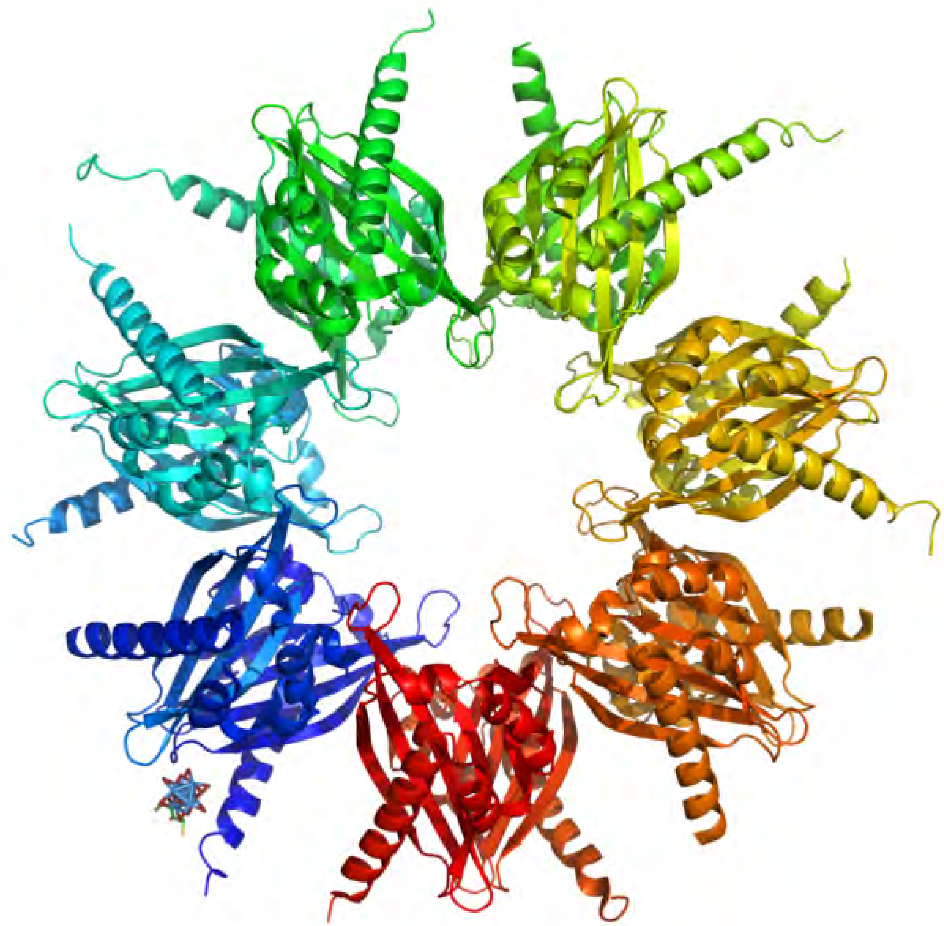
Points to Consider

In this lesson, you learned that living things have complex chemistry.

- Do you know which chemicals make up living things?
- All living things need energy to carry out the processes of life. Where do you think this energy comes from? For example, where do you get the energy you need to get through your day?

CHAPTER 2 The Chemistry of Life

CHAPTER OUTLINE



What do you see when you look at this picture? Is it just a mass of tangled ribbons? Look closely. It's actually a complex pattern of three-dimensional shapes. It represents the structure of a common chemical found inside living cells. The chemical is a protein called kinase. It is involved in many cellular processes. What are proteins? What other chemicals are found in living things? You will learn the answers to these questions as you read about the chemistry of life.

2.1 Matter and Organic Compounds

Lesson Objectives

- Define elements and compounds.
- Explain why carbon is essential to life on Earth.
- Describe the structure and function of the four major types of organic compounds.

Vocabulary

amino acid small molecule that is a building block of proteins

carbohydrate organic compound such as sugar or starch

chemical bond force that holds molecules together

chemical reaction process that changes some chemical substances into others

complementary base pair pair of nucleotide bases that bond together—either adenine and thymine (or uracil) or cytosine and guanine

compound substance with a unique, fixed composition that consists of two or more elements

DNA double-stranded nucleic acid that makes up genes and chromosomes

double helix double spiral shape of the DNA molecule

element pure substance that cannot be broken down into other types of substances

lipid organic compound such as fat or oil

matter anything that takes up space and has mass

monosaccharide simple sugar such as glucose that is a building block of carbohydrates

nucleic acid organic compound such as DNA or RNA

nucleotide small molecule containing a sugar, phosphate group, and base that is a building block of nucleic acids

organic compound compound found in living things that contains mainly carbon

polynucleotide chain of nucleotides that alone or with another such chain makes up a nucleic acid

polypeptide chain of amino acids that alone or with other such chains makes up a protein

polysaccharide chain of monosaccharides that makes up a complex carbohydrate such as starch

protein organic compound made up of amino acids

RNA single-stranded nucleic acid that helps make proteins

saturated fatty acid molecule in lipids in which carbon atoms are bonded to as many hydrogen atoms as possible

unsaturated fatty acid molecule in lipids in which some carbon atoms are bonded to other groups of atoms rather than to hydrogen atoms

Introduction

If you look at your hand, what do you see? Of course, you see skin, which consists of cells. But what are skin cells made of? Like all living cells, they are made of matter. In fact, all things are made of matter. **Matter** is anything that takes up space and has mass. Matter, in turn, is made up of chemical substances. In this lesson you will learn about the chemical substances that make up living things.

Chemical Substances

A chemical substance is matter that has a definite composition. It also has the same composition throughout. A chemical substance may be either an element or a compound.

Elements

An **element** is a pure substance. It cannot be broken down into other types of substances. Each element is made up of just one type of atom. An atom is the smallest particle of an element that still has the properties of that element.

There are almost 120 known elements. As you can see from **Figure** 2.1 , the majority of elements are metals. Examples of metals are iron (Fe) and copper (Cu). Metals are shiny and good conductors of electricity and heat. Nonmetal elements are far fewer in number. They include hydrogen (H) and oxygen (O). They lack the properties of metals.

Compounds

A **compound** is a substance that consists of two or more elements. A compound has a unique composition that is always the same. The smallest particle of a compound is called a molecule. Consider water as an example. A molecule of water always contains one atom of oxygen and two atoms of hydrogen. The composition of water is expressed by the chemical formula H_2O. A model of a water molecule is shown in **Figure** 2.2 .

What causes the atoms of a water molecule to "stick" together? The answer is chemical bonds. A **chemical bond** is a force that holds molecules together. Chemical bonds form when substances react with one another. A **chemical reaction** is a process that changes some chemical substances into others. A chemical reaction is needed to form a compound. Another chemical reaction is needed to separate the substances in a compound.

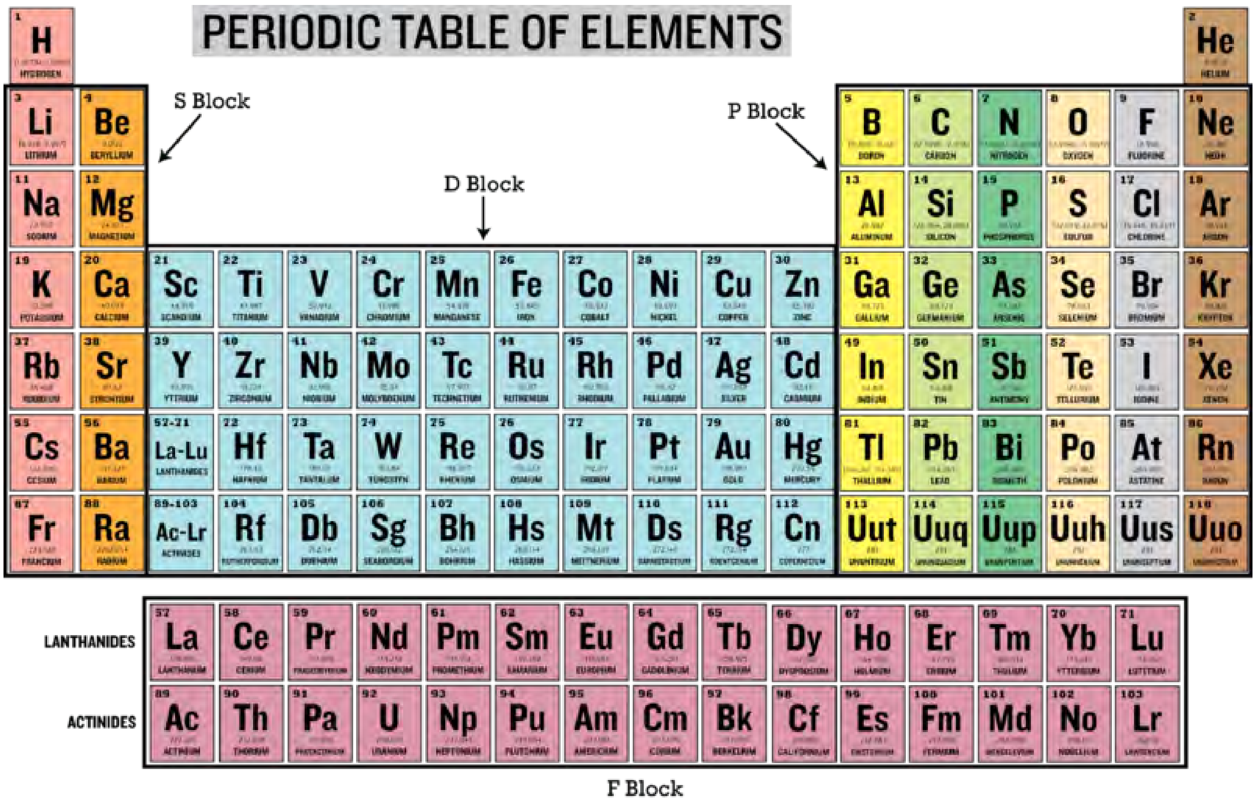


FIGURE 2.1
Periodic Table of the Elements. The Periodic Table of the Elements arranges elements in groups based on their properties. The element most important to life is carbon C. Find carbon in the table. What type of element is it metal or nonmetal

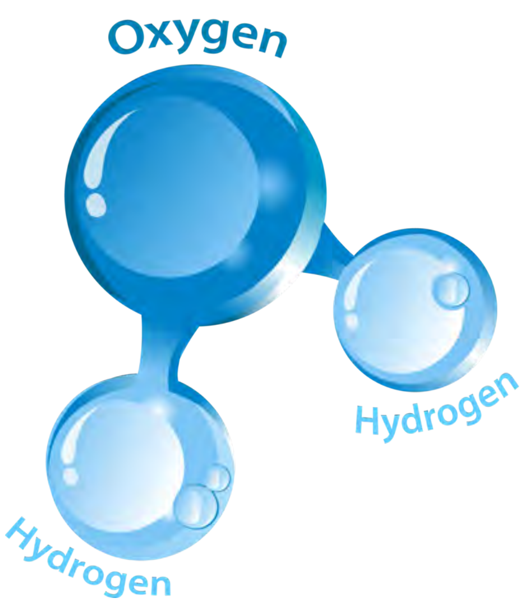


FIGURE 2.2
Water Molecule. A water molecule always has this composition one atom of oxygen and two atoms of hydrogen.

The Significance of Carbon

A compound found mainly in living things is known as an **organic compound**. Organic compounds make up the cells and other structures of organisms and carry out life processes. Carbon is the main element in organic compounds, so carbon is essential to life on Earth. Without carbon, life as we know it could not exist. Why is carbon so basic to life? The reason is carbon's ability to form stable bonds with many elements, including itself. This property allows carbon to form a huge variety of very large and complex molecules. In fact, there are nearly 10 million carbon-based compounds in living things! However, the millions of organic compounds can be grouped into just four major types: carbohydrates, lipids, proteins, and nucleic acids. You can compare the four types in **Table** 2.1 . Each type is also described below.

TABLE 2.1: Types of Organic Compounds

Type of Compound	Examples	Elements	Functions
Carbohydrates	sugars, starches	carbon, hydrogen, oxygen	provides energy to cells, stores energy, forms body structures
Lipids	fats, oils	carbon, hydrogen, oxygen	stores energy, forms cell membranes, carries messages
Proteins	enzymes, antibodies	carbon, hydrogen, oxygen, nitrogen, sulfur	helps cells keep their shape, makes up muscles, speeds up chemical reactions, carries messages and materials
Nucleic Acids	DNA, RNA	carbon, hydrogen, oxygen, nitrogen, phosphorus	contains instructions for proteins, passes instructions from parents to offspring, helps make proteins

The Miracle of Life: Carbohydrates, Proteins, Lipids #38; Nucleic Acids video can be viewed at http://www.youtube.com/watch?v=nMevuu0Hxuc (3:28).

KQED: Energy From Carbon?

It may look like waste, but to some people it's green power. Find out how California dairy farms and white tablecloth restaurants are taking their leftover waste and transforming it into clean energy. See *From Waste To Watts: Biofuel Bonanza* at http://www.kqed.org/quest/television/from-waste-to-watts-biofuel-bonanza for further information.

Carbohydrates

Carbohydrates are the most common type of organic compound. A **carbohydrate** is an organic compound such as sugar or starch, and is used to store energy. Like most organic compounds, carbohydrates are built of small, repeating units that form bonds with each other to make a larger molecule. In the case of carbohydrates, the small repeating units are called monosaccharides.

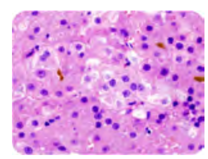
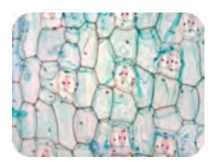
Monosaccharides

A **monosaccharide** is a simple sugar such as fructose or glucose. Fructose is found in fruits, whereas glucose generally results from the digestion of other carbohydrates. Glucose is used for energy by the cells of most organisms.

Polysaccharides

A **polysaccharide** is a complex carbohydrate that forms when simple sugars bind together in a chain. Polysaccharides may contain just a few simple sugars or thousands of them. Complex carbohydrates have two main functions: storing energy and forming structures of living things. Some examples of complex carbohydrates and their functions are shown in **Table** 2.2 . Which type of complex carbohydrate does your own body use to store energy?

TABLE 2.2: Complex Carbohydrates

Name	Function	Example
Starch	Used by plants to store energy.	A potato stores starch in underground tubers. 
Glycogen	Used by animals to store energy.	A human being stores glycogen in liver cells. 
Cellulose	Used by plants to form rigid walls around cells.	Plants use cellulose for their cell walls. 
Chitin	Used by some animals to form an external skeleton.	A housefly uses chitin for its exoskeleton. 

KQED: Biofuels: From Sugar to Energy

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

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Lipids

A **lipid** is an organic compound such as fat or oil. Organisms use lipids to store energy, but lipids have other important roles as well. Lipids consist of repeating units called fatty acids. There are two types of fatty acids: saturated fatty acids and unsaturated fatty acids.

Saturated Fatty Acids

In **saturated fatty acids**, carbon atoms are bonded to as many hydrogen atoms as possible. This causes the molecules to form straight chains, as shown in **Figure** 2.3 . The straight chains can be packed together very tightly, allowing them to store energy in a compact form. This explains why saturated fatty acids are solids at room temperature. Animals use saturated fatty acids to store energy.

Unsaturated Fatty Acids

In **unsaturated fatty acids**, some carbon atoms are not bonded to as many hydrogen atoms as possible. Instead, they are bonded to other groups of atoms. Wherever carbon binds with these other groups of atoms, it causes chains to bend (see **Figure** 2.3). The bent chains cannot be packed together very tightly, so unsaturated fatty acids are liquids at room temperature. Plants use unsaturated fatty acids to store energy. Some examples are shown in **Figure** 2.4 .

Types of Lipids

Lipids may consist of fatty acids alone, or they may contain other molecules as well. For example, some lipids contain alcohol or phosphate groups. They include

a. triglycerides: the main form of stored energy in animals
b. phospholipids: the major components of cell membranes
c. steroids: serve as chemical messengers and have other roles

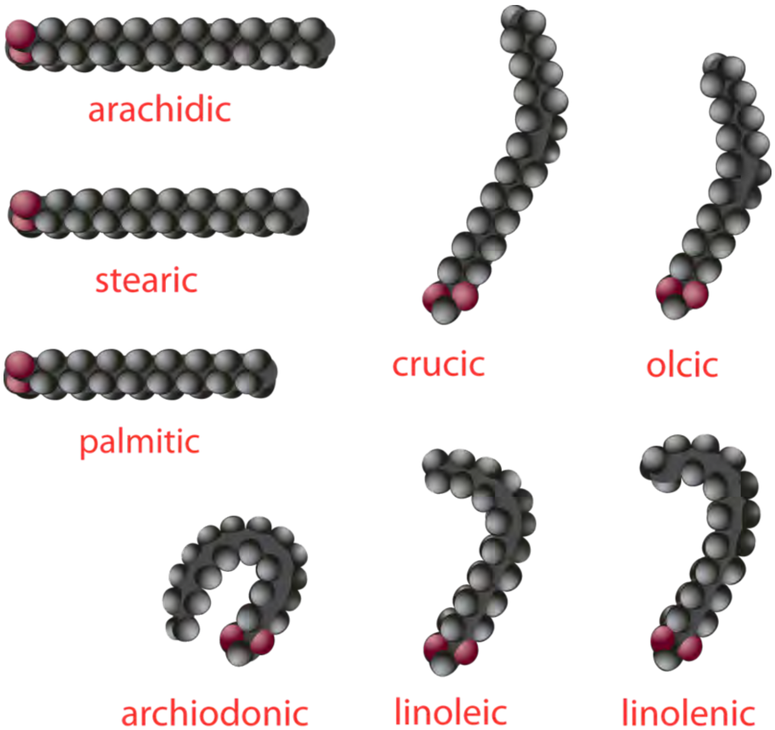


FIGURE 2.3
Fatty Acids. Saturated fatty acids have straight chains like the three fatty acids shown on the left. Unsaturated fatty acids have bent chains like all the other fatty acids in the figure.

FIGURE 2.4
These plant products all contain unsaturated fatty acids.

Proteins

A **protein** is an organic compound made up of small molecules called **amino acids**. There are 20 different amino acids commonly found in the proteins of living things. Small proteins may contain just a few hundred amino acids, whereas large proteins may contain thousands of amino acids.

Protein Structure

When amino acids bind together, they form a long chain called a **polypeptide**. A protein consists of one or more polypeptide chains. A protein may have up to four levels of structure. The lowest level, a protein's primary structure, is its sequence of amino acids. Higher levels of protein structure are described in **Figure** 2.5 . The complex structures of different proteins give them unique properties, which they need to carry out their various jobs in living organisms. You can learn more about protein structure by watching the animation at the link below. http://www.stolaf.edu/people/giannini/flashanimat/proteins/protein%20structure.swf

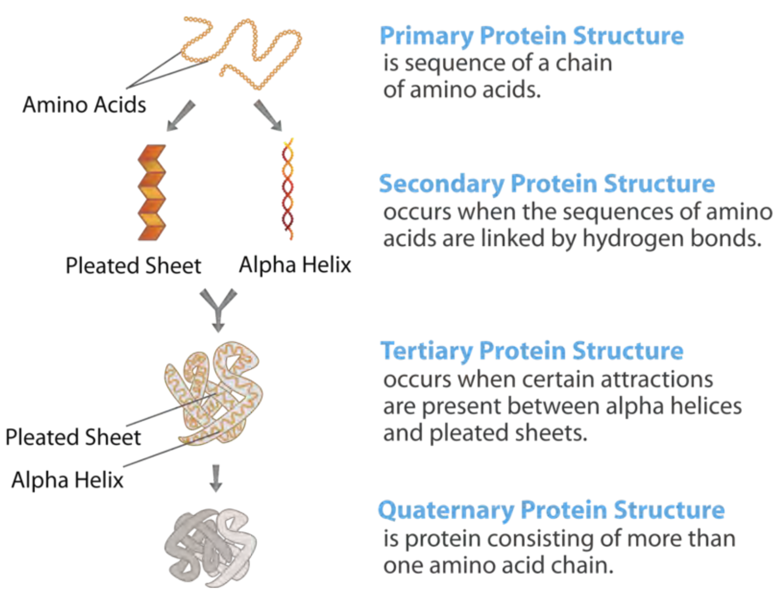


FIGURE 2.5

Protein Structure. The structure of a protein starts with its sequence of amino acids. What determines the secondary structure of a protein What are two types of secondary protein structure

Functions of Proteins

Proteins play many important roles in living things. Some proteins help cells keep their shape, and some make up muscle tissues. Many proteins speed up chemical reactions in cells. Other proteins are antibodies, which bind to foreign substances such as bacteria and target them for destruction. Still other proteins carry messages or materials. For example, human red blood cells contain a protein called hemoglobin, which binds with oxygen. Hemoglobin allows the blood to carry oxygen from the lungs to cells throughout the body. A model of the hemoglobin molecule is shown in **Figure** 2.6 .

A short video describing protein function can be viewed at http://www.youtube.com/watch?v=T500B5yTy58#38;feature=related (4:02).

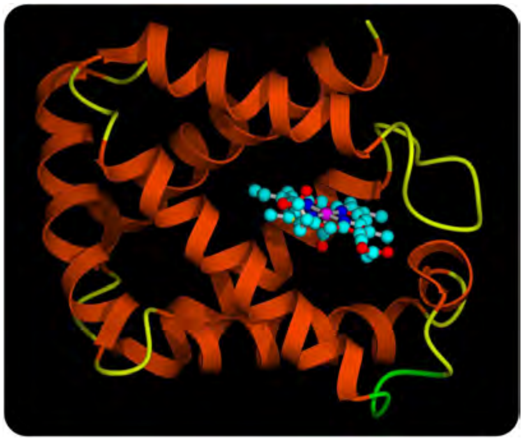
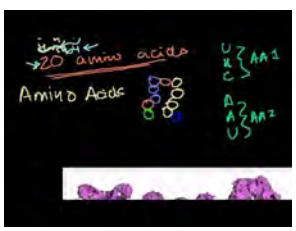


FIGURE 2.6
Hemoglobin Molecule. This model represents the protein hemoglobin. The red parts of the molecule contain iron. The iron binds with oxygen molecules.

Nucleic Acids

A **nucleic acid** is an organic compound, such as DNA or RNA, that is built of small units called **nucleotides**. Many nucleotides bind together to form a chain called a **polynucleotide**. The nucleic acid **DNA** (deoxyribonucleic acid) consists of two polynucleotide chains. The nucleic acid **RNA** (ribonucleic acid) consists of just one polynucleotide chain.

An overview of DNA can be seen at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/4/_-vZ_g7K6P0 (28:05).



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Structure of Nucleic Acids

Each nucleotide consists of three smaller molecules:

a. sugar
b. phosphate group
c. nitrogen base

If you look at **Figure** 2.7 , you will see that the sugar of one nucleotide binds to the phosphate group of the next nucleotide. These two molecules alternate to form the backbone of the nucleotide chain. The nitrogen bases in a nucleic acid stick out from the backbone. There are four different types of bases: cytosine, adenine, guanine, and either thymine (in DNA) or uracil (in RNA). In DNA, bonds form between bases on the two nucleotide chains and hold the chains together. Each type of base binds with just one other type of base: cytosine always binds with guanine, and adenine always binds with thymine. These pairs of bases are called **complementary base pairs**.

The binding of complementary bases allows DNA molecules to take their well-known shape, called a **double helix**, which is shown in **Figure** 2.8 . A double helix is like a spiral staircase. The double helix shape forms naturally and

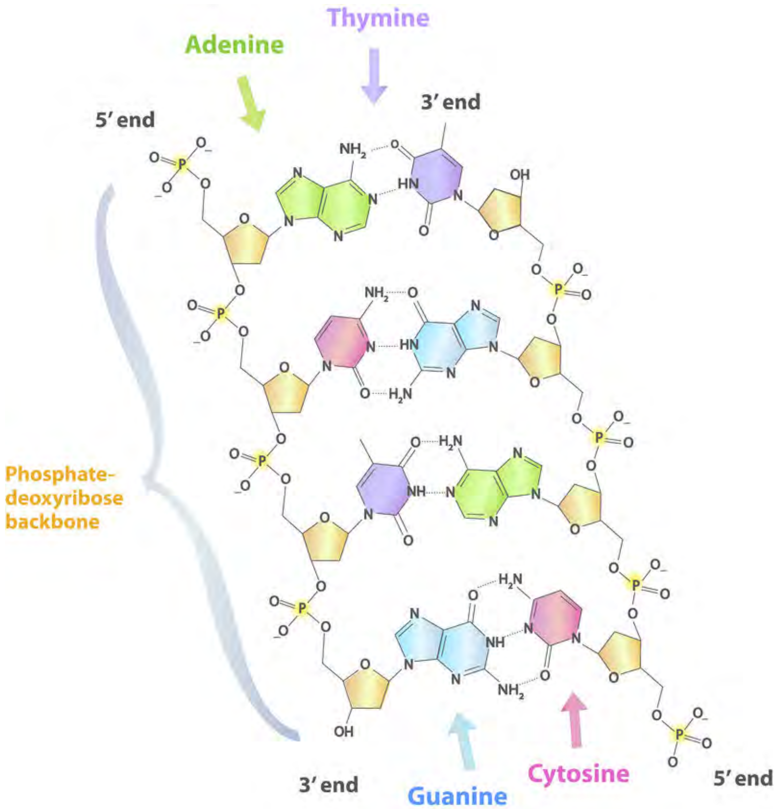


FIGURE 2.7

Nucleic Acid. Sugars and phosphate groups form the backbone of a polynucleotide chain. Hydrogen bonds between complementary bases hold two polynucleotide chains together.

is very strong, making the two polynucleotide chains difficult to break apart. The structure of DNA will be further discussed in the chapter *Molecular Genetics: From DNA to Proteins*.

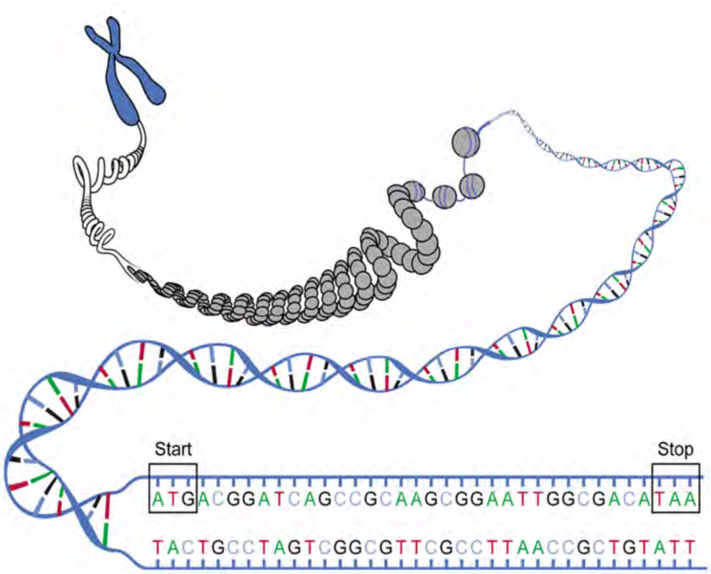


FIGURE 2.8

DNA Molecule. Bonds between complementary bases help form the double helix of a DNA molecule. The letters A T G and C stand for the bases adenine thymine guanine and cytosine. The sequence of these four bases in DNA is a code that carries instructions for making proteins. The start and stop codons are shown these will be discussed in the Molecular Genetics From DNA to Proteins chapter.

An animation of DNA structure can be viewed at http://www.youtube.com/watch?v=qy8dk5iS1f0#38;feature=related.

Roles of Nucleic Acids

DNA is found in genes, and its sequence of bases makes up a code. Between "starts" and "stops," the code carries instructions for the correct sequence of amino acids in a protein (see **Figure** 2.8). RNA uses the information in DNA to assemble the correct amino acids and help make the protein. The information in DNA is passed from parent cells to daughter cells whenever cells divide. The information in DNA is also passed from parents to offspring when organisms reproduce. This is how inherited characteristics are passed from one generation to the next.

Lesson Summary

- Living things consist of matter, which can be an element or a compound. A compound consists of two or more elements and forms as a result of a chemical reaction.
- Carbon's unique ability to form chemical bonds allows it to form millions of different large, organic compounds. These compounds make up living things and carry out life processes.
- Carbohydrates are organic compounds such as sugars and starches. They provide energy and form structures such as cell walls.
- Lipids are organic compounds such as fats and oils. They store energy and help form cell membranes in addition to having other functions in organisms.
- Proteins are organic compounds made up of amino acids. They form muscles, speed up chemical reactions, and perform many other cellular functions.
- Nucleic acids are organic compounds that include DNA and RNA. DNA contains genetic instructions for proteins, and RNA helps assemble the proteins.

Lesson Review Questions

Recall

1. What are elements and compounds? Give an example of each.

2. List the four major types of organic compounds.

3. What determines the primary structure of a protein?

4. State two functions of proteins.

5. Identify the three parts of a nucleotide.

Apply Concepts

6. Butter is a fat that is a solid at room temperature. What type of fatty acids does butter contain? How do you know?

7. Assume that you are trying to identify an unknown organic molecule. It contains only carbon, hydrogen, and oxygen and is found in the cell walls of a newly discovered plant species. What type of organic compound is it?

Think Critically

8. Explain why carbon is essential to all known life on Earth.

9. Compare and contrast the structures and functions of simple sugars and complex carbohydrates.

10. Explain why molecules of saturated and unsaturated fatty acids have different shapes.

Further Reading / Supplemental Links

- James D. Watson, *The Double Helix: A Personal Account of the Discovery of DNA*. Touchstone, 2001.
- The Chemistry of Biology http://www.infoplease.com/cig/biology/organic-chemistry.html

Points to Consider

Large organic compounds consist of many smaller units that are linked together in chains.

- How can the smaller units become linked together? What process do you think is involved?
- What do you think holds the smaller units together in a chain?

2.2 Biochemical Reactions

Lesson Objectives

- Describe what happens in chemical reactions.
- State the role of energy in chemical reactions.
- Explain the importance of enzymes to living organisms.

Vocabulary

activation energy energy needed to start a chemical reaction

anabolic reaction endothermic reaction in organisms

biochemical reaction chemical reaction that occurs inside the cells of living things

catabolic reaction exothermic reaction in organisms

endothermic reaction chemical reaction that absorbs energy

enzyme protein that speeds up biochemical reactions

exothermic reaction chemical reaction that releases energy

metabolism sum of all the biochemical reactions in an organism

product substance that forms as the result of a chemical reaction

reactant starting material in a chemical reaction

Introduction

The element chlorine (Cl) is a greenish poison. Would you eat chlorine? Of course not, but you often eat a compound containing chlorine. In fact, you probably eat this chlorine compound just about every day. Do you know what it is? It's table salt. Table salt is sodium chloride (NaCl), which forms when chlorine and sodium (Na) combine in certain proportions. How does chlorine, a toxic green chemical, change into harmless white table salt? It happens in a chemical reaction.

What Are Chemical Reactions?

A chemical reaction is a process that changes some chemical substances into others. A substance that starts a chemical reaction is called a **reactant**, and a substance that forms as a result of a chemical reaction is called a **product**. During a chemical reaction, the reactants are used up to create the products.

An example of a chemical reaction is the burning of methane, which is shown in **Figure** 2.9 . In this chemical reaction, the reactants are methane (CH_4) and oxygen (O_2), and the products are carbon dioxide (CO_2) and water (H_2O). A chemical reaction involves the breaking and forming of chemical bonds. When methane burns, bonds break in the methane and oxygen molecules, and new bonds form in the molecules of carbon dioxide and water.

FIGURE 2.9

Methane Burning. When methane burns it combines with oxygen. What are the products of this chemical reaction

Chemical Equations

A chemical reaction can be represented by a chemical equation. For example, the burning of methane can be represented by the chemical equation

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

The arrow in a chemical equation separates the reactants from the products and shows the direction in which the reaction proceeds. If the reaction could occur in the opposite direction as well, two arrows pointing in opposite directions would be used. The number 2 in front of O_2 and H_2O shows that two oxygen molecules and two water molecules are involved in the reaction. (With no number in front of a chemical symbol, just one molecule is involved.)

Conservation of Matter

In a chemical reaction, the quantity of each element does not change; there is the same amount of each element in the products as there was in the reactants. This is because matter is always conserved. The conservation of matter is reflected in a reaction's chemical equation. The same number of atoms of each element appears on each side of the arrow. For example, in the chemical equation above, there are four hydrogen atoms on each side of the arrow. Can you find all four of them on each side of this equation?

Chemical Reactions and Energy

Chemical reactions always involve energy. When methane burns, for example, it releases energy in the form of heat and light. Other chemical reactions absorb energy rather than release it.

Exothermic Reactions

A chemical reaction that releases energy (as heat) is called an **exothermic reaction**. This type of reaction can be represented by a general chemical equation:

Reactants $\rightarrow$ Products + Heat

In addition to methane burning, another example of an exothermic reaction is chlorine combining with sodium to form table salt. This reaction also releases energy.

Endothermic Reactions

A chemical reaction that absorbs energy is called an **endothermic reaction**. This type of reaction can also be represented by a general chemical equation:

Reactants + Heat $\rightarrow$ Products

Did you ever use a chemical cold pack like the one in **Figure** 2.10 ? The pack cools down because of an endothermic reaction. When a tube inside the pack is broken, it releases a chemical that reacts with water inside the pack. This reaction absorbs heat energy and quickly cools down the pack.

Activation Energy

All chemical reactions need energy to get started. Even reactions that release energy need a boost of energy in order to begin. The energy needed to start a chemical reaction is called **activation energy**. Activation energy is like the push a child needs to start going down a playground slide. The push gives the child enough energy to start moving, but once she starts, she keeps moving without being pushed again. Activation energy is illustrated in **Figure** 2.11 .

Why do all chemical reactions need energy to get started? In order for reactions to begin, reactant molecules must bump into each other, so they must be moving, and movement requires energy. When reactant molecules bump together, they may repel each other because of intermolecular forces pushing them apart. Overcoming these forces so the molecules can come together and react also takes energy.

An overview of activation energy can be viewed at http://www.youtube.com/watch?v=VbIaK6PLrRM#38;feature=related (1:16).

Biochemical Reactions and Enzymes

Biochemical reactions are chemical reactions that take place inside the cells of living things. The field of biochemistry demonstrates that knowledge of chemistry as well as biology is needed to understand fully the life processes of

FIGURE 2.10
This pack gets cold due to an endothermic reaction.

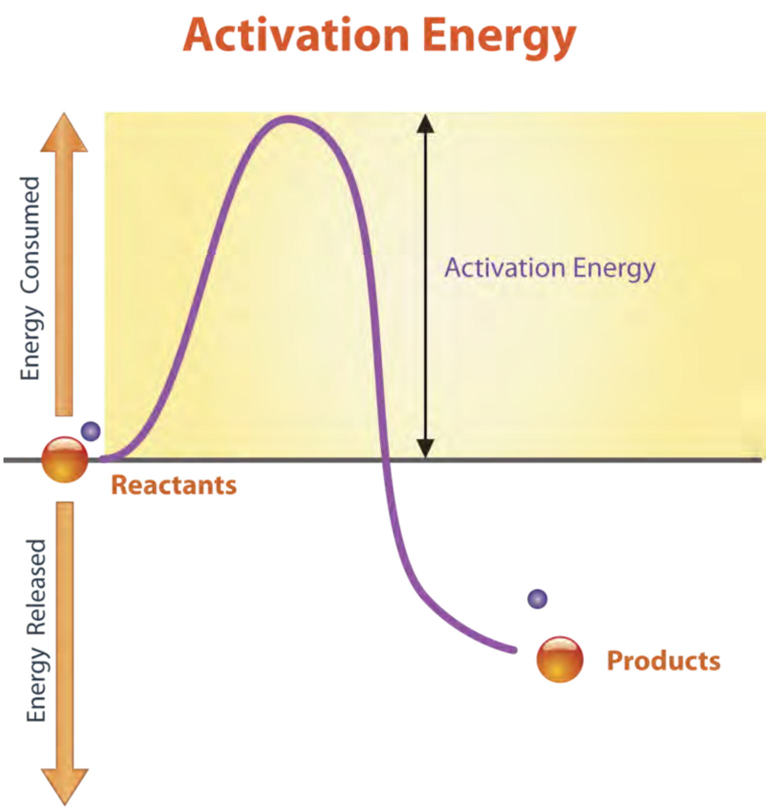


FIGURE 2.11
Activation Energy. Activation energy provides the &#8220 push&#8221 needed to start a chemical reaction. Is the chemical reaction in this figure an exothermic or endothermic reaction

organisms at the level of the cell. The sum of all the biochemical reactions in an organism is called **metabolism**. It includes both exothermic and endothermic reactions.

Types of Biochemical Reactions

Exothermic reactions in organisms are called **catabolic reactions**. These reactions break down molecules into smaller units and release energy. An example of a catabolic reaction is the breakdown of glucose, which releases energy that cells need to carry out life processes. Endothermic reactions in organisms are called **anabolic reactions**. These reactions build up bigger molecules from smaller ones. An example of an anabolic reaction is the joining of amino acids to form a protein. Which type of reactions—catabolic or anabolic—do you think occur when your body digests food?

Enzymes

Most biochemical reactions in organisms need help in order to take place. Why is this the case? For one thing, temperatures are usually too low inside living things for biochemical reactions to occur quickly enough to maintain life. The concentrations of reactants may also be too low for them to come together and react. Where do the biochemical reactions get the help they need to proceed? The help comes from enzymes.

An **enzyme** is a protein that speeds up a biochemical reaction. An enzyme works by reducing the amount of activation energy needed to start the reaction. The graph in **Figure** 2.12 shows the activation energy needed for glucose to combine with oxygen. Less activation energy is needed when the correct enzyme is present than when it is not present. You can watch an animation of a biochemical reaction with and without an enzyme at the link below. This animation shows how the enzyme brings reactant molecules together so they can react: http://www.stolaf.edu/people/giannini/flashanimat/enzymes/prox-orien.swf.

An overview of enzymes can be viewed at http://www.youtube.com/watch?v=E90D4BmaVJM#38;feature=related (9:43).

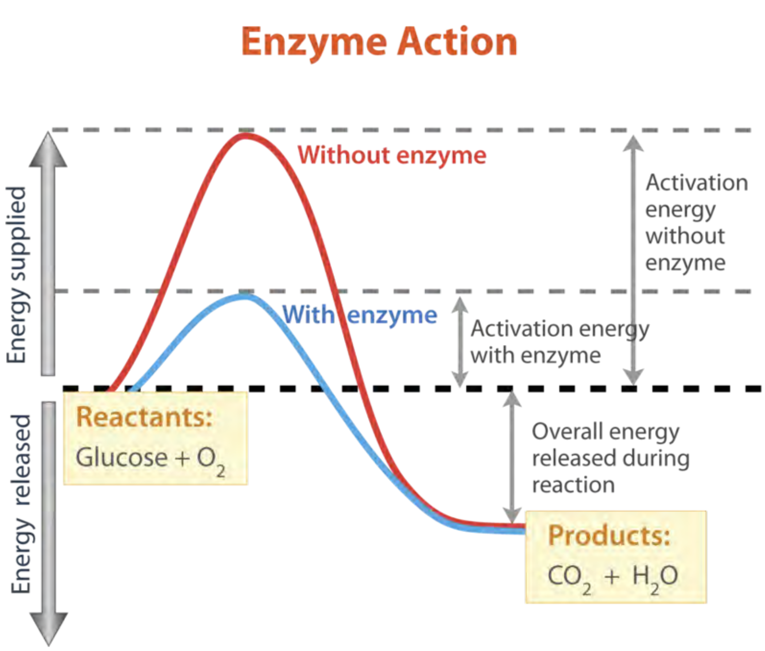


FIGURE 2.12
Enzyme Action. This graph shows what happens when glucose combines with oxygen. An enzyme speeds up the reaction by lowering the activation energy. Compare the activation energy needed with and without the enzyme.

Enzymes are involved in most biochemical reactions, and they do their job extremely well. A typical biochemical reaction could take several days to occur without an enzyme. With the proper enzyme, the same reaction can occur in just a split second! Without enzymes to speed up biochemical reactions, most organisms could not survive. The activities of enzymes depend on the temperature, ionic conditions, and the pH of the surroundings. Some enzymes work best at acidic pHs, while others work best in neutral environments.

An animation of how enzymes work can be seen at http://www.youtube.com/watch?v=CZD5xsOKres#38;feature=related (2:02).

Lesson Summary

- A chemical reaction is a process that changes some chemical substances into others. It involves breaking and forming chemical bonds.
- Some chemical reactions release energy, whereas other chemical reactions absorb energy. All chemical reactions require activation energy to get started.
- Enzymes are needed to speed up biochemical reactions in organisms. They work by lowering activation energy.

Lesson Review Questions

Recall

1. Identify the roles of reactants and products in chemical reactions.

2. What is the general chemical equation for an endothermic reaction?

3. What are biochemical reactions? What is an example?

4. How do enzymes speed up biochemical reactions?

Apply Concepts

5. What is wrong with the chemical equation below? How could you fix it?

$CH_4 + O_2 \rightarrow CO_2 + 2H_2O$

6. What type of reaction is represented by the following chemical equation? Explain your answer.

$2Na + 2HCl \rightarrow 2NaCl + H_2 + \text{heat}$

Think Critically

7. How does a chemical equation show that matter is always conserved in a chemical reaction?

8. Why do all chemical reactions require activation energy?

9. Explain why organisms need enzymes to survive.

Points to Consider

Most chemical reactions in organisms take place in an environment that is mostly water.

- What do you know about water? How would you describe it?
- Water behaves differently than most other substances. Do you know why?

2.3 Water, Acids, and Bases

Lesson Objectives

- Describe the distribution of Earth's water.
- Identify water's structure and properties.
- Define acids, bases, and pH.
- Explain why water is essential for life.

Vocabulary

acid solution with a pH lower than 7

base solution with a pH higher than 7

hydrogen bond type of chemical bond that forms between molecules: found between water molecules

pH scale that is used to measure acidity

polarity difference in electrical charge between different parts of the same molecule

solution mixture that has the same composition throughout

Introduction

Water, like carbon, has a special role in living things. It is needed by all known forms of life. As you have seen, water is a simple molecule, containing just three atoms. Nonetheless, water's structure gives it unique properties that help explain why it is vital to all living organisms.

Water, Water Everywhere

Water is a common chemical substance on planet Earth. In fact, Earth is sometimes called the "water planet" because almost 75% of its surface is covered with water. If you look at **Figure** 2.13 , you will see where Earth's water is found. The term *water* generally refers to its liquid state, and water is a liquid over a wide range of temperatures on Earth. However, water also occurs on Earth as a solid (ice) and as a gas (water vapor).

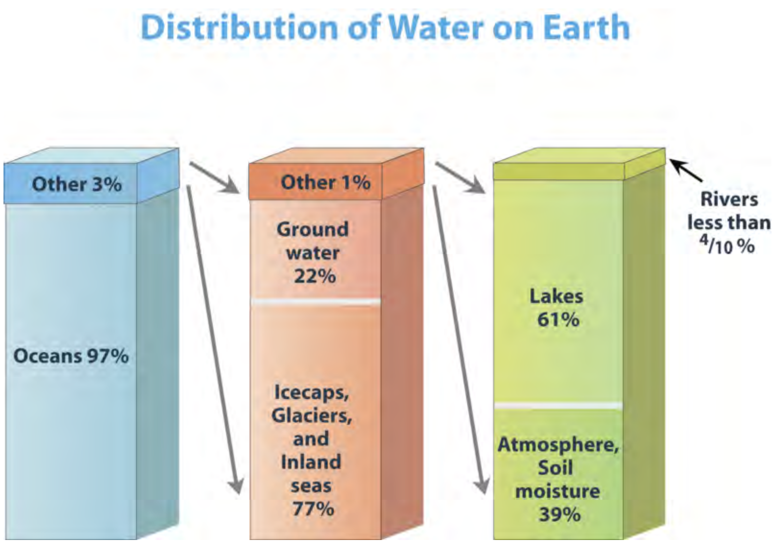


FIGURE 2.13
Most of the water on Earth consists of saltwater in the oceans. What percent of Earth&#8217 s water is freshwater Where is most of the freshwater found

Structure and Properties of Water

No doubt, you are already aware of some of the properties of water. For example, you probably know that water is tasteless and odorless. You also probably know that water is transparent, which means that light can pass through it. This is important for organisms that live in the water, because some of them need sunlight to make food.

Chemical Structure of Water

To understand some of water's properties, you need to know more about its chemical structure. As you have seen, each molecule of water consists of one atom of oxygen and two atoms of hydrogen. The oxygen atom in a water molecule attracts electrons more strongly than the hydrogen atoms do. As a result, the oxygen atom has a slightly negative charge, and the hydrogen atoms have a slightly positive charge. A difference in electrical charge between different parts of the same molecule is called **polarity**. The diagram in **Figure** 2.14 shows water's polarity.

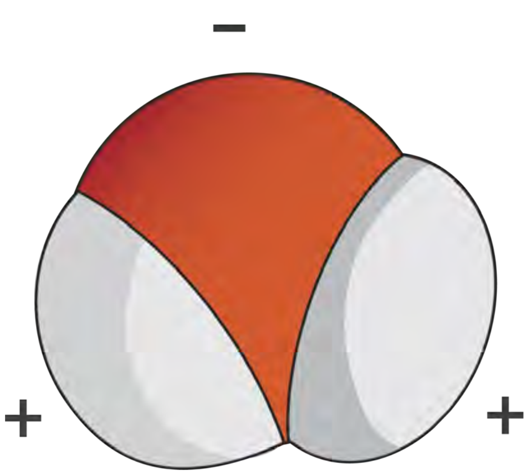


FIGURE 2.14
Water Molecule. This diagram shows the positive and negative parts of a water molecule.

Opposites attract when it comes to charged molecules. In the case of water, the positive (hydrogen) end of one water molecule is attracted to the negative (oxygen) end of a nearby water molecule. Because of this attraction, weak bonds form between adjacent water molecules, as shown in **Figure** 2.15 . The type of bond that forms between molecules is called a **hydrogen bond**. Bonds between molecules are not as strong as bonds within molecules, but in water they are strong enough to hold together nearby molecules.

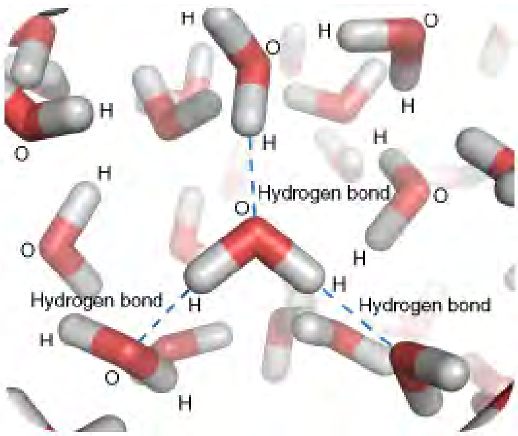


FIGURE 2.15

Hydrogen Bonding in Water Molecules. Hydrogen bonds form between nearby water molecules. How do you think this might affect water&#8217 s properties

Properties of Water

Hydrogen bonds between water molecules explain some of water's properties. For example, hydrogen bonds explain why water molecules tend to stick together. Did you ever watch water drip from a leaky faucet or from a melting icicle? If you did, then you know that water always falls in drops rather than as separate molecules. The dew drops in **Figure** 2.16 are another example of water molecules sticking together.

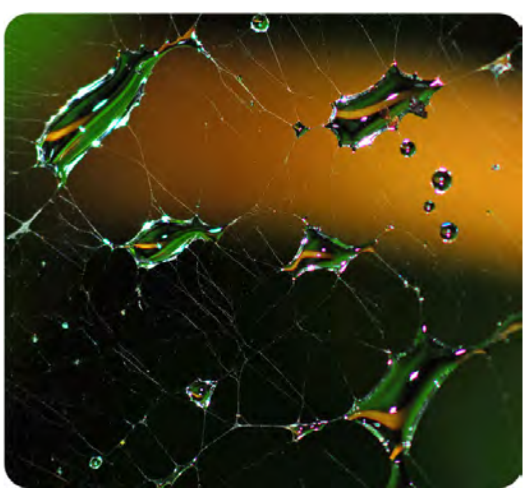


FIGURE 2.16

Droplets of Dew. Drops of dew cling to a spider web in this picture. Can you think of other examples of water forming drops *Hint What happens when rain falls on a newly waxed car*

Hydrogen bonds cause water to have a relatively high boiling point of 100°C (212°F). Because of its high boiling point, most water on Earth is in a liquid state rather than in a gaseous state. Water in its liquid state is needed by all living things. Hydrogen bonds also cause water to expand when it freezes. This, in turn, causes ice to have a lower density (mass/volume) than liquid water. The lower density of ice means that it floats on water. For example, in cold climates, ice floats on top of the water in lakes. This allows lake animals such as fish to survive the winter by staying in the water under the ice.

Acids and Bases

Water is the main ingredient of many solutions. A **solution** is a mixture of two or more substances that has the same composition throughout. Some solutions are acids and some are bases. To understand acids and bases, you need to know more about pure water. In pure water (such as distilled water), a tiny fraction of water molecules naturally breaks down to form ions. An ion is an electrically charged atom or molecule. The breakdown of water is represented by the chemical equation

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

The products of this reaction are a hydronium ion (H_3O^+) and a hydroxide ion (OH^-). The hydroxide ion, which has a negative charge, forms when a water molecule gives up a positively charged hydrogen ion (H^+). The hydronium ion, which has positive charge, forms when another water molecule accepts the hydrogen ion.

Acidity and pH

The concentration of hydronium ions in a solution is known as acidity. In pure water, the concentration of hydronium ions is very low; only about 1 in 10 million water molecules naturally breaks down to form a hydronium ion. As a result, pure water is essentially neutral. Acidity is measured on a scale called **pH**, as shown in **Figure** 2.17 . Pure water has a pH of 7, so the point of neutrality on the pH scale is 7.

Acids

If a solution has a higher concentration of hydronium ions than pure water, it has a pH lower than 7. A solution with a pH lower than 7 is called an **acid**. As the hydronium ion concentration increases, the pH value decreases. Therefore, the more acidic a solution is, the lower its pH value is. Did you ever taste vinegar? Like other acids, it tastes sour. Stronger acids can be harmful to organisms. For example, stomach acid would eat through the stomach if it were not lined with a layer of mucus. Strong acids can also damage materials, even hard materials such as glass.

Bases

If a solution has a lower concentration of hydronium ions than pure water, it has a pH higher than 7. A solution with a pH higher than 7 is called a **base**. Bases, such as baking soda, have a bitter taste. Like strong acids, strong bases can harm organisms and damage materials. For example, lye can burn the skin, and bleach can remove the color from clothing.

Acids and Bases in Organisms

Acids and bases are important in living things because most enzymes can do their job only at a certain level of acidity. Cells secrete acids and bases to maintain the proper pH for enzymes to work. For example, every time you digest food, acids and bases are at work in your digestive system. Consider the enzyme pepsin, which helps break down proteins in the stomach. Pepsin needs an acidic environment to do its job, and the stomach secretes a strong acid that allows pepsin to work. However, when stomach contents enter the small intestine, the acid must be

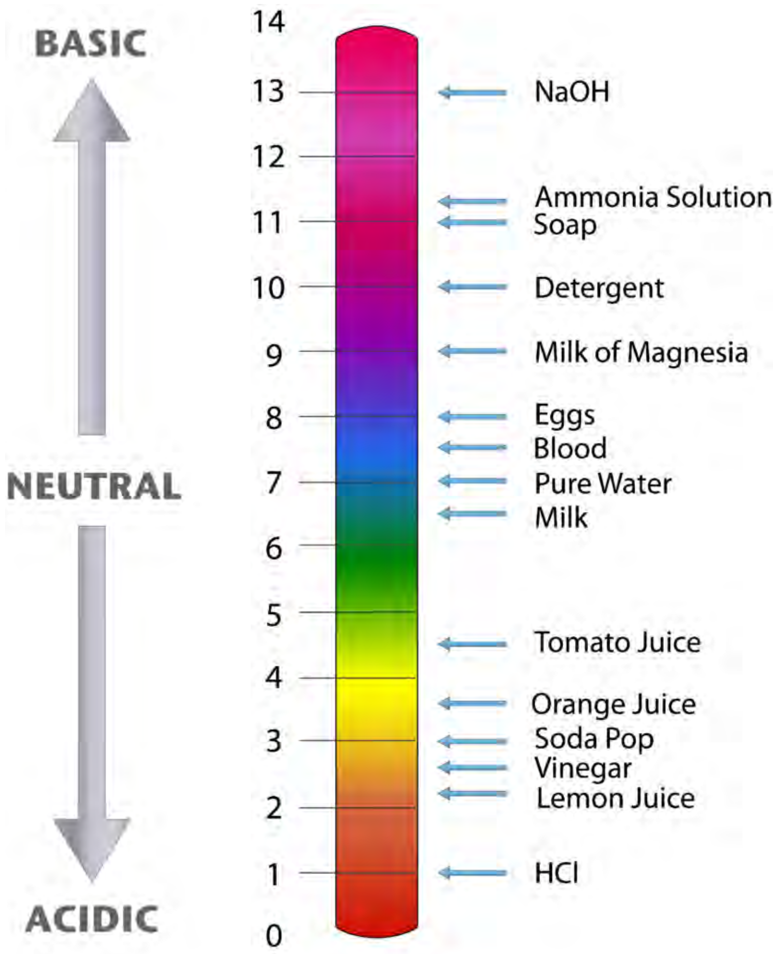


FIGURE 2.17

pH Scale. The pH scale ranges from 0 to 14 with 7 being the point of neutrality. What is the pH of lemon juice Of milk neutralized. This is because enzymes in the small intestine need a basic environment in order to work. An organ called the pancreas secretes a strong base into the small intestine, and this base neutralizes the acid.

Water and Life

The human body is about 70% water (not counting the water in body fat, which varies from person to person). The body needs all this water to function normally. Just why is so much water required by human beings and other organisms? Water can dissolve many substances that organisms need, and it is necessary for many biochemical reactions. The examples below are among the most important biochemical processes that occur in living things, but they are just two of many ways that water is involved in biochemical reactions.

- Photosynthesis—In this process, cells use the energy in sunlight to change carbon dioxide and water to glucose and oxygen. The reactions of photosynthesis can be represented by the chemical equation

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

- Cellular respiration—In this process, cells break down glucose in the presence of oxygen and release carbon dioxide, water, and energy. The reactions of cellular respiration can be represented by the chemical equation

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

Water is involved in many other biochemical reactions. As a result, just about all life processes depend on water. Clearly, life as we know it could not exist without water.

Lesson Summary

- Most of Earth's water is salt water in the oceans. Less than 3% is freshwater.
- Water molecules are polar, so they form hydrogen bonds. This gives water unique properties, such as a relatively high boiling point.
- The extremely low hydronium ion concentration of pure water gives pure water a neutral pH of 7. Acids have a pH lower than 7, and bases have a pH higher than 7.
- Water is involved in most biochemical reactions. Therefore, water is essential to life.

Lesson Review Questions

Recall

1. Where is most of Earth's water found?
2. What is polarity? Describe the polarity of water.
3. What is the pH of a neutral solution?
4. Describe an example of an acid or a base that is involved in human digestion.

Apply Concepts

5. Assume that you test an unknown solution and find that it has a pH of 7.2. What type of solution is it? How do you know?

6. How could you demonstrate to a child that solid water is less dense than liquid water?

Think Critically

7. Explain how water's polarity is related to its boiling point.

8. Explain why metabolism in organisms depends on water.

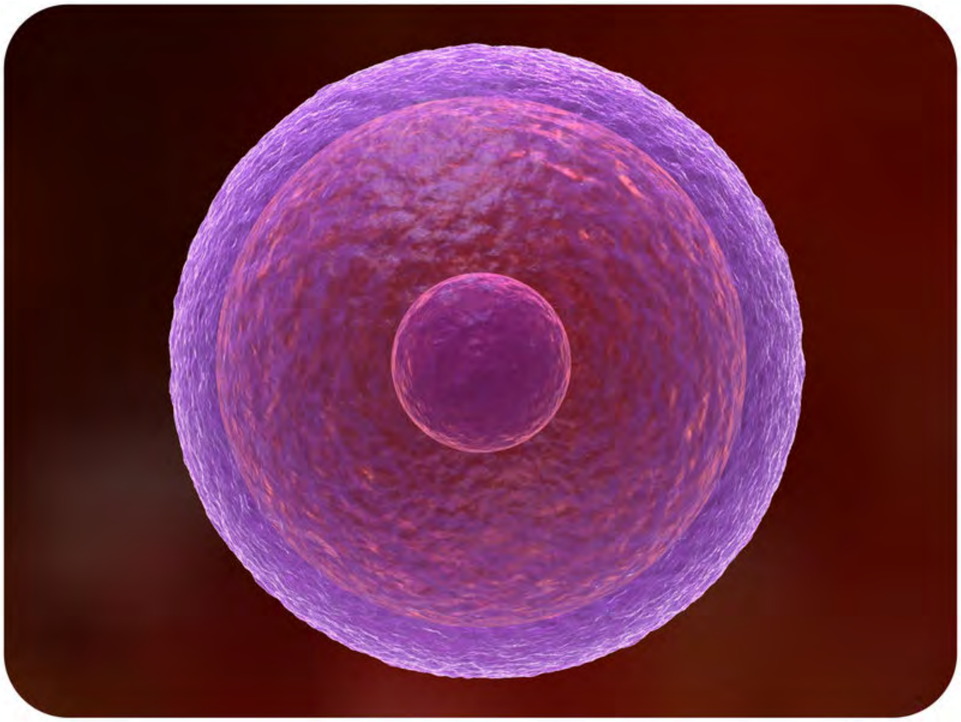
Points to Consider

Most biochemical reactions take place within cells. Cells are the microscopic building blocks of organisms.

- What do you think you would see if you could look inside the cell of an organism? What structures do you think you might observe?
- What biochemical processes might be occurring?

CHAPTER 3 Cellular Structure and Function

CHAPTER OUTLINE



What is this incredible object? Would it surprise you to learn that it is a human cell? The image represents a cell, similar to one that may be produced by a type of modern microscope called an electron microscope. Without this technology, we wouldn't be able to see the structures inside cells. Cells may be small in size, but they are extremely important to life. Like all other living things, you are made of cells. Cells are the basis of life, and without cells, life as we know it would not exist. You will learn more about these amazing building blocks of life when you read this chapter.

3.1 Introduction to Cells

Lesson Objectives

- State the cell theory, and list the discoveries that led to it.
- Describe the diversity of cell shapes, and explain why cells are so small.
- Identify the parts that all cells have in common.
- Contrast prokaryotic and eukaryotic cells.

Vocabulary

cytoplasm all of the material inside the plasma membrane of a cell (excluding organelles)

eukaryote organism that has cells containing a nucleus and other organelles

eukaryotic cell cell that contains a nucleus and other organelles

nucleus (plural, nuclei) organelle inside eukaryotic cells that contains most of the cell's DNA and acts as the control center of the cell

organelle structure within the cytoplasm of a cell that is enclosed within a membrane and performs a specific job

plasma membrane thin coat of lipids (phospholipids) that surrounds and encloses a cell

prokaryote single-celled organism that lacks a nucleus

prokaryotic cell cell without a nucleus that is found in single-celled organisms

ribosome organelle inside all cells where proteins are made

virus tiny, nonliving particle that contains DNA but lacks other characteristics of living cells

Introduction

If you look at living matter with a microscope—even a simple light microscope—you will see that it consists of cells. Cells are the basic units of the structure and function of living things. They are the smallest units that can carry out the processes of life. All organisms are made up of one or more cells, and all cells have many of the same structures and carry out the same basic life processes. Knowing the structures of cells and the processes they carry out is necessary to understanding life itself.

Discovery of Cells

The first time the word *cell* was used to refer to these tiny units of life was in 1665 by a British scientist named Robert Hooke. Hooke was one of the earliest scientists to study living things under a microscope. The microscopes of his day were not very strong, but Hooke was still able to make an important discovery. When he looked at a thin slice of cork under his microscope, he was surprised to see what looked like a honeycomb. Hooke made the drawing in **Figure** 3.1 to show what he saw. As you can see, the cork was made up of many tiny units, which Hooke called cells.

FIGURE 3.1
Cork Cells. This is what Robert Hooke saw when he looked at a thin slice of cork under his microscope. What type of material is cork Do you know where cork comes from

Leeuwenhoek's Discoveries

Soon after Robert Hooke discovered cells in cork, Anton van Leeuwenhoek in Holland made other important discoveries using a microscope. Leeuwenhoek made his own microscope lenses, and he was so good at it that his microscope was more powerful than other microscopes of his day. In fact, Leeuwenhoek's microscope was almost as strong as modern light microscopes. Using his microscope, Leeuwenhoek discovered tiny animals such as rotifers. The magnified image of a rotifer in **Figure** 3.2 is similar to what Leeuwenhoek observed. Leeuwenhoek also discovered human blood cells. He even scraped plaque from his own teeth and observed it under the microscope. What do you think Leeuwenhoek saw in the plaque? He saw tiny living things with a single cell that he named *animalcules* ("tiny animals"). Today, we call Leeuwenhoek's animalcules bacteria.

The Cell Theory

By the early 1800s, scientists had observed the cells of many different organisms. These observations led two German scientists, named Theodor Schwann and Matthias Jakob Schleiden, to propose that cells are the basic building blocks of all living things. Around 1850, a German doctor named Rudolf Virchow was studying cells under a microscope when he happened to see them dividing and forming new cells. He realized that living cells produce new cells through division. Based on this realization, Virchow proposed that living cells arise only from other living cells. The ideas of all three scientists—Schwann, Schleiden, and Virchow—led to the cell theory, which is one of the fundamental theories of biology. The cell theory states that:

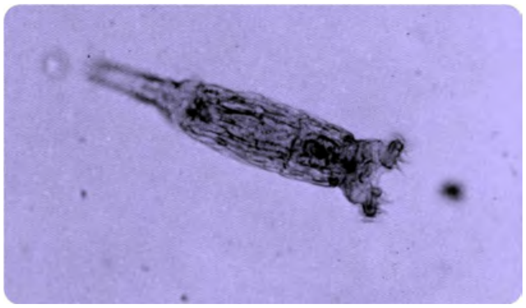


FIGURE 3.2
Microscopic Rotifer. Rotifers like this one were first observed by Aton van Leeuwenhoek. This tiny animal is too small to be seen without a microscope.

- All organisms are made of one or more cells.
- All the life functions of organisms occur within cells.
- All cells come from already existing cells.

Microscopes

Starting with Robert Hooke in the 1600s, the microscope opened up an amazing new world—the world of life at the level of the cell. As microscopes continued to improve, more discoveries were made about the cells of living things. However, by the late 1800s, light microscopes had reached their limit. Objects much smaller than cells, including the structures inside cells, were too small to be seen with even the strongest light microscope. Then, in the 1950s, a new type of microscope was invented. Called the electron microscope, it used a beam of electrons instead of light to observe extremely small objects. With an electron microscope, scientists could finally see the tiny structures inside cells. In fact, they could even see individual molecules and atoms. The electron microscope had a huge impact on biology. It allowed scientists to study organisms at the level of their molecules and led to the emergence of the field of molecular biology. With the electron microscope, many more cell discoveries were made. **Figure** 3.3 shows how the cell structures called organelles appear when scanned by an electron microscope.

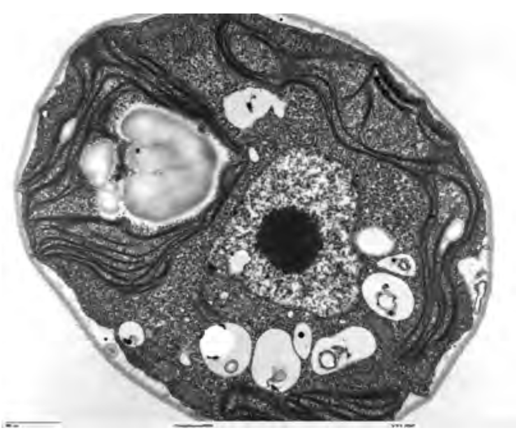


FIGURE 3.3
Electron Microscope Image of Organelles. An electron microscope produced this image of a cell.

KQED: The World's Most Powerful Microscope

Lawrence Berkeley National labs uses a $27 million electron microscope to make images to a resolution of half the width of a hydrogen atom. This makes it the world's most powerful microscope. See http://www.kqed.org/

quest/television/the-worlds-most-powerful-microscope and http://www.kqed.org/quest/slideshow/web-extra-images-from-the-worlds-most-powerful-microscope for more information.

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KQED: Confocal Microscopy

Cutting-edge microscopes, called confocal microscopes, at the University of California, San Francisco are helping scientists create three-dimensional images of cells, and may help lead to new medical breakthroughs, including a treatment for Type 1 diabetes. See http://www.kqed.org/quest/television/super-microscope for a description of this work.

Diversity of Cells

Today, we know that all living cells have certain things in common. For example, all cells share functions such as obtaining and using energy, responding to the environment, and reproducing. We also know that different types of cells—even within the same organism—may have their own unique functions as well. Cells with different functions generally have different shapes that suit them for their particular job. Cells vary in size as well as shape, but all cells are very small. In fact, most cells are much smaller than the period at the end of this sentence. If cells have such an important role in living organisms, why are they so small? Even the largest organisms have microscopic cells. What limits cell size?

Cell Size

The answer to these questions is clear once you know how a cell functions. To carry out life processes, a cell must be able to quickly pass substances into and out of the cell. For example, it must be able to pass nutrients and oxygen into the cell and waste products out of the cell. Anything that enters or leaves a cell must cross its outer surface. It is this need to pass substances across the surface that limits how large a cell can be. Look at the two cubes in **Figure** 3.4 . As this figure shows, a larger cube has less surface area relative to its volume than a smaller cube. This relationship also applies to cells; a larger cell has less surface area relative to its volume than a smaller cell. A cell with a larger volume also needs more nutrients and oxygen and produces more wastes. Because all of these substances must pass through the surface of the cell, a cell with a large volume will not have enough surface area to allow it to meet its needs. The larger the cell is, the smaller its ratio of surface area to volume, and the harder it will be for the cell to get rid of its wastes and take in necessary substances. This is what limits the size of the cell.

Cell Shape

Cells with different functions often have different shapes. The cells pictured in **Figure** 3.5 are just a few examples of the many different shapes that cells may have. Each type of cell in the figure has a shape that helps it do its job. For example, the job of the nerve cell is to carry messages to other cells. The nerve cell has many long extensions that reach out in all directions, allowing it to pass messages to many other cells at once. Do you see the tail-like projections on the algae cells? Algae live in water, and their tails help them swim. Pollen grains have spikes that

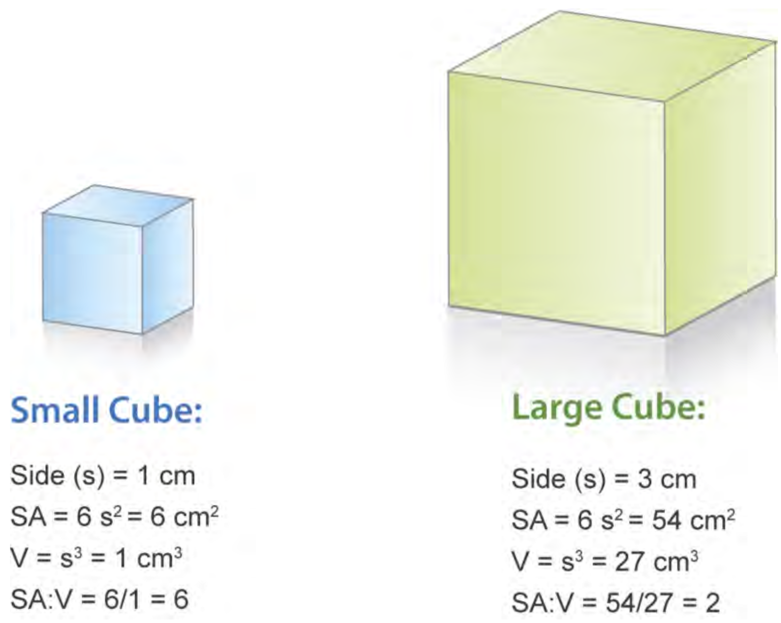

FIGURE 3.4
Surface Area to Volume Comparison. A larger cube has a smaller surface area SA to volume V ratio than a smaller cube. This also holds true for cells and limits how large they can be.

help them stick to insects such as bees. How do you think the spikes help the pollen grains do their job? (*Hint:* Insects pollinate flowers.)

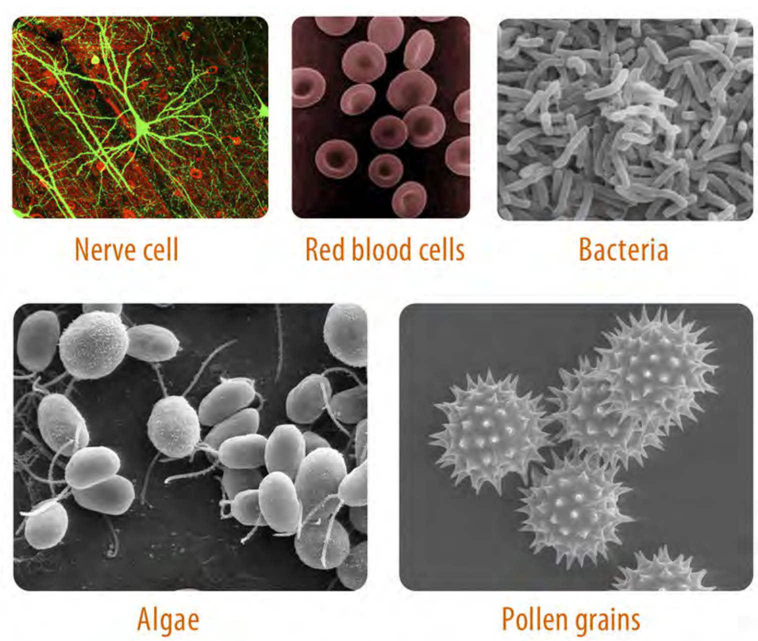

FIGURE 3.5
As these pictures show cells come in many different shapes. Clockwise from the upper left photo are a nerve cell red blood cells bacteria pollen grains and algae. How are the shapes of these cells related to their functions

Parts of a Cell

Although cells are diverse, all cells have certain parts in common. The parts include a plasma membrane, cytoplasm, ribosomes, and DNA.

a. The **plasma membrane** (also called the cell membrane) is a thin coat of lipids that surrounds a cell. It forms the physical boundary between the cell and its environment, so you can think of it as the "skin" of the cell.
b. **Cytoplasm** refers to all of the cellular material inside the plasma membrane. Cytoplasm is made up of a watery substance called cytosol and contains other cell structures such as ribosomes.
c. **Ribosomes** are structures in the cytoplasm where proteins are made.
d. DNA is a nucleic acid found in cells. It contains the genetic instructions that cells need to make proteins.

These parts are common to all cells, from organisms as different as bacteria and human beings. How did all known organisms come to have such similar cells? The similarities show that all life on Earth has a common evolutionary history.

A nice introduction to the cell is available at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/33/Hmwvj9X4GNY (21:03).

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Two Types of Cells

There is another basic cell structure that is present in many but not all living cells: the nucleus. The **nucleus** of a cell is a structure in the cytoplasm that is surrounded by a membrane (the nuclear membrane) and contains DNA. Based on whether they have a nucleus, there are two basic types of cells: prokaryotic cells and eukaryotic cells. You can watch animations of both types of cells at the link below. http://www.learnerstv.com/animation/animation.php?ani=162#38;cat=biology

Prokaryotic Cells

Prokaryotic cells are cells without a nucleus. The DNA in prokaryotic cells is in the cytoplasm rather than enclosed within a nuclear membrane. Prokaryotic cells are found in single-celled organisms, such as bacteria, like the one shown in **Figure** 3.6 . Organisms with prokaryotic cells are called **prokaryotes**. They were the first type of organisms to evolve and are still the most common organisms today.

Bacteria are described in the following video http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/16/TDoGrbpJJ14 (18:26).

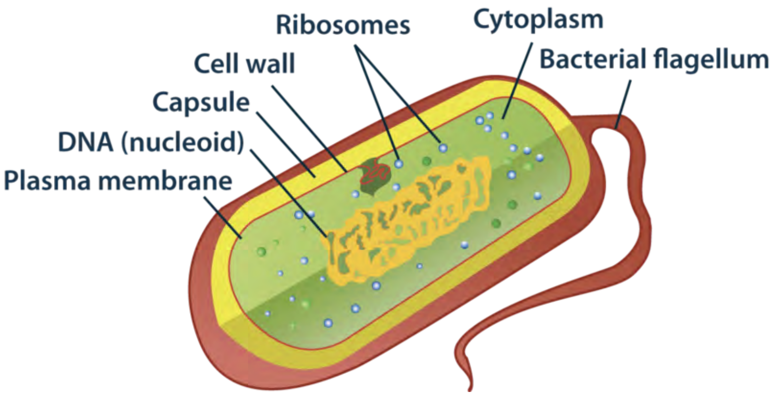
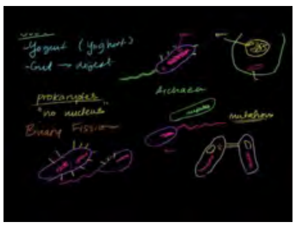


FIGURE 3.6
Prokaryotic Cell. This diagram shows the structure of a typical prokaryotic cell a bacterium. Like other prokaryotic cells this bacterial cell lacks a nucleus but has other cell parts including a plasma membrane cytoplasm ribosomes and DNA. Identify each of these parts in the diagram.



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Eukaryotic Cells

Eukaryotic cells are cells that contain a nucleus. A typical eukaryotic cell is shown in **Figure** 3.7 . Eukaryotic cells are usually larger than prokaryotic cells, and they are found mainly in multicellular organisms. Organisms with eukaryotic cells are called **eukaryotes**, and they range from fungi to people. Eukaryotic cells also contain other organelles besides the nucleus. An **organelle** is a structure within the cytoplasm that performs a specific job in the cell. Organelles called mitochondria, for example, provide energy to the cell, and organelles called vacuoles store substances in the cell. Organelles allow eukaryotic cells to carry out more functions than prokaryotic cells can.

Viruses: Prokaryotes or Eukaryotes?

Viruses, like the one depicted in **Figure** 3.8 , are tiny particles that may cause disease. Human diseases caused by viruses include the common cold and flu. Do you think viruses are prokaryotes or eukaryotes? The answer may surprise you. Viruses are not cells at all, so they are neither prokaryotes nor eukaryotes.

Viruses contain DNA but not much else. They lack the other parts shared by all cells, including a plasma membrane, cytoplasm, and ribosomes. Therefore, viruses are not cells, but are they alive? All living things not only have cells; they are also capable of reproduction. Viruses cannot reproduce by themselves. Instead, they infect living hosts, and use the hosts' cells to make copies of their own DNA. For these reasons, most scientists do not consider viruses to be living things.

An overview of viruses can be seen at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/17/0h5Jd7sgQWY (23:17).

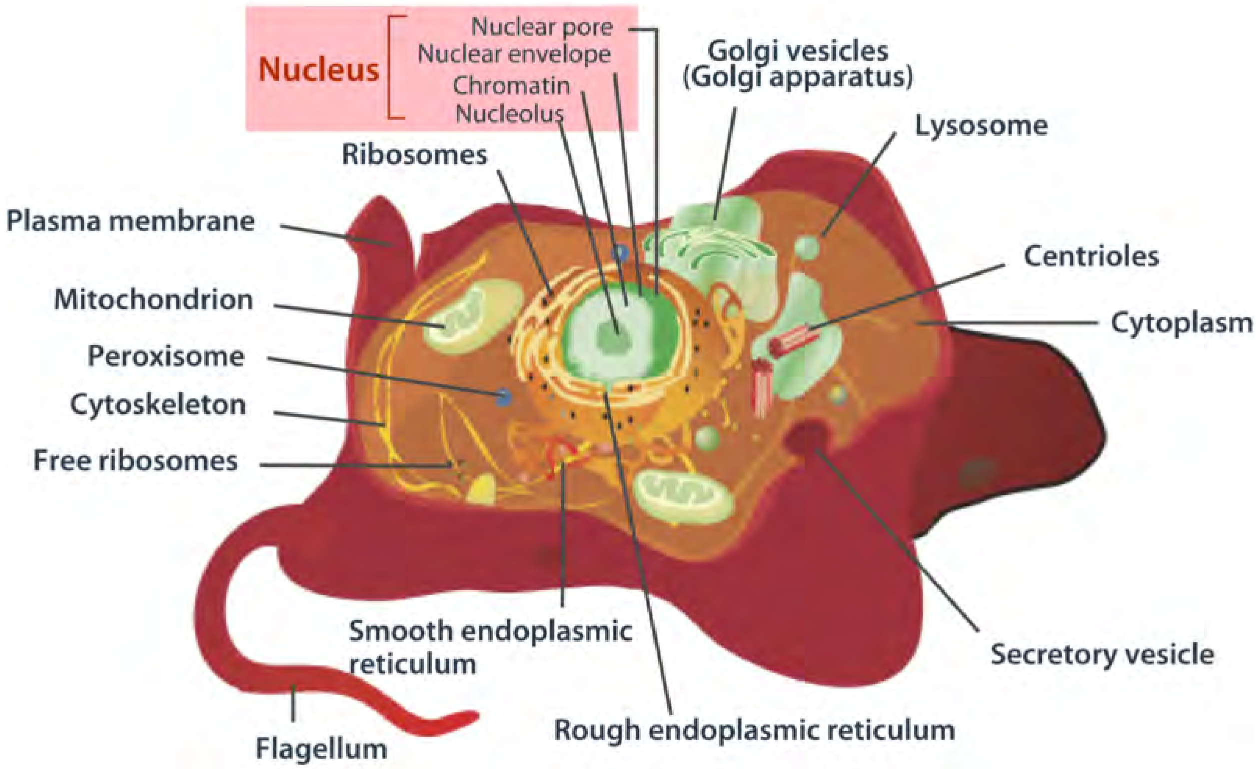
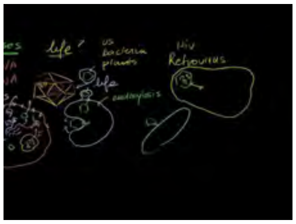


FIGURE 3.7

Eukaryotic Cell. Compare and contrast the eukaryotic cell shown here with the prokaryotic cell. What similarities and differences do you see

FIGURE 3.8

Cartoon of a flu virus. The flu virus is a tiny particle that may cause illness in humans. What is a virus Is it a cell Is it even alive



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Lesson Summary

- Discoveries about cells using the microscope led to the development of the cell theory. This theory states that all organisms are made of one or more cells, all the life functions of organisms occur within cells, and all cells come from already existing cells.
- All cells are very small because they need to pass substances across their surface. Their small size gives them a relatively large ratio of surface area to volume, facilitating the transfer of substances. The shapes of cells may vary, and a cell's shape generally suits its function.
- Cells are diverse, but all cells contain a plasma membrane, cytoplasm, ribosomes, and DNA.
- Prokaryotic cells are cells without a nucleus. They are found in single-celled organisms. Eukaryotic cells are cells with a nucleus and other organelles. They are found mainly in multicellular organisms.

Review Questions

Recall

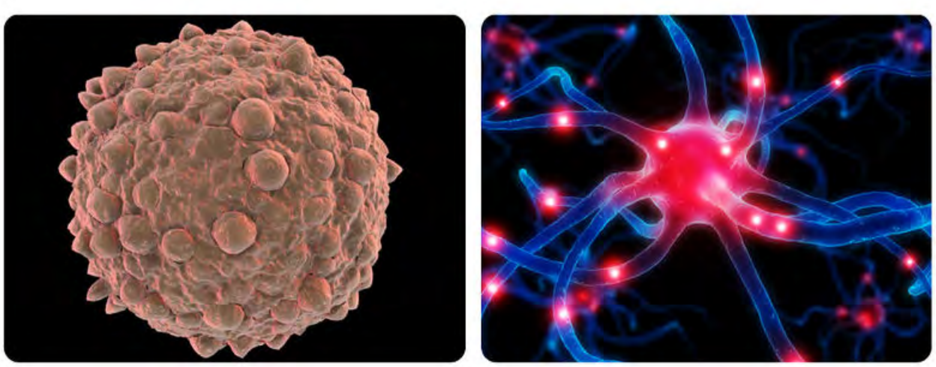
1. What did Hooke and Leeuwenhoek discover about cells by using a microscope?

2. What does the cell theory state? Name the three scientists mainly responsible for developing the cell theory.

3. List the four parts that are found in all living cells.

Apply Concepts

4. One of the cells pictured below is a human brain cell. The other cell is found in human blood. Which cell came from the brain? Explain your answer.



Think Critically

5. Why are all cells very small? Explain what limits the size of cells.
6. Compare and contrast prokaryotic cells and eukaryotic cells.
7. Explain why viruses are not considered to be living.

Points to Consider

Cells have many different structures that carry out the processes of life.

- Beside the cell parts described in this lesson, what other structures do you think cells might have? What life processes might these other structures carry out?
- Do you think plant and animal cells are just alike? Or do they differ in some way? How might they differ?

3.2 Cell Structures

Lesson Objectives

- Describe the structure and function of the plasma membrane.
- Identify the roles of the cytoplasm and exoskeleton.
- Outline the form and function of the nucleus and other organelles.
- List special structures of plant cells, and state what they do.
- Explain how cells are organized in living things.

Vocabulary

ATP (adenosine triphosphate) energy-carrying molecule that cells use to power their metabolic processes

cell wall rigid layer that surrounds the plasma membrane of a plant cell and helps support and protect the cell

central vacuole large saclike organelle in plant cells that stores substances such as water and helps keep plant tissues rigid

chloroplast organelle in the cells of plants and algae where photosynthesis takes place

cytoskeleton structure of filaments and tubules in the cytoplasm that provides a cell with an internal framework

endoplasmic reticulum (ER) organelle in eukaryotic cells that helps make and transport proteins

endosymbiotic theory theory that eukaryotic organelles such as mitochondria evolved from ancient, free-living prokaryotes that invaded primitive eukaryotic cells

Golgi apparatus organelle in eukaryotic cells that processes proteins and prepares them for use both inside and outside the cell

mitochondria (singular, mitochondrion) organelle in eukaryotic cells that makes energy available to the cell in the form of ATP molecules

phospholipid bilayer double layer of phospholipid molecules that makes up a plasma membrane

vacuole large saclike organelle that stores and transports materials inside a cell

vesicle small saclike organelle that stores and transports materials inside a cell

Introduction

Your body is made up of trillions of cells, but all of them perform the same basic life functions. They all obtain and use energy, respond to the environment, and reproduce. How do your cells carry out these basic functions and keep themselves—and you—alive? To answer these questions, you need to know more about the structures that make up cells.

Overview of Cell Structures

In some ways, a cell resembles a plastic bag full of Jell-O. Its basic structure is a plasma membrane filled with cytoplasm. Like Jell-O containing mixed fruit, the cytoplasm of the cell also contains various structures, such as a nucleus and other organelles. **Figure** 3.9 shows the structures inside a typical eukaryotic cell, in this case the cell of an animal. Refer to the figure as you read about the structures below. You can also explore the structures of an interactive animal cell at this link: http://www.cellsalive.com/cells/cell_model.htm.

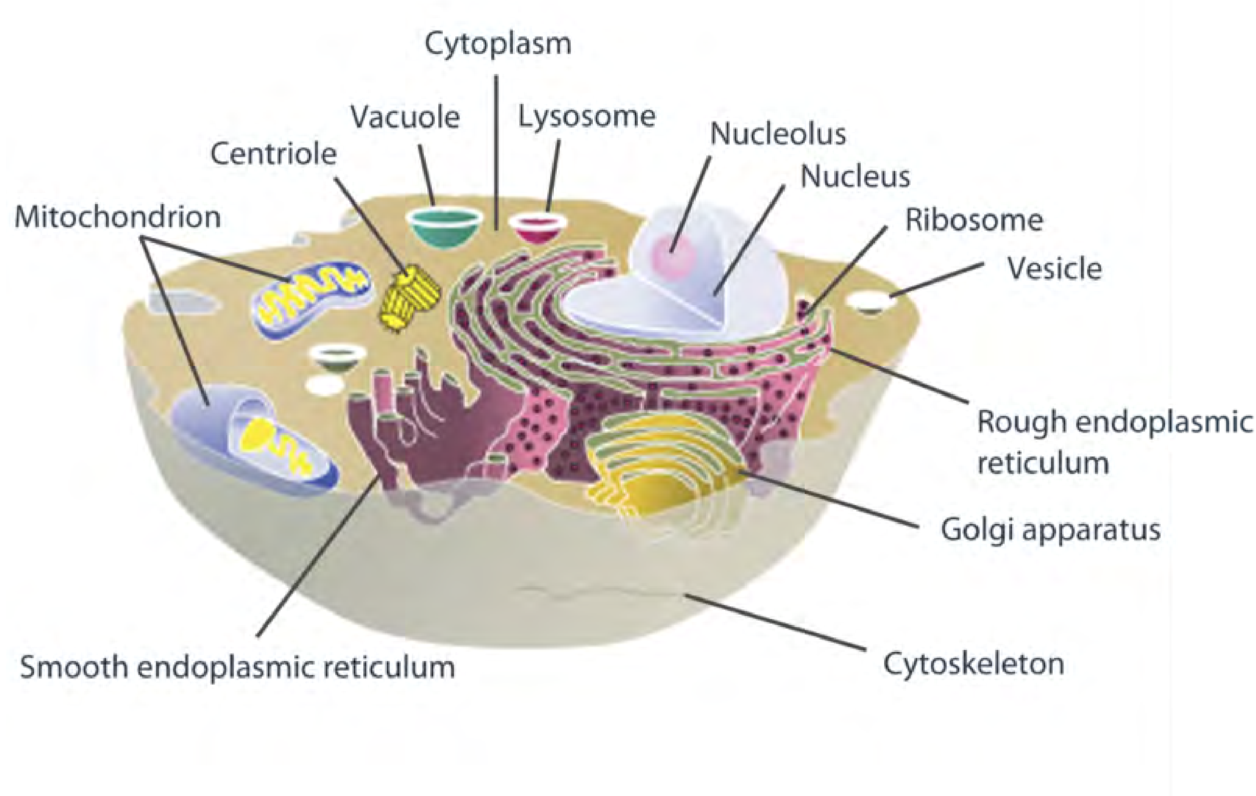


FIGURE 3.9

Animal Cell. This animal cell consists of cytoplasm enclosed within a plasma membrane. The cytoplasm contains many different organelles.

The Plasma Membrane

The plasma membrane forms a barrier between the cytoplasm inside the cell and the environment outside the cell. It protects and supports the cell and also controls everything that enters and leaves the cell. It allows only certain substances to pass through, while keeping others in or out. The ability to allow only certain molecules in or out of the cell is referred to as selective permeability or semipermeability. To understand how the plasma membrane controls what crosses into or out of the cell, you need to know its composition.

The plasma membrane is discussed at http://www.youtube.com/watch?v=-aSfoB8Cmic (6:16). The cell wall (see below) is also discussed in this video.

The Phospholipid Bilayer

The plasma membrane is composed mainly of phospholipids, which consist of fatty acids and alcohol. The phospholipids in the plasma membrane are arranged in two layers, called a **phospholipid bilayer**. As shown in **Figure** 3.10 , each phospholipid molecule has a head and two tails. The head "loves" water (hydrophilic) and the tails "hate" water (hydrophobic). The water-hating tails are on the interior of the membrane, whereas the water-loving heads point outwards, toward either the cytoplasm or the fluid that surrounds the cell. Molecules that are hydrophobic can easily pass through the plasma membrane, if they are small enough, because they are water-hating like the interior of the membrane. Molecules that are hydrophilic, on the other hand, cannot pass through the plasma membrane—at least not without help—because they are water-loving like the exterior of the membrane.

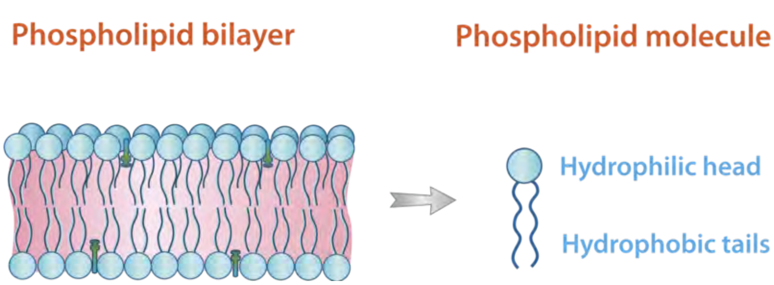


FIGURE 3.10
Phospholipid Bilayer. The phospholipid bilayer consists of two layers of phospholipids $left$ with a hydrophobic or water-hating interior and a hydrophilic or water-loving exterior. A single phospholipid molecule is depicted on the right.

Other Molecules in the Plasma Membrane

The plasma membrane also contains other molecules, primarily other lipids and proteins. The green molecules in **Figure** 3.10 , for example, are the lipid cholesterol. Molecules of cholesterol help the plasma membrane keep its shape. Many of the proteins in the plasma membrane assist other substances in crossing the membrane.

Extensions of the Plasma Membrane

The plasma membrane may have extensions, such as whip-like flagella or brush-like cilia. In single-celled organisms, like those shown in **Figure** 3.11 and **Figure** 3.12 , the membrane extensions may help the organisms move. In multicellular organisms, the extensions have other functions. For example, the cilia on human lung cells sweep foreign particles and mucus toward the mouth and nose.

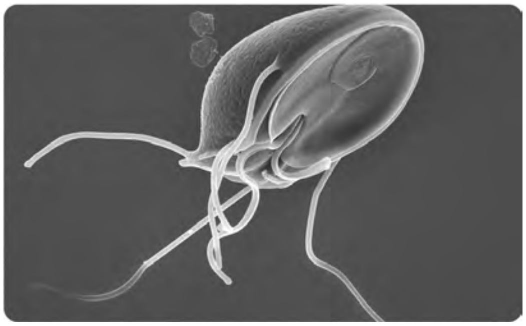


FIGURE 3.11
Flagella

FIGURE 3.12
Cilia. Cilia and flagella are extensions of the plasma membrane of many cells.

Cytoplasm and Cytoskeleton

The cytoplasm consists of everything inside the plasma membrane of the cell. It includes the watery, gel-like material called cytosol, as well as various structures. The water in the cytoplasm makes up about two thirds of the cell's weight and gives the cell many of its properties.

Functions of the Cytoplasm

The cytoplasm has several important functions, including

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

Cytoskeleton

Crisscrossing the cytoplasm is a structure called the **cytoskeleton**, which consists of thread-like filaments and tubules. You can see these filaments and tubules in the cells in **Figure** 3.13 . As its name suggests, the cytoskeleton is like a cellular "skeleton." It helps the cell maintain its shape and also holds cell organelles in place within the cytoplasm.

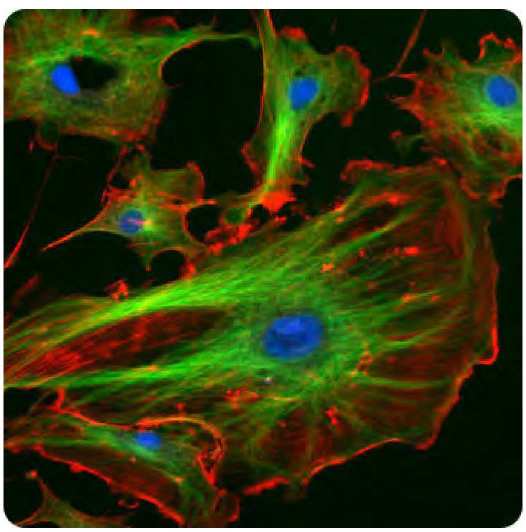


FIGURE 3.13
Cytoskeleton. The cytoskeleton gives the cell an internal structure like the frame of a house. In this photograph filaments and tubules of the cytoskeleton are green and red respectively. The blue dots are cell nuclei.

The cytoskeleton is discussed in the following video http://www.youtube.com/watch?v=5rqbmLiSkpk#38;feature=related (4:50).

The Nucleus and Other Organelles

Eukaryotic cells contain a nucleus and several other types of organelles. These structures are involved in many vital cell functions.

The Nucleus

The nucleus is the largest organelle in a eukaryotic cell and is often considered to be the cell's control center. This is because the nucleus controls which proteins the cell makes. The nucleus of a eukaryotic cell contains most of the cell's DNA, which makes up chromosomes and is encoded with genetic instructions for making proteins.

Mitochondria

The mitochondrion (plural, **mitochondria**) is an organelle that makes energy available to the cell. This is why mitochondria are sometimes referred to as the power plants of the cell. They use energy from organic compounds such as glucose to make molecules of **ATP** (adenosine triphosphate), an energy-carrying molecule that is used almost universally inside cells for energy. Scientists think that mitochondria were once free-living organisms because they contain their own DNA. They theorize that ancient prokaryotes infected (or were engulfed by) larger prokaryotic cells, and the two organisms evolved a symbiotic relationship that benefited both of them. The larger cells provided the smaller prokaryotes with a place to live. In return, the larger cells got extra energy from the smaller prokaryotes. Eventually, the prokaryotes became permanent *guests* of the larger cells, as organelles inside them. This theory is called the **endosymbiotic theory,** and it is widely accepted by biologists today

Endoplasmic Reticulum

The **endoplasmic reticulum** (ER) is an organelle that helps make and transport proteins and lipids. There are two types of endoplasmic reticulum: rough endoplasmic reticulum (RER) and smooth endoplasmic reticulum (SER). Both types are shown in **Figure** 3.14 .

- RER looks rough because it is studded with ribosomes. It provides a framework for the ribosomes, which make proteins.
- SER looks smooth because it does not have ribosomes. Bits of its membrane pinch off to form tiny sacs called vesicles, which carry proteins away from the ER. SER also makes lipids, stores substances, and plays other roles.

Ribosomes

Ribosomes are small organelles where proteins are made. They contain the nucleic acid RNA, which assembles and joins amino acids to make proteins. Ribosomes can be found alone or in groups within the cytoplasm as well as on the RER.

Golgi Apparatus

The **Golgi apparatus** is a large organelle that processes proteins and prepares them for use both inside and outside the cell. It is shown in **Figure** 3.14 . The Golgi apparatus is somewhat like a post office. It receives items (proteins from the ER), packages and labels them, and then sends them on to their destinations (to different parts of the cell or to the cell membrane for transport out of the cell). The Golgi apparatus is also involved in the transport of lipids around the cell. At the link below, you can watch an animation showing how the Golgi apparatus does all these jobs. http://www.johnkyrk.com/golgiAlone.html

Vesicles and Vacuoles

Both **vesicles** and **vacuoles** are sac-like organelles that store and transport materials in the cell. Vesicles are much smaller than vacuoles and have a variety of functions. The vesicles that pinch off from the membranes of the ER

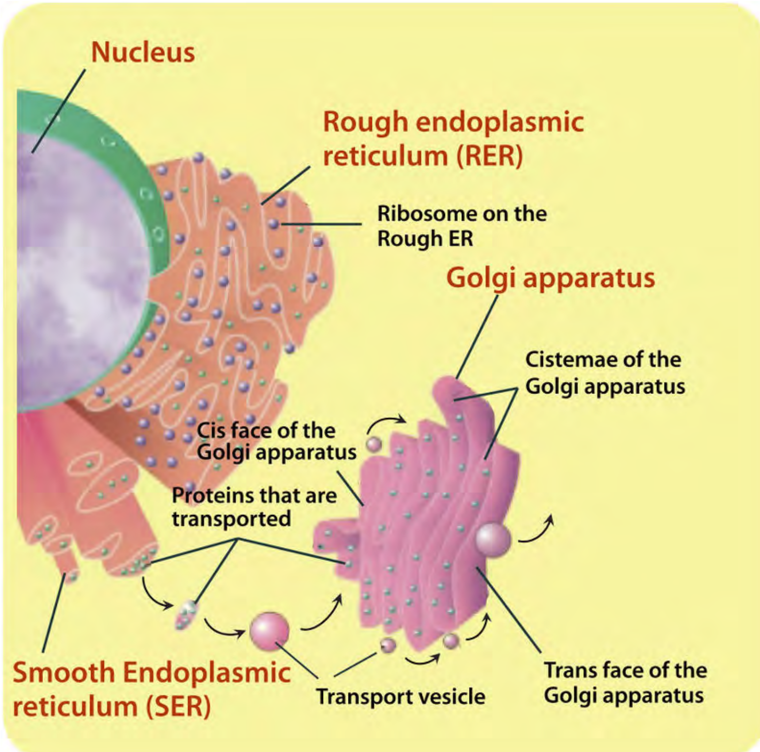


FIGURE 3.14
This drawing includes the nucleus RER SER and Golgi apparatus. From the drawing you can see how all these organelles work together to make and transport proteins.

and Golgi apparatus (see **Figure** 3.14) store and transport protein and lipid molecules. Some vesicles are used as chambers for biochemical reactions. Other vesicles include:

- Lysosomes, which use enzymes to break down foreign matter and dead cells.
- Peroxisomes, which use oxygen to break down poisons.

Centrioles

Centrioles are organelles involved in cell division. They help organize the chromosomes before cell division so that each daughter cell has the correct number of chromosomes after the cell divides. Centrioles are found only in animal cells and are located near the nucleus (see **Figure** 3.9).

Special Structures in Plant Cells

Plant cells have several structures that are not found in animal cells, including a cell wall, a large central vacuole, and organelles called plastids. You can see each of these structures in **Figure** 3.15 . You can also view them in an interactive plant cell at the link below. http://www.cellsalive.com/cells/cell_model.htm

Cell Wall

The **cell wall** is a rigid layer that surrounds the plasma membrane of a plant cell. It supports and protects the cell. Tiny holes, or pores, in the cell wall allow water, nutrients, and other substances to move into and out of the cell. The cell wall is made up mainly of complex carbohydrates, including cellulose.

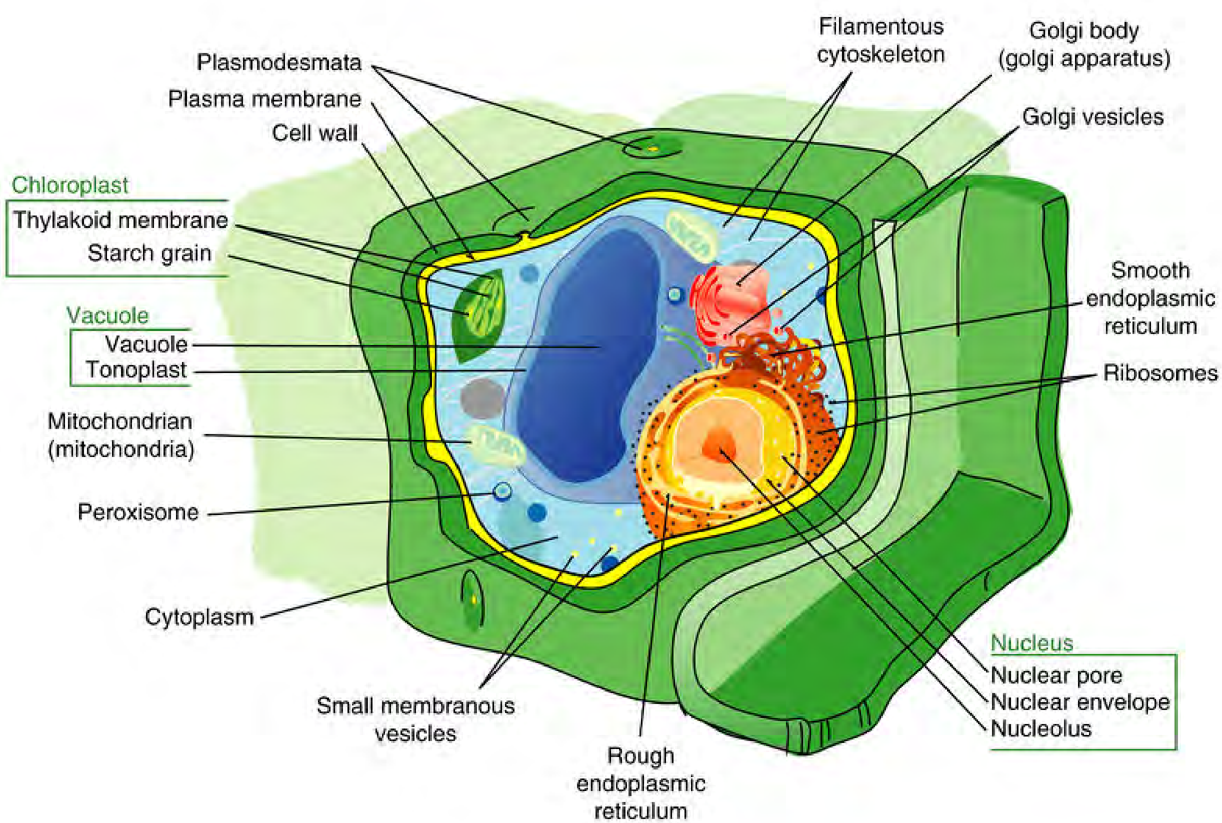


FIGURE 3.15

Plant Cell. In addition to the organelles and other structures found inside animal cells plant cells also have a cell wall a large central vacuole and plastids such as chloroplasts. Can you find each of these structures in the figure

Central Vacuole

Most mature plant cells have a large **central vacuole**. This vacuole can make up as much as 90% of the cell's volume. The central vacuole has a number of functions, including storing substances such as water, enzymes, and salts. It also helps plant tissues, such as stems and leaves, stay rigid and hold their shape. It even helps give flowers, like the ones in **Figure** 3.16 , their beautiful colors.

FIGURE 3.16
These flowers are red because of red pigment molecules in the central vacuoles of their cells. The bright colors are an important adaptation. They help the flowers attract pollinators such as hummingbirds so the plants can reproduce.

Plastids

Plastids are organelles in plant cells that carry out a variety of different functions. The main types of plastids and their functions are described below.

- **Chloroplasts** are plastids that contain the green pigment chlorophyll. They capture light energy from the sun and use it to make food. A chloroplast is shown in **Figure** 3.15 .
- Chromoplasts are plastids that make and store other pigments. The red pigment that colors the flower petals in **Figure** 3.16 was made by chromoplasts.
- Leucoplasts are plastids that store substances such as starch or make small molecules such as amino acids.

Like mitochondria, plastids contain their own DNA. Therefore, according to endosymbiotic theory, plastids may also have evolved from ancient, free-living prokaryotes that invaded larger prokaryotic cells. If so, they allowed early eukaryotes to make food and produce oxygen.

Organization of Cells

Cells can exist as individual cells or as groups of cells. Cells in groups can be organized at several levels.

From One Cell to Many

The simplest level of cell organization is a single-celled organism, and the most complex level is a multicellular organism. In between these two levels are biofilms and colonies.

- A single-celled organism floats freely and lives independently. Its single cell is able to carry out all the processes of life without any help from other cells.

- A biofilm is a thin layer of bacteria that sticks to a surface. Cells in a biofilm are all alike, but they may play different roles, such as taking in nutrients or making the "glue" that sticks the biofilm to the surface. The sticky plaque that forms on teeth is a biofilm of bacterial cells.
- Some single-celled organisms, such as algae, live in colonies. A colony is an organized structure composed of many cells, like the Volvox sphere in **Figure** 3.17 . Volvox are algae that live in colonies of hundreds of cells. All of the cells in the colony live and work cooperatively. For example, they can coordinate the movement of their flagella, allowing them to swim together through the water as though they were part of a single organism.
- A multicellular organism consists of many cells and has different types of cells that are specialized for various functions. All the cells work together and depend on each other to carry out the life processes of the organism. Individual cells are unable to survive on their own.

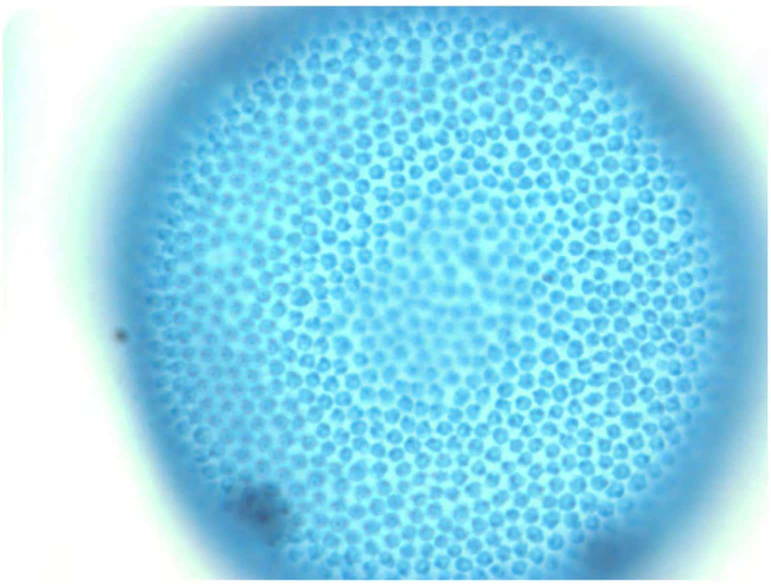


FIGURE 3.17
Volvox Colony. Volvox cells live in a colony shaped like a hollow ball. The cells of the colony may be connected by strands of cytoplasm and can function together. For example the whole colony can swim from one place to another as one.

Levels of Organization in Multicellular Organisms

Scientists think that multicellular organisms evolved when many single-celled organisms of the same species started to work together and benefited from the relationship. The oldest known multicellular organisms are algae that lived 1.2 billion years ago. As multicellular organisms continued to evolve, they developed increasingly complex levels of organization. Today there are multicellular organisms at all levels of organization, from the simplest, cell level of organization to the most complex, organ-system level of organization. Consider these examples:

- Sponges have cell-level organization, in which different cells are specialized for different functions, but each cell works alone. For example, some cells digest food, while other cells let water pass through the sponge.
- Jellyfish have tissue-level organization, in which groups of cells of the same kind that do the same job form tissues. For example, jellyfish have some tissues that digest food and other tissues that sense the environment.
- Roundworms have organ-level organization, in which two or more types of tissues work together to perform a particular function as an organ. For example, a roundworm has a primitive brain that controls how the organism responds to the environment.
- Human beings have organ system-level organization, in which groups of organs work together to do a certain job, with each organ doing part of the overall task. An example is the human digestive system. Each digestive system organ—from the mouth to the small intestine—does part of the overall task of breaking down food and absorbing nutrients.

Lesson Summary

- The plasma membrane is a phospholipid bilayer that supports and protects a cell and controls what enters and leaves it.
- The cytoplasm consists of everything inside the plasma membrane, including watery cytosol and organelles. The cytoplasm suspends the organelles and does other jobs. The cytoskeleton crisscrosses the cytoplasm and gives the cell an internal framework.
- The nucleus is the largest organelle in a eukaryotic cell and contains most of the cell's DNA. Other organelles in eukaryotic cells include the mitochondria, endoplasmic reticulum, ribosomes, Golgi apparatus, vesicles, vacuoles, and centrioles (in animal cells only). Each type of organelle has important functions in the cell.
- Plant cells have special structures that are not found in animal cells, including a cell wall, a large central vacuole, and organelles called plastids.
- Cells can exist independently as single-celled organisms or with other cells as multicellular organisms. Cells of a multicellular organism can be organized at the level of cells, tissues, organs, and organ systems.

Lesson Review Questions

Recall

1. Describe the composition of the plasma membrane.

2. List functions of the cytoplasm and cytoskeleton.

3. What is the role of the nucleus of a eukaryotic cell?

4. List three structures that are found in plant cells but not in animal cells.

5. Outline the levels of organization of cells in living things, starting with the simplest level, that of single-celled organisms.

Apply Concepts

6. Create a diagram to show how the cells of multicellular organisms may be organized at different levels, from the level of the cell to the level of the organ system. Give an example of a multicellular organism at each level of organization.

Think Critically

7. Explain why hydrophobic ("water-hating") molecules can easily cross the plasma membrane, while hydrophilic ("water-loving") molecules cannot.

8. What is endosymbiotic theory? How does it explain the presence of certain organelles in eukaryotic cells?

9. Explain how the following organelles ensure that a cell has the proteins it needs: nucleus, rough and smooth ER, vesicles, and Golgi apparatus.

Points to Consider

Cells carry out all the functions of life, and they use nutrients and oxygen and produce wastes. These substances must cross the plasma membrane.

- How do you think substances cross the plasma membrane to enter or leave the cell? Does the membrane have tiny holes in it like a sieve?
- What if the substances are large? Protein molecules, for example, are very large. How do they enter or leave the cell?

3.3 Cell Transport and Homeostasis

Lesson Objectives

- Describe different types of passive transport.
- Explain how different types of active transport occur.
- Outline the role of cell transport in homeostasis.

Vocabulary

active transport movement of substances across a plasma membrane that requires energy

diffusion type of passive transport that does not require the help of transport proteins

endocytosis type of vesicle transport that moves substances into a cell

exocytosis type of vesicle transport that moves substances out of a cell

facilitated diffusion diffusion with the help of transport proteins

osmosis diffusion of water molecules across a membrane

passive transport movement of substances across a plasma membrane that does not require energy

sodium-potassium pump type of active transport in which sodium ions are pumped out of the cell and potassium ions are pumped into the cell with the help of a carrier protein and energy from ATP

transport protein protein in a plasma membrane that helps other substances cross the membrane

vesicle transport type of active transport in which substances are carried across the cell membrane by vesicles

Introduction

Imagine living in a house that has walls without any windows or doors. Nothing could enter or leave the house. Now imagine living in a house with holes in the walls instead of windows and doors. Things could enter or leave the house, but you wouldn't be able to control what came in or went out. Only if a house has walls with windows and doors that can be opened or closed can you control what enters or leaves. For example, windows and doors allow you to let the dog in and keep the bugs out.

Transport Across Membranes

If a cell were a house, the plasma membrane would be walls with windows and doors. Moving things in and out of the cell is an important role of the plasma membrane. It controls everything that enters and leaves the cell. There are two basic ways that substances can cross the plasma membrane: passive transport and active transport.

Passive Transport

Passive transport occurs when substances cross the plasma membrane without any input of energy from the cell. No energy is needed because the substances are moving from an area where they have a higher concentration to an area where they have a lower concentration. Concentration refers to the number of particles of a substance per unit of volume. The more particles of a substance in a given volume, the higher the concentration. A substance always moves from an area where it is more concentrated to an area where it is less concentrated. It's a little like a ball rolling down a hill. It goes by itself without any input of extra energy.

There are several different types of passive transport, including simple diffusion, osmosis, and facilitated diffusion. Each type is described below. You can also watch an animation of each type at this link: http://www.northland.cc.mn.us/biology/BIOLOGY1111/animations/passive1.swf.

Simple Diffusion

Diffusion is the movement of a substance across a membrane, due to a difference in concentration, without any help from other molecules. The substance simply moves from the side of the membrane where it is more concentrated to the side where it is less concentrated. **Figure** 3.18 shows how diffusion works. Substances that can squeeze between the lipid molecules in the plasma membrane by simple diffusion are generally very small, hydrophobic molecules, such as molecules of oxygen and carbon dioxide.

Osmosis

Osmosis is a special type of diffusion — the diffusion of water molecules across a membrane. Like other molecules, water moves from an area of higher concentration to an area of lower concentration. Water moves in or out of a cell until its concentration is the same on both sides of the plasma membrane.

Diffusion and osmosis are discussed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/34/aubZU0iWtgI.

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Facilitated Diffusion

Water and many other substances cannot simply diffuse across a membrane. Hydrophilic molecules, charged ions, and relatively large molecules such as glucose all need help with diffusion. The help comes from special proteins

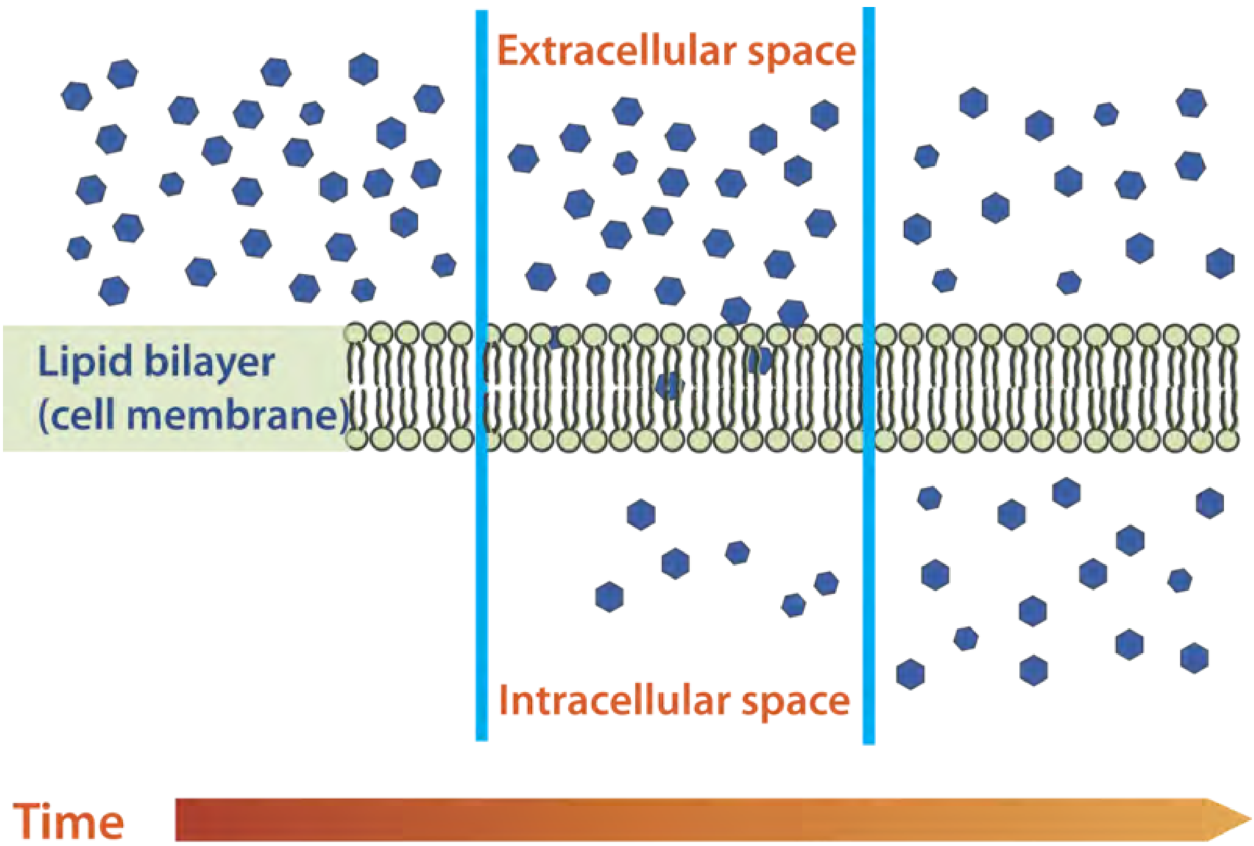

FIGURE 3.18

Diffusion Across a Cell Membrane. Molecules diffuse across a membrane from an area of higher concentration to an area of lower concentration until the concentration is the same on both sides of the membrane.

in the membrane known as **transport proteins**. Diffusion with the help of transport proteins is called **facilitated diffusion**. There are several types of transport proteins, including channel proteins and carrier proteins. Both are shown in **Figure** 3.19 .

- Channel proteins form pores, or tiny holes, in the membrane. This allows water molecules and small ions to pass through the membrane without coming into contact with the hydrophobic tails of the lipid molecules in the interior of the membrane.
- Carrier proteins bind with specific ions or molecules, and in doing so, they change shape. As carrier proteins change shape, they carry the ions or molecules across the membrane.

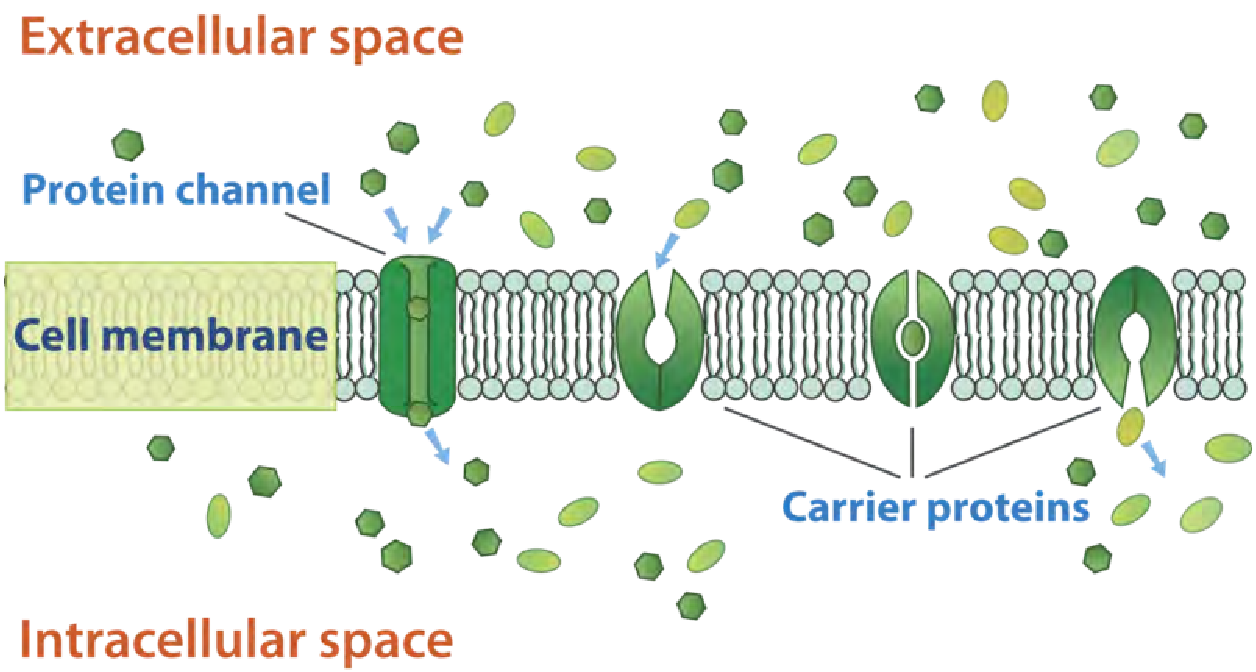

FIGURE 3.19

Facilitated Diffusion Across a Cell Membrane. Channel proteins and carrier proteins help substances diffuse across a cell membrane. In this diagram the channel and carrier proteins are helping substances move into the cell *from the extracellular space to the intracellular space*.

Active Transport

Active transport occurs when energy is needed for a substance to move across a plasma membrane. Energy is needed because the substance is moving from an area of lower concentration to an area of higher concentration. This is a little like moving a ball uphill; it can't be done without adding energy. The energy for active transport comes from the energy-carrying molecule called ATP. Like passive transport, active transport may also involve transport proteins. You can watch an animation of active transport at the link below. http://www.northland.cc.mn.us/biology/BIOLOGY1111/animations/active1.swf

Sodium-Potassium Pump

An example of active transport is the **sodium-potassium pump**. When this pump is in operation, sodium ions are pumped out of the cell, and potassium ions are pumped into the cell. Both ions move from areas of lower to higher concentration, so ATP is needed to provide energy for this "uphill" process. **Figure** 3.20 explains in more detail how this type of active transport occurs.

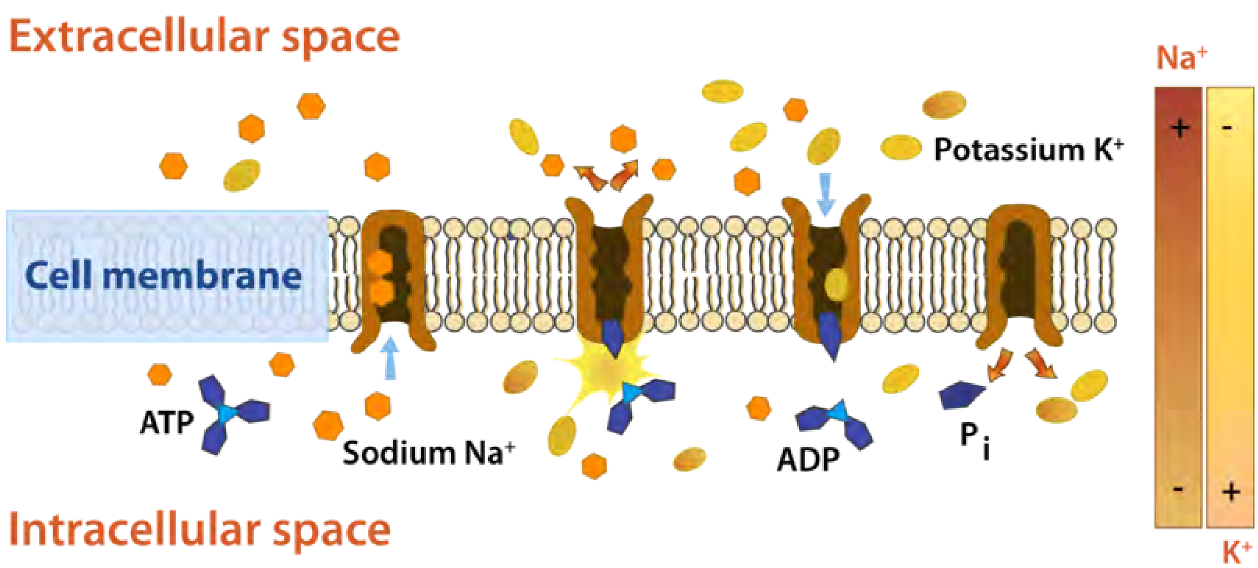

FIGURE 3.20

The sodium-potassium pump. The sodium-potassium pump moves sodium ions Na out of the cell and potassium ions K into the cell. First three sodium ions bind with a carrier protein in the cell membrane. Then the carrier protein receives a phosphate group from ATP. When ATP loses a phosphate group energy is released. The carrier protein changes shape and as it does it pumps the three sodium ions out of the cell. At that point two potassium ions bind to the carrier protein. The process is reversed and the potassium ions are pumped into the cell.

A more detailed look at the sodium-potassium pump is available at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/40/C_H-ONQFjpQ and http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/41/ye3rTjLCvAU.

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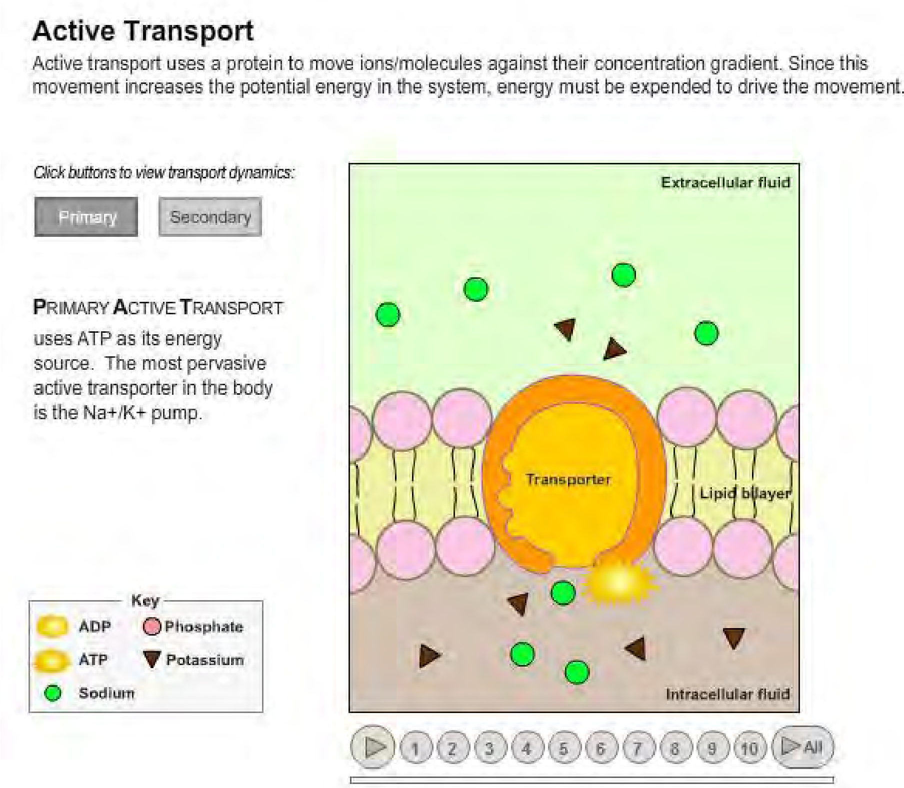
The following interactive animation demonstrates active transport. http://authors.ck12.org/wiki/images/f/f4/Activetransport.swf



Vesicle Transport

Some molecules, such as proteins, are too large to pass through the plasma membrane, regardless of their concentration inside and outside the cell. Very large molecules cross the plasma membrane with a different sort of help, called **vesicle transport**. Vesicle transport requires energy, so it is also a form of active transport. There are two types of vesicle transport: endocytosis and exocytosis. Both types are shown in **Figure** 3.21 and described below.

- **Endocytosis** is the type of vesicle transport that moves a substance into the cell. The plasma membrane completely engulfs the substance, a vesicle pinches off from the membrane, and the vesicle carries the substance into the cell. When an entire cell is engulfed, the process is called phagocytosis. When fluid is engulfed, the process is called pinocytosis.
- **Exocytosis** is the type of vesicle transport that moves a substance out of the cell. A vesicle containing the substance moves through the cytoplasm to the cell membrane. Then, the vesicle membrane fuses with the cell membrane, and the substance is released outside the cell. You can watch an animation of exocytosis at the link below.

http://www.stanford.edu/group/Urchin/GIFS/exocyt.gif

Homeostasis and Cell Function

For a cell to function normally, a stable state must be maintained inside the cell. For example, the concentration of salts, nutrients, and other substances must be kept within a certain range. The process of maintaining stable

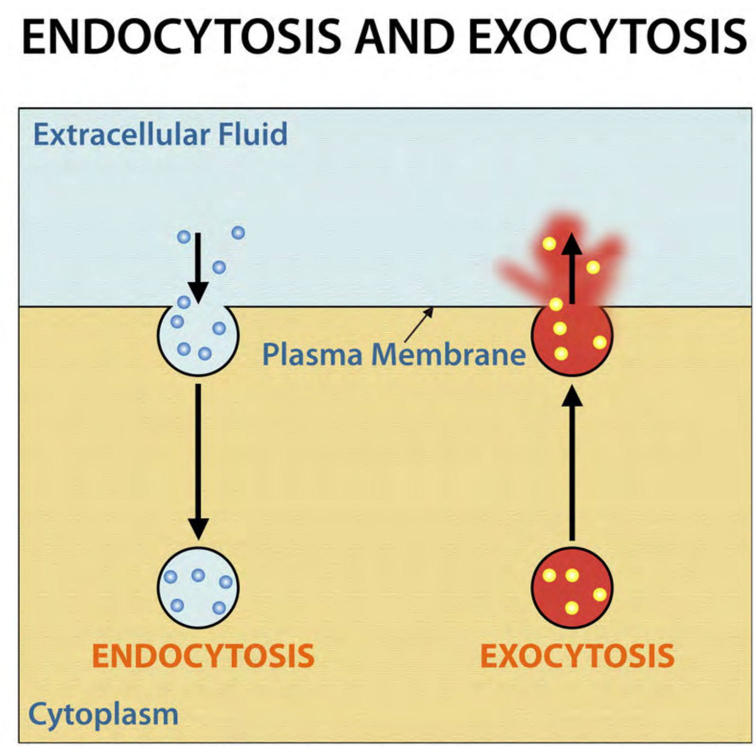


FIGURE 3.21
Endocytosis and exocytosis are types of vesicle transport that carry very large molecules across the cell membrane.

conditions inside a cell (or an entire organism) is homeostasis. Homeostasis requires constant adjustments, because conditions are always changing both inside and outside the cell. The processes described in this lesson play important roles in homeostasis. By moving substances into and out of cells, they keep conditions within normal ranges inside the cells and the organism as a whole.

Lesson Summary

- A major role of the plasma membrane is transporting substances into and out of the cell. There are two major types of cell transport: passive transport and active transport.
- Passive transport requires no energy. It occurs when substances move from areas of higher to lower concentration. Types of passive transport include simple diffusion, osmosis, and facilitated diffusion.
- Active transport requires energy from the cell. It occurs when substances move from areas of lower to higher concentration or when very large molecules are transported. Types of active transport include ion pumps, such as the sodium-potassium pump, and vesicle transport, which includes endocytosis and exocytosis.
- Cell transport helps cells maintain homeostasis by keeping conditions within normal ranges inside all of an organism's cells.

Lesson Review Questions

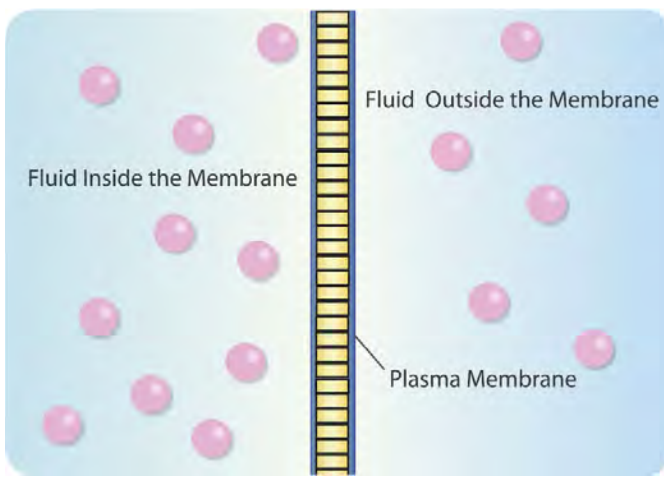
Recall

1. What is osmosis? What type of transport is it?
2. Describe the roles of transport proteins in cell transport.
3. What is the sodium-potassium pump?
4. Name two types of vesicle transport. Which type moves substances out of the cell?

Apply Concepts

5. Assume a molecule must cross the plasma membrane into a cell. The molecule is a very large protein. How will it be transported into the cell? Explain your answer.

6. The drawing below shows the fluid inside and outside a cell. The dots represent molecules of a substance needed by the cell. The molecules are very small and hydrophobic. What type of transport will move the molecules into the cell?



Think Critically

7. Compare and contrast simple diffusion and facilitated diffusion. For each type of diffusion, give an example of a molecule that is transported that way.

8. Explain how cell transport helps an organism maintain homeostasis.

Points to Consider

All cells share some of the same structures and basic functions, but cells also vary.

- Plant cells have structures that animal cells lack. What important process takes place in plant cells but not in animal cells that might explain their differences?
- All cells, including both plant and animal cells, need energy for processes such as active transport. How do cells obtain the energy they need?

CHAPTER 4 Photosynthesis and Cellular Respiration

CHAPTER OUTLINE

This caterpillar is busily munching its way through leaf after leaf. In fact, caterpillars do little more than eat, day and night. Like all living things, they need food to provide their cells with energy. The caterpillar will soon go through an amazing transformation to become a beautiful butterfly. These changes require a lot of energy. Like this caterpillar and all other living things, you need energy to power everything you do. Whether it's running a race or blinking an eye, it takes energy. In fact, every cell of your body constantly needs energy to carry out life processes. You probably know that you get energy from the food you eat, but where does food come from? How does it come to contain energy, and how do your cells get the energy from food? When you read this chapter, you will learn the answers to these questions.

4.1 Energy for Life

Lesson Objectives

- State why living things need energy.
- Describe how autotrophs and heterotrophs obtain energy.
- Compare and contrast glucose and ATP.
- Outline how living things make and use food.

Vocabulary

autotroph organism that makes its own food

cellular respiration process in which cells break down glucose and make ATP for energy

consumer organism that consumes other organisms for food

energy ability to do work

food organic molecules such as glucose that organisms use for chemical energy

glucose simple carbohydrate with the chemical formula $C_6H_{12}O_6$ that is the nearly universal food for life

heterotroph organism that gets food by consuming other organisms

photosynthesis process of using the energy in sunlight to make food (glucose)

producer organism that produces food for itself and other organisms

Introduction

All living things need **energy**, which is defined as the ability to do work. You can often see energy at work in living things—a bird flies through the air, a firefly glows in the dark, a dog wags its tail. These are obvious ways that living things use energy, but living things constantly use energy in less obvious ways as well.

Why Living Things Need Energy

Inside every cell of all living things, energy is needed to carry out life processes. Energy is required to break down and build up molecules and to transport molecules across plasma membranes. All life's work needs energy. A lot of energy is also simply lost to the environment as heat. The story of life is a story of energy flow—its capture, its change of form, its use for work, and its loss as heat. Energy, unlike matter, cannot be recycled, so organisms require a constant input of energy. Life runs on chemical energy. Where do living organisms get this chemical energy?

How Organisms Get Energy: Autotrophs and Heterotrophs

The chemical energy that organisms need comes from food. **Food** consists of organic molecules that store energy in their chemical bonds. In terms of obtaining food for energy, there are two types of organisms: autotrophs and heterotrophs.

Autotrophs

Autotrophs are organisms that make their own food. Most autotrophs use the energy in sunlight to make food in a process called **photosynthesis**. Only three types of organisms—plants, algae, and some bacteria—can make food through photosynthesis. Examples of each type of photosynthetic organism are shown in **Figure** 4.1 .

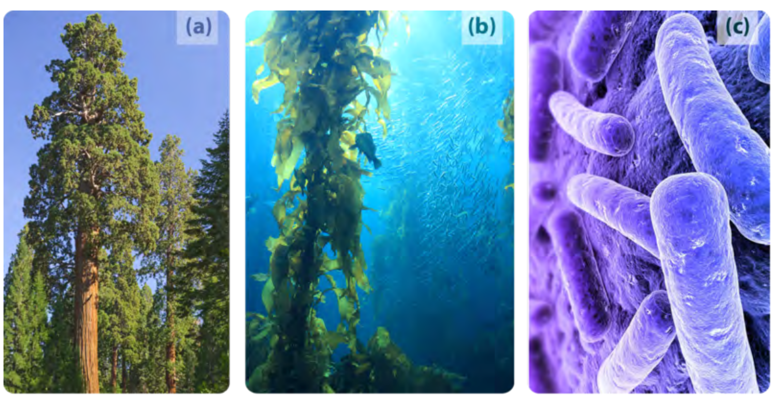


FIGURE 4.1

Photosynthetic autotrophs which make food using the energy in sunlight include *a* plants *b* algae and *c* certain bacteria.

Autotrophs are also called **producers**. They produce food not only for themselves but for all other living things as well (which are known as consumers). This is why autotrophs form the basis of food chains, such as the food chain shown in **Figure** 4.2 .

Heterotrophs

Heterotrophs are living things that cannot make their own food. Instead, they get their food by consuming other organisms, which is why they are also called **consumers**. They may consume autotrophs or other heterotrophs. Heterotrophs include all animals and fungi and many single-celled organisms. In **Figure** 4.2 , all of the organisms are consumers except for the grass. What do you think would happen to consumers if all producers were to vanish from Earth?

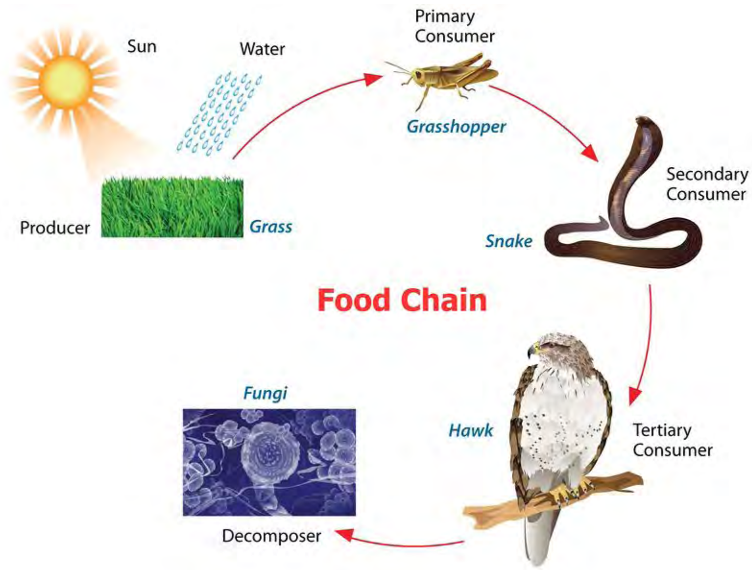


FIGURE 4.2
A food chain shows how energy and matter flow from producers to consumers. Matter is recycled but energy must keep flowing into the system. Where does this energy come from

Energy Molecules: Glucose and ATP

Organisms mainly use two types of molecules for chemical energy: glucose and ATP. Both molecules are used as fuels throughout the living world. Both molecules are also key players in the process of photosynthesis.

Glucose

Glucose is a simple carbohydrate with the chemical formula $C_6H_{12}O_6$. It 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. Glucose is the end product of photosynthesis, and it is the nearly universal food for life.

ATP

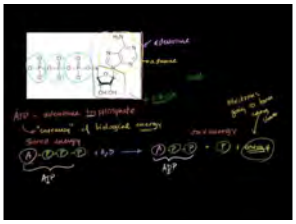
ATP (adenosine triphosphate) is the energy-carrying molecule that cells use for energy. ATP is made during the first half of photosynthesis and then used for energy during the second half of photosynthesis, when glucose is made. It is also used for energy by cells for most other cellular processes. ATP releases energy when it gives up one of its three phosphate groups and changes to ADP (adenosine diphosphate [*two phosphates*]).

Why Organisms Need Both Glucose and ATP

Why do living things need glucose if ATP is the molecule that cells use for energy? Why don't autotrophs just make ATP and be done with it? The answer is in the "packaging." A molecule of glucose contains more chemical energy in a smaller "package" than a molecule of ATP. Glucose is also more stable than ATP. Therefore, glucose is better for storing and transporting energy. However, glucose is too powerful for cells to use. ATP, on the other hand, contains just the right amount of energy to power life processes within cells. For these reasons, both glucose and ATP are needed by living things.

A explanation of ATP as *biological energy* is found at http://www.youtube.com/user/khanacademy#p/c/7A9646B

C5110CF64/18/YQfWiDlFEcA.



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Making and Using Food

The flow of energy through living organisms begins with photosynthesis. This process stores energy from sunlight in the chemical bonds of glucose. By breaking the chemical bonds in glucose, cells release the stored energy and make the ATP they need. The process in which glucose is broken down and ATP is made is called **cellular respiration**. Photosynthesis and cellular respiration are like two sides of the same coin. This is apparent from **Figure** 4.3 . The products of one process are the reactants of the other. Together, the two processes store and release energy in living organisms. The two processes also work together to recycle oxygen in Earth's atmosphere.

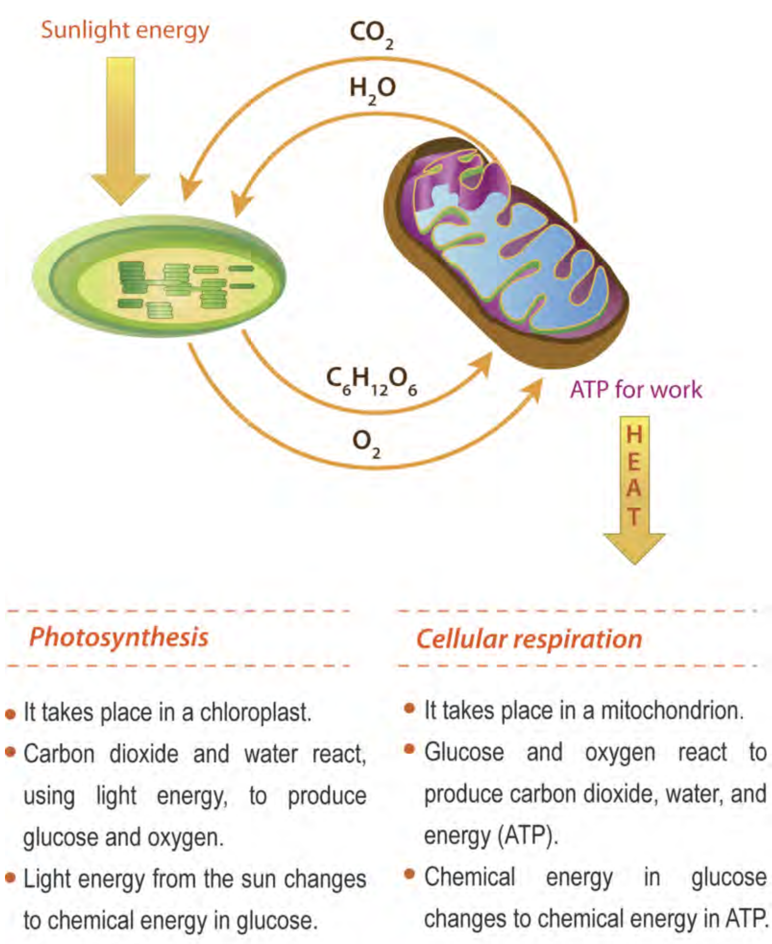


FIGURE 4.3

This diagram compares and contrasts photosynthesis and cellular respiration. It also shows how the two processes are related.

Photosynthesis

Photosynthesis is often considered to be the single most important life process on Earth. It changes light energy into chemical energy and also releases oxygen. Without photosynthesis, there would be no oxygen in the atmosphere. Photosynthesis involves many chemical reactions, but they can be summed up in a single chemical equation:

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

Photosynthetic autotrophs capture light energy from the sun and absorb carbon dioxide and water from their environment. Using the light energy, they combine the reactants to produce glucose and oxygen, which is a waste product. They store the glucose, usually as starch, and they release the oxygen into the atmosphere.

Cellular Respiration

Cellular respiration actually "burns" glucose for energy. However, it doesn't produce light or intense heat as some other types of burning do. This is because it releases the energy in glucose slowly, in many small steps. It uses the energy that is released to form molecules of ATP. Cellular respiration involves many chemical reactions, which can be summed up with this chemical equation:

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

Cellular respiration occurs in the cells of all living things. It takes place in the cells of both autotrophs and heterotrophs. All of them burn glucose to form ATP.

Lesson Summary

- Living things need energy to carry out all life processes. They get energy from food.
- Autotrophs make their own food. Heterotrophs get food by eating other living things.
- Glucose and ATP are used for energy by nearly all living things. Glucose is used to store and transport energy, and ATP is used to power life processes inside cells.
- Many autotrophs make food through the process of photosynthesis, in which light energy from the sun is changed to chemical energy that is stored in glucose. All organisms use cellular respiration to break down glucose, release its energy, and make ATP.

Lesson Review Questions

Recall

1. Define energy, and state where living things get the energy they need.

2. What is an autotroph? Give an example.

3. How does photosynthesis change energy?

4. How do heterotrophs obtain food?

Apply Concepts

5. ATP and glucose are both molecules that organisms use for energy. They are like the tank of a tanker truck that delivers gas to a gas station and the gas tank that holds the fuel for a car. Which molecule is like the tank of the

delivery truck, and which is like the gas tank of the car? Explain your answer.

Think Critically

6. Compare and contrast photosynthesis and cellular respiration. Why are the processes like two sides of the same coin?

7. Explain why living things need both glucose and ATP.

8. Explain how living things recycle oxygen in Earth's atmosphere.

Points to Consider

Living things must have chemical energy from food to power life processes. Most of the chemical energy in food comes ultimately from the energy in sunlight.

- Do you know how the energy in sunlight is captured by plants and other photosynthetic autotrophs?
- How do you think light energy changes to chemical energy during the process of photosynthesis?
- Some producers live in places that do not receive sunlight. How do you think they make food?

4.2 Photosynthesis: Sugar as Food

Lesson Objectives

- Outline the stages of photosynthesis.
- Describe the chloroplast and its role in photosynthesis.
- List the steps of the light reactions.
- Describe the Calvin cycle.
- Define chemosynthesis.

Vocabulary

Calvin cycle second stage of photosynthesis in which carbon atoms from carbon dioxide are combined, using the energy in ATP and NADPH, to make glucose

chemosynthesis process of using the energy in chemical compounds to make food

chlorophyll green pigment in a chloroplast that absorbs sunlight in the light reactions of photosynthesis

electron transport chain series of electron-transport molecules that pass high-energy electrons from molecule to molecule and capture their energy

grana within the chloroplast, consists of sac-like membranes, known as thylakoid membranes

light reactions first stage of photosynthesis in which light energy from the sun is captured and changed into chemical energy that is stored in ATP and NADPH

photosystem group of molecules, including chlorophyll, in the thylakoid membrane of a chloroplast that captures light energy

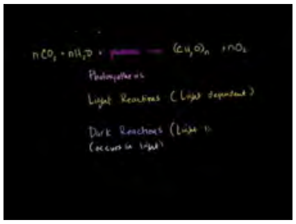
stroma space outside the thylakoid membranes of a chloroplast where the Calvin cycle of photosynthesis takes place

thylakoid membrane membrane in a chloroplast where the light reactions of photosynthesis occur

Introduction

Plants and other autotrophs make food out of "thin air"—at least, they use carbon dioxide from the air to make food. Most food is made in the process of photosynthesis. This process provides more than 99% of the energy used by living things on Earth. Photosynthesis also supplies Earth's atmosphere with oxygen.

An overview of photosynthesis is available at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/26/-rsYk4eCKnA (13:37).



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Stages of Photosynthesis

Photosynthesis occurs in two stages, which are shown in **Figure** 4.4 .

a. Stage I is called the **light reactions**. This stage uses water and changes light energy from the sun into chemical energy stored in ATP and NADPH (another energy-carrying molecule). This stage also releases oxygen as a waste product.
b. Stage II is called the **Calvin cycle**. This stage combines carbon from carbon dioxide in the air and uses the chemical energy in ATP and NADPH to make glucose.

Before you read about these two stages of photosynthesis in greater detail, you need to know more about the chloroplast, where the two stages take place.

The Chloroplast: Theater for Photosynthesis

The "theater" where both stages of photosynthesis take place is the chloroplast. Chloroplasts are organelles that are found in the cells of plants and algae. (Photosynthetic bacteria do not have chloroplasts, but they contain structures similar to chloroplasts and produce food in the same way.) Look at the **Figure** 4.5 . The figure is a high power microscopic photo of the upper part of a Winter Jasmine leaf. If you could look at a single leaf of this plant under a microscope, you would see small green ovals, like those shown. These small green ovals are chloroplasts.

Figure 4.6 shows the components of a chloroplast. Each chloroplast contains neat stacks called **grana** (singular, granum). The grana consist of sac-like membranes, known as **thylakoid membranes**. These membranes contain **photosystems**, which are groups of molecules that include **chlorophyll**, a green pigment. The light reactions of photosynthesis occur in the thylakoid membranes. The **stroma** is the space outside the thylakoid membranes. This is where the reactions of the Calvin cycle take place. You can take a video tour of a chloroplast at the link below. http://www.cells.de/cellseng/1medienarchiv/Zellstruktur/Plastiden/Chloroplasten/Feinaufbau/Flug_Chloroplast/index.jsp

Photosynthesis Stage I: The Light Reactions

The first stage of photosynthesis is called the light reactions. During this stage, light is absorbed and transformed to chemical energy in the bonds of NADPH and ATP. You can follow the process in the figure as you read about it below.

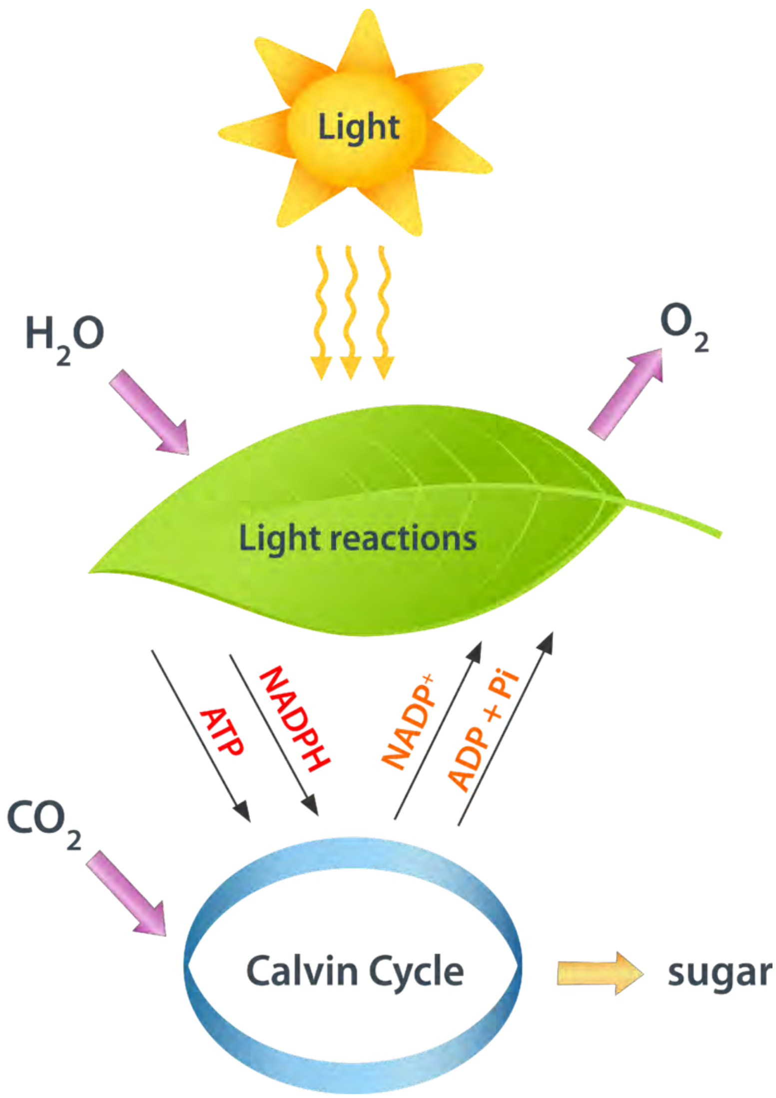


FIGURE 4.4

The two stages of photosynthesis are the light reactions and the Calvin cycle. Do you see how the two stages are related

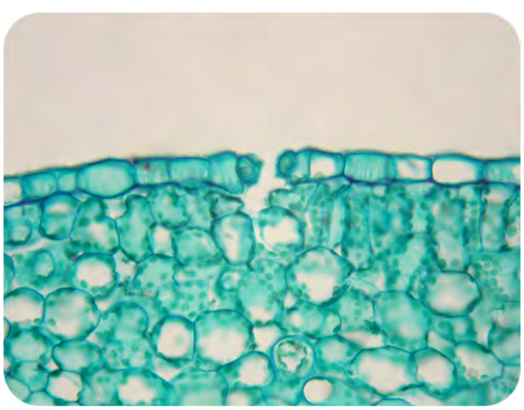


FIGURE 4.5

High power microscopic photo of the upper part of a Winter Jasmine leaf. Viewed under a microscope many green chloroplasts are visible.

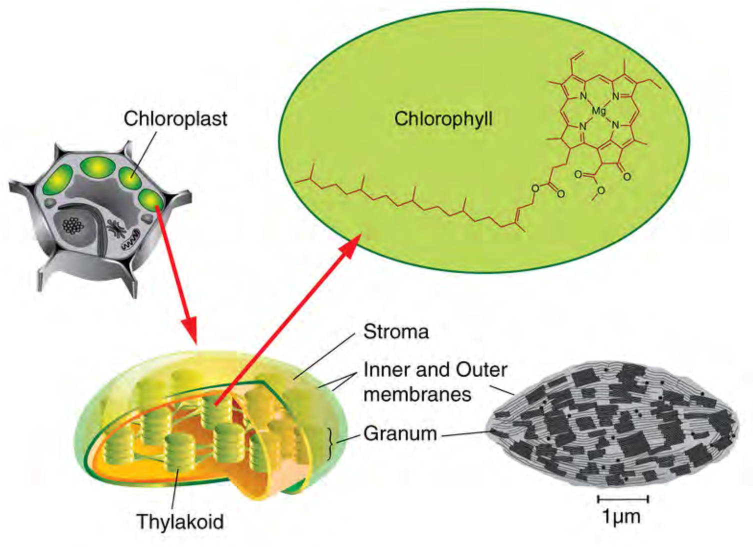


FIGURE 4.6
A chloroplast consists of thylakoid membranes surrounded by stroma. The thylakoid membranes contain molecules of the green pigment chlorophyll.

Steps of the Light Reactions

The light reactions occur in several steps, all of which take place in the thylakoid membrane, as shown in **Figure** 4.7
.

- Step 1: Units of sunlight, called photons, strike a molecule of chlorophyll in photosystem II of the thylakoid membrane. The light energy is absorbed by two electrons (2 e^-) in the chlorophyll molecule, giving them enough energy to leave the molecule.
- Step 2: At the same time, enzymes in the thylakoid membrane use light energy to split apart a water molecule. This produces:

a. two electrons (2 e^-). These electrons replace the two electrons that were lost from the chlorophyll molecule in Step 1.
b. an atom of oxygen (O). This atom combines with another oxygen atom to produce a molecule of oxygen gas (O_2), which is released as a waste product.
c. two hydrogen ions ($2H^+$). The hydrogen ions, which are positively charged, are released inside the membrane in the thylakoid interior space.

- Step 3: The two excited electrons from Step 1 contain a great deal of energy, so, like hot potatoes, they need something to carry them. They are carried by a series of electron-transport molecules, which make up an **electron transport chain**. The two electrons are passed from molecule to molecule down the chain. As this happens, their energy is captured and used to pump more hydrogen ions into the thylakoid interior space.
- Step 4: When the two electrons reach photosystem I, they are no longer excited. Their energy has been captured and used, and they need more energy. They get energy from light, which is absorbed by chlorophyll in photosystem I. Then, the two re-energized electrons pass down another electron transport chain.
- Step 5: Enzymes in the thylakoid membrane transfer the newly re-energized electrons to a compound called $NADP^+$. Along with a hydrogen ion, this produces the energy-carrying molecule NADPH. This molecule is needed to make glucose in the Calvin cycle.
- Step 6: By now, there is a greater concentration of hydrogen ions—and positive charge—in the thylakoid interior space. This difference in concentration and charge creates what is called a chemiosmotic gradient. It causes hydrogen ions to flow back across the thylakoid membrane to the stroma, where their concentration

is lower. Like water flowing through a hole in a dam, the hydrogen ions have energy as they flow down the chemiosmotic gradient. The enzyme ATP synthase acts as a channel protein and helps the ions cross the membrane. ATP synthase also uses their energy to add a phosphate group (Pi) to a molecule of ADP, producing a molecule of ATP. The energy in ATP is needed for the Calvin cycle.

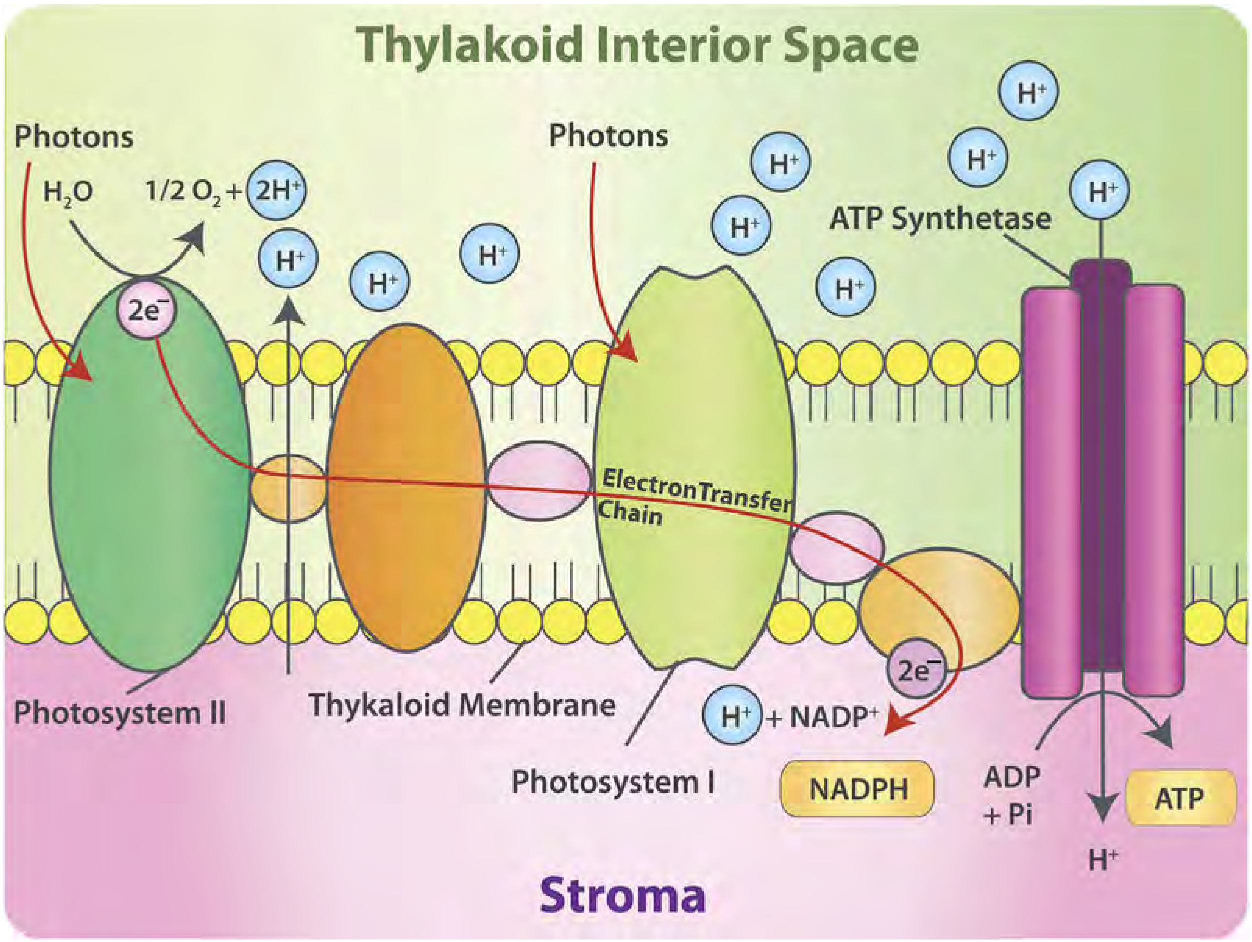


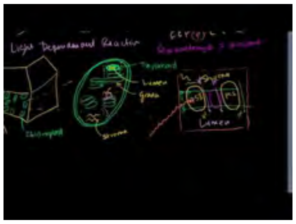
FIGURE 4.7

This figure shows the light reactions of photosynthesis. This stage of photosynthesis begins with photosystem II *so named because it was discovered after photosystem I*. Find the two electrons $2\ e-$ in photosystem II and then follow them through the electron transport chain to the formation of NADPH in Step 5. In Step 6 where do the hydrogen ions H come from that help make ATP

Summary of Stage I

By the time Step 6 is finished, energy from sunlight has been stored in chemical bonds of NADPH and ATP. Thus, light energy has been changed to chemical energy, and the first stage of photosynthesis is now complete.

For a more detailed discussion see http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/27/GR2GA7chA_c (20:16) and http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/28/yfR36PMWegg (18:51).



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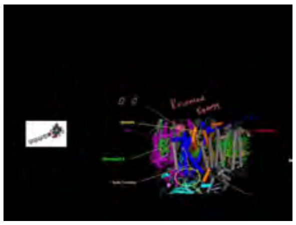

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Photosynthesis Stage II: The Calvin Cycle

The second stage of photosynthesis takes place in the stroma surrounding the thylakoid membranes of the chloroplast. The reactions of this stage can occur without light, so they are sometimes called light-independent or dark reactions. This stage of photosynthesis is also known as the Calvin cycle because its reactions were discovered by a scientist named Melvin Calvin. He won a Nobel Prize in 1961 for this important discovery. In the Calvin cycle, chemical energy in NADPH and ATP from the light reactions is used to make glucose. You can follow the Calvin cycle in **Figure** 4.8 as you read about it in this section. You can also watch an animation of the Calvin cycle at this link: http://www.science.smith.edu/departments/Biology/Bio231/calvin.html.

Steps of the Calvin Cycle

The Calvin cycle has three major steps: carbon fixation, reduction, and regeneration. All three steps take place in the stroma of a chloroplast.

- Step 1: Carbon Fixation. Carbon dioxide from the atmosphere combines with a simple, five-carbon compound called RuBP. This reaction occurs with the help of an enzyme named RuBisCo and produces molecules known as 3PG (a three-carbon compound, 3-Phosphoglyceric acid).
- Step 2: Reduction. Molecules of 3PG (from Step 1) gain energy from ATP and NADPH (from the light reactions) and re-arrange themselves to form G3P (glycerate 3-phosphate). This molecule also has three carbon atoms, but it has more energy than 3PG. One of the G3P molecules goes on to form glucose, while the rest of the G3P molecules go on to Step 3.
- Step 3: Regeneration. The remaining G3P molecules use energy from ATP to form RuBP, the five-carbon molecule that started the Calvin cycle. This allows the cycle to repeat.

Summary of Stage II

The Calvin cycle takes over where the light reactions end. It uses chemical energy stored in ATP and NADPH (from the light reactions) and carbon dioxide from the air to produce glucose, the molecule that virtually all organisms use for food.

The Calvin Cycle is discussed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/29/slm6D2VEXYs (13:28).

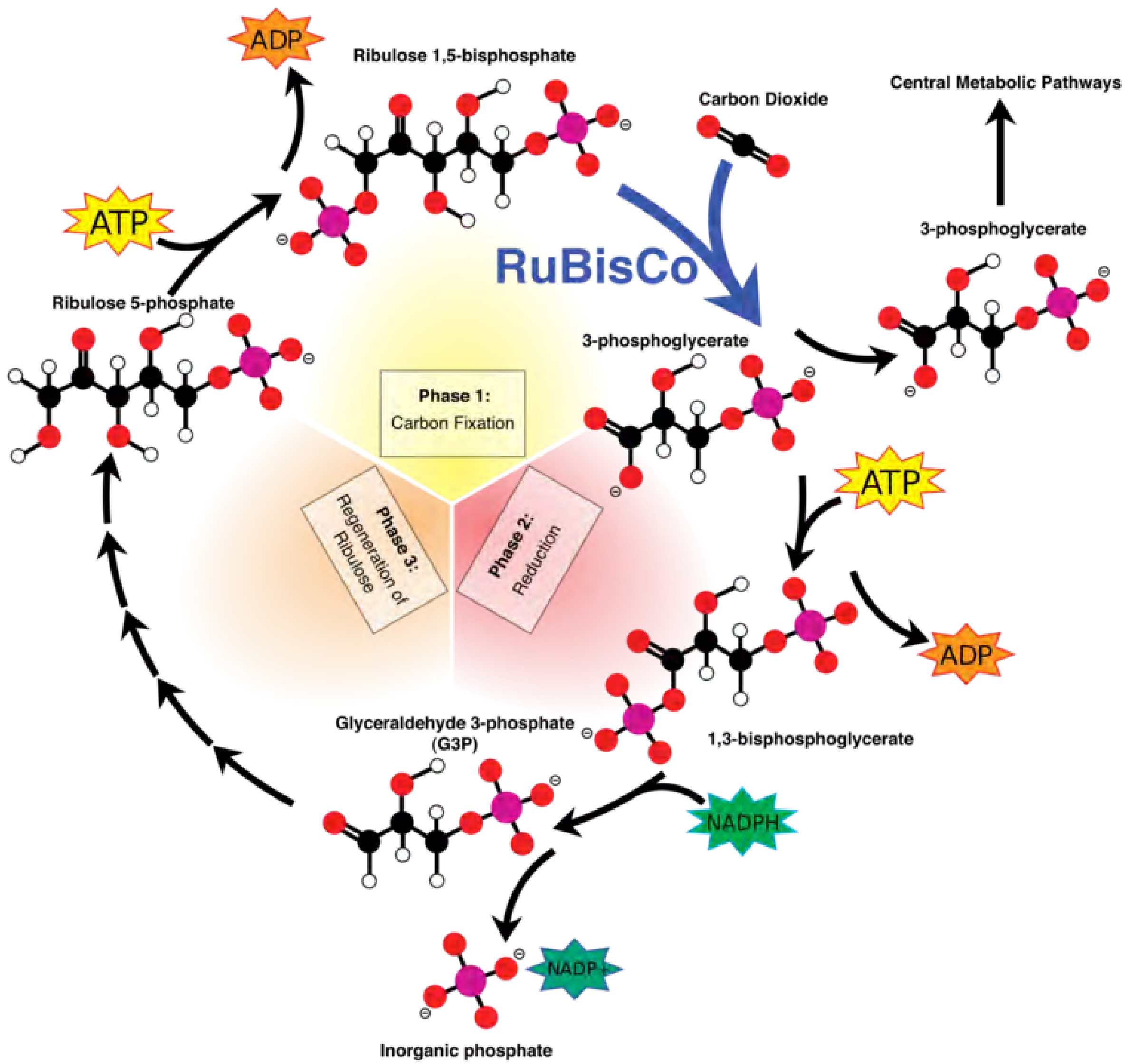

FIGURE 4.8

The Calvin cycle begins with a molecule named RuBP $a\ five-carbon\ sugar\ Ribulose-15-bisphosphate$ and uses the energy in ATP and NADPH from the light reactions. Follow the cycle to see what happens to all three of these molecules. Two turns of the cycle produce one molecule of glucose $called\ sucrose\ in\ the\ figure$. In this diagram each black dot represents a carbon atom. Keep track of what happens to the carbon atoms as the cycle proceeds.

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Chemosynthesis

Most autotrophs make food by photosynthesis, but this isn't the only way that autotrophs produce food. Some bacteria make food by another process, which uses chemical energy instead of light energy. This process is called **chemosynthesis**. Some chemosynthetic bacteria live around deep-ocean vents known as "black smokers." Compounds such as hydrogen sulfide, which flow out of the vents from Earth's interior, are used by the bacteria for energy to make food. Consumers that depend on these bacteria to produce food for them include giant tubeworms, like these pictured in **Figure** 4.9 . Why do bacteria that live deep below the ocean's surface rely on chemical compounds instead of sunlight for energy to make food?

FIGURE 4.9

Tubeworms deep in the Gulf of Mexico get their energy from chemosynthetic bacteria. The bacteria actually live inside the worms.

Lesson Summary

- Most autotrophs make food using photosynthesis. This process occurs in two stages: the light reactions and the Calvin cycle.
- Both stages of photosynthesis take place in chloroplasts. The light reactions take place in the thylakoid membranes, and the Calvin cycle takes place in the stroma.
- The light reactions capture energy from sunlight, which they change to chemical energy that is stored in molecules of NADPH and ATP. The light reactions also release oxygen gas as a waste product.
- The reactions of the Calvin cycle add carbon (from carbon dioxide in the atmosphere) to a simple five-carbon molecule called RuBP. These reactions use chemical energy from NADPH and ATP that were produced in the light reactions. The final product of the Calvin cycle is glucose.
- Some bacterial autotrophs make food using chemosynthesis. This process uses chemical energy instead of light energy to produce food.

Lesson Review Questions

Recall

1. What are the stages of photosynthesis? Which stage occurs first?
2. Describe the chloroplast and its role in photosynthesis.
3. Summarize what happens during the light reactions of photosynthesis.
4. What happens during the carbon fixation step of the Calvin cycle?
5. During which stage of photosynthesis is glucose made?

Apply Concepts

6. The first living things appeared on Earth at least a billion years before photosynthetic organisms appeared. How might the earliest organisms have obtained energy before photosynthesis evolved? What process could they have used to make food?

Think Critically

7. Explain the role of the first electron transport chain in the formation of ATP during the light reactions of photosynthesis.
8. Explain what might happen if the third step of the Calvin cycle did not occur.
9. Plants release oxygen during the day but not during the night. Explain why.

Points to Consider

All living things need to break down glucose to make ATP for energy. Cellular respiration is the process in which this occurs.

- How do you think cellular respiration occurs? What steps do you think might be involved?
- How many molecules of ATP do you think cells get from a single molecule of glucose?

4.3 Powering the Cell: Cellular Respiration

Lesson Objectives

- Name the three stages of cellular respiration.
- Give an overview of glycolysis.
- Explain why glycolysis probably evolved before the other stages of aerobic respiration.
- Describe the mitochondrion and its role in aerobic respiration.
- List the steps of the Krebs cycle, and identify its products.
- Explain how electron transport results in many molecules of ATP.
- State the possible number of ATP molecules that can result from aerobic respiration.

Vocabulary

aerobic respiration type of cellular respiration that requires oxygen

anaerobic respiration type of cellular respiration that does not require oxygen

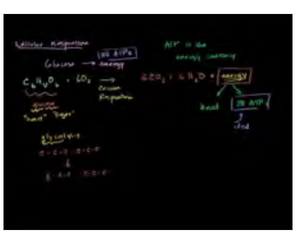
glycolysis first stage of cellular respiration in which glucose is split, in the absence of oxygen, to form two molecules of pyruvate (pyruvic acid) and two (net) molecules of ATP

Krebs cycle second stage of aerobic respiration in which two pyruvate (pyruvic acid) molecules from the first stage react to form ATP, NADH, and $FADH_2$

Introduction

You have just read how photosynthesis stores energy in glucose. How do living things make use of this stored energy? The answer is cellular respiration. This process releases the energy in glucose to make ATP, the molecule that powers all the work of cells.

An introduction to cellular respiration can be viewed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/19/2f7YwCtHcgk (14:19).



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Stages of Cellular Respiration

Cellular respiration involves many chemical reactions. As you saw earlier, the reactions can be summed up in this equation:

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + Chemical Energy (in ATP)

The reactions of cellular respiration can be grouped into three stages: glycolysis, the Krebs cycle (also called the citric acid cycle), and electron transport. **Figure** 4.10 gives an overview of these three stages, which are also described below.

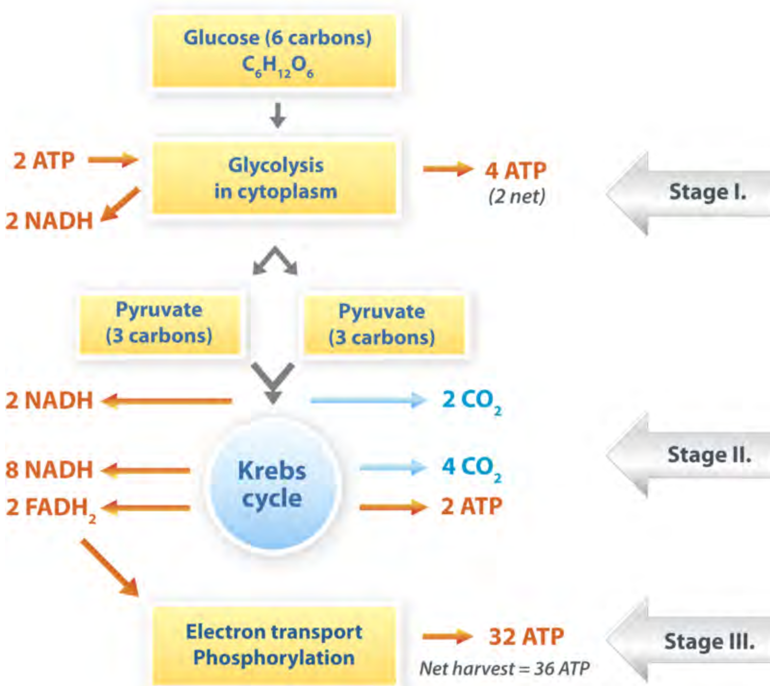

FIGURE 4.10
Cellular respiration takes place in the stages shown here. The process begins with a molecule of glucose which has six carbon atoms. What happens to each of these atoms of carbon

Cellular Respiration Stage I: Glycolysis

The first stage of cellular respiration is **glycolysis**. It takes place in the cytosol of the cytoplasm.

Splitting Glucose

The word *glycolysis* means "glucose splitting," which is exactly what happens in this stage. Enzymes split a molecule of glucose into two molecules of pyruvate (also known as pyruvic acid). This occurs in several steps, as shown in **Figure** 4.11 . You can watch an animation of the steps of glycolysis at the following link: http://www.youtube.com/watch?v=6JGXayUyNVw.

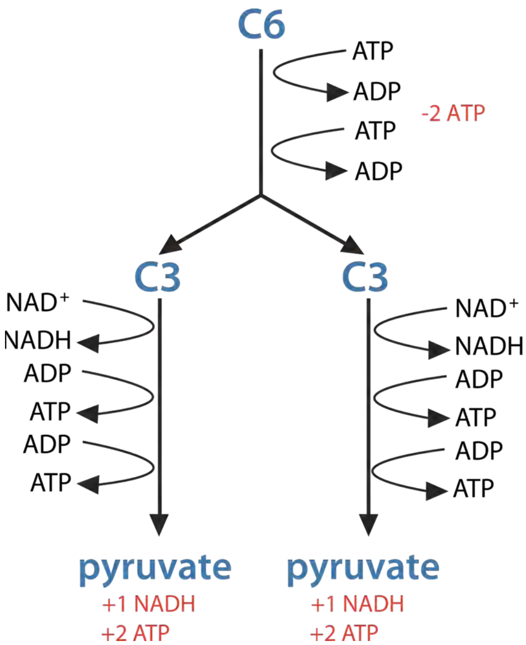

FIGURE 4.11

In glycolysis glucose $C6$ is split into two 3-carbon $C3$ pyruvate molecules. This releases energy which is transferred to ATP. How many ATP molecules are made during this stage of cellular respiration

Results of Glycolysis

Energy is needed at the start of glycolysis to split the glucose molecule into two pyruvate molecules. These two molecules go on to stage II of cellular respiration. The energy to split glucose is provided by two molecules of ATP. As glycolysis proceeds, energy is released, and the energy is used to make four molecules of ATP. As a result, there is a net gain of two ATP molecules during glycolysis. During this stage, high-energy electrons are also transferred to molecules of NAD^+ to produce two molecules of NADH, another energy-carrying molecule. NADH is used in stage III of cellular respiration to make more ATP.

A summary of glycolysis can be viewed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/22/FE2jfTXAJHg.

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Anaerobic and Aerobic Respiration

Scientists think that glycolysis evolved before the other stages of cellular respiration. This is because the other stages need oxygen, whereas glycolysis does not, and there was no oxygen in Earth's atmosphere when life first evolved about 3.5 to 4 billion years ago. Cellular respiration that proceeds without oxygen is called **anaerobic respiration**. Then, about 2 or 3 billion years ago, oxygen was gradually added to the atmosphere by early photosynthetic bacteria. After that, living things could use oxygen to break down glucose and make ATP. Today, most organisms make ATP with oxygen. They follow glycolysis with the Krebs cycle and electron transport to make more ATP than by glycolysis alone. Cellular respiration that proceeds in the presence of oxygen is called **aerobic respiration**.

Structure of the Mitochondrion: Key to Aerobic Respiration

Before you read about the last two stages of aerobic respiration, you need to know more about the mitochondrion, where these two stages take place. A diagram of a mitochondrion is shown in **Figure** 4.12 .

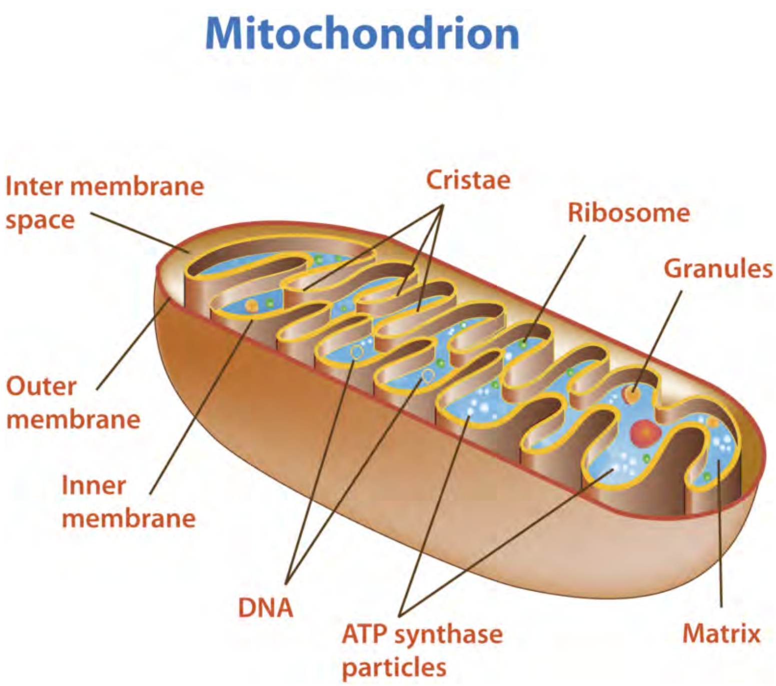

FIGURE 4.12
The structure of a mitochondrion is defined by an inner and outer membrane. This structure plays an important role in aerobic respiration.

As you can see from **Figure** 4.12 , a mitochondrion has an inner and outer membrane. The space between the inner and outer membrane is called the intermembrane space. The space enclosed by the inner membrane is called the matrix. The second stage of cellular respiration, the Krebs cycle, takes place in the matrix. The third stage, electron transport, takes place on the inner membrane.

Cellular Respiration Stage II: The Krebs Cycle

Recall that glycolysis produces two molecules of pyruvate (pyruvic acid). These molecules enter the matrix of a mitochondrion, where they start the **Krebs cycle**. The reactions that occur next are shown in **Figure** 4.13 . You can watch an animated version at this link: http://www.youtube.com/watch?v=p-k0biO1DT8#38;feature=related.

Before the Krebs cycle begins, pyruvic acid, which has three carbon atoms, is split apart and combined with an enzyme known as CoA, which stands for coenzyme A. The product of this reaction is a two-carbon molecule called acetyl-CoA. The third carbon from pyruvic acid combines with oxygen to form carbon dioxide, which is released as a waste product. High-energy electrons are also released and captured in NADH.

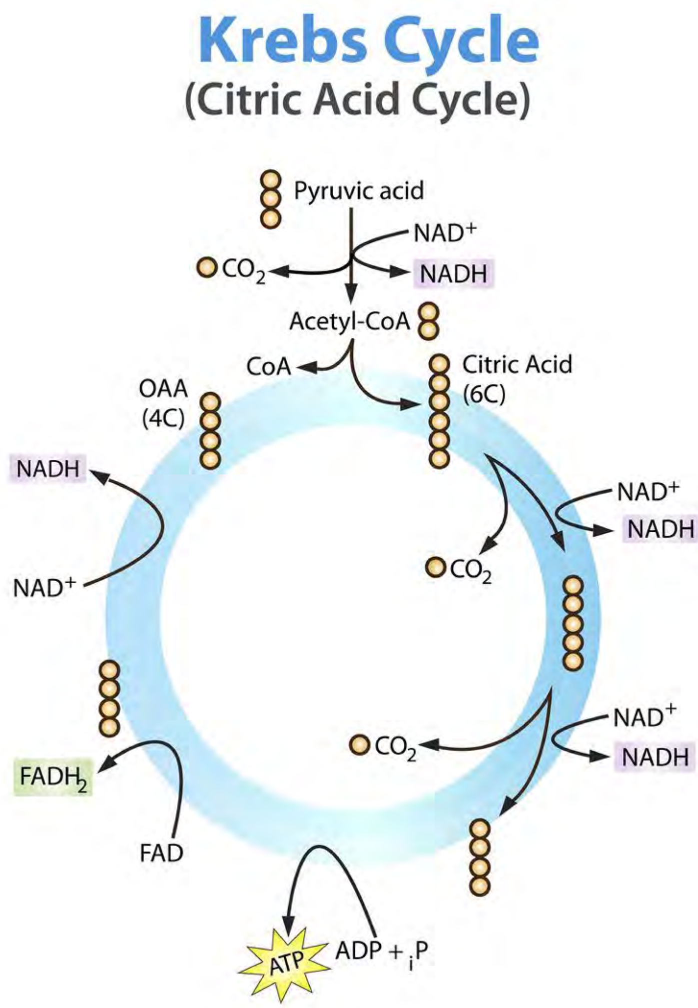

FIGURE 4.13

The Krebs cycle starts with pyruvic acid from glycolysis. Each small circle in the diagram represents one carbon atom. For example citric acid is a six carbon molecule and OAA *oxaloacetate* is a four carbon molecule. Follow what happens to the carbon atoms as the cycle proceeds. In one turn through the cycle how many molecules are produced of ATP How many molecules of NADH and FADH2 are produced

Steps of the Krebs Cycle

The Krebs cycle itself actually begins when acetyl-CoA combines with a four-carbon molecule called OAA (oxaloacetate) (see **Figure** 4.13). This produces citric acid, which has six carbon atoms. This is why the Krebs cycle is also called the citric acid cycle. After citric acid forms, it goes through a series of reactions that release energy. The energy is captured in molecules of NADH, ATP, and $FADH_2$, another energy-carrying compound. Carbon dioxide is also released as a waste product of these reactions. The final step of the Krebs cycle regenerates OAA, the molecule that began the Krebs cycle. This molecule is needed for the next turn through the cycle. Two turns are needed because glycolysis produces two pyruvic acid molecules when it splits glucose. Watch the OSU band present the Krebs cycle: http://www.youtube.com/watch?v=FgXnH087JIk#38;feature=related.

Results of the Krebs Cycle

After the second turn through the Krebs cycle, the original glucose molecule has been broken down completely. All six of its carbon atoms have combined with oxygen to form carbon dioxide. The energy from its chemical bonds has been stored in a total of 16 energy-carrier molecules. These molecules are:

- 4 ATP (including 2 from glycolysis)
- 10 NADH (including 2 from glycolysis)
- 2 $FADH_2$

The Krebs cycle is reviewed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/23/juM2ROSLWfw.

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Cellular Respiration Stage III: Electron Transport

Electron transport is the final stage of aerobic respiration. In this stage, energy from NADH and $FADH_2$, which result from the Krebs cycle, is transferred to ATP. Can you predict how this happens? (*Hint:* How does electron transport occur in photosynthesis?)

See http://www.youtube.com/watch?v=1engJR_XWVU#38;feature=related for an overview of the electron transport chain.

Transporting Electrons

High-energy electrons are released from NADH and $FADH_2$, and they move along electron transport chains, like those used in photosynthesis. The electron transport chains are on the inner membrane of the mitochondrion. As the high-energy electrons are transported along the chains, some of their energy is captured. This energy is used to pump hydrogen ions (from NADH and $FADH_2$) across the inner membrane, from the matrix into the intermembrane space. Electron transport in a mitochondrion is shown in **Figure** 4.14 . You can also see an animation of the process at this link: http://www.youtube.com/watch?v=Idy2XAlZIVA#38;feature=related.

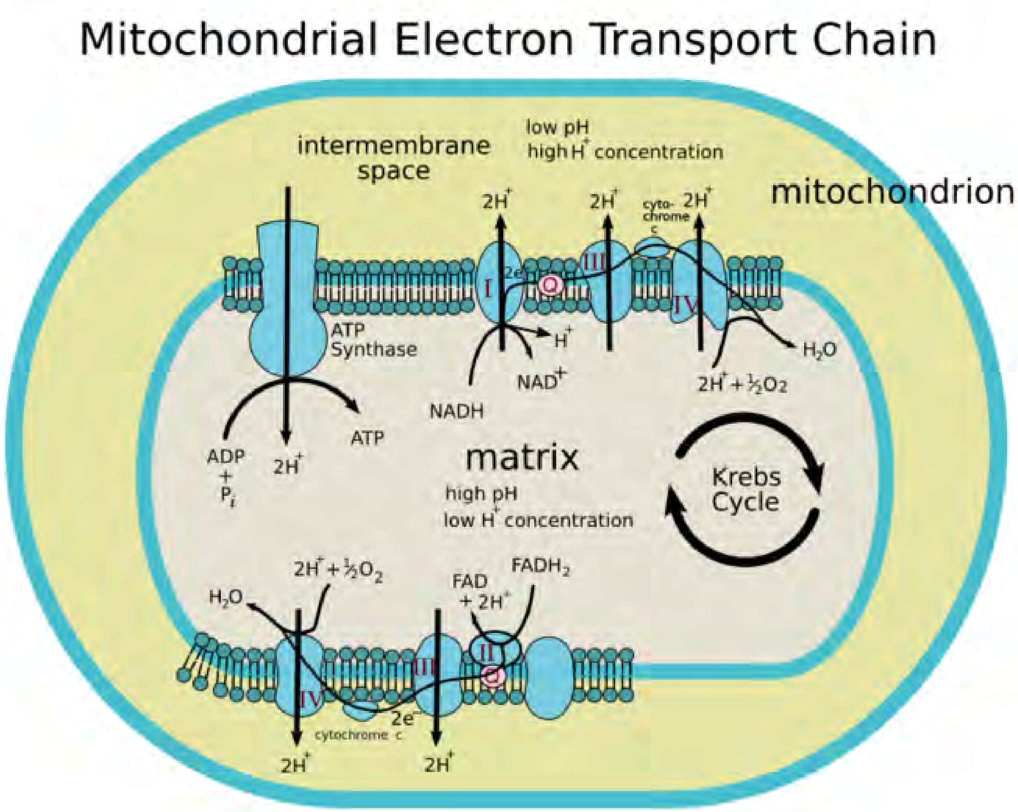

FIGURE 4.14

Electron-transport chains on the inner membrane of the mitochondrion carry out the last stage of cellular respiration.

Making ATP

The pumping of hydrogen ions across the inner membrane creates a greater concentration of the ions in the intermembrane space than in the matrix. This chemiosmotic gradient causes the ions to flow back across the membrane into the matrix, where their concentration is lower. ATP synthase acts as a channel protein, helping the hydrogen ions cross the membrane. It also acts as an enzyme, forming ATP from ADP and inorganic phosphate. After passing through the electron-transport chain, the "spent" electrons combine with oxygen to form water. This is why oxygen is needed; in the absence of oxygen, this process cannot occur. You can see how all these events occur at the following link: http://www.sp.uconn.edu/ terry/images/anim/ATPmito.html.

A summary of this process can be seen at the following sites: http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/24/mfgCcFXUZRk (17:16) and http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/25/W_Q17tqw_7A (4:59).

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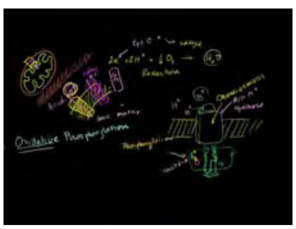

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How Much ATP?

You have seen how the three stages of aerobic respiration use the energy in glucose to make ATP. How much ATP is produced in all three stages? Glycolysis produces 2 ATP molecules, and the Krebs cycle produces 2 more. Electron transport begins with several molecules of NADH and $FADH_2$ from the Krebs cycle and transfers their energy into as many as 34 more ATP molecules. All told, then, up to 38 molecules of ATP can be produced from just one molecule of glucose in the process of aerobic respiration.

Lesson Summary

- Cellular respiration uses energy in glucose to make ATP. Aerobic ("oxygen-using") respiration occurs in three stages: glycolysis, the Krebs cycle, and electron transport.
- In glycolysis, glucose is split into two molecules of pyruvate. This results in a net gain of two ATP molecules.
- Life first evolved in the absence of oxygen, and glycolysis does not require oxygen. Therefore, glycolysis was probably the earliest way of making ATP from glucose.
- The Krebs cycle and electron transport occur in the mitochondria. The Krebs cycle takes place in the matrix, and electron transport takes place on the inner membrane.

- During the Krebs cycle, pyruvate undergoes a series of reactions to produce two more molecules of ATP and also several molecules of NADH and $FADH_2$.
- During electron transport, energy from NADH and $FADH_2$ is used to make many more molecules of ATP.
- In all three stages of aerobic respiration, up to 38 molecules of ATP may be produced from a single molecule of glucose.

Lesson Review Questions

Recall

1. List the stages of aerobic respiration in the order in which they occur.

2. Describe what happens during glycolysis. How many ATP molecules are gained during this stage?

3. Define aerobic and anaerobic respiration.

4. What role do mitochondria play in cellular respiration?

5. What are the products of the Krebs cycle?

6. What is the maximum number of ATP molecules that can be produced during the electron transport stage of aerobic respiration?

Apply Concepts

7. When you exhale onto a cold window pane, water vapor in your breath condenses on the glass. Where does the water vapor come from?

8. Assume that a new species of organism has been discovered. Scientists have observed its cells under a microscope and determined that they lack mitochondria. What type of cellular respiration would you predict that the new species uses? Explain your prediction.

Think Critically

9. Why do scientists think that glycolysis evolved before the other stages of cellular respiration?

10. Explain why two turns of the Krebs cycle are needed for each molecule of glucose.

Points to Consider

The last two stages of aerobic respiration require oxygen. However, not all organisms live in places where there is a plentiful supply of oxygen.

- How do you think organisms get energy from glucose to make ATP if they cannot use oxygen?
- Do they just use glycolysis, which produces only two ATP molecules? Or do you think there might be other steps involved?

4.4 Anaerobic Respiration

Lesson Objectives

- Define fermentation.
- Describe lactic acid fermentation and alcoholic fermentation.
- Compare the advantages of aerobic and anaerobic respiration.

Vocabulary

alcoholic fermentation type of anaerobic respiration that includes glycolysis followed by the conversion of pyruvic acid to ethanol and carbon dioxide and the formation of NAD^+

fermentation type of anaerobic respiration that includes glycolysis followed by the conversion of pyruvic acid to one or more other compounds and the formation of NAD^+

lactic acid fermentation type of anaerobic respiration that includes glycolysis followed by the conversion of pyruvic acid to lactic acid and the formation of NAD^+

Introduction

Today, most living things use oxygen to make ATP from glucose. However, many living things can also make ATP without oxygen. This is true of some plants and fungi and also of many bacteria. These organisms use aerobic respiration when oxygen is present, but when oxygen is in short supply, they use anaerobic respiration instead. Certain bacteria can only use anaerobic respiration. In fact, they may not be able to survive at all in the presence of oxygen.

Fermentation

An important way of making ATP without oxygen is called **fermentation**. It involves glycolysis but not the other two stages of aerobic respiration. Many bacteria and yeasts carry out fermentation. People use these organisms to make yogurt, bread, wine, and biofuels. Human muscle cells also use fermentation. This occurs when muscle cells cannot get oxygen fast enough to meet their energy needs through aerobic respiration. There are two types of fermentation: lactic acid fermentation and alcoholic fermentation. Both types of fermentation are described below. You can also watch animations of both types at this link: http://www.cst.cmich.edu/users/schul1te/animations/fermentation.swf.

Lactic Acid Fermentation

In **lactic acid fermentation**, pyruvic acid from glycolysis changes to lactic acid. This is shown in **Figure** 4.15 . In the process, NAD^+ forms from NADH. NAD^+, in turn, lets glycolysis continue. This results in additional molecules of ATP. This type of fermentation is carried out by the bacteria in yogurt. It is also used by your own muscle cells when you work them hard and fast.

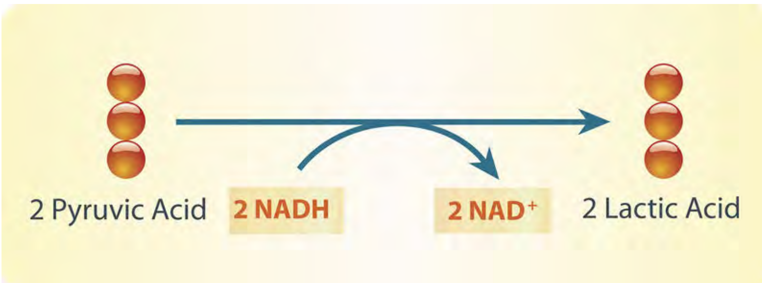


FIGURE 4.15
Lactic acid fermentation produces lactic acid and NAD. The NAD cycles back to allow glycolysis to continue so more ATP is made. Each circle represents a carbon atom.

Did you ever run a race and notice that your muscles feel tired and sore afterward? This is because your muscle cells used lactic acid fermentation for energy. This causes lactic acid to build up in the muscles. It is the buildup of lactic acid that makes the muscles feel tired and sore.

Alcoholic Fermentation

In **alcoholic fermentation**, pyruvic acid changes to alcohol and carbon dioxide. This is shown in **Figure** 4.16 . NAD^+ also forms from NADH, allowing glycolysis to continue making ATP. This type of fermentation is carried out by yeasts and some bacteria. It is used to make bread, wine, and biofuels.

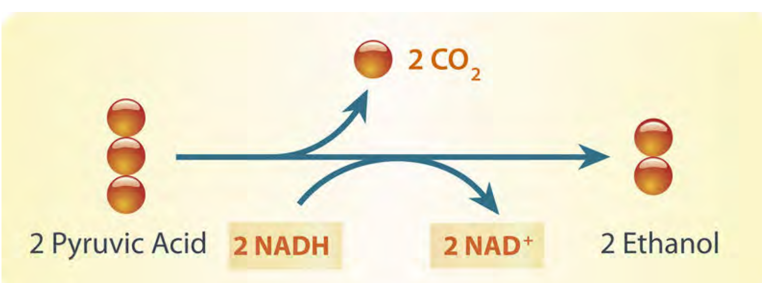


FIGURE 4.16
Alcoholic fermentation produces ethanol and NAD. The NAD allows glycolysis to continue making ATP.

Have your parents ever put corn in the gas tank of their car? They did if they used gas containing ethanol. Ethanol is produced by alcoholic fermentation of the glucose in corn or other plants. This type of fermentation also explains why bread dough rises. Yeasts in bread dough use alcoholic fermentation and produce carbon dioxide gas. The gas forms bubbles in the dough, which cause the dough to expand. The bubbles also leave small holes in the bread after it bakes, making the bread light and fluffy. Do you see the small holes in the slice of bread in **Figure** 4.17 ?

FIGURE 4.17
The small holes in bread are formed by bubbles of carbon dioxide gas. The gas was produced by alcoholic fermentation carried out by yeast.

Aerobic vs. Anaerobic Respiration: A Comparison

Aerobic respiration evolved after oxygen was added to Earth's atmosphere. This type of respiration is useful today because the atmosphere is now 21% oxygen. However, some anaerobic organisms that evolved before the atmosphere contained oxygen have survived to the present. Therefore, anaerobic respiration must also have advantages.

Advantages of Aerobic Respiration

A major advantage of aerobic respiration is the amount of energy it releases. Without oxygen, organisms can just split glucose into two molecules of pyruvate. This releases only enough energy to make two ATP molecules. With oxygen, organisms can break down glucose all the way to carbon dioxide. This releases enough energy to produce up to 38 ATP molecules. Thus, aerobic respiration releases much more energy than anaerobic respiration. The amount of energy produced by aerobic respiration may explain why aerobic organisms came to dominate life on Earth. It may also explain how organisms were able to become multicellular and increase in size.

Advantages of Anaerobic Respiration

One advantage of anaerobic respiration is obvious. It lets organisms live in places where there is little or no oxygen. Such places include deep water, soil, and the digestive tracts of animals such as humans (see **Figure** 4.18).

Another advantage of anaerobic respiration is its speed. It produces ATP very quickly. For example, it lets your muscles get the energy they need for short bursts of intense activity (see **Figure** 4.19). Aerobic respiration, on the other hand, produces ATP more slowly.

Lesson Summary

- Fermentation is a way of making ATP from glucose without oxygen. There are two types of fermentation: lactic acid fermentation and alcoholic fermentation.

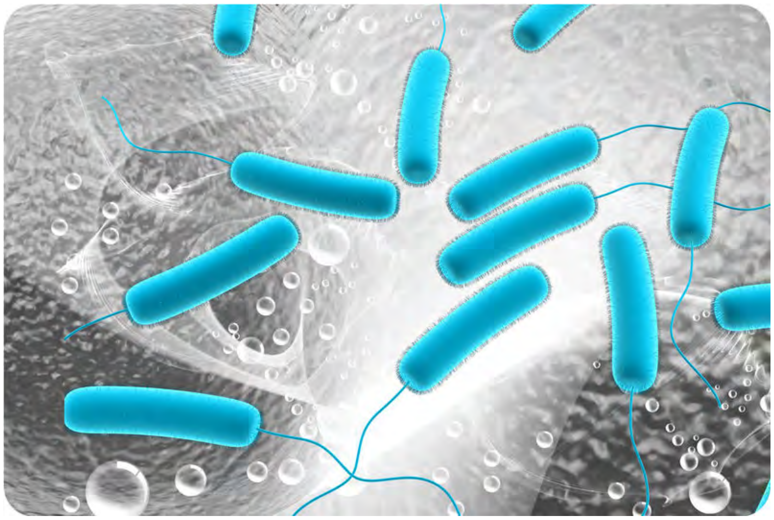


FIGURE 4.18
E. coli bacteria are anaerobic bacteria that live in the human digestive tract.

FIGURE 4.19
The muscles of these hurdlers need to use anaerobic respiration for energy. It gives them the energy they need for the short-term intense activity of this sport.

- Lactic acid fermentation changes pyruvic acid to lactic acid and forms NAD^+. The NAD^+ allows glycolysis to continue so it can make more ATP.
- Alcohol fermentation changes pyruvic acid to ethanol and carbon dioxide and forms NAD^+. Again, the NAD^+ allows glycolysis to keep making ATP.
- Aerobic respiration produces much more ATP than anaerobic respiration. However, anaerobic respiration occurs more quickly.

Lesson Review Questions

Recall

1. What is fermentation?

2. Name two types of fermentation.

3. What is the main advantage of aerobic respiration? Of anaerobic respiration?

4. What process produces fuel for motor vehicles from living plant products? What is the waste product of this process?

Apply Concepts

5. Tanya is on the high school track team and runs the 100-meter sprint. Marissa is on the cross-country team and runs 5-kilometer races. Explain which type of respiration the muscle cells in each runner's legs use.

Think Critically

6. Compare and contrast lactic acid fermentation and alcoholic fermentation. Include examples of organisms that use each type of fermentation.

7. Explain why bread dough rises when it is set aside in a warm place.

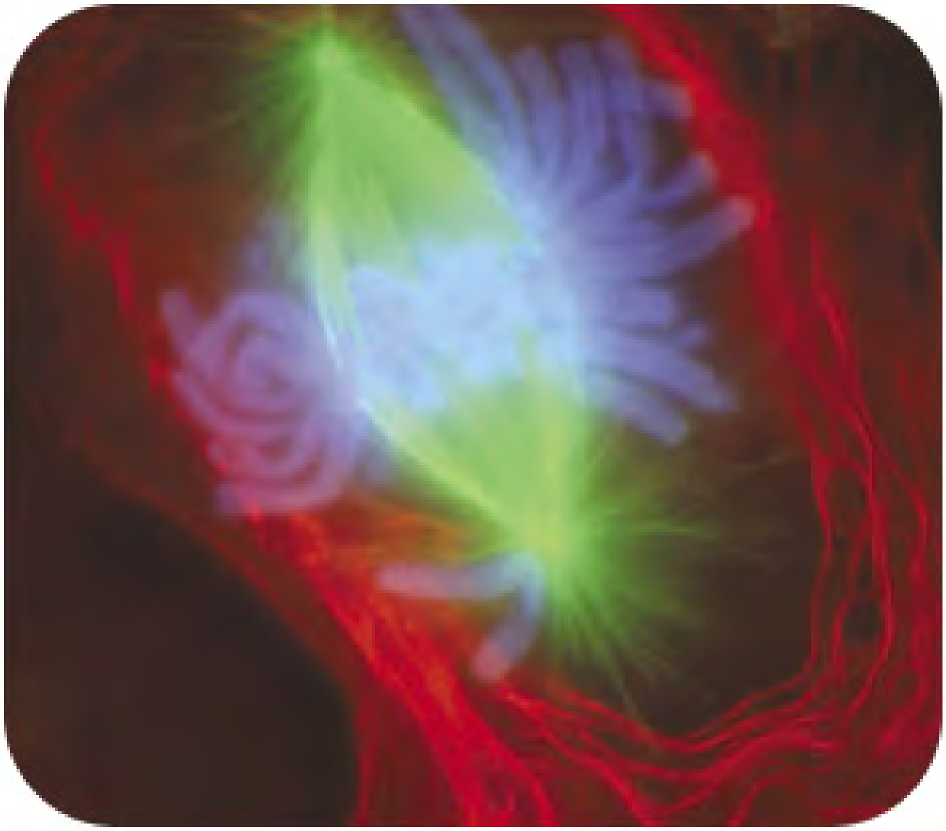
Points to Consider

Two important functions of cells are making food and using it for energy. Photosynthesis and cellular respiration are the processes that carry out these functions. Other important functions of cells are growing and dividing.

- Do you know how cells grow? What do you think controls the growth of cells?
- How do you think cells divide? Do all cells divide in the same way?

CHAPTER 5 The Cell Cycle, Mitosis, and Meiosis

CHAPTER OUTLINE



What do you think this colorful picture shows? If you guessed that it's a picture of a cell undergoing cell division, you are right. In fact, the picture is an image of a lung cell stained with fluorescent dyes undergoing mitosis, specifically during early anaphase. You will read about mitosis, a type of cell division, in this chapter.

Cell division is just one of the stages that all cells go through during their life. This includes cells that are harmful, such as cancer cells. Cancer cells divide more often than normal cells, and grow out of control. In fact, this is how cancer cells cause illness. In this chapter, you will read about how cells divide, what other stages cells go through, and what causes cancer cells to divide out of control and harm the body.

5.1 Cell Division and the Cell Cycle

Lesson Objectives

- Contrast cell division in prokaryotes and eukaryotes.
- Identify the phases of the eukaryotic cell cycle.
- Explain how the cell cycle is controlled.
- Define cancer, and relate it to the cell cycle.

Vocabulary

binary fission type of cell division that occurs in prokaryotic cells in which a parent cells divides into two identical daughter cells

cancer disease that occurs when the cell cycle is no longer regulated and cells divide out of control

cell cycle repeating series of events that a cell goes through during its life, including growth, DNA, synthesis, and cell division

cell division process in which a parent cell divides to form two daughter cells

cytokinesis splitting of the cytoplasm to form daughter cells when a cell divides

DNA replication process of copying of DNA prior to cell division

interphase stage of the eukaryotic cell cycle when the cell grows, synthesizes DNA, and prepares to divide

mitosis process in which the nucleus of a eukaryotic cell divides

tumor abnormal mass of cells that may be cancerous

Introduction

You consist of a great many cells, but like all other organisms, you started life as a single cell. How did you develop from a single cell into an organism with trillions of cells? The answer is cell division. After cells grow to their maximum size, they divide into two new cells. These new cells are small at first, but they grow quickly and eventually divide and produce more new cells. This process keeps repeating in a continuous cycle.

Cell Division

Cell division is the process in which one cell, called the parent cell, divides to form two new cells, referred to as daughter cells. How this happens depends on whether the cell is prokaryotic or eukaryotic.

Cell division is simpler in prokaryotes than eukaryotes because prokaryotic cells themselves are simpler. Prokaryotic cells have a single circular chromosome, no nucleus, and few other organelles. Eukaryotic cells, in contrast, have multiple chromosomes contained within a nucleus and many other organelles. All of these cell parts must be duplicated and then separated when the cell divides.

Cell Division in Prokaryotes

Most prokaryotic cells divide by the process of **binary fission**. A bacterial cell dividing this way is depicted in **Figure** 5.1 . You can also watch an animation of binary fission at this link: http://en.wikipedia.org/wiki/File:Binary_fission_anim.gif.

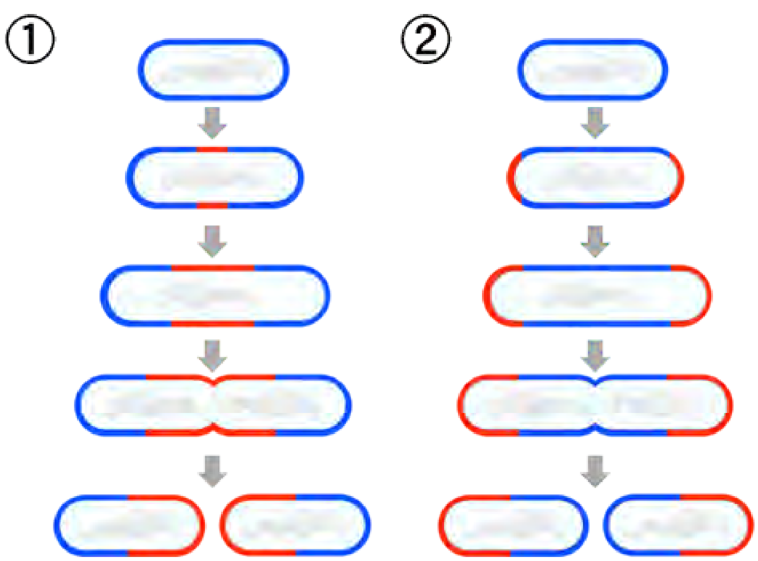


FIGURE 5.1

Binary Fission in a Bacterial Cell. Cell division is relatively simple in prokaryotic cells. The two cells are dividing by binary fission. Blue and red lines indicate old and newly-generated bacterial cell walls respectively. Eventually the parent cell will pinch apart to form two identical daughter cells. Left growth at the center of bacterial body. Right apical growth from the ends of the bacterial body.

Binary fission can be broken down into a series of three steps, although it is actually a continuous process. The steps are described below and also illustrated in **Figure** 5.2 . They include DNA replication, chromosome segregation, and cytokinesis.

- **Step 1: DNA Replication**. Just before the cell divides, its DNA is copied in a process called **DNA replication**. This results in two identical chromosomes instead of just one. This step is necessary so that when the cell divides, each daughter cell will have its own chromosome.
- **Step 2: Chromosome Segregation**. The two chromosomes segregate, or separate, and move to opposite ends (known as *poles*) of the cell.
- **Step 3: Cytokinesis**. A new plasma membrane starts growing into the center of the cell, and the cytoplasm splits apart, forming two daughter cells. This process is called **cytokinesis**. The two daughter cells that result are genetically identical to each other and to the parent cell.

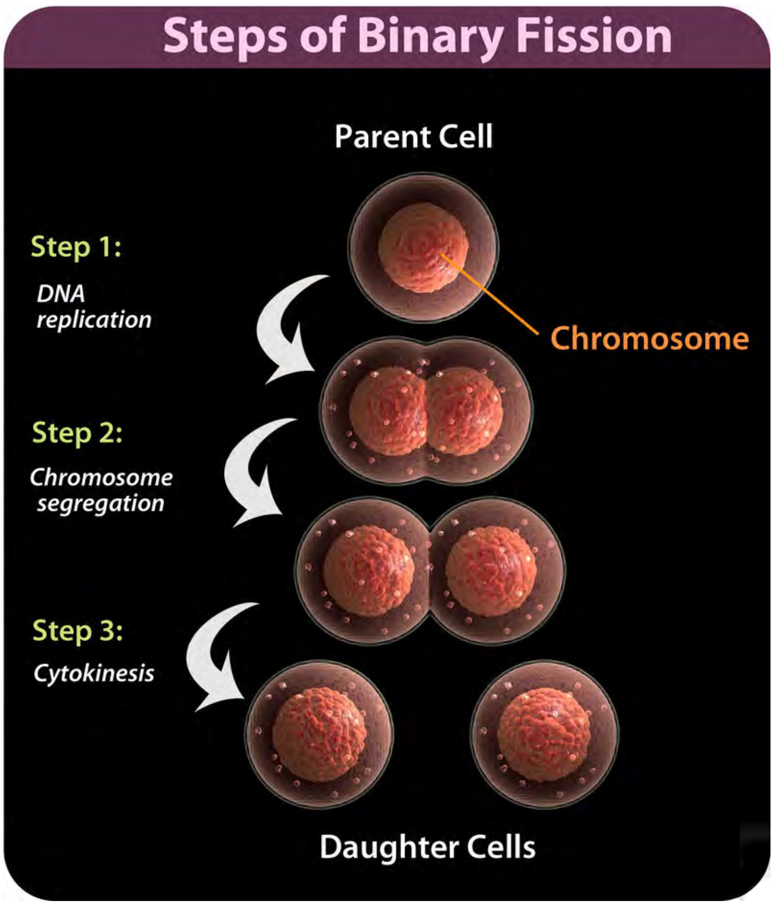


FIGURE 5.2
Steps of Binary Fission. Prokaryotic cells divide by binary fission. This is also how many single-celled organisms reproduce.

Cell Division in Eukaryotes

Cell division is more complex in eukaryotes than prokaryotes. Prior to dividing, all the DNA in a eukaryotic cell's multiple chromosomes is replicated. Its organelles are also duplicated. Then, when the cell divides, it occurs in two major steps:

- The first step is **mitosis**, a multi-phase process in which the nucleus of the cell divides. During mitosis, the nuclear membrane breaks down and later reforms. The chromosomes are also sorted and separated to ensure that each daughter cell receives a complete set of chromosomes. Mitosis is described in greater detail in Lesson 5.2.
- The second major step is cytokinesis. As in prokaryotic cells, during this step the cytoplasm divides and two daughter cells form.

The Cell Cycle

Cell division is just one of several stages that a cell goes through during its lifetime. The **cell cycle** is a repeating series of events that include growth, DNA synthesis, and cell division. The cell cycle in prokaryotes is quite simple: the cell grows, its DNA replicates, and the cell divides. In eukaryotes, the cell cycle is more complicated.

Eukaryotic Cell Cycle

The diagram in **Figure** 5.3 represents the cell cycle of a eukaryotic cell. As you can see, the eukaryotic cell cycle has several phases. The mitosis phase (M) actually includes both mitosis and cytokinesis. This is when the nucleus and then the cytoplasm divide. The other three phases (G1, S, and G2) are generally grouped together as **interphase**. During interphase, the cell grows, performs routine life processes, and prepares to divide. These phases are discussed below. You can watch a eukaryotic cell going through these phases of the cell cycle at the following link: http://www.cellsalive.com/cell_cycle.htm.

Interphase

Interphase of the eukaryotic cell cycle can be subdivided into the following three phases, which are represented in **Figure** 5.3 :

- **Growth Phase 1 (G1):** during this phase, the cell grows rapidly, while performing routine metabolic processes. It also makes proteins needed for DNA replication and copies some of its organelles in preparation for cell division. A cell typically spends most of its life in this phase.
- **Synthesis Phase (S):** during this phase, the cell's DNA is copied in the process of DNA replication.
- **Growth Phase 2 (G2):** during this phase, the cell makes final preparations to divide. For example, it makes additional proteins and organelles.

Control of the Cell Cycle

If the cell cycle occurred without regulation, cells might go from one phase to the next before they were ready. What controls the cell cycle? How does the cell know when to grow, synthesize DNA, and divide? The cell cycle is controlled mainly by regulatory proteins. These proteins control the cycle by signaling the cell to either start or delay the next phase of the cycle. They ensure that the cell completes the previous phase before moving on. Regulatory proteins control the cell cycle at key checkpoints, which are shown in **Figure** 5.4 . There are a number of main checkpoints.

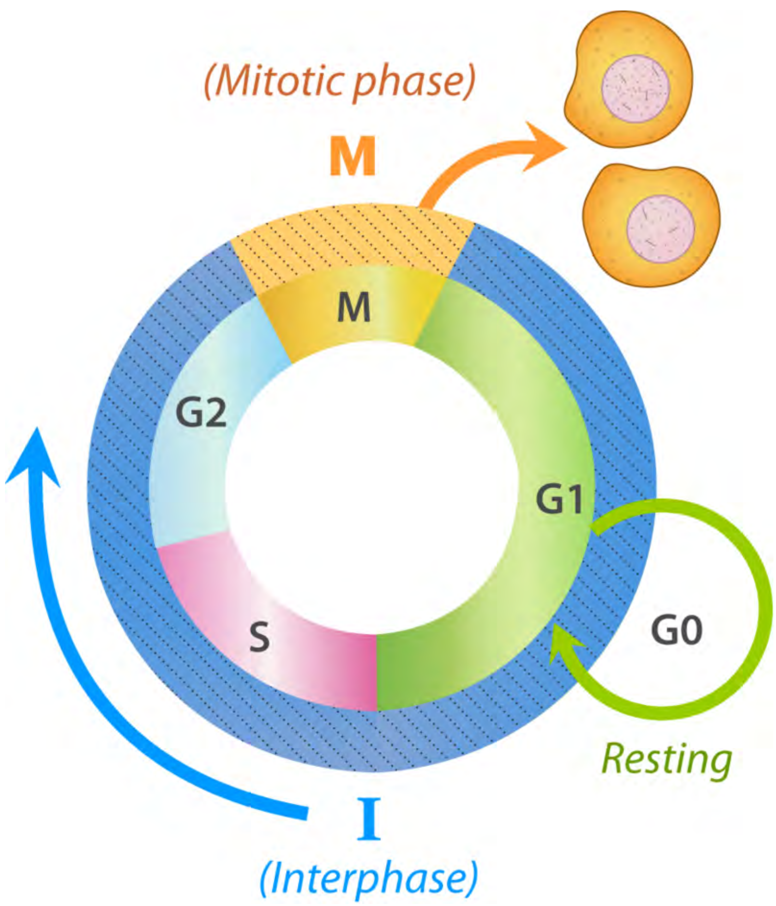


FIGURE 5.3

Eukaryotic Cell Cycle. This diagram represents the cell cycle in eukaryotes. The G1 S and G2 phases make up interphase I. The M phase includes mitosis and cytokinesis. After the M phase two cells result.

- The G1 checkpoint, just before entry into S phase, makes the key decision of whether the cell should divide.
- The S checkpoint determines if the DNA has been replicated properly.
- The mitotic spindle checkpoint occurs at the point in metaphase where all the chromosomes should have aligned at the mitotic plate.

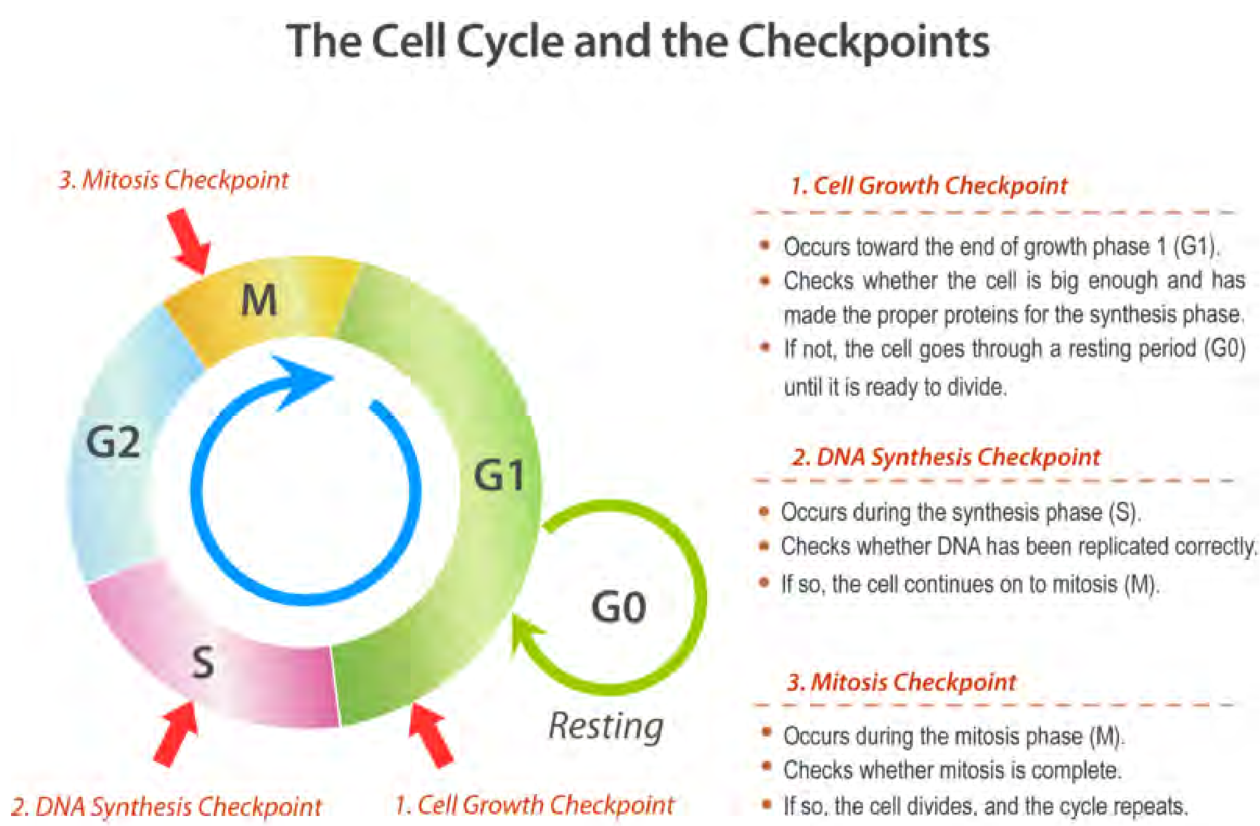


FIGURE 5.4

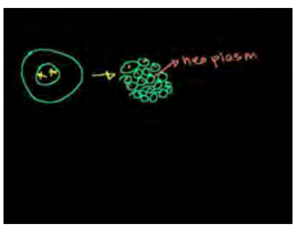
Checkpoints *arrows* in the eukaryotic cell cycle ensure that the cell is ready to proceed before it moves on to the next phase of the cycle.

Cancer and the Cell Cycle

Cancer is a disease that occurs when the cell cycle is no longer regulated. This may happen because a cell's DNA becomes damaged. Damage can occur due to exposure to hazards such as radiation or toxic chemicals. Cancerous cells generally divide much faster than normal cells. They may form a mass of abnormal cells called a **tumor** (see **Figure** 5.5). The rapidly dividing cells take up nutrients and space that normal cells need. This can damage tissues and organs and eventually lead to death.

Cancer is discussed in the video at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/11/RZhL7LDPk8w.

FIGURE 5.5
These cells are cancer cells growing out of control and forming a tumor.



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Lesson Summary

- Cell division is part of the life cycle of virtually all cells. It is a more complicated process in eukaryotic than prokaryotic cells because eukaryotic cells have multiple chromosomes and a nucleus.
- The cell cycle is a repeating series of events that cells go through. It includes growth, DNA synthesis, and cell division. In eukaryotic cells, there are two growth phases, and cell division includes mitosis.
- The cell cycle is controlled by regulatory proteins at three key checkpoints in the cycle. The proteins signal the cell to either start or delay the next phase of the cycle.
- Cancer is a disease that occurs when the cell cycle is no longer regulated. Cancer cells grow rapidly and may form a mass of abnormal cells called a tumor.

Lesson Review Questions

Recall

1. Describe binary fission.
2. What is mitosis?
3. Identify the phases of the eukaryotic cell cycle.
4. What happens during interphase?

5. Define cancer.

Apply Concepts

6. How might the relationship between cancer and the cell cycle be used in the search for causes of cancer?

Think Critically

7. Cells go through a series of events that include growth, DNA synthesis, and cell division. Why are these events best represented by a cycle diagram?

8. Contrast cell division in prokaryotes and eukaryotes. Why are the two types of cell division different?

9. Explain how the cell cycle is regulated.

10. Why is DNA replication essential to the cell cycle?

Points to Consider

When a eukaryotic cell divides, the nucleus divides first in the process of mitosis.

- What do you think happens during mitosis? Can you predict what molecules and cell structures are involved in this process?
- How do you think mitosis might differ from binary fission? What steps might be involved in mitosis?

5.2 Chromosomes and Mitosis

Lesson Objectives

- Describe chromosomes and their role in mitosis.
- Outline the phases of mitosis.

Vocabulary

anaphase third phase of mitosis during which sister chromatids separate and move to opposite poles of the cell

centromere region of sister chromatids where they are joined together

chromatid one of two identical copies of a chromosome that are joined together at a centromere before a cell divides

chromatin grainy material that DNA forms when it is not coiled into chromosomes

chromosome coiled structure made of DNA and proteins containing sister chromatids that is the form in which the genetic material of a cell goes through cell division

gene unit of DNA on a chromosome that is encoded with the instructions for a single protein

homologous chromosomes pair of chromosomes that have the same size and shape and contain the same genes

metaphase second phase of mitosis during which chromosomes line up at the equator of the cell

prophase first phase of mitosis during which chromatin condense into chromosomes, the nuclear envelope breaks down, centrioles separate, and a spindle begins to form

telophase last stage of mitosis during which chromosomes uncoil to form chromatin, the spindle breaks down, and new nuclear membranes form

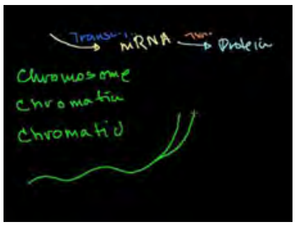
Introduction

In eukaryotic cells, the nucleus divides before the cell itself divides. The process in which the nucleus divides is called mitosis. Before mitosis occurs, a cell's DNA is replicated. This is necessary so that each daughter cell will have a complete copy of the genetic material from the parent cell. How is the replicated DNA sorted and separated so that each daughter cell gets a complete set of the genetic material? To understand how this happens, you need to know more chromosomes.

Chromosomes

Chromosomes are coiled structures made of DNA and proteins. Chromosomes are the form of the genetic material of a cell during cell division. During other phases of the cell cycle, DNA is not coiled into chromosomes. Instead, it exists as a grainy material called **chromatin**.

The vocabulary of DNA: chromosomes, chromatids, chromatin, transcription, translation, and replication is discussed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/6/s9HPNwXd9fk (18:23).



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Chromatids and the Centromere

DNA condenses and coils into the familiar X-shaped form of a chromosome, shown in **Figure** 5.6 , only after it has replicated. (You can watch DNA coiling into a chromosome at the link below.) Because DNA has already replicated, each chromosome actually consists of two identical copies. The two copies are called sister **chromatids**. They are attached to one another at a region called the **centromere**. A remarkable animation can be viewed at http://www.hhmi.org/biointeractive/media/DNAi_packaging_vo2-sm.mov.

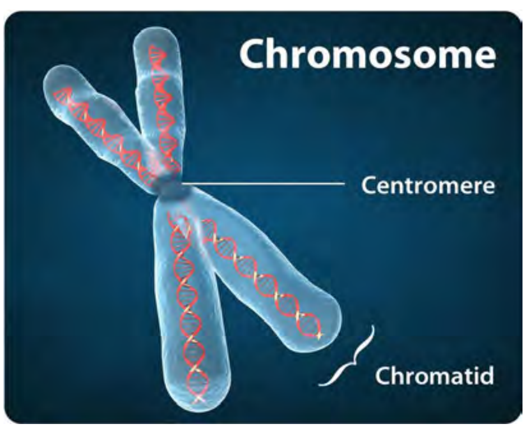


FIGURE 5.6

Chromosome. After DNA replicates it forms chromosomes like the one shown here.

Chromosomes and Genes

The DNA of a chromosome is encoded with genetic instructions for making proteins. These instructions are organized into units called **genes**. Most genes contain the instructions for a single protein. There may be hundreds or even thousands of genes on a single chromosome.

Human Chromosomes

Human cells normally have two sets of chromosomes, one set inherited from each parent. There are 23 chromosomes in each set, for a total of 46 chromosomes per cell. Each chromosome in one set is matched by a chromosome of the same type in the other set, so there are actually 23 pairs of chromosomes per cell. Each pair consists of chromosomes of the same size and shape that also contain the same genes. The chromosomes in a pair are known as **homologous chromosomes**.

Mitosis and Cytokinesis

During mitosis, when the nucleus divides, the two chromatids that make up each chromosome separate from each other and move to opposite poles of the cell. This is shown in **Figure** 5.7 . You can watch an animation of the process at the following link: http://www.biology.arizona.edu/Cell_bio/tutorials/cell_cycle/MitosisFlash.html.

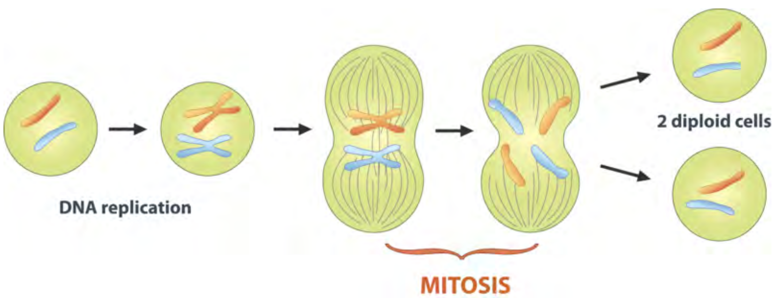


FIGURE 5.7
Mitosis is the phase of the eukaryotic cell cycle that occurs between DNA replication and the formation of two daughter cells. What happens during mitosis

Mitosis actually occurs in four phases. The phases are called prophase, metaphase, anaphase, and telophase. They are shown in **Figure** 5.8 and described in greater detail in the following sections.

Prophase

The first and longest phase of mitosis is **prophase**. During prophase, chromatin condenses into chromosomes, and the nuclear envelope, or membrane, breaks down. In animal cells, the centrioles near the nucleus begin to separate and move to opposite poles of the cell. As the centrioles move, a spindle starts to form between them. The spindle, shown in **Figure** 5.9 , consists of fibers made of microtubules.

Metaphase

During **metaphase**, spindle fibers attach to the centromere of each pair of sister chromatids (see **Figure** 5.10). The sister chromatids line up at the equator, or center, of the cell. The spindle fibers ensure that sister chromatids will separate and go to different daughter cells when the cell divides.

Anaphase

During **anaphase**, sister chromatids separate and the centromeres divide. The sister chromatids are pulled apart by the shortening of the spindle fibers. This is like reeling in a fish by shortening the fishing line. One sister chromatid moves to one pole of the cell, and the other sister chromatid moves to the opposite pole. At the end of anaphase, each pole of the cell has a complete set of chromosomes.

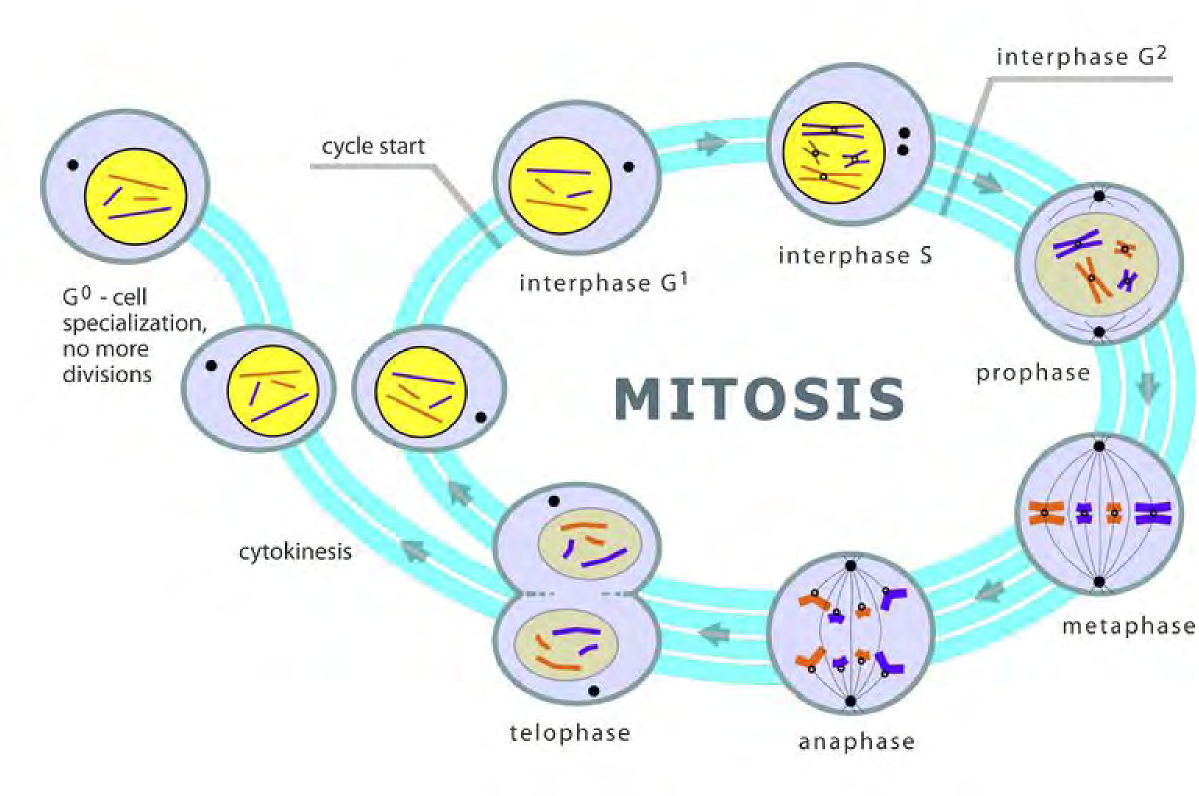


FIGURE 5.8
Mitosis in the Eukaryotic Cell Cycle. Mitosis is the multi-phase process in which the nucleus of a eukaryotic cell divides.

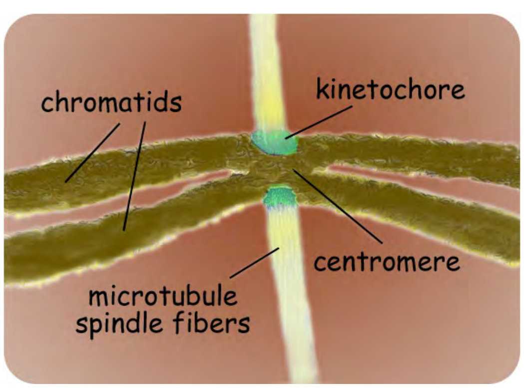


FIGURE 5.9
Spindle. The spindle starts to form during prophase of mitosis. Kinetochores on the spindle attach to the centromeres of sister chromatids.

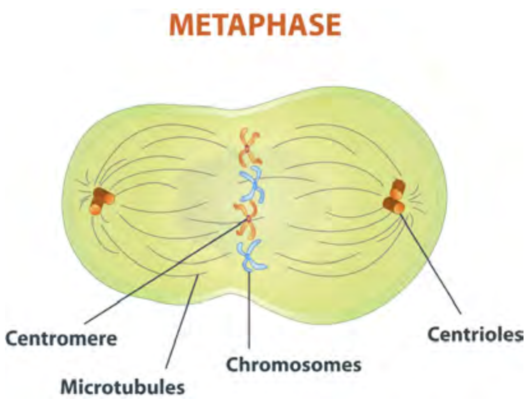


FIGURE 5.10
Chromosomes consisting of sister chromatids line up at the equator of the cell during metaphase.

Telophase

During **telophase**, the chromosomes begin to uncoil and form chromatin. This prepares the genetic material for directing the metabolic activities of the new cells. The spindle also breaks down, and new nuclear membranes form.

Cytokinesis

Cytokinesis is the final stage of cell division in eukaryotes as well as prokaryotes. During cytokinesis, the cytoplasm splits in two and the cell divides. Cytokinesis occurs somewhat differently in plant and animal cells, as shown in **Figure** 5.11 . In animal cells, the plasma membrane of the parent cell pinches inward along the cell's equator until two daughter cells form. In plant cells, a cell plate forms along the equator of the parent cell. Then, a new plasma membrane and cell wall form along each side of the cell plate.

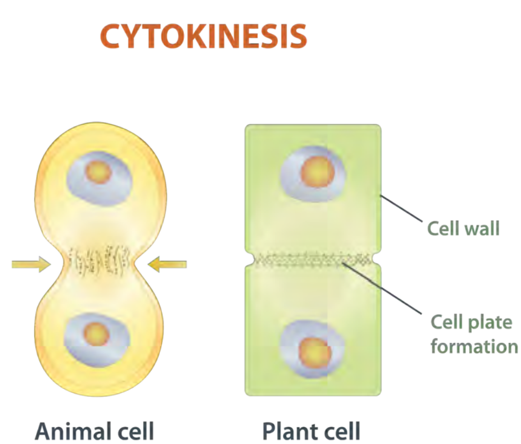
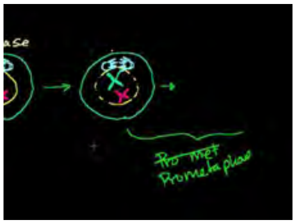


FIGURE 5.11
Cytokinesis is the final stage of eukaryotic cell division. It occurs differently in animal and plant cells.

The phases of mitosis are discussed in the video: http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/8/LLKX_4DHE3I.



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Lesson Summary

- Chromosomes are coiled structures made of DNA and proteins. They form after DNA replicates and are the form in which the genetic material goes through cell division. Chromosomes contain genes, which code for proteins.
- Cell division in eukaryotic cells includes mitosis, in which the nucleus divides, and cytokinesis, in which the cytoplasm divides and daughter cells form.
- Mitosis occurs in four phases, called prophase, metaphase, anaphase, and telophase.

Lesson Review Questions

Recall

1. What are chromosomes? When do they form?
2. Identify the chromatids and the centromere of a chromosome.
3. List the phases of mitosis.
4. What happens during prophase of mitosis?
5. During which phase of mitosis do sister chromatids separate?
6. Describe what happens during cytokinesis in animal cells.

Apply Concepts

7. If a cell skipped metaphase during mitosis, how might this affect the two daughter cells?

Think Critically

8. Explain how chromosomes are related to chromatin. Why are chromosomes important for mitosis?
9. Explain the significance of the spindle in mitosis.

Points to Consider

Cell division occurs not only as organisms grow. It also occurs when they reproduce.

- What role do you think cell division plays when prokaryotes such as bacteria reproduce?
- How do you think cell division is involved in the reproduction of eukaryotes such as humans?

5.3 Reproduction and Meiosis

Lesson Objectives

- Compare and contrast asexual and sexual reproduction.
- Give an overview of sexual reproduction, and outline the phases of meiosis.
- Explain why sexual reproduction leads to variation in offspring.
- Define life cycle, and identify different types of sexual life cycles.

Vocabulary

asexual reproduction reproduction that involves a single parent and results in offspring that are all genetically identical to the parent

crossing-over exchange of genetic material between homologous chromosomes when they are closely paired during meiosis I

diploid having two of each type of chromosome

egg female gamete

fertilization union of two gametes that produces a diploid zygote

gamete reproductive cell produced during meiosis that has the haploid number of chromosomes

gametogenesis development of haploid cells into gametes such as sperm and egg

haploid having only one chromosome of each type

independent assortment independent segregation of chromosomes to gametes during meiosis

life cycle series of stages a sexually reproducing organism goes through from one generation to the next

meiosis type of cell division in which the number of chromosomes is reduced by half and four haploid cells result

sexual reproduction type of reproduction that involves the fertilization of gametes produced by two parents and produces genetically variable offspring

sperm male gamete

zygote diploid cell that forms when two haploid gametes unite during fertilization

Introduction

Cell division is how organisms grow and repair themselves. It is also how they produce offspring. Many single-celled organisms reproduce by binary fission. The parent cell simply divides to form two daughter cells that are identical to the parent. In many other organisms, two parents are involved, and the offspring are not identical to the parents. In fact, each offspring is unique. Look at the family in **Figure** 5.12 . The children resemble their parents, but they are not identical to them. Instead, each has a unique combination of characteristics inherited from both parents. In this lesson, you will learn how this happens.

FIGURE 5.12

Family Portrait Mother Daughter Father and Son. Children resemble their parents but they are never identical to them. Do you know why this is the case

Reproduction: Asexual vs. Sexual

Reproduction is the process by which organisms give rise to offspring. It is one of the defining characteristics of living things. There are two basic types of reproduction: asexual reproduction and sexual reproduction.

Asexual Reproduction

Asexual reproduction involves a single parent. It results in offspring that 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.

- Binary fission occurs when a parent cell splits into two identical daughter cells of the same size. This process was described in detail in Lesson 5.1.
- Fragmentation occurs when a parent organism breaks into fragments, or pieces, and each fragment develops into a new organism. Starfish, like the one in **Figure** 5.13 , reproduce this way. A new starfish can develop from a single ray, or arm.
- Budding occurs when a parent cell forms a bubble-like bud. The bud stays attached to the parent cell while it grows and develops. When the bud is fully developed, it breaks away from the parent cell and forms a new organism. Budding in yeast is shown in **Figure** 5.14 .

Asexual reproduction can be very rapid. This is an advantage for many organisms. It allows them to crowd out other organisms that reproduce more slowly. Bacteria, for example, may divide several times per hour. Under ideal

FIGURE 5.13
Starfish reproduce by fragmentation. Starfish however are also capable of sexual reproduction.

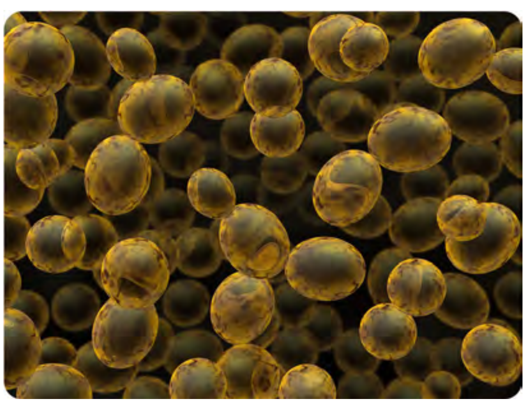

FIGURE 5.14
Yeast reproduces by budding. Both are types of asexual reproduction.

conditions, 100 bacteria can divide to produce millions of bacterial cells in just a few hours! However, most bacteria do not live under ideal conditions. If they did, the entire surface of the planet would soon be covered with them. Instead, their reproduction is kept in check by limited resources, predators, and their own wastes. This is true of most other organisms as well.

Sexual Reproduction

Sexual reproduction involves two parents. As you can see from **Figure** 5.15 , in sexual reproduction, parents produce reproductive cells—called **gametes**—that unite to form an offspring. Gametes are **haploid** cells. This means they contain only half the number of chromosomes found in other cells of the organism. Gametes are produced by a type of cell division called meiosis, which is described in detail below. The process in which two gametes unite is called **fertilization**. The fertilized cell that results is referred to as a **zygote**. A zygote is **diploid** cell, which means that it has twice the number of chromosomes as a gamete.

Mitosis, Meiosis and Sexual Reproduction is discussed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/7/kaSIjIzAtYA.

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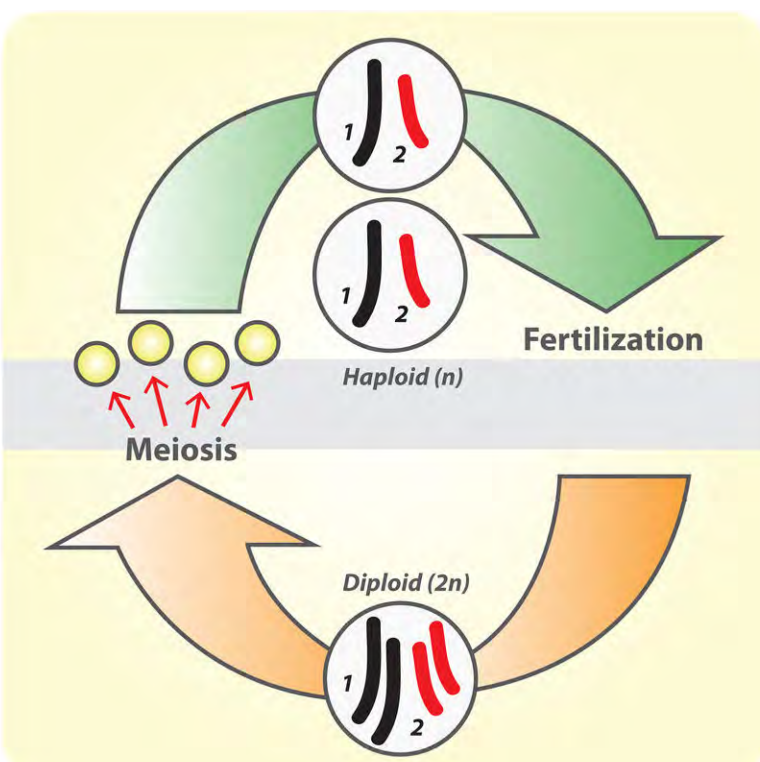

FIGURE 5.15

Cycle of Sexual Reproduction. Sexual reproduction involves the production of haploid gametes by meiosis. This is followed by fertilization and the formation of a diploid zygote. The number of chromosomes in a gamete is represented by the letter n. Why does the zygote have 2n or twice as many chromosomes

Meiosis

The process that produces haploid gametes is meiosis (see **Figure** 5.15). **Meiosis** is a type of cell division in which the number of chromosomes is reduced by half. It occurs only in certain special cells of the organisms. During meiosis, homologous chromosomes separate, and haploid cells form that have only one chromosome from each pair. Two cell divisions occur during meiosis, and a total of four haploid cells are produced. The two cell divisions are called meiosis I and meiosis II. The overall process of meiosis is summarized in **Figure** 5.16 . It is also described in detail below. You can watch an animation of meiosis at this link: http://www.youtube.com/watch?v=D1_-mQS_FZ0#38;#38;feature=related.

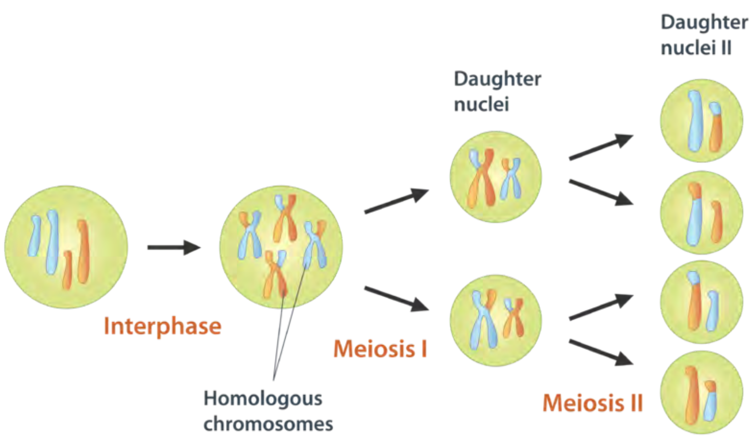

FIGURE 5.16
Overview of Meiosis. During meiosis homologous chromosomes separate and go to different daughter cells. This diagram shows just the nuclei of the cells.

Phases of Meiosis

Meiosis I begins after DNA replicates during interphase. In both meiosis I and meiosis II, cells go through the same four phases as mitosis. However, there are important differences between meiosis I and mitosis. The flowchart in **Figure** 5.17 shows what happens in both meiosis I and II. You can follow the changes in the flowchart as you read about them below.

The phases of meiosis are discussed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/9/ijLc52LmFQg (27:23).

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Meiosis I

a. Prophase I: The nuclear envelope begins to break down, and the chromosomes condense. Centrioles start moving to opposite poles of the cell, and a spindle begins to form. Importantly, homologous chromosomes

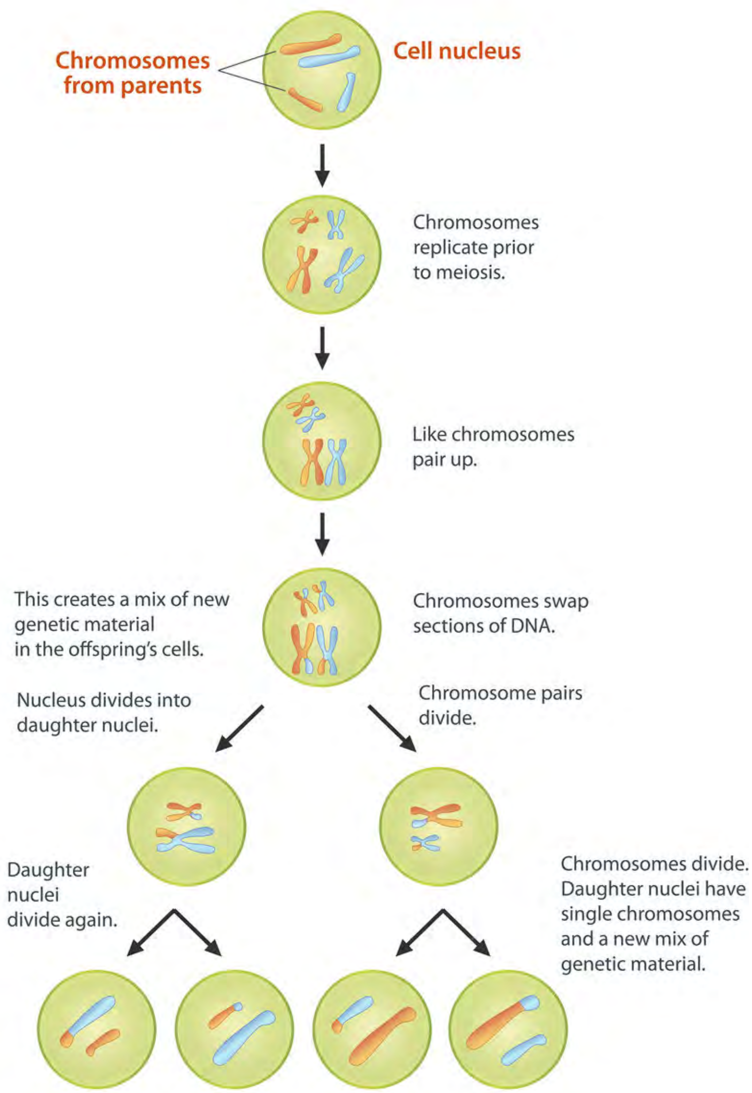

FIGURE 5.17

Phases of Meiosis. This flowchart of meiosis shows meiosis I in greater detail than meiosis II. Meiosis I&#8212 but not meiosis II&#8212 differs somewhat from mitosis. Compare meiosis I in this flowchart with the earlier figure featuring mitosis. How does meiosis I differ from mitosis pair up, which is unique to prophase I. In prophase of mitosis and meiosis II, homologous chromosomes do not form pairs in this way.

b. Metaphase I: Spindle fibers attach to the paired homologous chromosomes. The paired chromosomes line up along the equator of the cell. This occurs only in metaphase I. In metaphase of mitosis and meiosis II, it is sister chromatids that line up along the equator of the cell.
c. Anaphase I: Spindle fibers shorten, and the chromosomes of each homologous pair start to separate from each other. One chromosome of each pair moves toward one pole of the cell, and the other chromosome moves toward the opposite pole.
d. Telophase I and Cytokinesis: The spindle breaks down, and new nuclear membranes form. The cytoplasm of the cell divides, and two haploid daughter cells result. The daughter cells each have a random assortment of chromosomes, with one from each homologous pair. Both daughter cells go on to meiosis II.

Meiosis II

a. Prophase II: The nuclear envelope breaks down and the spindle begins to form in each haploid daughter cell from meiosis I. The centrioles also start to separate.
b. Metaphase II: Spindle fibers line up the sister chromatids of each chromosome along the equator of the cell.
c. Anaphase II: Sister chromatids separate and move to opposite poles.
d. Telophase II and Cytokinesis: The spindle breaks down, and new nuclear membranes form. The cytoplasm of each cell divides, and four haploid cells result. Each cell has a unique combination of chromosomes.

Mitosis, Meiosis and Sexual Reproduction is discussed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/7/kaSIjIzAtYA (18:23).

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You can watch an animation of meiosis at this link: http://www.youtube.com/watch?v=D1_-mQS_FZ0#38;#38;feature=related.

Gametogenesis

At the end of meiosis, four haploid cells have been produced, but the cells are not yet gametes. The cells need to develop before they become mature gametes capable of fertilization. The development of haploid cells into gametes is called **gametogenesis**. Gametogenesis may differ between males and females. Male gametes are called **sperm**. Female gametes are called **eggs**. In human males, for example, the process that produces mature sperm cells is called spermatogenesis. During this process, sperm cells grow a tail and gain the ability to "swim," like the human sperm cell shown in **Figure** 5.18 . In human females, the process that produces mature eggs is called oogenesis. Just one egg is produced from the four haploid cells that result from meiosis. The single egg is a very large cell, as you can see from the human egg in **Figure** 5.18 .

FIGURE 5.18

A human sperm is a tiny cell with a tail. A human egg is much larger. Both cells are mature haploid gametes that are capable of fertilization. What process is shown in this photograph

Sexual Reproduction and Genetic Variation

Sexual reproduction results in offspring that are genetically unique. They differ from both parents and also from each other. This occurs for a number of reasons.

- When homologous chromosomes pair up during meiosis I, crossing-over can occur. **Crossing-over** is the exchange of genetic material between homologous chromosomes. It results in new combinations of genes on each chromosome.
- When cells divide during meiosis, homologous chromosomes are randomly distributed to daughter cells, and different chromosomes segregate independently of each other. This called is called **independent assortment**. It results in gametes that have unique combinations of chromosomes.
- In sexual reproduction, two gametes unite to produce an offspring. But which two of the millions of possible gametes will it be? This is likely to be a matter of chance. It is obviously another source of genetic variation in offspring.

All of these mechanisms working together result in an amazing amount of potential variation. Each human couple, for example, has the potential to produce more than 64 trillion genetically unique children. No wonder we are all different!

Sexual Reproduction and Life Cycles

Sexual reproduction occurs in a cycle. Diploid parents produce haploid gametes that unite and develop into diploid adults, which repeat the cycle. This series of life stages and events that a sexually reproducing organism goes through is called its **life cycle**. Sexually reproducing organisms can have different types of life cycles. Three are represented in **Figure** 5.19 and described following sections.

Haploid Life Cycle

The haploid life cycle is the simplest life cycle. It is found in many single-celled organisms. Organisms with a haploid life cycle spend the majority of their lives as haploid gametes. When the haploid gametes fuse, they form a diploid zygote. It quickly undergoes meiosis to produce more haploid gametes that repeat the life cycle.

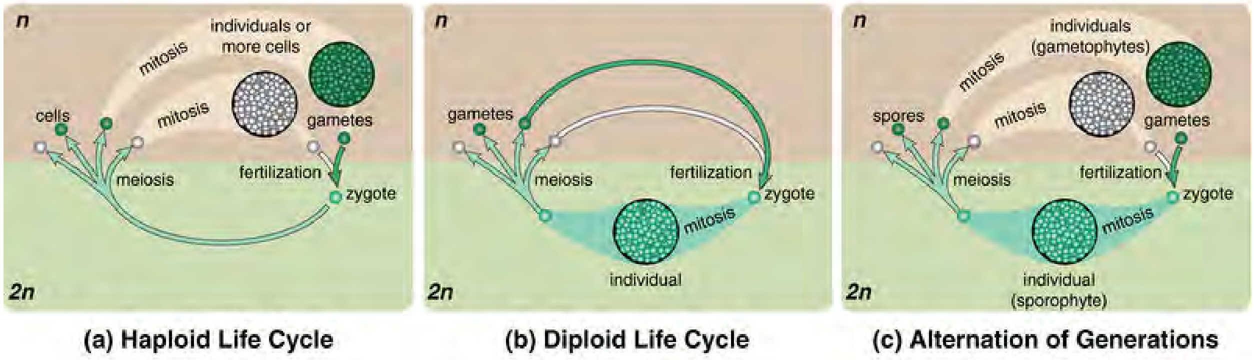

FIGURE 5.19

Life cycles can vary in sexually reproducing organisms. Three types of sexual life cycles are shown here. Do you see how they differ The letter n indicates haploid stages of the life cycles and 2n indicates diploid stages.

Diploid Life Cycle

Organisms with a diploid life cycle spend the majority of their lives as diploid adults. When they are ready to reproduce, they undergo meiosis and produce haploid gametes. Gametes then unite in fertilization and form a diploid zygote. The zygote develops into a diploid adult that repeats the life cycle. Can you think of an organism with a diploid life cycle? (*Hint:* What type of life cycle do humans have?)

Alternation of Generations

Organisms that have a life cycle with alternating generations switch back and forth between diploid and haploid stages. Organisms with this type of life cycle include plants, algae, and some protists. These life cycles may be quite complicated. You can read about them in later chapters.

Lesson Summary

- Asexual reproduction involves one parent and produces offspring that are genetically identical to each other and to the parent. Sexual reproduction involves two parents and produces offspring that are genetically unique.
- During sexual reproduction, two haploid gametes join in the process of fertilization to produce a diploid zygote. Meiosis is the type of cell division that produces gametes. It involves two cell divisions and produces four haploid cells.
- Sexual reproduction has the potential to produce tremendous genetic variation in offspring. This variation is due to independent assortment and crossing-over during meiosis and random union of gametes during fertilization.
- A life cycle is the sequence of stages an organisms goes through from one generation to the next. Organisms that reproduce sexually can have different types of life cycles, such as haploid or diploid life cycles.

Lesson Review Questions

Recall

1. What are three types of asexual reproduction?

2. Define gamete and zygote. What number of chromosomes does each have?

3. What happens during fertilization?

4. Outline the phases of meiosis.

5. What is a life cycle?

6. What is gametogenesis, and when does it occur?

Apply Concepts

7. Create a diagram to show how crossing-over occurs and how it creates new gene combinations on each chromosome.

8. An adult organism produces gametes that quickly go through fertilization and form diploid zygotes. The zygotes mature into adults, which live for many years. Eventually the adults produce gametes and the cycle repeats. What type of life cycle does this organism have? Explain your answer.

Think Critically

9. Compare and contrast asexual and sexual reproduction.

10. Explain why sexual reproduction results in genetically unique offspring.

11. Explain how meiosis I differs from mitosis.

Points to Consider

In sexually reproducing organisms, parents pass a copy of each type of chromosome to their offspring by producing gametes. When gametes are fertilized and form offspring, each has a unique combination of chromosomes and genes from both parents. The inherited gene combination determines the characteristics of the offspring.

- Is it possible to predict possible gene combinations in offspring from the genes of their parents?
- Can the characteristics of offspring be predicted from the characteristics of their parents?

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CHAPTER 6 Gregor Mendel and Genetics

CHAPTER OUTLINE

These purple-flowered plants are not just pretty to look at. Plants like these led to a huge leap forward in biology. The plants are common garden peas, and they were studied in the mid-1800s by an Austrian monk named Gregor Mendel. With his careful experiments, Mendel uncovered the secrets of heredity, or how parents pass characteristics to their offspring. You may not care much about heredity in pea plants, but you probably care about your own heredity. Mendel's discoveries apply to you as well as to peas—and to all other living things that reproduce sexually. In this chapter, you will read about Mendel's experiments and the secrets of heredity that he discovered.

6.1 Mendel's Investigations

Lesson Objectives

- Explain why and how Mendel studied pea plants.
- Describe the results of Mendel's experiments.
- State Mendel's laws of segregation and independent assortment.
- Outline the genetics of inheritance.

Vocabulary

allele one of two or more different versions of the same gene

dominant allele allele that masks the presence of another allele for the same gene when they occur together in a heterozygote

genetics the science of heredity

genotype alleles an individual inherits at a particular genetic locus

heterozygote organism that inherits two different alleles for a given gene

homozygote organism that inherits two alleles of the same type for a given gene

hybrid offspring that results from a cross between two different types of parents

law of independent assortment Mendel's second law stating that factors controlling different characteristics are inherited independently of each other

law of segregation Mendel's first law stating that the two factors controlling a characteristics separate and go to different gametes

locus position of a gene on a chromosome

phenotype characteristics of an organism that depend on how the organism's genotype is expressed

pollen tiny grains that bear the male gametes of seed plants and transfer sperm to female reproductive structures

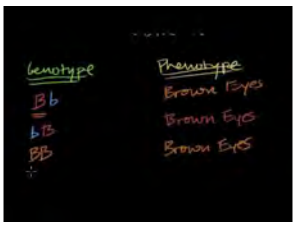
pollination fertilization in plants in which pollen is transferred to female gametes in an ovary

recessive allele allele that is masked by the presence of another allele for the same gene when they occur together in a heterozygote

Introduction

People have long known that the characteristics of living things are similar in parents and their offspring. Whether it's the flower color in pea plants or nose shape in people, it is obvious that offspring resemble their parents. However, it wasn't until the experiments of Gregor Mendel that scientists understood how characteristics are inherited. Mendel's discoveries formed the basis of **genetics**, the science of heredity. That's why Mendel is often called the "father of genetics." It's not common for a single researcher to have such an important impact on science. The importance of Mendel's work was due to three things: a curious mind, sound scientific methods, and good luck. You'll see why when you read about Mendel's experiments.

An introduction to heredity can be seen at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/12/eEUvRrhmcxM (17:27).



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Mendel and His Pea Plants

Gregor Mendel was born in 1822 and grew up on his parents' farm in Austria. He did well in school and became a monk. He also went to the University of Vienna, where he studied science and math. His professors encouraged him to learn science through experimentation and to use math to make sense of his results. Mendel is best known for his experiments with the pea plant *Pisum sativum* (see **Figure** 6.1). You can watch a video about Mendel and his research at the following link: http://www.metacafe.com/watch/hl-19246625/milestones_in_science_engineering_gregor_mendel_and_classical_genetics/.

Blending Theory of Inheritance

During Mendel's time, the blending theory of inheritance was popular. This is the theory that offspring have a blend, or mix, of the characteristics of their parents. Mendel noticed plants in his own garden that weren't a blend of the parents. For example, a tall plant and a short plant had offspring that were either tall or short but not medium in height. Observations such as these led Mendel to question the blending theory. He wondered if there was a different underlying principle that could explain how characteristics are inherited. He decided to experiment with pea plants to find out. In fact, Mendel experimented with almost 30,000 pea plants over the next several years! At the following link, you can watch an animation in which Mendel explains how he arrived at his decision to study inheritance in pea plants: http://www.dnalc.org/view/16170-Animation-3-Gene-s-don-t-blend-.html.

Why Study Pea Plants?

Why did Mendel choose common, garden-variety pea plants for his experiments? Pea plants are a good choice because they are fast growing and easy to raise. They also have several visible characteristics that may vary. These characteristics, which are shown in **Figure** 6.2 , include seed form and color, flower color, pod form and color, placement of pods and flowers on stems, and stem length. Each characteristic has two common values. For example, seed form may be round or wrinkled, and flower color may be white or purple (violet).

FIGURE 6.1
Gregor Mendel. The Austrian monk Gregor Mendel experimented with pea plants. He did all of his research in the garden of the monastery where he lived.

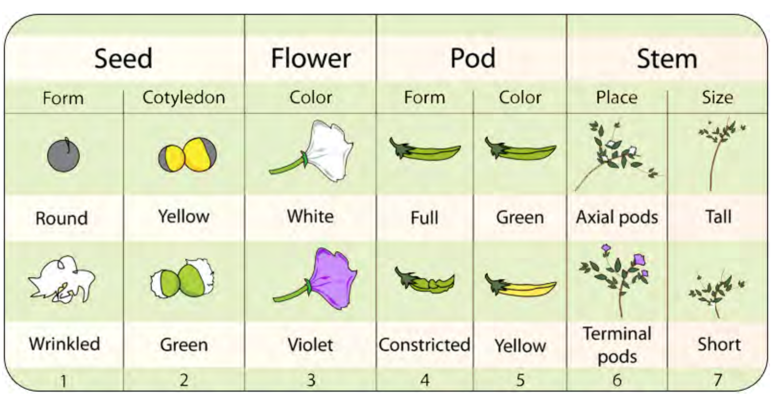

FIGURE 6.2
Mendel investigated seven different characteristics in pea plants. In this chart cotyledons refer to the tiny leaves inside seeds. Axial pods are located along the stems. Terminal pods are located at the ends of the stems.

Controlling Pollination

To research how characteristics are passed from parents to offspring, Mendel needed to control pollination. **Pollination** is the fertilization step in the sexual reproduction of plants. **Pollen** consists of tiny grains that are the male gametes of plants. They are produced by a male flower part called the anther (see **Figure** 6.3). Pollination occurs when pollen is transferred from the anther to the stigma of the same or another flower. The stigma is a female part of a flower. It passes the pollen grains to female gametes in the ovary.

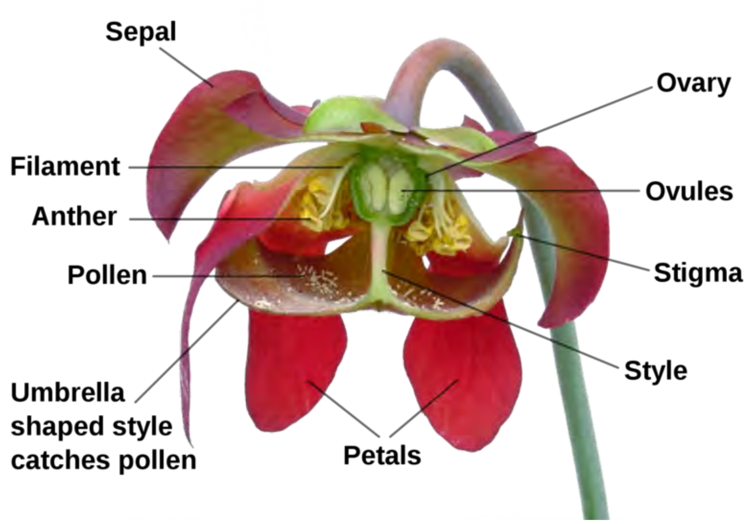

FIGURE 6.3
Flowers are the reproductive organs of plants. Each pea plant flower has both male and female parts. The anther is part of the stamen the male structure that produces male gametes *pollen*. The stigma is part of the pistil the female structure that produces female gametes and guides the pollen grains to them. The stigma receives the pollen grains and passes them to the ovary which contains female gametes.

Pea plants are naturally self-pollinating. In self-pollination, pollen grains from anthers on one plant are transferred to stigmas of flowers on the same plant. Mendel was interested in the offspring of two different parent plants, so he had to prevent self-pollination. He removed the anthers from the flowers of some of the plants in his experiments. Then he pollinated them by hand with pollen from other parent plants of his choice. When pollen from one plant fertilizes another plant of the same species, it is called cross-pollination. The offspring that result from such a cross are called **hybrids.**

Mendel's First Set of Experiments

At first, Mendel experimented with just one characteristic at a time. He began with flower color. As shown in **Figure** 6.4 , Mendel cross-pollinated purple- and white-flowered parent plants. The parent plants in the experiments are referred to as the P (for parent) generation. You can explore an interactive animation of Mendel's first set of experiments at this link: http://www2.edc.org/weblabs/Mendel/mendel.html.

F1 and F2 Generations

The offspring of the P generation are called the F1 (for filial, or "offspring") generation. As you can see from **Figure** 6.4 , all of the plants in the F1 generation had purple flowers. None of them had white flowers. Mendel wondered what had happened to the white-flower characteristic. He assumed some type of inherited factor produces white flowers and some other inherited factor produces purple flowers. Did the white-flower factor just disappear in the F1

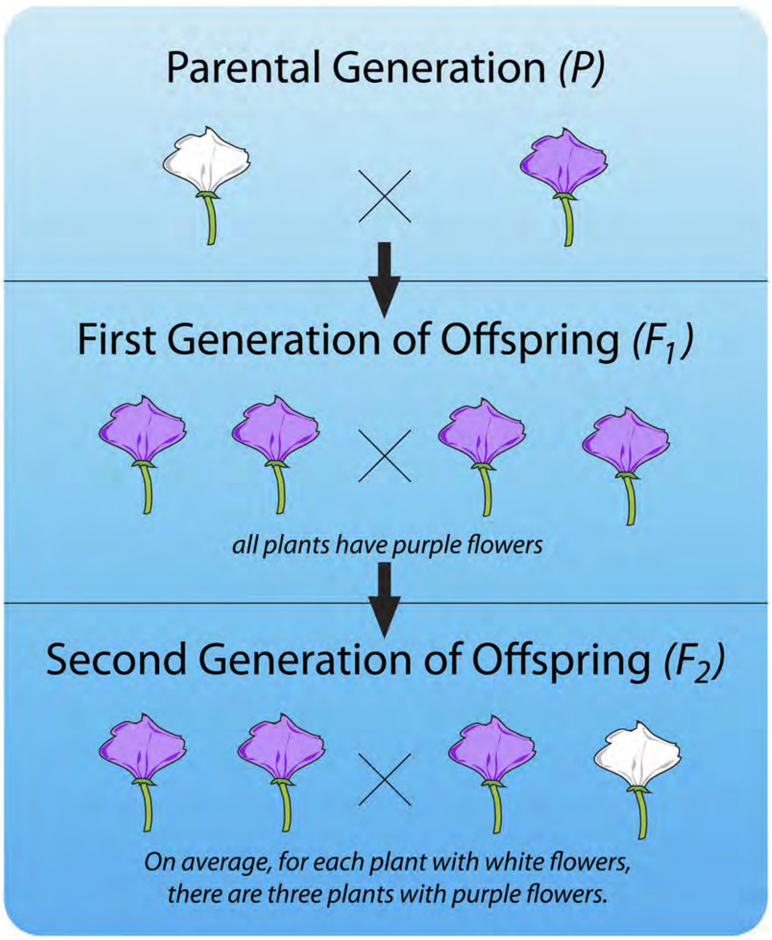

FIGURE 6.4
This diagram shows Mendelś first experiment with pea plants. The F1 generation results from cross-pollination of two parent *P* plants. The F2 generation results from self-pollination of F1 plants.

generation? If so, then the offspring of the F1 generation—called the F2 generation—should all have purple flowers like their parents. To test this prediction, Mendel allowed the F1 generation plants to self-pollinate. He was surprised by the results. Some of the F2 generation plants had white flowers. He studied hundreds of F2 generation plants, and for every three purple-flowered plants, there was an average of one white-flowered plant.

Law of Segregation

Mendel did the same experiment for all seven characteristics. In each case, one value of the characteristic disappeared in the F1 plants and then showed up again in the F2 plants. And in each case, 75 percent of F2 plants had one value of the characteristic and 25 percent had the other value. Based on these observations, Mendel formulated his first law of inheritance. This law is called the **law of segregation**. It states that there are two factors controlling a given characteristic, one of which dominates the other, and these factors separate and go to different gametes when a parent reproduces.

Mendel's Second Set of Experiments

Mendel wondered whether different characteristics are inherited together. For example, are purple flowers and tall stems always inherited together? Or do these two characteristics show up in different combinations in offspring? To answer these questions, Mendel next investigated two characteristics at a time. For example, he crossed plants with yellow round seeds and plants with green wrinkled seeds. The results of this cross are shown in **Figure** 6.5 .

F1 and F2 Generations

In this set of experiments, Mendel observed that plants in the F1 generation were all alike. All of them had yellow and round seeds like one of the two parents. When the F1 generation plants self-pollinated, however, their offspring—the F2 generation—showed all possible combinations of the two characteristics. Some had green round seeds, for example, and some had yellow wrinkled seeds. These combinations of characteristics were not present in the F1 or P generations.

Law of Independent Assortment

Mendel repeated this experiment with other combinations of characteristics, such as flower color and stem length. Each time, the results were the same as those in **Figure** 6.5 . The results of Mendel's second set of experiments led to his second law. This is the **law of independent assortment**. It states that factors controlling different characteristics are inherited independently of each other.

Mendel's Laws and Genetics

You might think that Mendel's discoveries would have made a big impact on science as soon as he made them. But you would be wrong. Why? Mendel never published his work. Charles Darwin published his landmark book on evolution in 1869, not long after Mendel had discovered his laws, but Darwin knew nothing of Mendel's discoveries. As a result, Darwin didn't understand heredity. This made his arguments about evolution less convincing to many people. This example shows why it is important for scientists to communicate the results of their investigations.

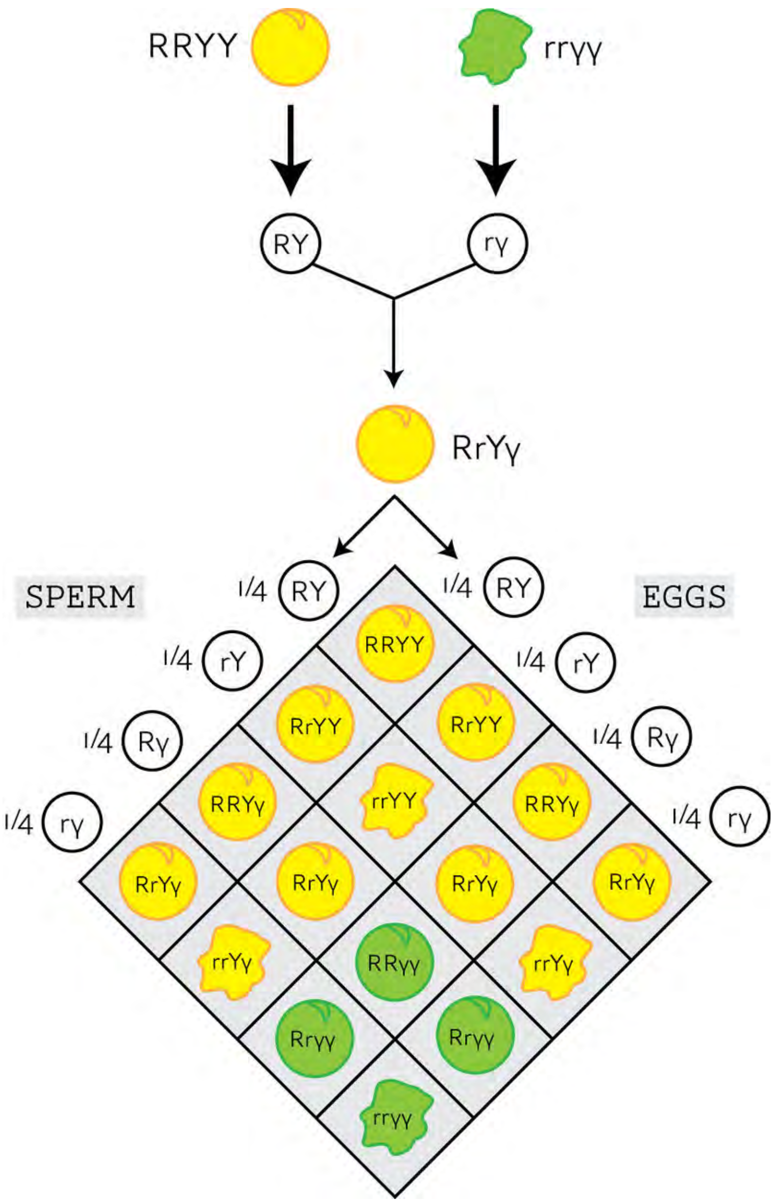

FIGURE 6.5

This chart represents Mendelś second set of experiments. It shows the outcome of a cross between plants that differ in seed color *yellow or green* and seed form *shown here with a smooth round appearance or wrink* The letters R r Y and y represent genes for the characteristics Mendel was studying. Mendel didn&#8217 t know about genes however. Genes would not be discovered until several decades later. This experiment demonstrates that 9/16 were round yellow 3/16 were wrinkled yellow 3/16 were round green and 1/16 were wrinkled green.

Rediscovering Mendel's Work

Mendel's work was virtually unknown until 1900. Then, in that year, three different European scientists—named DeVries, Correns, and Tschermak—independently arrived at Mendel's laws. All three had done experiments similar to Mendel's. They came to the same conclusions that he had drawn almost half a century earlier. Only then was Mendel's actual work rediscovered. As scientists learned more about heredity over the next few decades, they were able to describe Mendel's ideas about inheritance in terms of genes. In this way, the field of genetics was born. At the link that follows, you can watch an animation of Mendel explaining his laws of inheritance in genetic terms. http://www.dnalc.org/view/16182-Animation-4-Some-genes-are-dominant-.html

Genetics of Inheritance

Today, we known that characteristics of organisms are controlled by genes on chromosomes (see **Figure** 6.6). The position of a gene on a chromosome is called its **locus**. In sexually reproducing organisms, each individual has two copies of the same gene. One copy comes from each parent. The gene for a characteristic may have different versions. The different versions are called **alleles**. For example, in pea plants, there is a purple-flower allele (B) and a white-flower allele (b). Different alleles account for much of the variation in the characteristics of organisms.

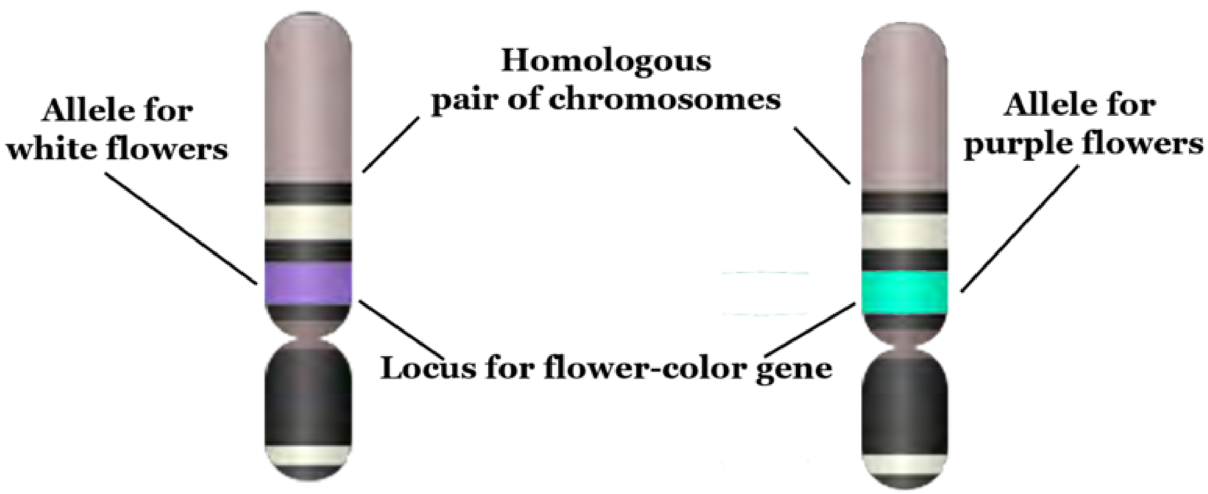

FIGURE 6.6

Chromosome Gene Locus and Allele. This diagram shows how the concepts of chromosome gene locus and allele are related. What is the different between a gene and a locus Between a gene and an allele

During meiosis, homologous chromosomes separate and go to different gametes. Thus, the two alleles for each gene also go to different gametes. At the same time, different chromosomes assort independently. As a result, alleles for different genes assort independently as well. In these ways, alleles are shuffled and recombined in each parent's gametes.

Genotype and Phenotype

When gametes unite during fertilization, the resulting zygote inherits two alleles for each gene. One allele comes from each parent. The alleles an individual inherits make up the individual's **genotype**. The two alleles may be the same or different. As shown in **Table** 6.1 , an organism with two alleles of the same type (*BB* or *bb*) is called a **homozygote**. An organism with two different alleles (*Bb*) is called a **heterozygote**.

TABLE 6.1: Genetics of Flower Color in Pea Plants

Alleles	Genotypes	Phenotypes
	BB (homozygote)	purple flowers
B (purple)	*Bb* (heterozygote)	purple flowers
b (white)	*bb* (homozygote)	white flowers

Table 6.2 There are two alleles, *B* and *b*, that control flower color in pea plants. This results in three possible genotypes. Why are there only two phenotypes?

The expression of an organism's genotype produces its **phenotype**. The phenotype refers to the organism's characteristics, such as purple or white flowers. As you can see from **Table** 6.1 , different genotypes may produce the same phenotype. For example, *BB* and *Bb* genotypes both produce plants with purple flowers. Why does this happen? In a *Bb* heterozygote, only the *B* allele is expressed, so the *b* allele doesn't influence the phenotype. In general, when only one of two alleles is expressed in the phenotype, the expressed allele is called the **dominant allele**. The allele that isn't expressed is called the **recessive allele**.

Lesson Summary

- Gregor Mendel experimented with pea plants to learn how characteristics are passed from parents to offspring.
- First, Mendel researched one characteristic at a time. This led to his law of segregation. This law states that each characteristic is controlled by two factors, which separate and go to different gametes when an organism reproduces.
- Then Mendel researched two characteristics at a time. This led to his law of independent assortment. This law states that the factors controlling different characteristics are inherited independently of each other.
- Mendel's work was rediscovered in 1900. Soon after that, genes and alleles were discovered. This allowed Mendel's laws to be stated in terms of the inheritance of alleles.
- *Gregor Mendel - From the Garden to the Genome* can be viewed at http://www.youtube.com/watch?v=6OPJnO9W_rQ (30.23).

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Lesson Review Questions

Recall

1. What is the blending theory of inheritance? Why did Mendel question this theory?

2. List the seven characteristics that Mendel investigated in pea plants.

3. How did Mendel control pollination in pea plants?

4. Describe in general terms Mendel's first set of experiments.

5. What was Mendel investigating with his second set of experiments? What was the outcome?

6. State Mendel's two laws.

Apply Concepts

7. Assume you are investigating the inheritance of stem length in pea plants. You cross-pollinate a short-stemmed plant with a long-stemmed plant. All of the offspring have long stems. Then, you let the offspring self-pollinate. Describe the stem lengths you would expect to find in the second generation of offspring.

8. If a purple-flowered, short-stemmed plant is crossed with a white-flowered, long-stemmed plant, would all of the purple-flowered offspring also have short stems? Why or why not?

Think Critically

9. If Darwin knew of Mendel's work, how might it have influenced his theory of evolution? Do you think this would have affected how well Darwin's work was accepted?

10. Explain Mendel's laws in genetic terms, that is, in terms of chromosomes, genes, and alleles.

11. Explain the relationship between genotype and phenotype. How can one phenotype result from more than one genotype?

Points to Consider

With his first set of experiments, Mendel found that characteristics appear to skip generations. With his second set of experiments, he found that different characteristics are inherited independently of one another.

- Why would this information be useful? Can you think of a practical application of Mendel's laws?
- Could Mendel's laws be used to predict the characteristics of the offspring of a given set of parents? How do you think this might be done?

6.2 Mendelian Inheritance

Lesson Objectives

- Define probability.
- Explain how probability is related to inheritance.
- Describe how to use a Punnett square.
- Explain how Mendel interpreted the results of his experiments.
- Describe complex patterns of inheritance.

Vocabulary

codominance relationship between two alleles for the same gene in which both alleles are expressed equally in the phenotype of the heterozygote

incomplete dominance relationship between the alleles for a gene in which one allele is only partly dominant to the other allele so an intermediate phenotype results

polygenic characteristic characteristic, or trait, controlled by more than one gene, each of which may have two or more alleles

probability the likelihood, or chance, than a certain event will occur

Punnett square chart for determining the expected percentages of different genotypes in the offspring of two parents

Introduction

Assume you are a plant breeder trying to develop a new variety of plant that is more useful to humans. You plan to cross-pollinate an insect-resistant plant with a plant that grows rapidly. Your goal is to produce a variety of plant that is both insect resistant and fast growing. What percent of the offspring would you expect to have both characteristics? Mendel's laws can be used to find out. However, to understand how Mendel's laws can be used in this way, you first need to know about probability.

Probability

Probability is the likelihood, or chance, that a certain event will occur. The easiest way to understand probability is with coin tosses (see **Figure** 6.7). When you toss a coin, the chance of a head turning up is 50 percent. This is because a coin has only two sides, so there is an equal chance of a head or tail turning up on any given toss.

FIGURE 6.7
Tossing a Coin. Competitions often begin with the toss of a coin. Why is this a fair way to decide who goes first If you choose heads what is the chance that the toss will go your way

If you toss a coin twice, you might expect to get one head and one tail. But each time you toss the coin, the chance of a head is still 50 percent. Therefore, it's quite likely that you will get two or even several heads (or tails) in a row. What if you tossed a coin ten times? You would probably get more or less than the expected five heads. For example, you might get seven heads (70 percent) and three tails (30 percent). The more times you toss the coin, however, the closer you will get to 50 percent heads. For example, if you tossed a coin 1000 times, you might get 510 heads and 490 tails.

Probability and Inheritance

The same rules of probability in coin tossing apply to the main events that determine the genotypes of offspring. These events are the formation of gametes during meiosis and the union of gametes during fertilization.

Probability and Gamete Formation

How is gamete formation like tossing a coin? Consider Mendel's purple-flowered pea plants again. Assume that a plant is heterozygous for the flower-color allele, so it has the genotype *Bb* (see **Figure** 6.8). During meiosis, homologous chromosomes—and the alleles they carry—segregate and go to different gametes. Therefore, when the *Bb* pea plant forms gametes, the *B* and *b* alleles segregate and go to different gametes. As a result, half the gametes produced by the *Bb* parent will have the *B* allele and half will have the *b* allele. Based on the rules of probability, any given gamete of this parent has a 50 percent chance of having the *B* allele and a 50 percent chance of having the *b* allele.

FIGURE 6.8
Formation of Gametes. Paired alleles always separate and go to different gametes during meiosis.

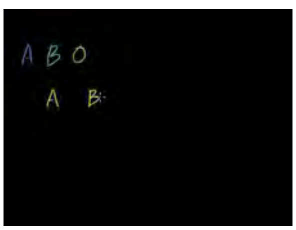
Probability and Fertilization

Which of these gametes joins in fertilization with the gamete of another parent plant? This is a matter of chance, like tossing a coin. Thus, we can assume that either type of gamete—one with the *B* allele or one with the *b* allele—has an equal chance of uniting with any of the gametes produced by the other parent. Now assume that the other parent is also *Bb*. If gametes of two *Bb* parents unite, what is the chance of the offspring having one of each allele like the parents (*Bb*)? What is the chance of them having a different combination of alleles than the parents (either *BB* or *bb*)? To answer these questions, geneticists use a simple tool called a Punnett square.

Using a Punnett Square

A **Punnett square** is a chart that allows you to easily determine the expected percents of different genotypes in the offspring of two parents. An example of a Punnett square for pea plants is shown in **Figure** 6.9 . In this example, both parents are heterozygous for flower color (*Bb*). The gametes produced by the male parent are at the top of the chart, and the gametes produced by the female parent are along the side. The different possible combinations of alleles in their offspring are determined by filling in the cells of the Punnett square with the correct letters (alleles). At the link below, you can watch an animation in which Reginald Punnett, inventor of the Punnett square, explains the purpose of his invention and how to use it. http://www.dnalc.org/view/16192-Animation-5-Genetic-inheritance-follows-rules-.html

An explanation of Punnett squares can be viewed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/13/D5ymMYcLtv0 (25:16).



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An example of the use of a Punnett square can be viewed at http://www.youtube.com/watch?v=nsHZbgOmVwg#38;feature=related (5:40).

Predicting Offspring Genotypes

In the cross shown in **Figure** 6.9 , you can see that one out of four offspring (25 percent) has the genotype *BB*, one out of four (25 percent) has the genotype *bb*, and two out of four (50 percent) have the genotype *Bb*. These percents of genotypes are what you would expect in any cross between two heterozygous parents. Of course, when just four offspring are produced, the actual percents of genotypes may vary by chance from the expected percents. However, if you considered hundreds of such crosses and thousands of offspring, you would get very close to the expected results—just like tossing a coin.

Predicting Offspring Phenotypes

You can predict the percents of phenotypes in the offspring of this cross from their genotypes. *B* is dominant to *b*, so offspring with either the *BB* or *Bb* genotype will have the purple-flower phenotype. Only offspring with the *bb* genotype will have the white-flower phenotype. Therefore, in this cross, you would expect three out of four (75 percent) of the offspring to have purple flowers and one out of four (25 percent) to have white flowers. These are the same percents that Mendel got in his first experiment.

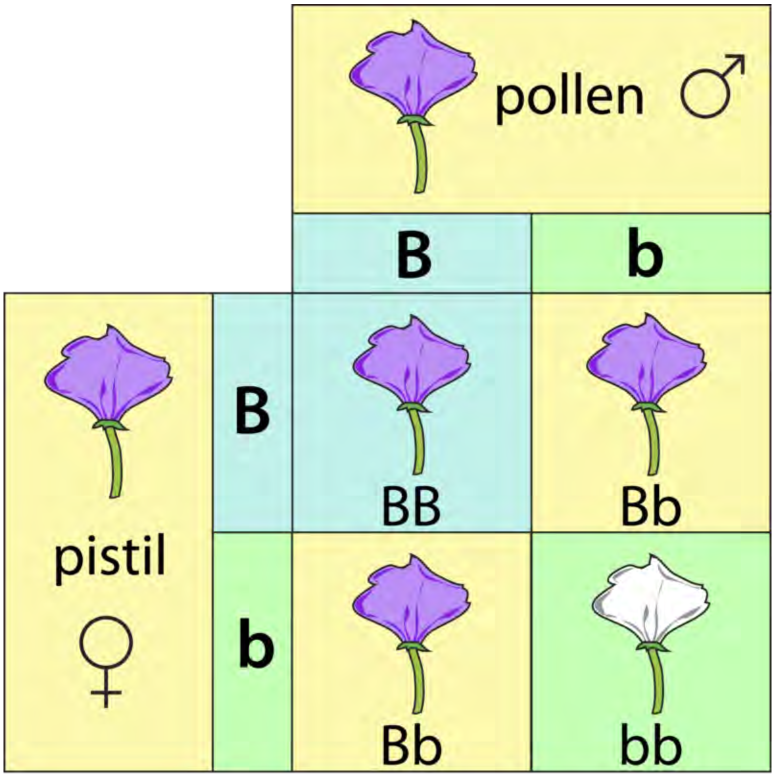


FIGURE 6.9
Punnett Square. This Punnett square shows a cross between two heterozygotes. Do you know where each letter *allele* in all four cells comes from

Determining Missing Genotypes

A Punnett square can also be used to determine a missing genotype based on the other genotypes involved in a cross. Suppose you have a parent plant with purple flowers and a parent plant with white flowers. Because the *b* allele is recessive, you know that the white-flowered parent must have the genotype *bb*. The purple-flowered parent, on the other hand, could have either the *BB* or the *Bb* genotype. The Punnett square in **Figure** 6.10 shows this cross. The question marks (?) in the chart could be either *B* or *b* alleles.

White Flowered Parent

	Parents	b	b
Purple Flowered Parent	B	Bb	Bb
	?	?b	?b

FIGURE 6.10
Punnett Square Cross Between White-Flowered and Purple-Flowered Pea Plants. This Punnett square shows a cross between a white-flowered pea plant and a purple-flowered pea plant. Can you fill in the missing alleles What do you need to know about the offspring to complete their genotypes

Can you tell what the genotype of the purple-flowered parent is from the information in the Punnett square? No; you also need to know the genotypes of the offspring in row 2. What if you found out that two of the four offspring have white flowers? Now you know that the offspring in the second row must have the *bb* genotype. One of their *b* alleles obviously comes from the white-flowered (*bb*) parent, because that's the only allele this parent has. The other *b* allele must come from the purple-flowered parent. Therefore, the parent with purple flowers must have the genotype *Bb*.

Punnett Square for Two Characteristics

When you consider more than one characteristic at a time, using a Punnett square is more complicated. This is because many more combinations of alleles are possible. For example, with two genes each having two alleles, an individual has four alleles, and these four alleles can occur in 16 different combinations. This is illustrated for pea plants in **Figure** 6.11 . In this cross, both parents are heterozygous for pod color (*Gg*) and seed color (*Yy*).

How Mendel Worked Backward to Get Ahead

Mendel used hundreds or even thousands of pea plants in each experiment he did. Therefore, his results were very close to those you would expect based on the rules of probability. For example, in one of his first experiments with flower color, there were 929 plants in the F2 generation. Of these, 705 (76 percent) had purple flowers and 224 (24 percent) had white flowers. Thus, Mendel's results were very close to the 75 percent purple and 25 percent white you would expect by the laws of probability for this type of cross. Of course, Mendel had only phenotypes to work with. He knew nothing about genes and genotypes. Instead, he had to work backward from phenotypes and their percents in offspring to understand inheritance. From the results of his first set of experiments, Mendel realized that there must be two factors controlling each of the characteristics he studied, with one of the factors being dominant to the other. He also realized that the two factors separate and go to different gametes and later recombine in the offspring. This is an example of Mendel's good luck. All of the characteristics he studied happened to be inherited in this way. Mendel also was lucky when he did his second set of experiments. He happened to pick characteristics that are inherited independently of one another. We now know that these characteristics are controlled by genes on nonhomologous chromosomes. What if Mendel had studied characteristics controlled by genes on homologous chromosomes? Would they be inherited together? If so, how do you think this would have affected Mendel's conclusions? Would he have been able to develop his second law of inheritance? To better understand how Mendel interpreted his findings and developed his laws of inheritance, you can visit the following link. It provides an animation in which Mendel explains how he came to understand heredity from his experimental results. http://www.dnalc.org/view/16154-Animation-2-Genes-Come-in-Pairs.html

Non-Mendelian Inheritance

The inheritance of characteristics is not always as simple as it is for the characteristics that Mendel studied in pea plants. Each characteristic Mendel investigated was controlled by one gene that had two possible alleles, one of which was completely dominant to the other. This resulted in just two possible phenotypes for each characteristic. Each characteristic Mendel studied was also controlled by a gene on a different (nonhomologous) chromosome. As a result, each characteristic was inherited independently of the other characteristics. Geneticists now know that inheritance is often more complex than this.

Codominance and Incomplete Dominance

A characteristic may be controlled by one gene with two alleles, but the two alleles may have a different relationship than the simple dominant-recessive relationship that you have read about so far. For example, the two alleles may

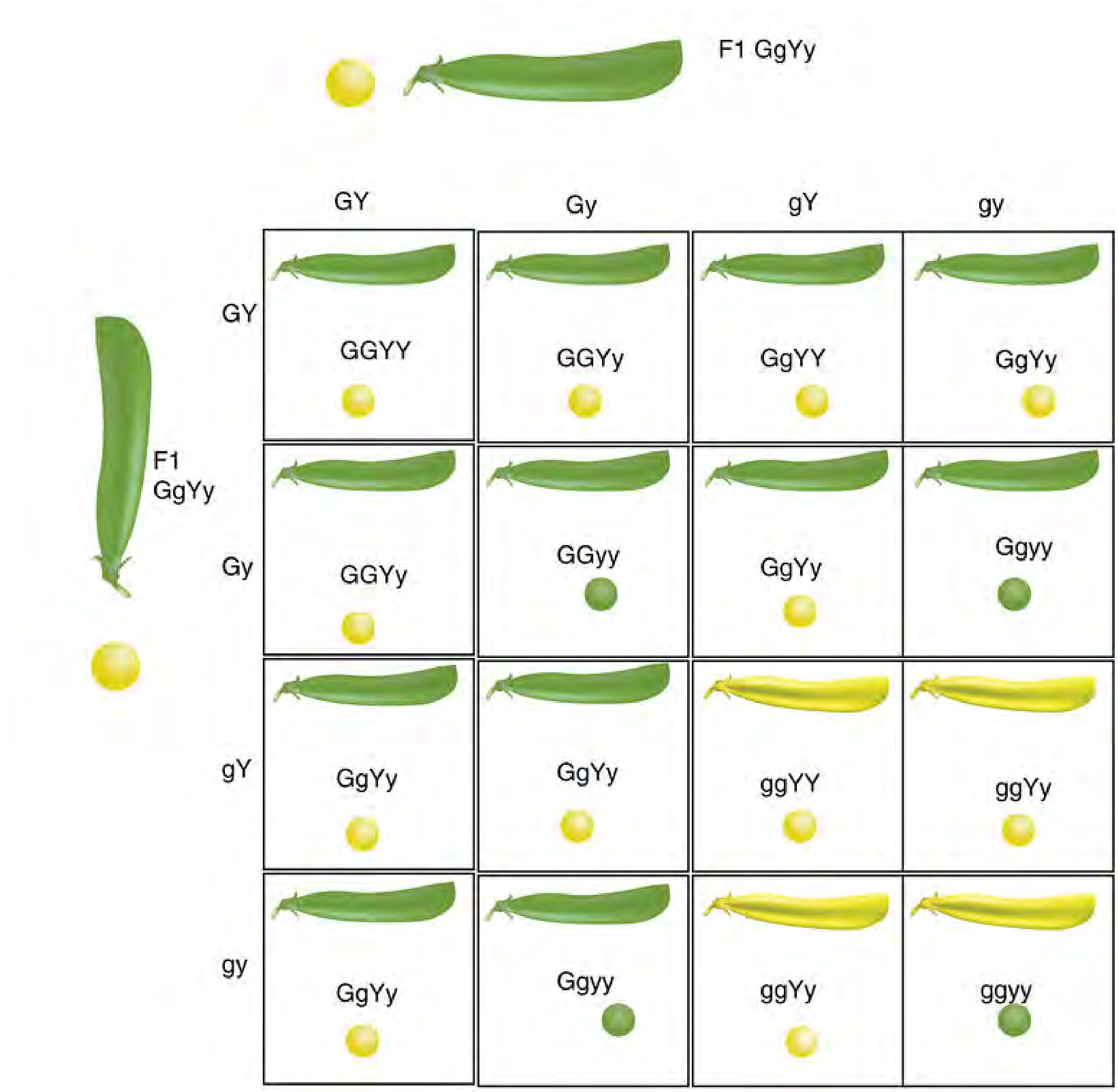


FIGURE 6.11

Punnett Square for Two Characteristics. This Punnett square represents a cross between two pea plants that are heterozygous for two characteristics. G represents the dominant allele for green pod color and g represents the recessive allele for yellow pod color. Y represents the dominant allele for yellow seed color and y represents the recessive allele for green seed color.

have a codominant or incompletely dominant relationship. The former is illustrated by the flower in **Figure** 6.12 , and the latter in **Figure** 6.13 .

Codominance

Codominance occurs when both alleles are expressed equally in the phenotype of the heterozygote. The red and white flower in the figure has codominant alleles for red petals and white petals.

Incomplete Dominance

Incomplete dominance occurs when the dominant allele is not completely dominant. Expression of the dominant allele is influenced by the recessive allele, and an intermediate phenotype results. The pink flower in the figure has an incompletely dominant allele for red petals and a recessive allele for white petals.

FIGURE 6.12
Codominance. The flower has red and white petals because of codominance of red-petal and white-petal alleles.

Multiple Alleles

Many genes have multiple (more than two) alleles. An example is ABO blood type in humans. There are three common alleles for the gene that controls this characteristic. The allele for type A is codominant with the allele for type B, and both alleles are dominant to the allele for type O. Therefore, the possible phenotypes are type A, B, AB, and O. Do you know what genotypes produce these phenotypes?

Polygenic Characteristics

Polygenic characteristics are controlled by more than one gene, and each gene may have two or more alleles. The genes may be on the same chromosome or on nonhomologous chromosomes.

- If the genes are located close together on the same chromosome, they are likely to be inherited together. However, it is possible that they will be separated by crossing-over during meiosis, in which case they may be inherited independently of one another.
- If the genes are on nonhomologous chromosomes, they may be recombined in various ways because of independent assortment.

FIGURE 6.13

Incomplete Dominance. The flower has pink petals because of incomplete dominance of a red-petal allele and a recessive white-petal allele.

For these reasons, the inheritance of polygenic characteristics is very complicated. Such characteristics may have many possible phenotypes. Skin color and adult height are examples of polygenic characteristics in humans. Do you have any idea how many phenotypes each characteristic has?

Effects of Environment on Phenotype

Genes play an important role in determining an organism's characteristics. However, for many characteristics, the individual's phenotype is influenced by other factors as well. Environmental factors, such as sunlight and food availability, can affect how genes are expressed in the phenotype of individuals. Here are just two examples:

- Genes play an important part in determining our adult height. However, factors such as poor nutrition can prevent us from achieving our full genetic potential.
- Genes are a major determinant of human skin color. However, exposure to ultraviolet radiation can increase the amount of pigment in the skin and make it appear darker.

Lesson Summary

- Probability is the chance that a certain event will occur. For example, the probability of a head turning up on any given coin toss is 50 percent.
- Probability can be used to predict the chance of gametes and offspring having certain alleles.
- A Punnett square is a chart for determining the expected percents of different genotypes and phenotypes in the offspring of two parents.
- Mendel used the percents of phenotypes in offspring to understand how characteristics are inherited.
- Many characteristics have more complex inheritance patterns than those studied by Mendel. They are complicated by factors such as codominance, incomplete dominance, multiple alleles, and environmental influences.

Lesson Review Questions

Recall

1. Define probability. Apply the term to a coin toss.

2. How is gamete formation like tossing a coin?

3. What is a Punnett square? How is it used?

4. What information must you know to determine the phenotypes of different genotypes for a gene with two alleles?

5. Based on the results of his experiments, what did Mendel conclude about the factors that control characteristics such as flower color?

Apply Concepts

6. Draw a Punnett square of an *Ss* x *ss* cross. The S allele codes for long stems in pea plants and the s allele codes for short stems. If S is dominant to s, what percent of offspring would you expect to have each phenotype?

7. What letter should replace the question marks (?) in this Punnett square? Explain how you know.

	A	A
?	A?	Aa
?	Aa	A?

Think Critically

8. Explain how Mendel used math and probability to understand the results of his experiments.

9. Compare and contrast codominance and incomplete dominance.

10. Mendel investigated stem length, or height, in pea plants. What if he had investigated human height instead? Why would his results have been harder to interpret?

Points to Consider

Like most of the characteristics of living things, the characteristics Mendel studied in pea plants are controlled by genes. All the cells of an organism contain the same genes, because all organisms begin as a single cell. Most of the genes code for proteins.

- How is the information encoded in a gene translated into a protein? Where does this occur, and what processes are involved?
- If cells have the same genes, how do you think different cells arise in an organism? For example, how did you come to have different skin, bone, and blood cells if all of your cells contain the same genes?

CHAPTER 7 Molecular Genetics: From DNA to Proteins

CHAPTER OUTLINE

The spiral structure in the picture is a large organic molecule. Can you guess what it is? Here's a hint: molecules like this one determine who you are. They contain genetic information that controls your characteristics. They determine your eye color, facial features, and other physical attributes. What molecule is it?

You probably answered "DNA." Today, it is commonly known that DNA is the genetic material. For a long time, scientists knew such molecules existed. They were aware that genetic information was contained within organic molecules. However, they didn't know which type of molecules play this role. In fact, for many decades, scientists thought that proteins were the molecules that carry genetic information. In this chapter, you will learn how scientists discovered that DNA carries the code of life.

7.1 DNA and RNA

Lesson Objectives

- State the central dogma of molecular biology.
- Outline discoveries that led to knowledge of DNA's structure and function.
- Describe the structure of RNA, and identify the three main types of RNA.

Vocabulary

central dogma of molecular biology doctrine that genetic instructions in DNA are copied by RNA, which carries them to a ribosome where they are used to synthesize a protein (DNA $\rightarrow$ RNA $\rightarrow$ protein)

Chargaff's rules observations by Erwin Chargaff that concentrations of the four nucleotide bases differ among species; and that, within a species, the concentrations of adenine and thymine are always about the same and the concentrations of cytosine and guanine are always about the same

messenger RNA (mRNA) type of RNA that copies genetic instructions from DNA in the nucleus and carries them to the cytoplasm

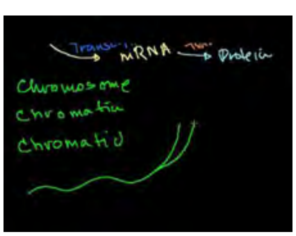
ribosomal RNA (rRNA) type of RNA that helps form ribosomes and assemble proteins

transfer RNA (tRNA) type of RNA that brings amino acids to ribosomes where they are joined together to form proteins

Introduction

Your DNA, or deoxyribonucleic acid, contains the genes that determine who you are. How can this organic molecule control your characteristics? DNA contains instructions for all the proteins your body makes. Proteins, in turn, determine the structure and function of all your cells. What determines a protein's structure? It begins with the sequence of amino acids that make up the protein. Instructions for making proteins with the correct sequence of amino acids are encoded in DNA.

The vocabulary of DNA: chromosomes, chromatids, chromatin, transcription, translation, and replication is discussed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/6/s9HPNwXd9fk (18:23).



MEDIA

Click image to the left for more content.

Central Dogma of Molecular Biology

DNA is found in chromosomes. In eukaryotic cells, chromosomes always remain in the nucleus, but proteins are made at ribosomes in the cytoplasm. How do the instructions in DNA get to the site of protein synthesis outside the nucleus? Another type of nucleic acid is responsible. This nucleic acid is RNA, or ribonucleic acid. RNA is a small molecule that can squeeze through pores in the nuclear membrane. It carries the information from DNA in the nucleus to a ribosome in the cytoplasm and then helps assemble the protein. In short:

DNA → RNA → Protein

Discovering this sequence of events was a major milestone in molecular biology. It is called the **central dogma of molecular biology**. You can watch a video about the central dogma and other concepts in this lesson at this link: http://www.youtube.com/watch?v=ZjRCmU0_dhY#38;feature=fvw (8:07). An overview of protein synthesis can be viewed at http://www.youtube.com/watch?v=-ygpqVr7_xs#38;feature=related (10:46).

DNA

DNA is the genetic material in your cells. It was passed on to you from your parents and determines your characteristics. The discovery that DNA is the genetic material was another important milestone in molecular biology.

Griffith Searches for the Genetic Material

Many scientists contributed to the identification of DNA as the genetic material. In the 1920s, Frederick Griffith made an important discovery. He was studying two different strains of a bacterium, called R (rough) strain and S (smooth) strain. He injected the two strains into mice. The S strain killed (virulent) the mice, but the R strain did not (nonvirulent) (see **Figure** 7.1). Griffith also injected mice with S-strain bacteria that had been killed by heat. As expected, the killed bacteria did not harm the mice. However, when the dead S-strain bacteria were mixed with live R-strain bacteria and injected, the mice died.

Based on his observations, Griffith deduced that something in the killed S-strain was transferred to the previously harmless R-strain, making the R-strain deadly. What was that something? What type of substance could change the characteristics of the organism that received it?

Avery's Team Makes a Major Contribution

In the early 1940s, a team of scientists led by Oswald Avery tried to answer the question raised by Griffith's results. They inactivated various substances in the S-strain bacteria. They then killed the S-strain bacteria and mixed the remains with live R-strain bacteria. (Keep in mind, the R-strain bacteria usually did not harm the mice.) When they inactivated proteins, the R-strain was deadly to the injected mice. This ruled out proteins as the genetic material. Why? Even without the S-strain proteins, the R-strain was changed, or transformed, into the deadly strain. However, when the researchers inactivated DNA in the S-strain, the R-strain remained harmless. This led to the conclusion that DNA is the substance that controls the characteristics of organisms. In other words, DNA is the genetic material. You can watch an animation about the research of both Griffith and Avery at this link: http://www.dnalc.org/view/16375-Animation-17-A-gene-is-made-of-DNA-.html.

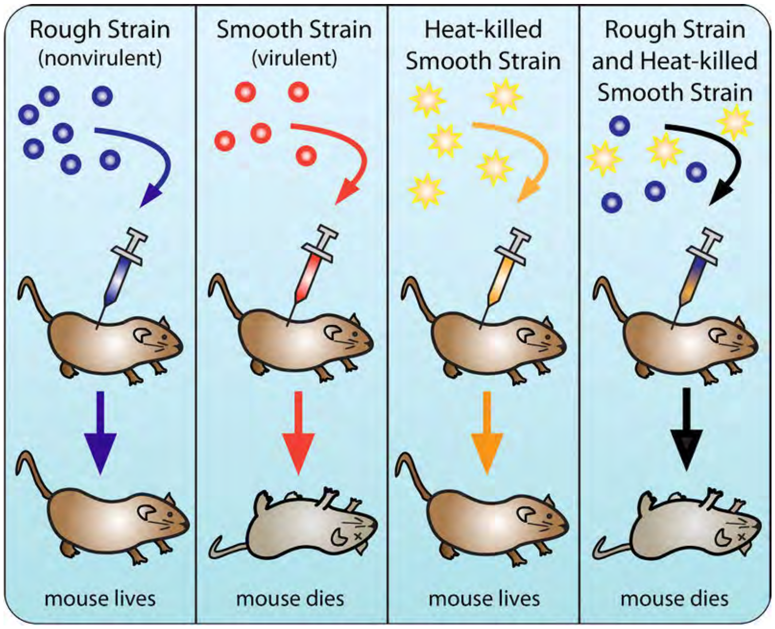


FIGURE 7.1
Griffith&#8217 s Experimental Results. Griffith showed that a substance could be transferred to harmless bacteria and make them deadly.

Hershey and Chase Seal the Deal

The conclusion that DNA is the genetic material was not widely accepted at first. It had to be confirmed by other research. In the 1950s, Alfred Hershey and Martha Chase did experiments with viruses and bacteria. Viruses are not cells. They are basically DNA inside a protein coat. To reproduce, a virus must insert its own genetic material into a cell (such as a bacterium). Then it uses the cell's machinery to make more viruses. The researchers used different radioactive elements to label the DNA and proteins in viruses. This allowed them to identify which molecule the viruses inserted into bacteria. DNA was the molecule they identified. This confirmed that DNA is the genetic material.

Chargaff Writes the Rules

Other important discoveries about DNA were made in the mid-1900s by Erwin Chargaff. He studied DNA from many different species. He was especially interested in the four different nitrogen bases of DNA: adenine (A), guanine (G), cytosine (C), and thymine (T) (see **Figure** 7.2). Chargaff found that concentrations of the four bases differed from one species to another. However, within each species, the concentration of adenine was always about the same as the concentration of thymine. The same was true of the concentrations of guanine and cytosine. These observations came to be known as **Chargaff's rules**. The significance of the rules would not be revealed until the structure of DNA was discovered.

The Double Helix

After DNA was found to be the genetic material, scientists wanted to learn more about it. James Watson and Francis Crick are usually given credit for discovering that DNA has a double helix shape, like a spiral staircase (see **Figure** 7.3). The discovery was based on the prior work of Rosalind Franklin and other scientists, who had used X rays to learn more about DNA's structure. Franklin and these other scientists have not always been given credit for their contributions. You can learn more about Franklin's work by watching the video at this link: http://www.youtube.com/watch?v=s3whouvZYG8 (7:47).

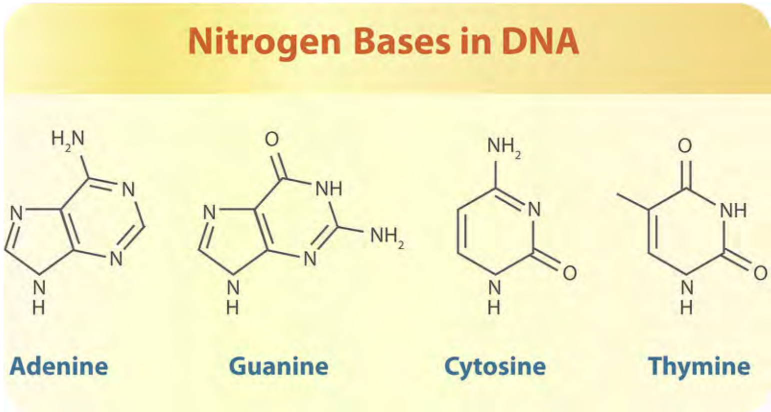


FIGURE 7.2

Nitrogen Bases in DNA. The DNA of all species has the same four nitrogen bases.

FIGURE 7.3

The DNA molecule has a double helix shape. This is the same basic shape as a spiral staircase. Do you see the resemblance Which parts of the DNA molecule are like the steps of the spiral staircase

The double helix shape of DNA, together with Chargaff's rules, led to a better understanding of DNA. DNA, as a nucleic acid, is made from nucleotide monomers, and the DNA double helix consists of two polynucleotide chains. Each nucleotide consists of a sugar (deoxyribose), a phosphate group, and a nitrogen-containing base (A, C, G, or T). The sugar-phosphate backbone of the double helix was discussed in the *Chemistry of Life* chapter.

Scientists concluded that bonds (hydrogen bonds) between complementary bases hold together the two polynucleotide chains of DNA. Adenine always bonds with its complementary base, thymine. Cytosine always bonds with its complementary base, guanine. If you look at the nitrogen bases in **Figure** 7.2 , you will see why. Adenine and guanine have a two-ring structure. Cytosine and thymine have just one ring. If adenine were to bind with guanine and cytosine with thymine, the distance between the two DNA chains would be variable. However, when a one-ring molecule binds with a two-ring molecule, the distance between the two chains is kept constant. This maintains the uniform shape of the DNA double helix. These *base pairs* (A-T or G-C) stick into the middle of the double helix, forming, in essence, the steps of the spiral staircase.

DNA Replication

Knowledge of DNA's structure helped scientists understand how DNA replicates. DNA replication is the process in which DNA is copied. It occurs during the synthesis (S) phase of the eukaryotic cell cycle. DNA replication begins when an enzyme breaks the bonds between complementary bases in DNA (see **Figure** 7.4). This exposes the bases inside the molecule so they can be "read" by another enzyme and used to build two new DNA strands with complementary bases. The two daughter molecules that result each contain one strand from the parent molecule and one new strand that is complementary to it. As a result, the two daughter molecules are both identical to the parent molecule. The process of DNA replication is actually much more complex than this simple summary. You can see a detailed animation of the process at this link: http://www.youtube.com/watch?v=-mtLXpgjHL0#38;NR=1 (2:05).

RNA

DNA alone cannot "tell" your cells how to make proteins. It needs the help of RNA, the other main player in the central dogma of molecular biology. Remember, DNA "lives" in the nucleus, but proteins are made on the ribosomes in the cytoplasm. How does the genetic information get from the nucleus to the cytoplasm? RNA is the answer.

RNA vs. DNA

RNA, like DNA, is a nucleic acid. However, RNA differs from DNA in several ways. In addition to being smaller than DNA, RNA also

- consists of one nucleotide chain instead of two,
- contains the nitrogen base uracil (U) instead of thymine,
- contains the sugar ribose instead of deoxyribose.

Types of RNA

There are three main types of RNA, all of which are involved in making proteins.

a. **Messenger RNA (mRNA)** copies the genetic instructions from DNA in the nucleus, and carries them to the cytoplasm.
b. **Ribosomal RNA (rRNA)** helps form ribosomes, where proteins are assembled.
c. **Transfer RNA (tRNA)** brings amino acids to ribosomes, where they are joined together to form proteins.

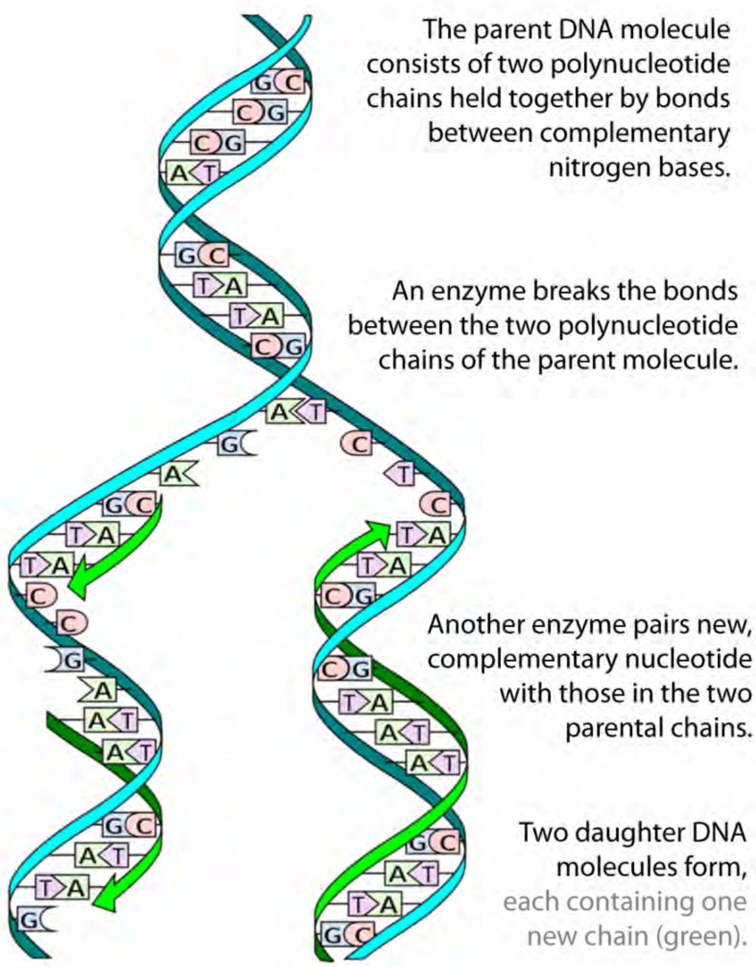


FIGURE 7.4

DNA Replication. DNA replication is a semi-conservative process. Half of the parent DNA molecule is conserved in each of the two daughter DNA molecules.

In the next lesson, you can read in detail how these three types of RNA help cells make proteins.

Lesson Summary

- The central dogma of molecular biology states that DNA contains instructions for making a protein, which are copied by RNA. RNA then uses the instructions to make a protein. In short: $DNA \rightarrow RNA \rightarrow Protein$.
- The work of several researchers led to the discovery that DNA is the genetic material. Other researchers discovered that DNA has a double helix shape, consisting of two polynucleotide chains held together by bonds between complementary bases.
- RNA differs from DNA in several ways. There three main types of RNA: messenger RNA (mRNA), ribosomal RNA (rRNA), and transfer RNA (tRNA). Each type plays a different in role in making proteins.

Lesson Review Questions

Recall

1. State the central dogma of molecular biology.
2. Outline research that determined that DNA is the genetic material.
3. What are Chargaff's rules?
4. Identify the structure of the DNA molecule.
5. Why is DNA replication said to be semi-conservative?

Apply Concepts

6. Create a diagram that shows how DNA replication occurs.

Think Critically

7. Explain why complementary base pairing is necessary to maintain the double helix shape of the DNA molecule.
8. Compare and contrast DNA and RNA.

Points to Consider

All three types of RNA are needed by cells to make proteins.

- Can you develop a model in which the three types of RNA interact to make a protein?
- How do you think mRNA copies the genetic instructions in DNA? How are these instructions encoded in the DNA molecule?

7.2 Protein Synthesis

Lesson Objectives

- Give an overview of transcription.
- Describe the genetic code.
- Explain how translation occurs.

Vocabulary

codon group of three nitrogen bases in nucleic acids that makes up a code "word" of the genetic code and stands for an amino acid, start, or stop

genetic code universal code of three-base codons that encodes the genetic instructions for the amino acid sequence of proteins

promoter region of a gene where a RNA polymerase binds to initiate transcription of the gene

protein synthesis process in which cells make proteins that includes transcription of DNA and translation of mRNA

transcription process in which genetic instructions in DNA are copied to form a complementary strand of mRNA

translation process in which genetic instructions in mRNA are "read" to synthesize a protein

Introduction

The process in which cells make proteins is called **protein synthesis**. It actually consists of two processes: transcription and translation. Transcription takes place in the nucleus. It uses DNA as a template to make an RNA molecule. RNA then leaves the nucleus and goes to a ribosome in the cytoplasm, where translation occurs. Translation reads the genetic code in mRNA and makes a protein.

Transcription

Transcription is the first part of the central dogma of molecular biology: **DNA** $\rightarrow$ **RNA**. It is the transfer of genetic instructions in DNA to mRNA. During transcription, a strand of mRNA is made that is complementary to a strand of DNA. **Figure** 7.5 shows how this occurs. You can watch an animation of the process at this link: http://www.biostudio.com/d_%20Transcription.htm.

- A detailed video about transcription is available at this link: http://vcell.ndsu.edu/animations/transcription/movie-flash.htm.

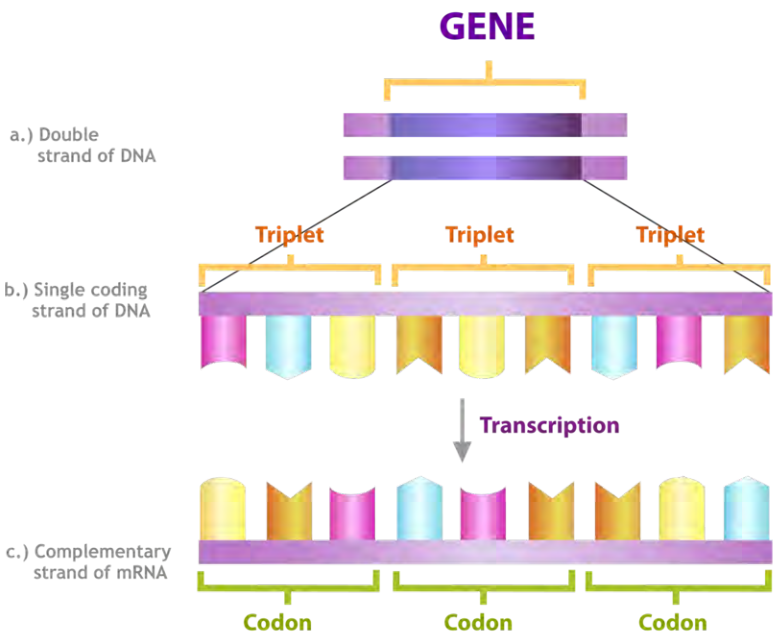


FIGURE 7.5

Overview of Transcription. Transcription uses the sequence of bases in a strand of DNA to make a complementary strand of mRNA. Triplets are groups of three successive nucleotide bases in DNA. Codons are complementary groups of bases in mRNA.

Steps of Transcription

Transcription takes place in three steps: initiation, elongation, and termination. The steps are illustrated in **Figure** 7.6 .

a. Initiation is the beginning of transcription. It occurs when the enzyme RNA polymerase binds to a region of a gene called the **promoter**. This signals the DNA to unwind so the enzyme can "read" the bases in one of the DNA strands. The enzyme is ready to make a strand of mRNA with a complementary sequence of bases.
b. Elongation is the addition of nucleotides to the mRNA strand.
c. Termination is the ending of transcription. The mRNA strand is complete, and it detaches from DNA.

Processing mRNA

In eukaryotes, the new mRNA is not yet ready for translation. It must go through more processing before it leaves the nucleus. This may include splicing, editing, and polyadenylation. These processes modify the mRNA in various ways. Such modifications allow a single gene to be used to make more than one protein.

- Splicing removes introns from mRNA (see **Figure ??**). Introns are regions that do not code for proteins. The remaining mRNA consists only of regions that do code for proteins, which are called exons. You can watch a video showing splicing in more detail at this link: http://vcell.ndsu.edu/animations/mrnasplicing/movie-flash.htm.
- Editing changes some of the nucleotides in mRNA. For example, the human protein called APOB, which helps transport lipids in the blood, has two different forms because of editing. One form is smaller than the other because editing adds a premature stop signal in mRNA.

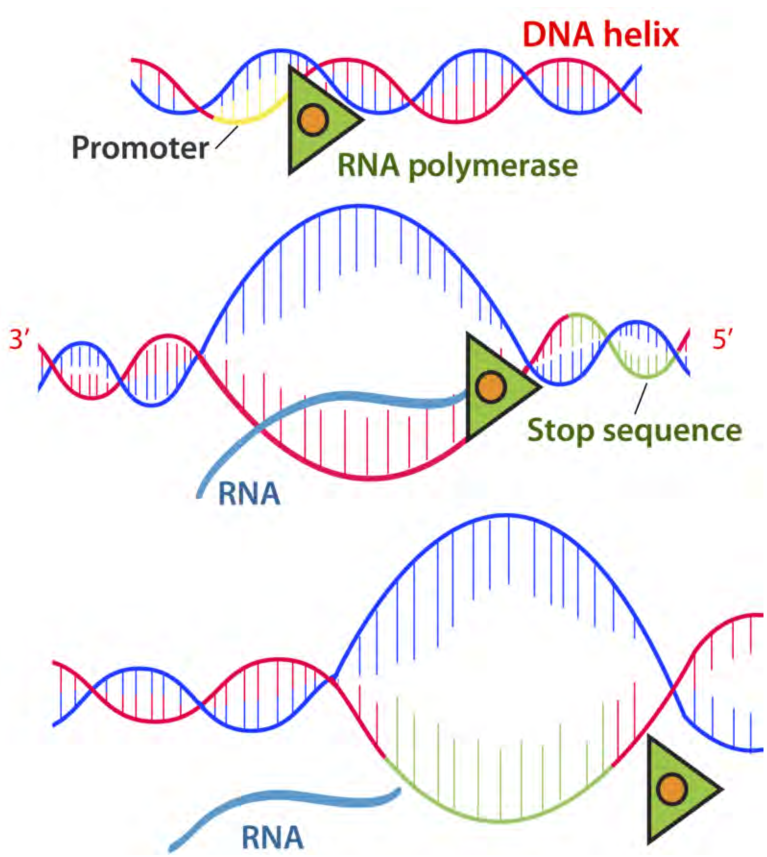


FIGURE 7.6
Steps of Transcription. Transcription occurs in the three steps - initiation elongation and termination - shown here.

- Polyadenylation adds a "tail" to the mRNA. The tail consists of a string of As (adenine bases). It signals the end of mRNA. It is also involved in exporting mRNA from the nucleus. In addition, the tail protects mRNA from enzymes that might break it down.

The Genetic Code

How is the information in a gene encoded? The answer is the genetic code. The **genetic code** consists of the sequence of nitrogen bases—A, C, G, T (or U)—in a polynucleotide chain. The four bases make up the "letters" of the genetic code. The letters are combined in groups of three to form code "words," called **codons**. Each codon stands for (encodes) one amino acid, unless it codes for a start or stop signal. There are 20 common amino acids in proteins. There are 64 possible codons, more than enough to code for the 20 amino acids. The genetic code is shown in **Figure** 7.7 . To see how scientists cracked the genetic code, go to this link: http://www.dnalc.org/view/16494-Animation-22-DNA-words-are-three-letters-long-.html.

1st base	2nd base U	2nd base C	2nd base A	2nd base G
U	UUU (Phe/F) Phenylalanine	UCU (Ser/S) Serine	UAU (Tyr/Y) Tyrosine	UGU (Cys/C) Cysteine
U	UUC (Phe/F) Phenylalanine	UCC (Ser/S) Serine	UAC (Tyr/Y) Tyrosine	UGC (Cys/C) Cysteine
U	UUA (Leu/L) Leucine	UCA (Ser/S) Serine	UAA Ochre (*Stop*)	UGA Opal (*Stop*)
U	UUG (Leu/L) Leucine	UCG (Ser/S) Serine	UAG Amber (*Stop*)	UGG (Trp/W) Tryptophan
C	CUU (Leu/L) Leucine	CCU (Pro/P) Proline	CAU (His/H) Histidine	CGU (Arg/R) Arginine
C	CUC (Leu/L) Leucine	CCC (Pro/P) Proline	CAC (His/H) Histidine	CGC (Arg/R) Arginine
C	CUA (Leu/L) Leucine	CCA (Pro/P) Proline	CAA (Gln/Q) Glutamine	CGA (Arg/R) Arginine
C	CUG (Leu/L) Leucine	CCG (Pro/P) Proline	CAG (Gln/Q) Glutamine	CGG (Arg/R) Arginine
A	AUU (Ile/I) Isoleucine	ACU (Thr/T) Threonine	AAU (Asn/N) Asparagine	AGU (Ser/S) Serine
A	AUC (Ile/I) Isoleucine	ACC (Thr/T) Threonine	AAC (Asn/N) Asparagine	AGC (Ser/S) Serine
A	AUA (Ile/I) Isoleucine	ACA (Thr/T) Threonine	AAA (Lys/K) Lysine	AGA (Arg/R) Arginine
A	AUG[A] (Met/M) Methionine	ACG (Thr/T) Threonine	AAG (Lys/K) Lysine	AGG (Arg/R) Arginine
G	GUU (Val/V) Valine	GCU (Ala/A) Alanine	GAU (Asp/D) Aspartic acid	GGU (Gly/G) Glycine
G	GUC (Val/V) Valine	GCC (Ala/A) Alanine	GAC (Asp/D) Aspartic acid	GGC (Gly/G) Glycine
G	GUA (Val/V) Valine	GCA (Ala/A) Alanine	GAA (Glu/E) Glutamic acid	GGA (Gly/G) Glycine
G	GUG (Val/V) Valine	GCG (Ala/A) Alanine	GAG (Glu/E) Glutamic acid	GGG (Gly/G) Glycine

nonpolar	polar	basic	acidic	(stop codon)

FIGURE 7.7

The Genetic Code. To find the amino acid for a particular codon find the cell in the table for the first and second bases of the codon. Then within that cell find the codon with the correct third base. For example CUG codes for leucine AAG codes for lysine and GGG codes for glycine.

Reading the Genetic Code

As shown in **Figure** 7.7 , the codon AUG codes for the amino acid methionine. This codon is also the start codon that begins translation. The start codon establishes the reading frame of mRNA. The reading frame is the way the letters are divided into codons. After the 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. This is illustrated in **Figure** 7.8 . The mRNA molecule is read, codon by codon, until a stop codon is reached. UAG, UGA, and UAA are all stop codons. They do not code for any amino acids.

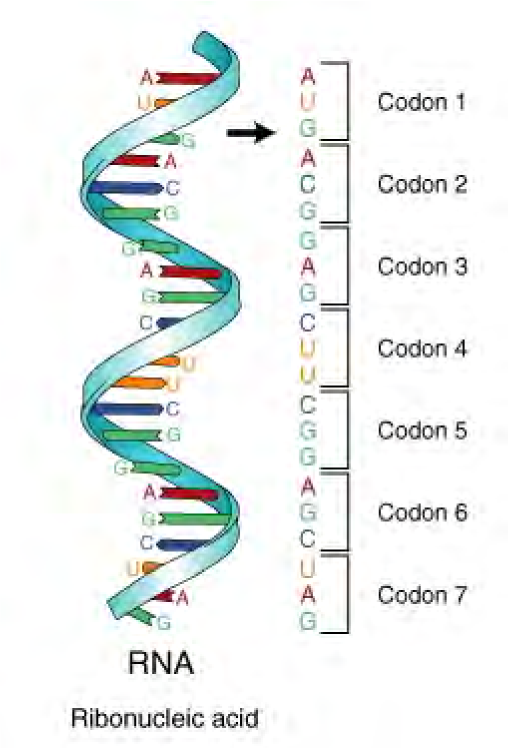


FIGURE 7.8
Reading the Genetic Code. The genetic code is read three bases at a time. Codons are the code words of the genetic code. Which amino acid does codon 2 in the drawing stand for

Characteristics of the Genetic Code

The genetic code has a number of important characteristics.

- The genetic code is universal. All known living things have the same genetic code. This shows that all organisms share a common evolutionary history.
- The genetic code is unambiguous. Each codon codes for just one amino acid (or start or stop). What might happen if codons encoded more than one amino acid?
- The genetic code is redundant. Most amino acids are encoded by more than one codon. In **Figure** 7.7 , how many codons code for the amino acid threonine? What might be an advantage of having more than one codon for the same amino acid?

Translation

Translation is the second part of the central dogma of molecular biology: **RNA** → **Protein**. It is the process in which the genetic code in mRNA is read to make a protein. **Figure** 7.9 shows how this happens. After mRNA leaves the nucleus, it moves to a ribosome, which consists of rRNA and proteins. The ribosome reads the sequence of codons in mRNA. Molecules of tRNA bring amino acids to the ribosome in the correct sequence. To understand the role of tRNA, you need to know more about its structure. Each tRNA molecule has an anticodon for the amino acid it carries. An anticodon is complementary to the codon for an amino acid. For example, the amino acid lysine has the codon AAG, so the anticodon is UUC. Therefore, lysine would be carried by a tRNA molecule with the anticodon UUC. Wherever the codon AAG appears in mRNA, a UUC anticodon of tRNA temporarily binds. While bound to mRNA, tRNA gives up its amino acid. Bonds form between the amino acids as they are brought one by one to the ribosome, forming a polypeptide chain. The chain of amino acids keeps growing until a stop codon is reached. To see how this happens, go the link below. http://www.youtube.com/watch?v=B6O6uRb1D38#38;feature=related (1:29)

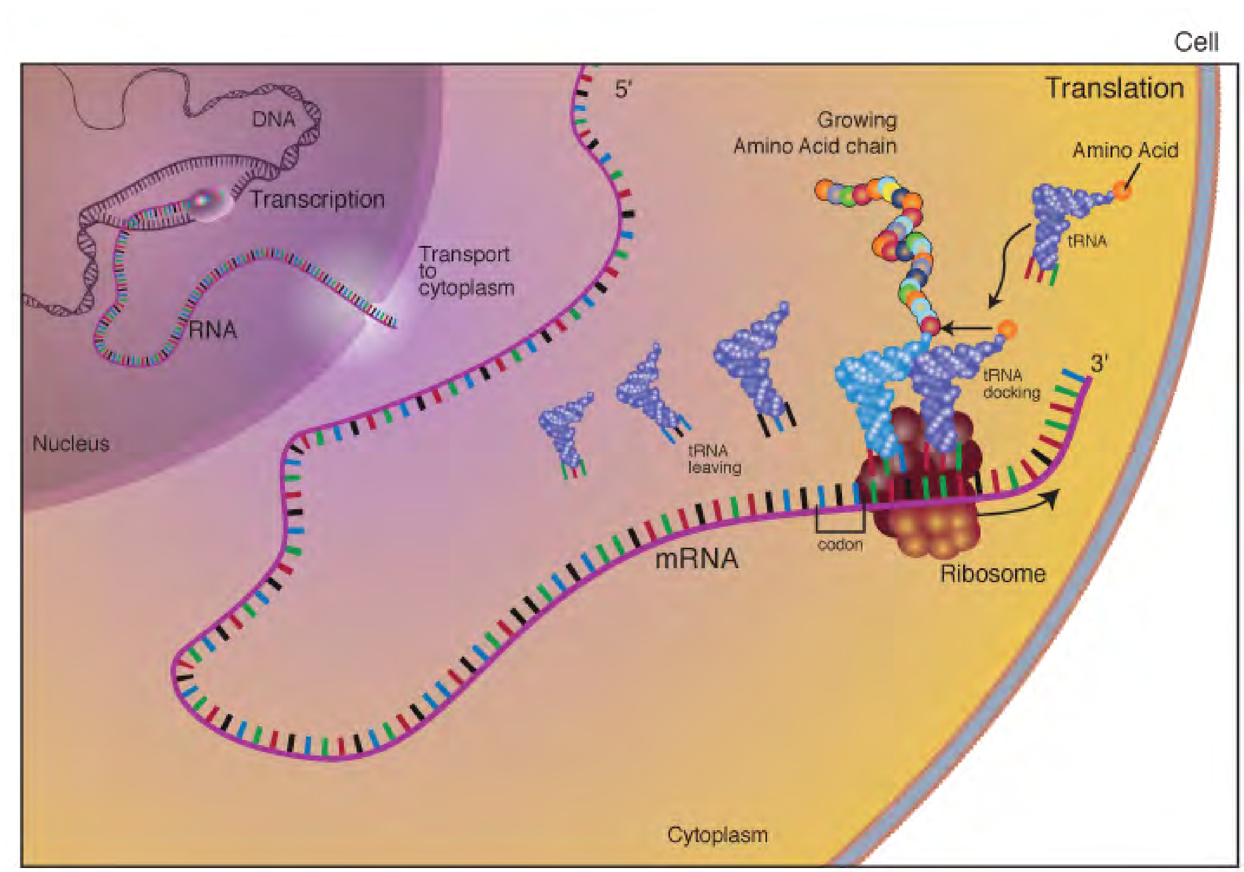


FIGURE 7.9

Translation. Translation of the codons in mRNA to a chain of amino acids occurs at a ribosome. Find the different types of RNA in the diagram. What are their roles in translation

After a polypeptide chain is synthesized, it may undergo additional processes. For example, it may assume a folded shape due to interactions among its amino acids. It may also bind with other polypeptides or with different types of molecules, such as lipids or carbohydrates. Many proteins travel to the Golgi apparatus to be modified for the specific job they will do. You can see how this occurs by watching the animation at this link: http://vcell.ndsu.edu/animations/proteinmodification/movie-flash.htm.

Lesson Summary

- Transcription is the *DNA* $\rightarrow$ *RNA* part of the central dogma of molecular biology. It occurs in the nucleus. During transcription, a copy of mRNA is made that is complementary to a strand of DNA. In eukaryotes, mRNA may be modified before it leaves the nucleus.
- The genetic code consists of the sequence of bases in DNA or RNA. Groups of three bases form codons, and each codon stands for one amino acid (or start or stop). The codons are read in sequence following the start codon until a stop codon is reached. The genetic code is universal, unambiguous, and redundant.
- Translation is the *RNA* $\rightarrow$ *protein* part of the central dogma. It occurs at a ribosome. During translation, a protein is synthesized using the codons in mRNA as a guide. All three types of RNA play a role in translation.

Lesson Review Questions

Recall

1. Describe transcription.

2. How may mRNA be modified before it leaves the nucleus?

3. What is the genetic code? What are codons?

4. Outline the steps of translation.

Apply Concepts

5. Use the genetic code in **Figure** 7.7 to translate the following segment of RNA into a sequence of five amino acids:

GUC-GCG-CAU-AGC-AAG

Think Critically

6. The genetic code is universal, unambiguous, and redundant. Explain what this means and why it is important.

7. How are transcription and translation related to the central dogma of molecular biology?

Points to Consider

When DNA is replicated or transcribed, accidents can happen, leading to a change in the base sequence.

- What do you think could cause such accidents to occur?
- How might the changes affect the reading frame? How might the encoded protein be affected?

7.3 Mutation

Lesson Objectives

- Identify causes of mutation.
- Compare and contrast types of mutations.
- Explain how mutations may affect the organisms in which they occur.

Vocabulary

chromosomal alteration mutation that changes chromosome structure

frameshift mutation deletion or insertion of one or more nucleotides that changes the reading frame of the genetic material

genetic disorder disease caused by a mutation in one or a few genes

germline mutation mutation that occur in gametes

mutagen environmental factors that causes mutations

mutation change in the sequence of bases in DNA or RNA

point mutation change in a single nucleotide base in the genetic material

somatic mutation mutation that occurs in cells of the body other than gametes

Introduction

A change in the sequence of bases in DNA or RNA is called a **mutation**. Does the word mutation make you think of science fiction and bug-eyed monsters? Think again. Everyone has mutations. In fact, most people have dozens or even hundreds of mutations in their DNA. Mutations are essential for evolution to occur. They are the ultimate source of all new genetic material in a species. Although most mutations have no effect on the organisms in which they occur, some mutations are beneficial. Even harmful mutations rarely cause drastic changes in organisms.

Causes of Mutation

Mutations have many possible causes. Some mutations seem to happen spontaneously without any outside influence. They occur when mistakes are made during DNA replication or transcription. Other mutations are caused by environmental factors. Anything in the environment that can cause a mutation is known as a **mutagen**. Examples of mutagens are pictured in **Figure** 7.10 . For a video about mutagens, go the link below. http://www.youtube.com/watch?v=0wrNxCGKCws#38;feature=related (0:36)

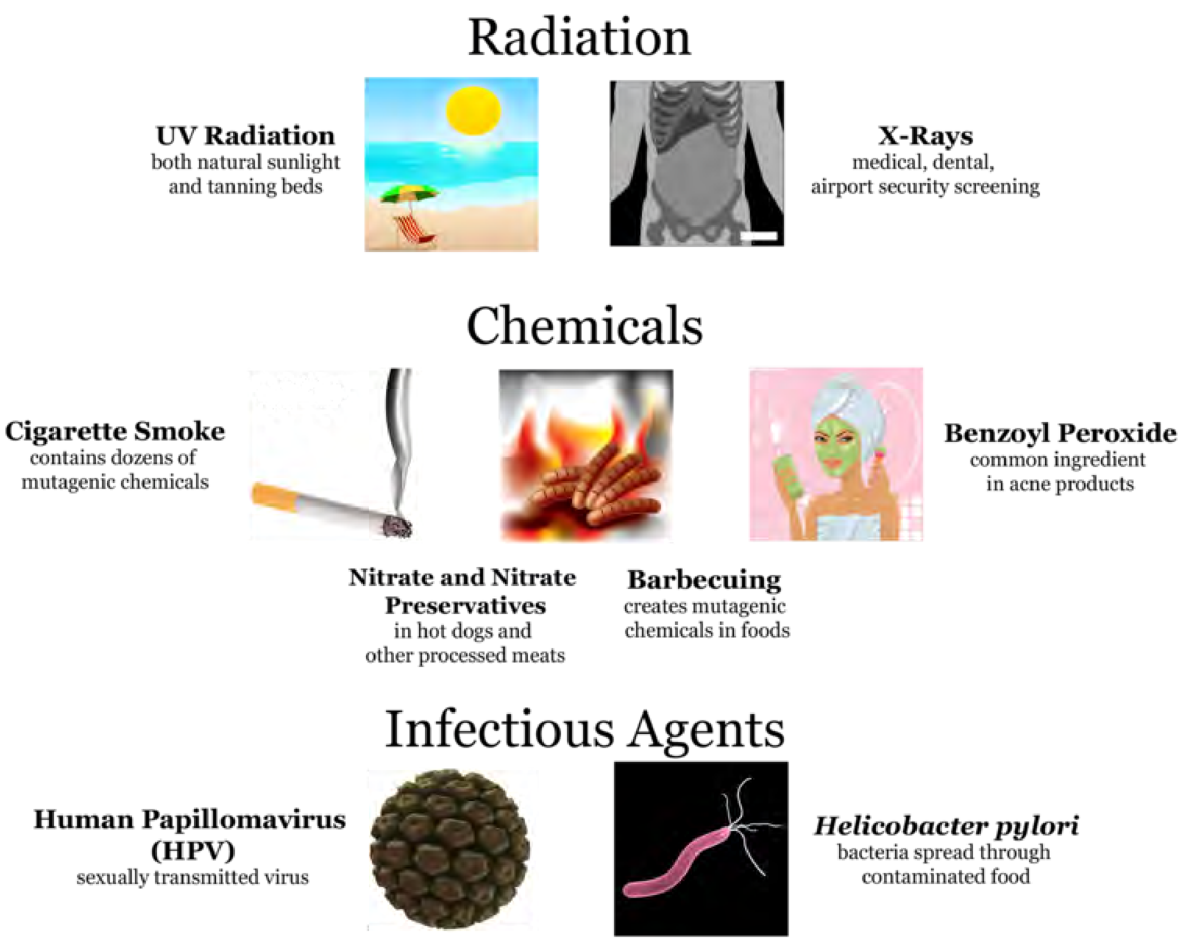


FIGURE 7.10

Examples of Mutagens. Types of mutagens include radiation chemicals and infectious agents. Do you know of other examples of each type of mutagen shown here

Types of Mutations

There are a variety of types of mutations. Two major categories of mutations are germline mutations and somatic mutations.

- **Germline mutations** occur in gametes. These mutations are especially significant because they can be transmitted to offspring and every cell in the offspring will have the mutation.
- **Somatic mutations** occur in other cells of the body. These mutations may have little effect on the organism because they are confined to just one cell and its daughter cells. Somatic mutations cannot be passed on to offspring.

Mutations also differ in the way that the genetic material is changed. Mutations may change the structure of a chromosome or just change a single nucleotide.

Chromosomal Alterations

Chromosomal alterations are mutations that change chromosome structure. They occur when a section of a chromosome breaks off and rejoins incorrectly or does not rejoin at all. Possible ways these mutations can occur are illustrated in **Figure** 7.11 . Go to this link for a video about chromosomal alterations: http://www.youtube.com/watch?v=OrXRSqa_3lU#38;feature=related (2:18).

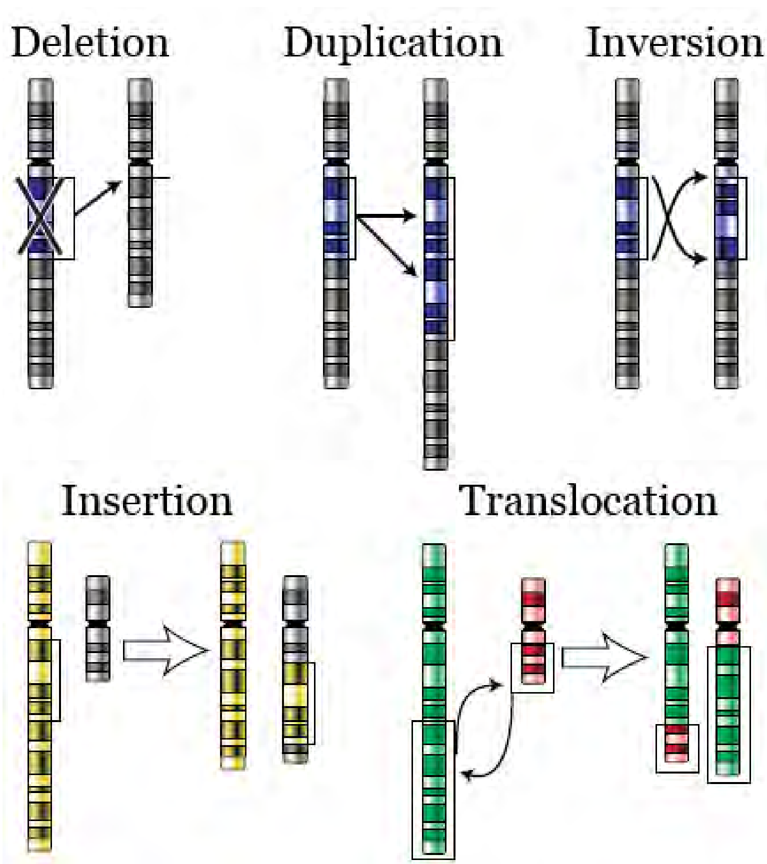


FIGURE 7.11
Chromosomal Alterations. Chromosomal alterations are major changes in the genetic material.

Chromosomal alterations are very serious. They often result in the death of the organism in which they occur. If the organism survives, it may be affected in multiple ways. An example of a human chromosomal alteration is the mutation that causes Down Syndrome. It is a duplication mutation that leads to developmental delays and other abnormalities.

Point Mutations

A **point mutation** is a change in a single nucleotide in DNA. This type of mutation is usually less serious than a chromosomal alteration. An example of a point mutation is a mutation that changes the codon UUU to the codon UCU. Point mutations can be silent, missense, or nonsense mutations, as shown in **Table** 7.1 . The effects of point mutations depend on how they change the genetic code. You can watch an animation about nonsense mutations at this link: http://www.biostudio.com/d_%20Nonsense%20Suppression%20I%20Nonsense%20Mutation.htm.

TABLE 7.1: **Point Mutations and Their Effects**

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) usually	serious

Frameshift Mutations

A **frameshift mutation** is a deletion or insertion of one or more nucleotides that changes the reading frame of the base sequence. Deletions remove nucleotides, and insertions add nucleotides. Consider the following sequence of bases in RNA:

AUG-AAU-ACG-GCU = start-asparagine-threonine-alanine

Now, assume an insertion occurs in this sequence. Let's say an **A** nucleotide is inserted after the start codon **AUG**:

AUG-AAA-UAC-GGC-U = start-lysine-tyrosine-glycine

Even though the rest of the sequence is unchanged, this insertion changes the reading frame and thus all of the codons that follow it. As this example shows, a frameshift mutation can dramatically change how the codons in mRNA are read. This can have a drastic effect on the protein product.

Effects of Mutations

The majority of mutations have neither negative nor positive effects on the organism in which they occur. These mutations are called neutral mutations. Examples include silent point mutations. They are neutral because they do not change the amino acids in the proteins they encode. Many other mutations have no effect on the organism because they are repaired before protein synthesis occurs. Cells have multiple repair mechanisms to fix mutations in DNA. One way DNA can be repaired is illustrated in **Figure** 7.12 . If a cell's DNA is permanently damaged and cannot be repaired, the cell is likely to be prevented from dividing.

Beneficial Mutations

Some mutations have a positive effect on the organism in which they occur. They are called beneficial mutations. They lead to new versions of proteins that help organisms adapt to changes in their environment. Beneficial mutations are essential for evolution to occur. They increase an organism's changes of surviving or reproducing, so they are likely to become more common over time. There are several well-known examples of beneficial mutations. Here are just two:

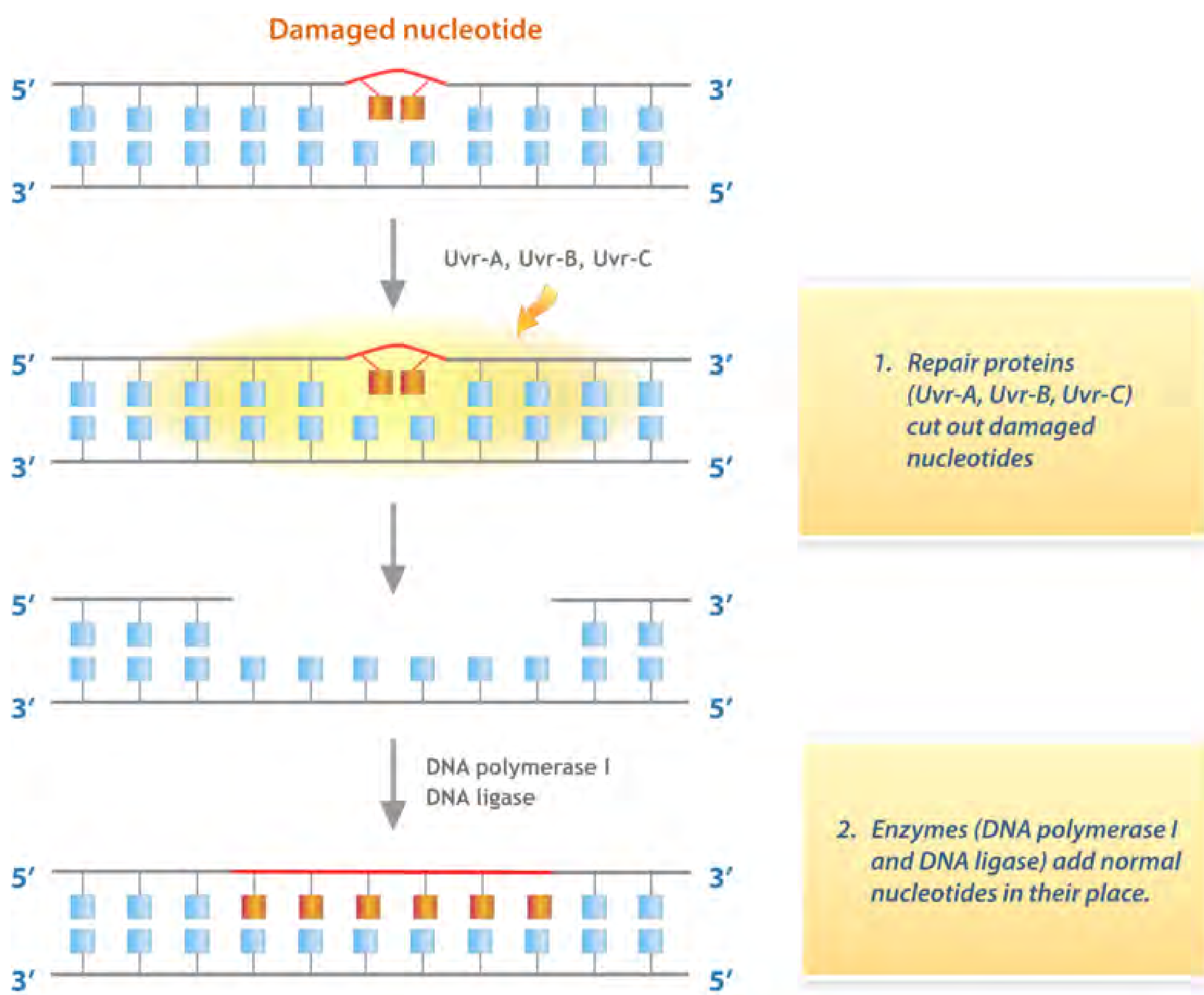


FIGURE 7.12

DNA Repair Pathway. This flow chart shows one way that damaged DNA is repaired in E. coli bacteria.

a. Mutations in many bacteria that allow them to survive in the presence of antibiotic drugs. The mutations lead to antibiotic-resistant strains of bacteria.
b. A unique mutation is found in people in a small town in Italy. The mutation protects them from developing atherosclerosis, which is the dangerous buildup of fatty materials in blood vessels. The individual in which the mutation first appeared has even been identified.

Harmful Mutations

Imagine making a random change in a complicated machine such as a car engine. The chance that the random change would improve the functioning of the car is very small. The change is far more likely to result in a car that does not run well or perhaps does not run at all. By the same token, any random change in a gene's DNA is likely to result in a protein that does not function normally or may not function at all. Such mutations are likely to be harmful. Harmful mutations may cause genetic disorders or cancer.

- A **genetic disorder** is a disease caused by a mutation in one or a few genes. A human example is cystic fibrosis. A mutation in a single gene causes the body to produce thick, sticky mucus that clogs the lungs and blocks ducts in digestive organs. You can watch a video about cystic fibrosis and other genetic disorders at this link: http://www.youtube.com/watch?v=8s4he3wLgkM#38;feature=PlayList#38;p=397710758E9BCB24#38;playnext_from=PL#38;playnext=1#38;index=17 (9:31).

- Cancer is a disease in which cells grow out of control and form abnormal masses of cells. It is generally caused by mutations in genes that regulate the cell cycle. Because of the mutations, cells with damaged DNA are allowed to divide without limits. Cancer genes can be inherited. You can learn more about hereditary cancer by watching the video at the following link: http://www.youtube.com/watch?v=LWk5FplsKwM (4:29)

Lesson Summary

- Mutations are caused by environmental factors known as mutagens. Types of mutagens include radiation, chemicals, and infectious agents.
- Germline mutations occur in gametes. Somatic mutations occur in other body cells. Chromosomal alterations are mutations that change chromosome structure. Point mutations change a single nucleotide. Frameshift mutations are additions or deletions of nucleotides that cause a shift in the reading frame.
- Mutations are essential for evolution to occur because they increase genetic variation and the potential for individuals to differ. The majority of mutations are neutral in their effects on the organisms in which they occur. Beneficial mutations may become more common through natural selection. Harmful mutations may cause genetic disorders or cancer.

Lesson Review Questions

Recall

1. Define mutation and mutagen.

2. List three examples of mutagens.

3. Identify three types of chromosomal alterations.

4. Distinguish among silent, missense, and nonsense point mutations.

5. What is a frameshift mutation? What causes this type of mutation?

Apply Concepts

6. Assume that a point mutation changes the codon AUU to AUC. Why is this a neutral mutation?

7. Look at the mutation shown below. The base A was inserted following the start codon AUG. Describe how this mutation affects the encoded amino acid sequence.

AUG-GUC-CCU-AAA $\rightarrow$ AUG-AGU-CCC-UAA-A

Think Critically

8. Compare and contrast germline mutations and somatic mutations.

9. Why are mutations essential for evolution to occur?

Points to Consider

Sometimes even drastic mutations do not affect the proteins produced by a particular type of cell. The reason? The genes affected by the mutations are not normally used to make proteins in that type of cell. In all cells, some genes are turned off - they are not transcribed - while other genes are turned on.

- How do cells control which genes are turned on and used to make proteins?
- Can you think of a mechanism that might prevent transcription of a gene?

7.4 Regulation of Gene Expression

Lesson Objectives

- Identify general mechanisms that regulate gene expression.
- Describe how gene regulation occurs in prokaryotes.
- Give an overview of gene regulation in eukaryotes.

Vocabulary

gene expression use of a gene to make a protein

homeobox gene gene that codes of regulatory proteins that control gene expression during development

operator a region of an operon where regulatory proteins bind

operon region of prokaryotic DNA that consists of a promoter, an operator, and one or more genes that encode proteins needed for a specific function

regulatory element region of DNA where a regulatory protein binds

regulatory protein protein that regulates gene expression

TATA box regulatory element that is part of the promoter of most eukaryotic genes

Introduction

Each of your cells has at least 20,000 genes. In fact, all of your cells have the same genes. Do all of your cells make the same proteins? Obviously not. If they did, then all your cells would be alike. Instead, you have cells with different structures and functions. This is because different cells make different proteins. They do this by using, or expressing, different genes. Using a gene to make a protein is called **gene expression**.

How Gene Expression is Regulated

Gene expression is regulated to ensure that the correct proteins are made when and where they are needed. Regulation may occur at any point in the expression of a gene, from the start of transcription to the processing of a protein after translation. The focus in this lesson is the regulation of transcription. As shown in **Figure** 7.13 , transcription is controlled by **regulatory proteins**. The proteins bind to regions of DNA, called **regulatory elements**, which are located near promoters. After regulatory proteins bind to regulatory elements, they can interact with RNA polymerase, the enzyme that transcribes DNA to mRNA. Regulatory proteins are typically either activators or repressors.

- Activators promote transcription by enhancing the interaction of RNA polymerase with the promoter.
- Repressors prevent transcription by impeding the progress of RNA polymerase along the DNA strand.

Other factors may also be involved in the regulation of transcription, but these are typically the key players.

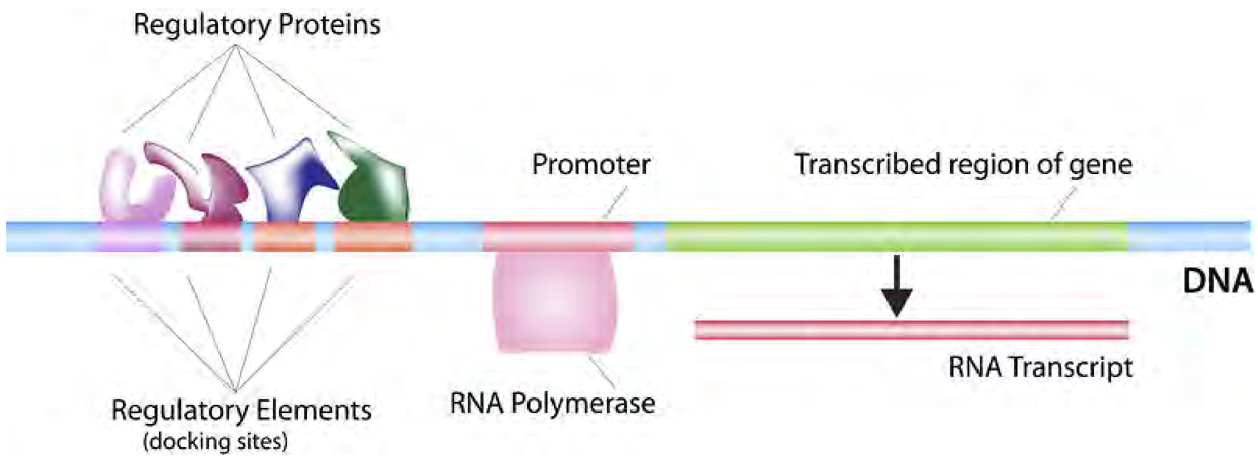


FIGURE 7.13

Regulation of Transcription. Regulatory proteins bind to regulatory elements to control transcription. The regulatory elements are embedded within the DNA.

Prokaryotic Gene Regulation

Transcription is regulated differently in prokaryotes and eukaryotes. In general, prokaryotic regulation is simpler than eukaryotic regulation.

The Role of Operons

Regulation of transcription in prokaryotes typically involves operons. An **operon** is a region of DNA that consists of one or more genes that encode the proteins needed for a specific function. The operon also includes a promoter and an operator. The **operator** is a region of the operon where regulatory proteins bind. It is located near the promoter and helps regulate transcription of the operon genes.

The Lac Operon

A well-known example of operon regulation involves the lac operon in *E. coli* bacteria (see **Figure** 7.14 and the video at the link below). The lac operon consists of a promoter, an operator, and three genes that encode the enzymes needed to digest lactose, the sugar found in milk. The lac operon is regulated by lactose in the environment. http://www.youtube.com/watch?v=oBwtxdI1zvk

- When lactose is absent, a repressor protein binds to the operator. The protein blocks the binding of RNA polymerase to the promoter. As a result, the lac genes are not expressed.
- When lactose is present, the repressor protein does not bind to the operator. This allows RNA polymerase to bind to the promoter and begin transcription. As a result, the lac genes are expressed, and lactose is digested.

Why might it be beneficial to express genes only when they are needed? (Hint: synthesizing proteins requires energy and materials.)

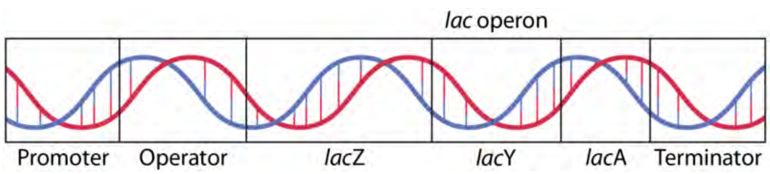


FIGURE 7.14
The three genes of the lac operon are lacZ lacY and lacA. They encode proteins needed to digest lactose. The genes are expressed only in the presence of lactose.

Eukaryotic Gene Regulation

In eukaryotic cells, the start of transcription is one of the most complicated parts of gene regulation. There may be many regulatory proteins and regulatory elements involved. Regulation may also involve enhancers. Enhancers are distant regions of DNA that can loop back to interact with a gene's promoter.

The TATA Box

Different types of cells have unique patterns of regulatory elements that result in only the necessary genes being transcribed. That's why a skin cell and nerve cell, for example, are so different from each other. However, some patterns of regulatory elements are common to all genes, regardless of the cells in which they occur. An example is the **TATA box**. This is a regulatory element that is part of the promoter of most eukaryotic genes. A number of regulatory proteins bind to the TATA box, forming a multi-protein complex. It is only when all of the appropriate proteins are bound to the TATA box that RNA polymerase recognizes the complex and binds to the promoter. Once RNA polymerase binds, transcription begins. To see a video showing the role of the TATA box in the initiation of transcription, go to this link: http://www.youtube.com/watch?v=6tqPsI-9aQA#38;feature=related.

Regulation During Development

The regulation of gene expression is extremely important during the development of an organism. Regulatory proteins must turn on certain genes in particular cells at just the right time so the organism develops normal organs and organ systems. **Homeobox genes** are an example of genes that regulate development. They code for regulatory proteins that switch on whole series of major developmental genes. In insects, homeobox genes called hox genes ensure that body parts such as limbs develop in the correct place. **Figure** 7.15 shows how a mutation in a hox gene can affect an insect's development. You can learn more about homeobox genes at this link: http://www.youtube.com/watch?v=LFG-aLidT8s.

FIGURE 7.15
Effect of Hox Gene Mutation. Scientists caused a mutation in a hox gene of this fruit fly. As a result of the mutation a leg grew out of its head where an antenna should have developed.

Gene Expression and Cancer

The mutations that cause cancer generally occur in two types of regulatory genes: tumor-suppressor genes and proto-oncogenes (see **Figure** 7.16). These genes produce regulatory proteins that control the cell cycle. When the genes mutate, cells with mutations divide rapidly and without limits.

Lesson Summary

- Gene transcription is controlled by regulatory proteins that bind to regulatory elements on DNA. The proteins usually either activate or repress transcription.
- Regulation of transcription in prokaryotes typically involves an operon, such as the lac operon in *E. coli*. The lac operon is regulated by proteins that behave differently depending on whether lactose is present.
- Regulation of transcription in eukaryotes is generally more complex. It involves unique regulatory elements in different cells as well as common regulatory elements such as the TATA box. Regulation is especially important during development. It may involve regulatory genes such as homeobox genes that switch other regulatory genes on or off. Mutations in regulatory genes that normally control the cell cycle cause cancer.

Lesson Review Questions

Recall

1. What is gene expression?

2. Describe how regulatory proteins regulate gene expression.

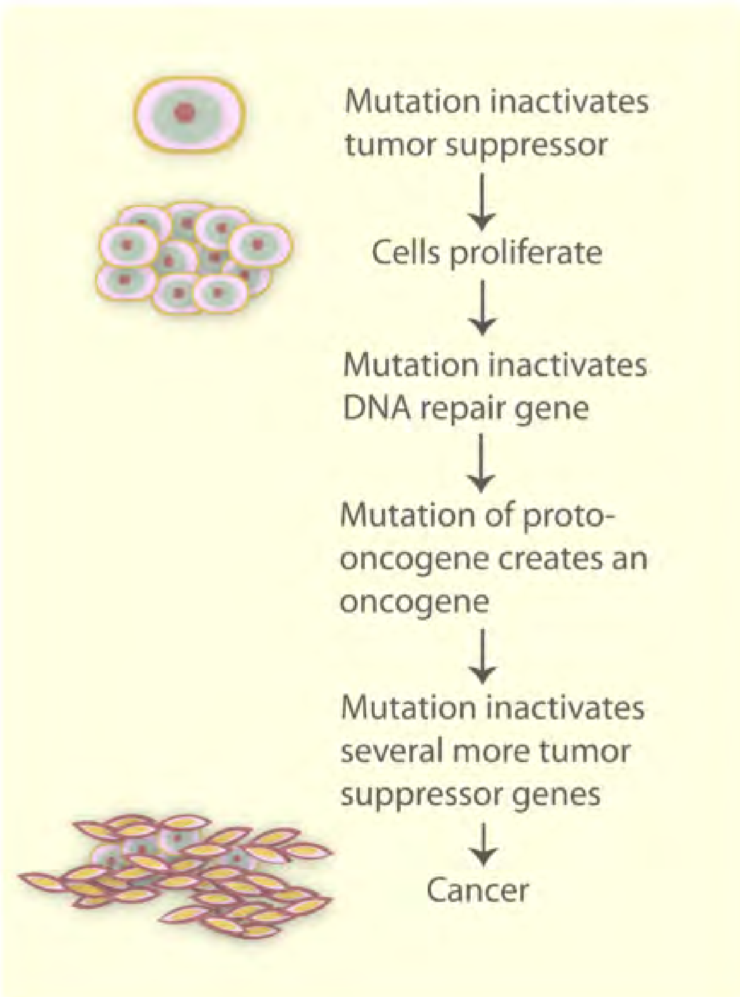


FIGURE 7.16

How Cancer Develops. This flow chart shows how a series of mutations in tumor-suppressor genes and proto-oncogenes leads to cancer.

3. Identify the TATA box and its function in transcription.
4. What is a homeobox gene?

Apply Concepts

5. Draw a diagram to show how the lac operon is regulated.
6. Sketch how an insect with a mutated hox gene might look. Explain your sketch.

Think Critically

7. Why is gene regulation especially important during development?

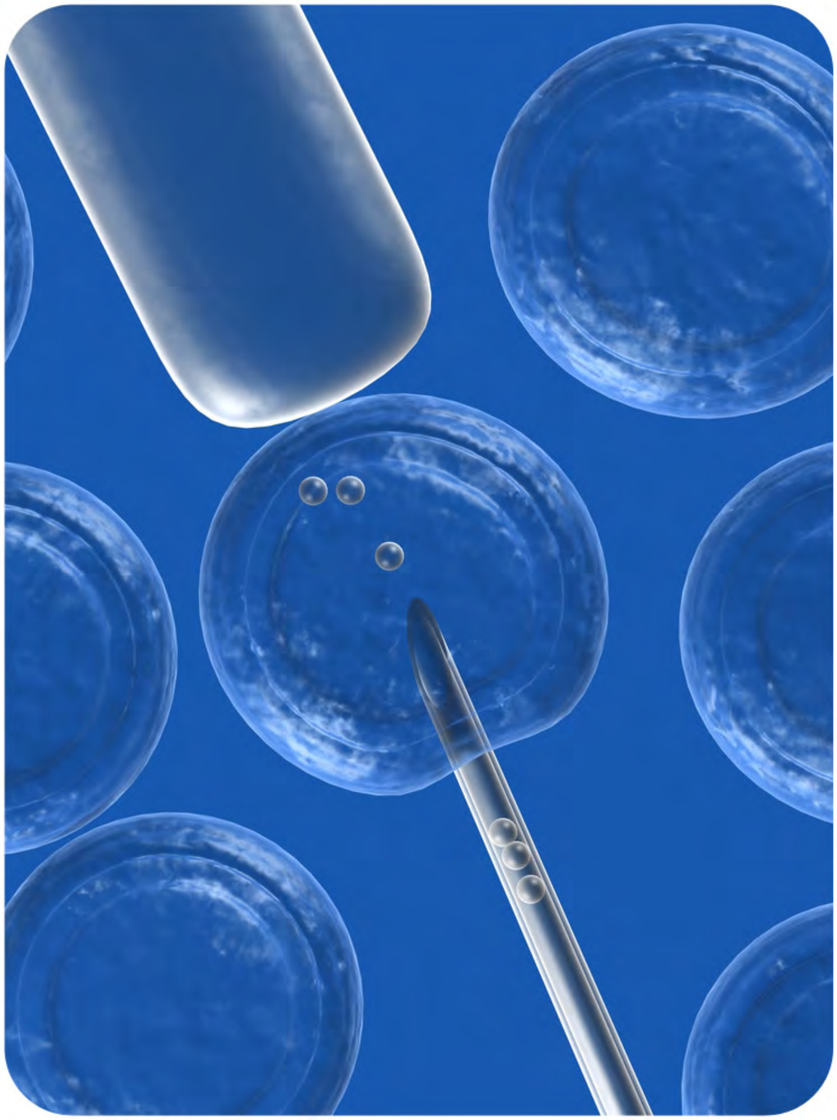
Points to Consider

Scientists know more about human chromosomes and genes than they know about the genetic material of most other species. In fact, scientists have identified all of the approximately 20,000-25,000 genes in human DNA.

- What do you know about human chromosomes and genes? For example, do you know how many chromosomes humans normally have?
- Do you know how human characteristics are inherited? Can you identify characteristics that are controlled by a single gene?

CHAPTER 8 Human Genetics and Biotechnology

CHAPTER OUTLINE



Biotechnology. Gene Therapy. Reality or fiction? During your lifetime, gene therapy may be mainstream medicine. Here we see a representation of the insertion of DNA into the nucleus of a cell. Is this possible? Yes. In this chapter, you will learn how human chromosomes and genes are inherited and how they control the traits that make each of us unique, how they can cause disease, and how those diseases can be treated.

8.1 Human Chromosomes and Genes

Lesson Objective

- Define the human genome.
- Describe human chromosomes and genes.
- Explain linkage and linkage maps.

Vocabulary

autosome chromosomes 1–22 in humans that contain genes for characteristics unrelated to sex

human genome all of the DNA of the human species

Human Genome Project international science project that sequenced all 3 billion base pairs of the human genome

linkage map map that shows the positions of genes on a chromosome based on the frequency of crossing-over between the genes

linked genes genes that are located on the same chromosome

sex chromosome X or Y chromosome (in humans)

sex-linked gene gene located on a sex chromosome

X-linked gene gene located on the X chromosome

Introduction

Nobody else in the world is exactly like you. What makes you different from everyone else? Genes have a lot to do with it. Unless you have an identical twin, no one else on Earth has exactly the same genes as you. What about identical twins? Are they identical in every way? They develop from the same fertilized egg, so they have all same genes, but even they are not completely identical. Why? The environment also influences human characteristics, and no two people have exactly the same environment.

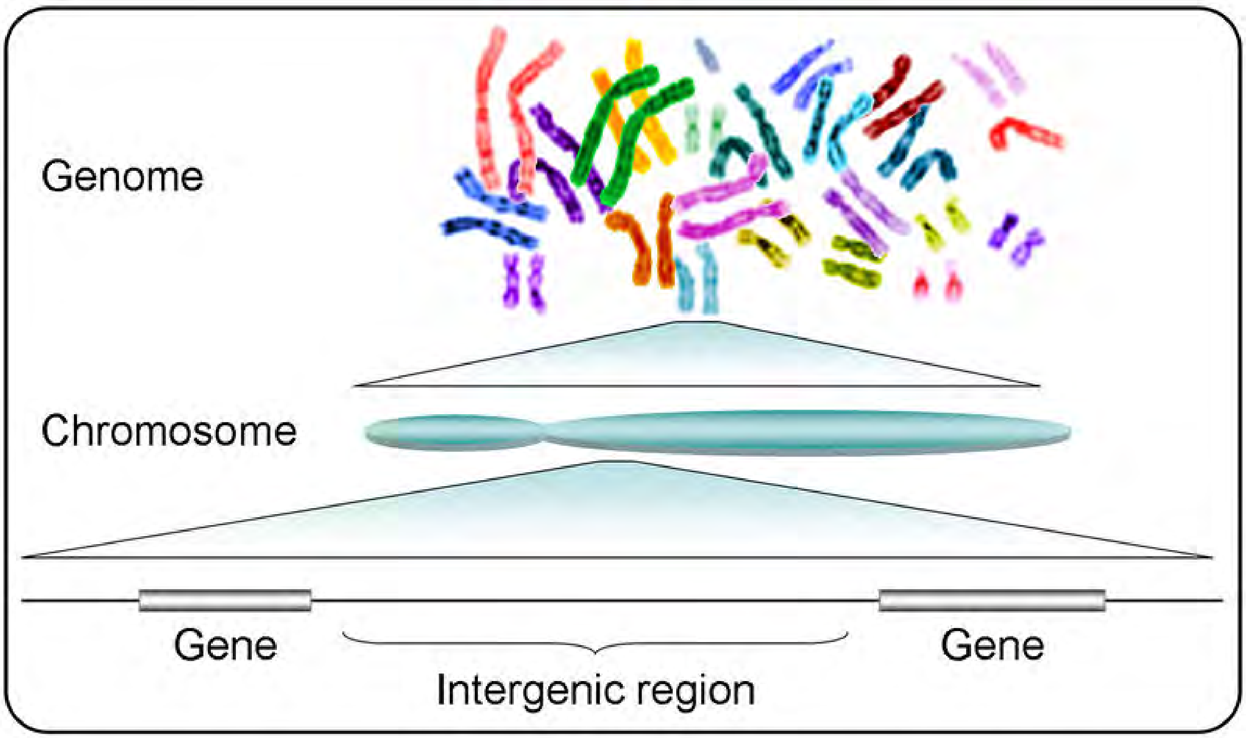


FIGURE 8.1

Human Genome Chromosomes and Genes. Each chromosome of the human genome contains many genes as well as noncoding intergenic *between genes* regions. Each pair of chromosomes is shown here in a different color.

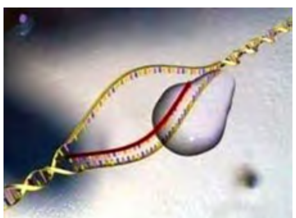
The Human Genome

All the DNA of the human species makes up the **human genome**. This DNA consists of about 3 billion base pairs and is divided into thousands of genes on 23 pairs of chromosomes. The human genome also includes noncoding sequences of DNA, as shown in **Figure** 8.1 .

Thanks to the **Human Genome Project**, scientists now know the DNA sequence of the entire human genome. The Human Genome Project is an international project that includes scientists from around the world. It began in 1990, and by 2003, scientists had sequenced all 3 billion base pairs of human DNA. Now they are trying to identify all the genes in the sequence.

You can watch a video about the Human Genome Project and how it cracked the *code of life* at this link: http://www.pbs.org/wgbh/nova/genome/program.html.

Our Molecular Selves video discusses the human genome, and is available at http://www.genome.gov/25520211 or http://www.youtube.com/watch?v=XuUpnAz5y1g#38;feature=related.



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Chromosomes and Genes

Each species has a characteristic number of chromosomes. The human species is characterized by 23 pairs of chromosomes, as shown in **Figure** 8.2 and **Figure** 8.3 . You can watch a short animation about human chromosomes at this link: http://www.dnalc.org/view/15520-DNA-is-organized-into-46-chromosomes-including-sex-chromosomes-3D-animation.html.

Autosomes

Of the 23 pairs of human chromosomes, 22 pairs are autosomes (numbers 1–22 in **Figure** 8.3). **Autosomes** are chromosomes that contain genes for characteristics that are unrelated to sex. These chromosomes are the same in males and females. The great majority of human genes are located on autosomes. At the link below, you can click on any human chromosome to see which traits its genes control. http://www.ornl.gov/sci/techresources/Human_Genome/posters/chromosome/chooser.shtml

Sex Chromosomes

The remaining pair of human chromosomes consists of the **sex chromosomes**, X and Y. Females have two X chromosomes, and males have one X and one Y chromosome. In females, one of the X chromosomes in each cell is inactivated and known as a Barr body. This ensures that females, like males, have only one functioning copy of the X chromosome in each cell. As you can see from **Figure** 8.2 and **Figure** 8.3 , the X chromosome is much larger than the Y chromosome. The X chromosome has about 2,000 genes, whereas the Y chromosome has fewer than 100, none of which are essential to survival. Virtually all of the X chromosome genes are unrelated to sex. Only the Y chromosome contains genes that determine sex. A single Y chromosome gene, called SRY (which stands for

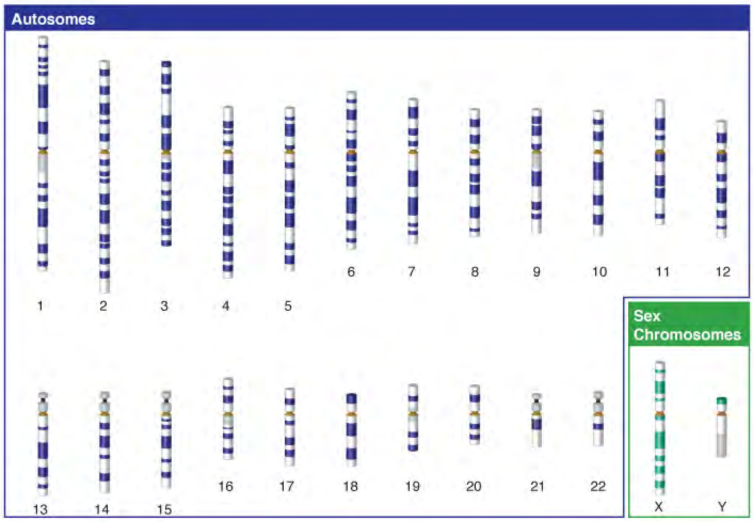


FIGURE 8.2

Human Chromosomes. Human chromosomes are shown here arranged by size. Chromosome 1 is the largest and chromosome 22 is the smallest. All normal human cells *except gametes* have two of each chromosome for a total of 46 chromosomes per cell. Only one of each pair is shown here.

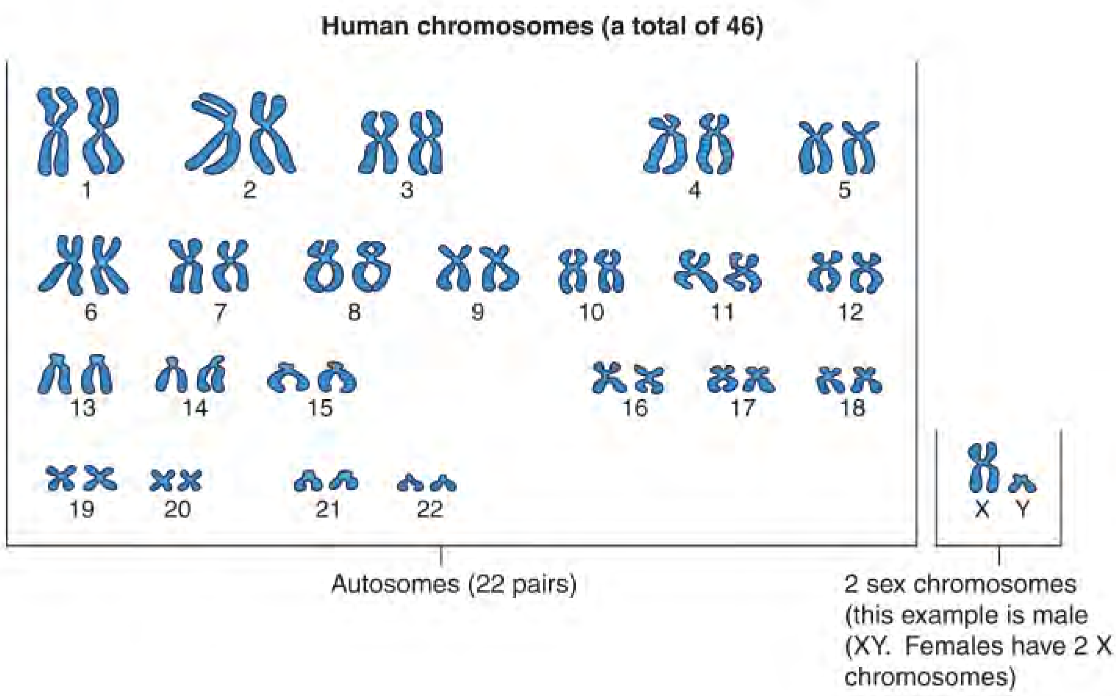


FIGURE 8.3

Human Chromosomes. Humans have 23 pairs of chromosomes. Pairs 1-22 are autosomes. Females have two X chromosomes and males have an X and a Y chromosome.

sex-determining region Y gene), triggers an embryo to develop into a male. Without a Y chromosome, an individual develops into a female, so you can think of female as the default sex of the human species. Can you think of a reason why the Y chromosome is so much smaller than the X chromosome? At the link that follows, you can watch an animation that explains why: http://www.hhmi.org/biointeractive/gender/Y_evolution.html.

Human Genes

Humans have an estimated 20,000 to 22,000 genes. This may sound like a lot, but it really isn't. Far simpler species have almost as many genes as humans. However, human cells use splicing and other processes to make multiple proteins from the instructions encoded in a single gene. Of the 3 billion base pairs in the human genome, only about 25 percent make up genes and their regulatory elements. The functions of many of the other base pairs are still unclear. To learn more about the coding and noncoding sequences of human DNA, watch the animation at this link: http://www.hhmi.org/biointeractive/dna/DNAi_coding_sequences.html.

The majority of human genes have two or more possible alleles. Differences in alleles account for the considerable genetic variation among people. In fact, most human genetic variation is the result of differences in individual DNA bases within alleles.

Linkage

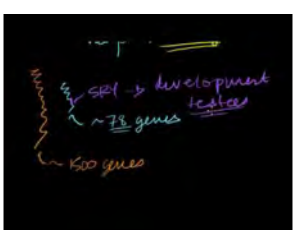
Genes that are located on the same chromosome are called **linked genes**. Alleles for these genes tend to segregate together during meiosis, unless they are separated by crossing-over. Crossing-over occurs when two homologous chromosomes exchange genetic material during meiosis I. The closer together two genes are on a chromosome, the less likely their alleles will be separated by crossing-over. At the following link, you can watch an animation showing how genes on the same chromosome may be separated by crossing-over: http://www.biostudio.com/d_%20Meiotic%20Recombination%20Between%20Linked%20Genes.htm.

Linkage explains why certain characteristics are frequently inherited together. For example, genes for hair color and eye color are linked, so certain hair and eye colors tend to be inherited together, such as blonde hair with blue eyes and brown hair with brown eyes. What other human traits seem to occur together? Do you think they might be controlled by linked genes?

Sex-Linked Genes

Genes located on the sex chromosomes are called **sex-linked genes**. Most sex-linked genes are on the X chromosome, because the Y chromosome has relatively few genes. Strictly speaking, genes on the X chromosome are **X-linked genes**, but the term sex-linked is often used to refer to them.

Sex-linked traits are discussed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/15/-ROhfKyxgCo (14:19).



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Mapping Linkage

Linkage can be assessed by determining how often crossing-over occurs between two genes on the same chromosome. Genes on different (nonhomologous) chromosomes are not linked. They assort independently during meiosis, so they have a 50 percent chance of ending up in different gametes. If genes show up in different gametes less than 50 percent of the time (that is, they tend to be inherited together), they are assumed to be on the same (homologous) chromosome. They may be separated by crossing-over, but this is likely to occur less than 50 percent of the time. The lower the frequency of crossing-over, the closer together on the same chromosome the genes are presumed to be. Frequencies of crossing-over can be used to construct a linkage map like the one in **Figure** 8.4 . A **linkage map** shows the locations of genes on a chromosome.

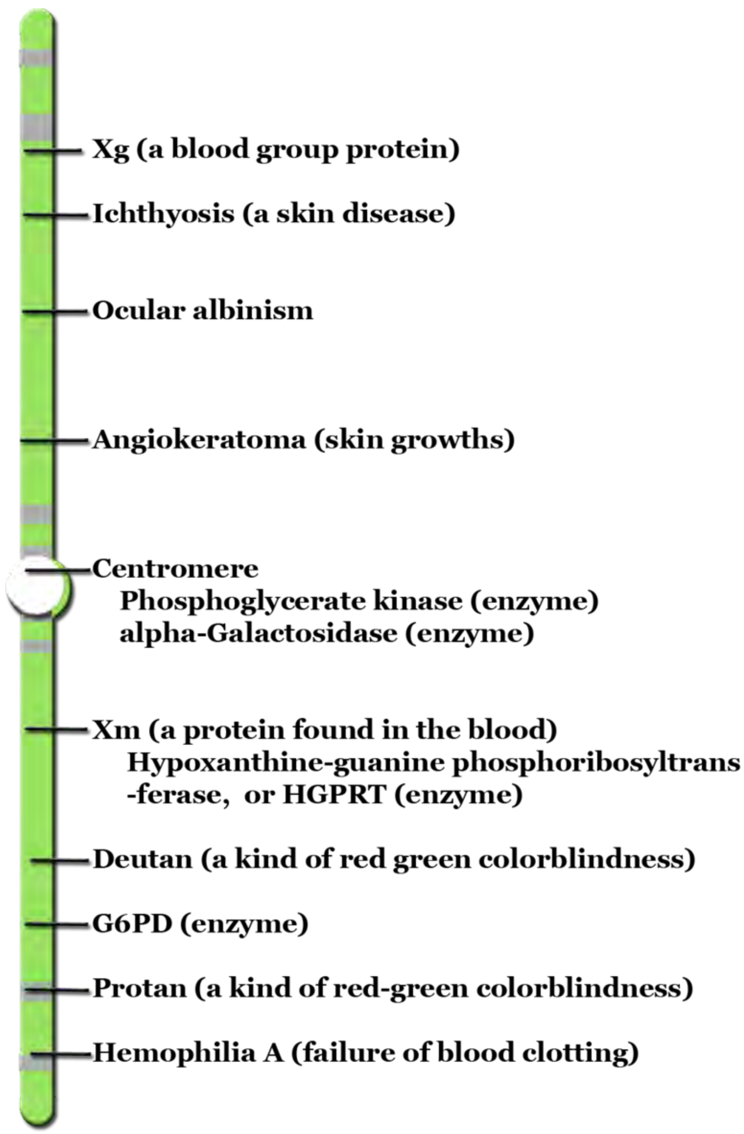


FIGURE 8.4

Linkage Map for the Human X Chromosome. This linkage map shows the locations of several genes on the X chromosome. Some of the genes code for normal proteins. Others code for abnormal proteins that lead to genetic disorders. Which pair of genes would you expect to have a lower frequency of crossing-over the genes that code for hemophilia A and G6PD deficiency or the genes that code for protan and Xm

Lesson Summary

- The human genome consists of about 3 billion base pairs of DNA. In 2003, the Human Genome Project finished sequencing all 3 billion base pairs.
- Humans have 23 pairs of chromosomes. Of these, 22 pairs are autosomes. The X and Y chromosomes are the sex chromosomes. Females have two X chromosomes, and males have one X and one Y. Human chromosomes contain a total of 20,000 to 22,000 genes, the majority of which have two or more alleles.
- Linked genes are located on the same chromosome. Sex-linked genes are located on a sex chromosome, and X-linked genes are located on the X chromosome. The frequency of crossing-over between genes is used to construct linkage maps that show the locations of genes on chromosomes.

Lesson Review Questions

Recall

1. Describe the human genome.
2. What has the Human Genome Project achieved?
3. What are linked genes?
4. Describe human genetic variation.

Apply Concepts

5. Explain how you would construct a linkage map for a human chromosome. What data would you need?

Think Critically

6. Compare and contrast human autosomes and sex chromosomes.
7. People with red hair usually have very light skin. What might be a genetic explanation for this observation?

Multimedia resources

Points to Consider

You read in this lesson about the chromosomes and genes that control human traits. Most traits are controlled by genes on autosomes, but many are controlled by genes on the X chromosome.

- Do you think it matters whether a gene is on an autosome or the X chromosome when it comes to how it is inherited?
- How do mothers and fathers pass their sex chromosomes to their sons and daughters? Their autosomes?

8.2 Human Inheritance

Lesson Objectives

- Describe inheritance in humans for autosomal and X-linked traits.
- Identify complex modes of human inheritance.
- Describe genetic disorders caused by mutations or abnormal numbers of chromosomes.

Vocabulary

epistasis situation in which one gene affects the expression of another gene

gene therapy way to cure genetic disorders by inserting normal genes into cells with mutant genes

genetic trait characteristic that is encoded in DNA

multiple allele trait trait controlled by one gene with more than two alleles

nondisjunction failure of replicated chromosomes to separate during meiosis II, resulting in some gametes with a missing chromosome and some with an extra chromosome

pedigree chart showing how a trait is passed from generation to generation within a family

pleiotropy situation in which a single gene affects more than one trait

sex-linked trait traits controlled by a gene located on a sex chromosome

X-linked trait trait controlled by a gene located on the X chromosome

Introduction

Characteristics that are encoded in DNA are called **genetic traits**. Different types of human traits are inherited in different ways. Some human traits have simple inheritance patterns like the traits that Gregor Mendel studied in pea plants. Other human traits have more complex inheritance patterns.

Mendelian Inheritance in Humans

Mendelian inheritance refers to the inheritance of traits controlled by a single gene with two alleles, one of which may be dominant to the other. Not many human traits are controlled by a single gene with two alleles, but they are a good starting point for understanding human heredity. How Mendelian traits are inherited depends on whether the traits are controlled by genes on autosomes or the X chromosome.

Autosomal Traits

Autosomal traits are controlled by genes on one of the 22 human autosomes. Consider earlobe attachment. A single autosomal gene with two alleles determines whether you have attached earlobes or free-hanging earlobes. The allele for free-hanging earlobes (F) is dominant to the allele for attached earlobes (f). Other single-gene autosomal traits include widow's peak and hitchhiker's thumb. The dominant and recessive forms of these traits are shown in **Figure** 8.5 . Which form of these traits do you have? What are your possible genotypes for the traits? The chart in **Figure** 8.5 is called a **pedigree**. It shows how the earlobe trait was passed from generation to generation within a family. Pedigrees are useful tools for studying inheritance patterns.

You can watch a video explaining how pedigrees are used and what they reveal at this link: http://www.youtube.com/watch?v=HbIHjsn5cHo.

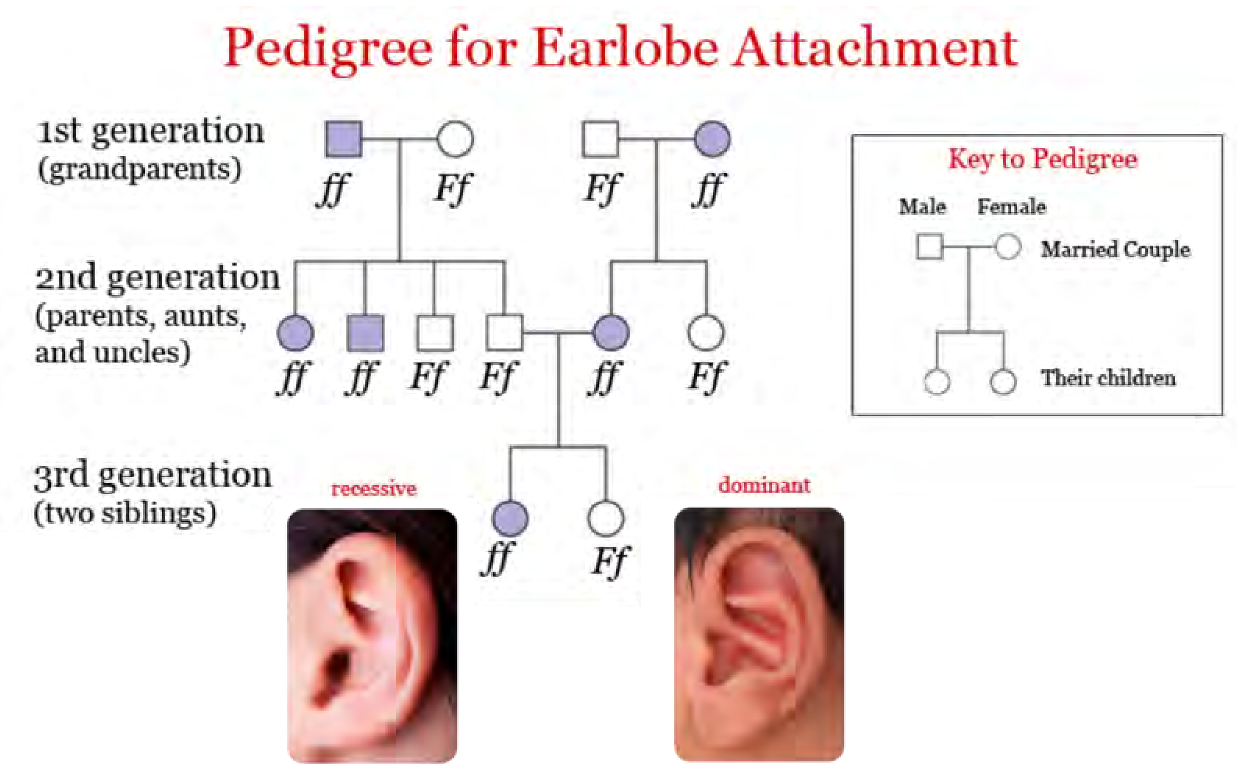


FIGURE 8.5

Having free-hanging earlobes is an autosomal dominant trait. This figure shows the trait and how it was inherited in a family over three generations. Shading indicates people who have the recessive form of the trait. Look at *or feel* your own earlobes. Which form of the trait do you have Can you tell which genotype you have

Other single-gene autosomal traits include widow's peak and hitchhiker's thumb. The dominant and recessive forms of these traits are shown in **Figure** 8.6 . Which form of these traits do you have? What are your possible genotypes for the traits?

Sex-Linked Traits

Traits controlled by genes on the sex chromosomes are called **sex-linked traits**, or **X-linked traits** in the case of the X chromosome. Single-gene X-linked traits have a different pattern of inheritance than single-gene autosomal

FIGURE 8.6
Widowś peak and hitchhikerś thumb are dominant traits controlled by a single autosomal gene.

traits. Do you know why? It's because males have just one X chromosome. In addition, they always inherit their X chromosome from their mother, and they pass it on to all their daughters but none of their sons. This is illustrated in **Figure** 8.7 .

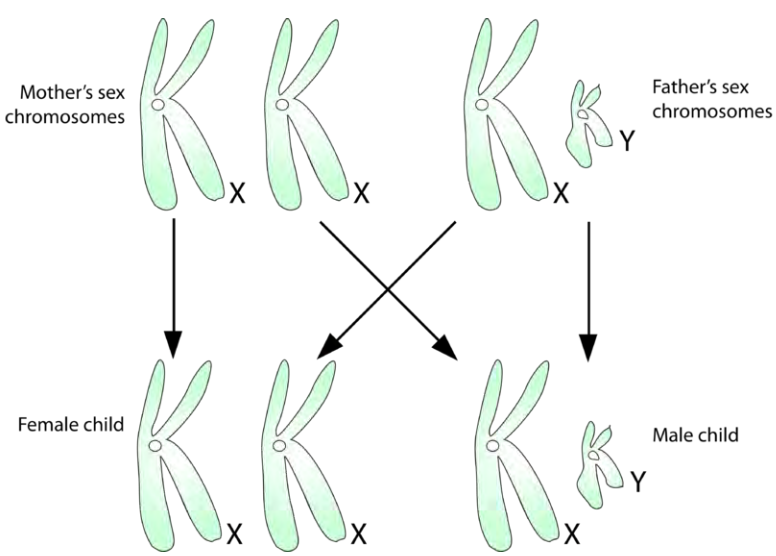


FIGURE 8.7
Inheritance of Sex Chromosomes. Mothers pass only X chromosomes to their children. Fathers always pass their X chromosome to their daughters and their Y chromosome to their sons. Can you explain why fathers always determine the sex of the offspring

Because males have just one X chromosome, they have only one allele for any X-linked trait. Therefore, a recessive X-linked allele is always expressed in males. Because females have two X chromosomes, they have two alleles for any X-linked trait. Therefore, they must inherit two copies of the recessive allele to express the recessive trait. This explains why X-linked recessive traits are less common in females than males. An example of a recessive X-linked trait is red-green color blindness. People with this trait cannot distinguish between the colors red and green. More than one recessive gene on the X chromosome codes for this trait, which is fairly common in males but relatively rare in females (**Figure** 8.8). At the link below, you can watch an animation about another X-linked recessive trait called hemophilia A. http://www.dnalc.org/view/16315-Animation-13-Mendelian-laws-apply-to-human-beings-.html

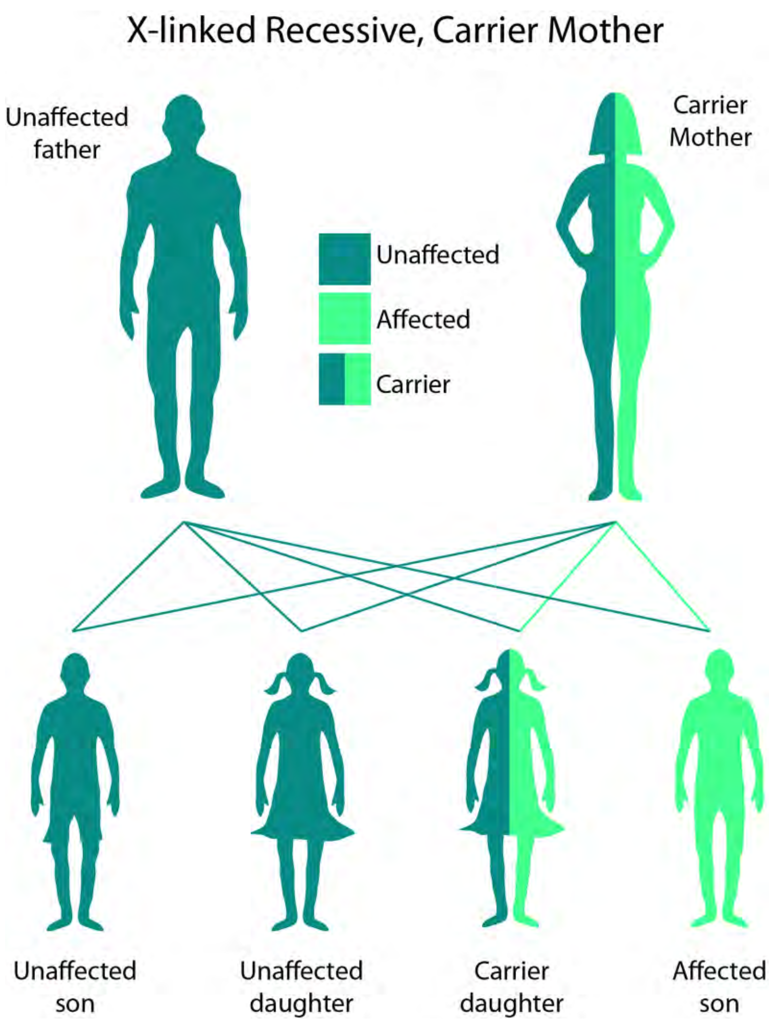
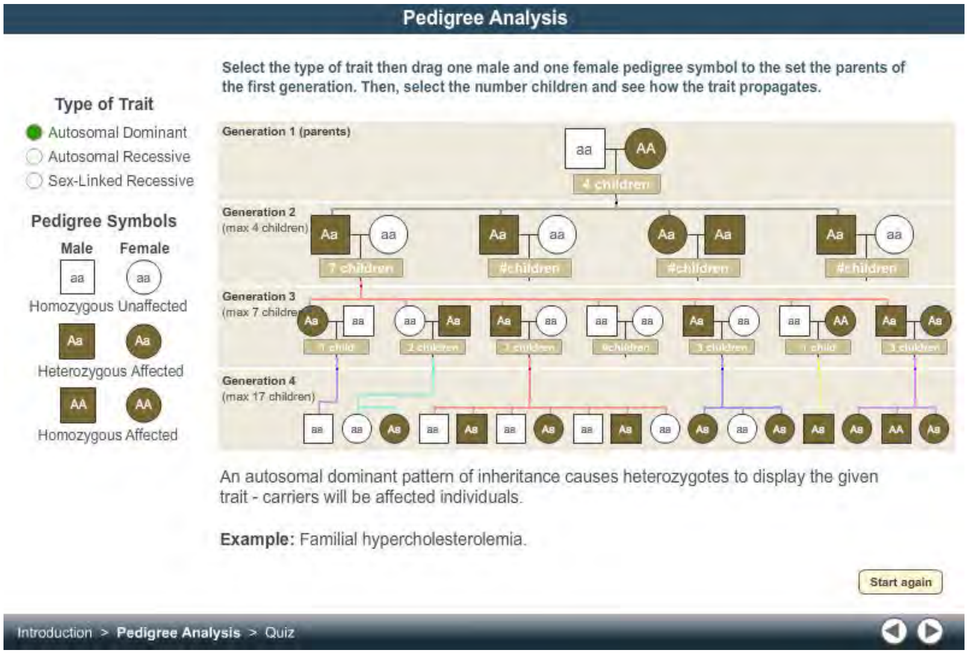


FIGURE 8.8
Pedigree for Color Blindness. Color blindness is an X-linked recessive trait. Mothers pass the recessive allele for the trait to their sons who pass it to their daughters.

Pedigree Analysis Activity

The following link is to a pedigree analysis activity. Autosomal dominant, autosomal recessive and sex-linked recessive inheritance is explored through an interactive activity. http://authors.ck12.org/wiki/images/9/91/Pedigree.swf



Non-Mendelian Inheritance

Most human traits have more complex modes of inheritance than simple Mendelian inheritance. For example, the traits may be controlled by multiple alleles or multiple genes.

Multiple Allele Traits

The majority of human genes are thought to have more than two alleles. Traits controlled by a single gene with more than two alleles are called **multiple allele traits**. An example is ABO blood type. There are three common alleles for this trait, which can be represented by the letters A, B, and O. As shown in **Table** 8.1 , there are six possible ABO genotypes but only four phenotypes. This is because alleles A and B are codominant to each other and both are dominant to O. You can learn more about ABO blood type by watching the video at this link: http://www.youtube.com/watch?v=oz4Ctau8mC8 (13:15).

TABLE 8.1: ABO Blood Type

Genotype	Phenotype
AA	A
AO	A
AB	AB
BB	B
BO	B
OO	O

Polygenic Traits

Many human traits are controlled by more than one gene. These traits are called polygenic traits (or characteristics). The alleles of each gene have a minor additive effect on the phenotype. There are many possible combinations of alleles, especially if each gene has multiple alleles. Therefore, a whole continuum of phenotypes is possible. An example of a human polygenic trait is adult height. Several genes, each with more than one allele, contribute to this trait, so there are many possible adult heights. For example, one adult's height might be 1.655 m (5.430 feet), and another adult's height might be 1.656 m (5.433 feet) tall. Adult height ranges from less than 5 feet to more than 6 feet, but the majority of people fall near the middle of the range, as shown in **Figure** 8.9 .

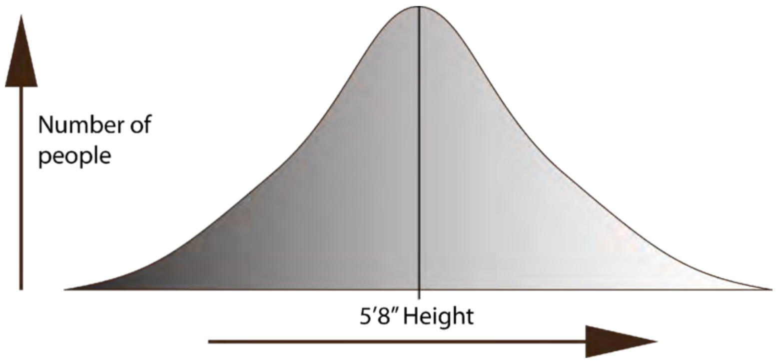


FIGURE 8.9
Human Adult Height. Like many other polygenic traits adult height has a bell-shaped distribution.

Many polygenic traits are affected by the environment. For example, adult height might be negatively impacted by poor diet or illness during childhood. Skin color is another polygenic trait. There is a wide range of skin colors in people worldwide. In addition to differences in skin color genes, differences in exposure to UV light explain most of the variation. As shown in **Figure** 8.10 , exposure to UV light darkens the skin.

FIGURE 8.10
Effects of UV Light on Skin Color. This picture shows clearly how exposure to UV light can affect skin color. UV light causes skin cells to produce more of a brown pigment called melanin which makes skin darker.

Pleiotropy

Sometimes a single gene may affect more than one trait. This is called **pleiotropy**. An example is the gene that codes for the main protein in collagen, a substance that helps form bones. The gene for this protein also affects the ears and eyes. This was discovered from mutations in the gene. They result in problems not only in bones but also in these sensory organs.

Epistasis

In other cases, one gene affects the expression of another gene. This is called **epistasis**. Epistasis is similar to dominance, except that it occurs between different genes rather than between different alleles for the same gene. An example is the gene coding for widow's peak. A gene that codes for baldness would "hide" the widow's peak trait if it occurred in the same person.

Genetic Disorders

Many genetic disorders are caused by mutations in one or a few genes. Other genetic disorders are caused by abnormal numbers of chromosomes.

Genetic Disorders Caused by Mutations

Table 8.2 lists several genetic disorders caused by mutations in just one gene. Some of the disorders are caused by mutations in autosomal genes, others by mutations in X-linked genes. Which disorder would you expect to be more common in males than females? You can watch a video about genetic disorders caused by mutations at this link: http://www.pbs.org/wgbh/nova/programs/ht/rv/2809_03.html.

You can click on any human chromosome at this link to see the genetic disorders associated with it: http://www.ornl.gov/sci/techresources/Human_Genome/posters/chromosome/chooser.shtml.

TABLE 8.2: Genetic Disorders Caused by Mutations

Genetic Disorder	Direct Effect of Mutation	Signs and Symptoms of the Disorder	Mode of Inheritance
Marfan syndrome	defective protein in connective tissue	heart and bone defects and unusually long, slender limbs and fingers	autosomal dominant
Sickle cell anemia	abnormal hemoglobin protein in red blood cells	sickle-shaped red blood cells that clog tiny blood vessels, causing pain and damaging organs and joints	autosomal recessive
Vitamin D-resistant rickets	lack of a substance needed for bones to absorb minerals	soft bones that easily become deformed, leading to bowed legs and other skeletal deformities	X-linked dominant
Hemophilia A	reduced activity of a protein needed for blood clotting	internal and external bleeding that occurs easily and is difficult to control	X-linked recessive

|+Genetic Disorders Caused by Mutations

Few genetic disorders are controlled by dominant alleles. A mutant dominant allele is expressed in every individual who inherits even one copy of it. If it causes a serious disorder, affected people may die young and fail to reproduce. Therefore, the mutant dominant allele is likely to die out of the population. A mutant recessive allele, such as the allele that causes sickle cell anemia (see **Figure** 8.11 and the link that follows), is not expressed in people who inherit just one copy of it. These people are called carriers. They do not have the disorder themselves, but they carry the mutant allele and can pass it to their offspring. Thus, the allele is likely to pass on to the next generation rather than die out. http://www.dnalc.org/resources/3d/17-sickle-cell.html

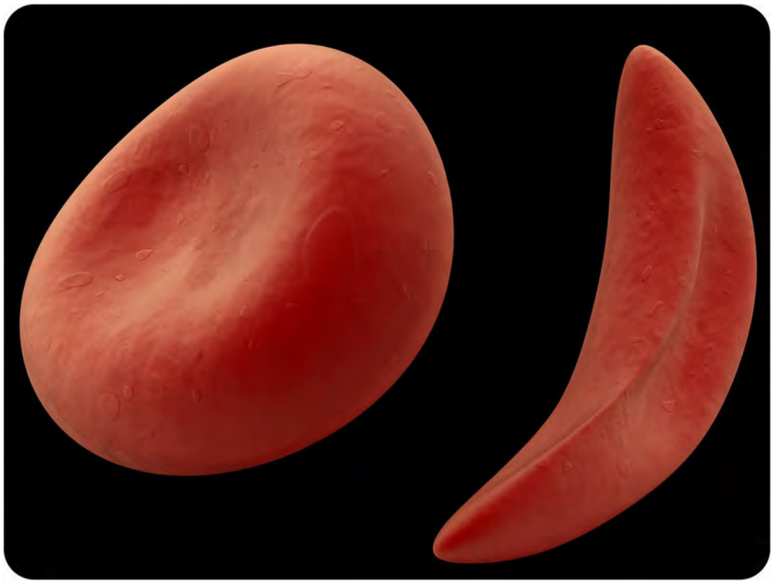


FIGURE 8.11
Sickle-Shaped and Normal Red Blood Cells. Sickle cell anemia is an autosomal recessive disorder. The mutation that causes the disorder affects just one amino acid in a single protein but it has serious consequences for the affected person. This photo shows the sickle shape of red blood cells in people with sickle cell anemia.

Cystic Fibrosis and Tay-Sachs disease are two additional severe genetic disorders. They are discussed in the following video: http://www.youtube.com/watch?v=8s4he3wLgkM#38;feature=related (9:31). Tay-Sachs is further discussed at http://www.youtube.com/watch?v=1RO0LOgHbIo#38;feature=channel (3:13) and http://www.youtube.com/watch?v=6zNj5LdDuTA (2:01).

Chromosomal Disorders

Mistakes may occur during meiosis that result in **nondisjunction**. This is the failure of replicated chromosomes to separate during meiosis (the animation at the link below shows how this happens). Some of the resulting gametes will be missing a chromosome, while others will have an extra copy of the chromosome. If such gametes are fertilized and form zygotes, they usually do not survive. If they do survive, the individuals are likely to have serious genetic disorders. **Table** 8.3 lists several genetic disorders that are caused by abnormal numbers of chromosomes. Most chromosomal disorders involve the X chromosome. Look back at the X and Y chromosomes and you will see why. The X and Y chromosomes are very different in size, so nondisjunction of the sex chromosomes occurs relatively often. http://learn.genetics.utah.edu/content/begin/traits/predictdisorder/index.html

TABLE 8.3: **Genetic Disorders Caused by Abnormal Numbers of Chromosomes**

Genetic Disorder	Genotype	Phenotypic Effects
Down syndrome	extra copy (complete or partial) of chromosome 21 (see **Figure** 8.12)	developmental delays, distinctive facial appearance, and other abnormalities (see **Figure** 8.13)
Turner's syndrome	one X chromosome but no other sex chromosome (XO)	female with short height and infertility (inability to reproduce)
Triple X syndrome	three X chromosomes (XXX)	female with mild developmental delays and menstrual irregularities

TABLE 8.3: (continued)

Genetic Disorder	Genotype	Phenotypic Effects
Klinefelter's syndrome	one Y chromosome and two or more X chromosomes (XXY, XXXY)	male with problems in sexual development and reduced levels of the male hormone testosterone

|+Genetic Disorders Caused by Abnormal Numbers of Chromosomes

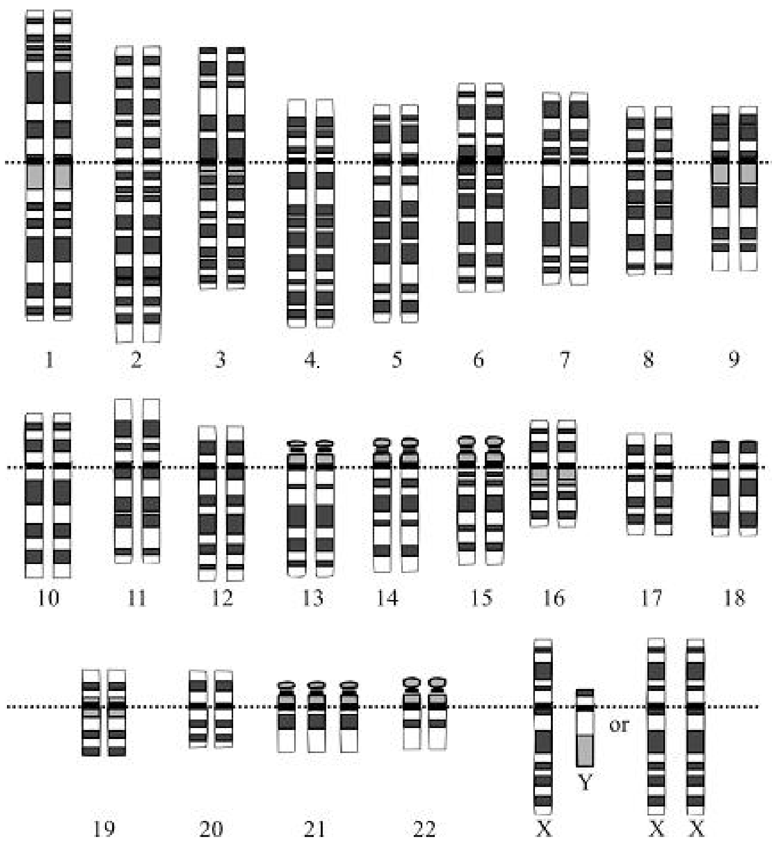


FIGURE 8.12

Trisomy 21 *Down Syndrome* Karyotype. A karyotype is a picture of a cellś chromosomes. Note the extra chromosome 21.

Diagnosing Genetic Disorders

A genetic disorder that is caused by a mutation can be inherited. Therefore, people with a genetic disorder in their family may be concerned about having children with the disorder. Professionals known as genetic counselors can help them understand the risks of their children being affected. If they decide to have children, they may be advised to have prenatal ("before birth") testing to see if the fetus has any genetic abnormalities. One method of prenatal testing is amniocentesis. In this procedure, a few fetal cells are extracted from the fluid surrounding the fetus, and the fetal chromosomes are examined.

KQED: Treating Genetic Disorders

The symptoms of genetic disorders can sometimes be treated, but cures for genetic disorders are still in the early stages of development. One potential cure that has already been used with some success is **gene therapy**. This

FIGURE 8.13
Child with Down syndrome exhibiting characteristic facial appearance.

involves inserting normal genes into cells with mutant genes. At the following link, you can watch the video *Sickle Cell Anemia: Hope from Gene Therapy,* to learn how scientists are trying to cure sickle-cell anemia with gene therapy. http://www.pubinfo.vcu.edu/secretsofthesequence/playlist_frame.asp

If you could learn your risk of getting cancer or another genetic disease, would you? Though this is a personal decision, it is a possibility. A San Francisco company now makes it easy to order medical genetic tests through the Web. See *Genetic Testing through the Web* at http://www.kqed.org/quest/television/genetic-testing-through-the-web .

Lesson Summary

- A minority of human traits are controlled by single genes with two alleles. They have different inheritance patterns depending on whether they are controlled by autosomal or X-linked genes.
- Most human traits have complex modes of inheritance. They may be controlled by one gene with multiple alleles or by multiple genes. More complexity may be introduced by pleiotropy (one gene, multiple effect) and epistasis (gene-gene interactions).
- Many genetic disorders are caused by mutations in one or a few genes. Other genetic disorders are caused by abnormal numbers of chromosomes.

Lesson Review Questions

Recall

1. Describe the inheritance pattern for a single-gene autosomal dominant trait, such as free-hanging earlobes.

2. Give an example of a multiple allele trait and a polygenic trait.

3. Identify factors that influence human skin color.

4. Describe a genetic disorder caused by a mutation in a single gene.

5. What causes Down syndrome?

6. What is gene therapy?

Apply Concepts

7. Draw a pedigree for hitchhiker's thumb. Your pedigree should cover at least two generations and include both dominant and recessive forms of the trait. Label the pedigree with genotypes, using the letter H to represent the dominant allele for the trait and the letter h to represent the recessive allele.

Think Critically

8. How might red-green color blindness affect the health of a person with this trait?

9. Compare and contrast dominance and epistasis.

10. Explain why genetic disorders caused by abnormal numbers of chromosomes most often involve the X chromosome.

Points to Consider

Technology has been developed to cure some genetic disorders with gene therapy. This involves inserting normal genes into cells with mutations. Scientists use genetic technology for other purposes as well.

- What other genetic problems might scientists try to solve with genetic technology? What about problems in agriculture?
- Why might scientists want to alter the genes of other organisms? How might this be done?

8.3 Biotechnology

Lesson Objectives

- Describe gene cloning and the polymerase chain reaction.
- Explain how DNA technology is applied in medicine and agriculture.
- Identify some of the ethical, legal, and social issues raised by biotechnology.

Vocabulary

biotechnology use of technology to change the genetic makeup of living things in order to produce useful products

gene cloning process of isolating and making copies of a gene

genetic engineering using biotechnology to change the genetic makeup of an organism

pharmacogenomics field that is tailoring medical treatments to fit our genetic profiles

polymerase chain reaction (PCR) biotechnology process that makes many copies of a gene or other DNA segment

recombinant DNA DNA that results when DNA from two organisms is combined

synthetic biology field of biology involved in engineering new functions from living systems

transgenic crop crop that has been genetically modified with new genes that code for traits useful to humans

Introduction

Biotechnology is the use of technology to change the genetic makeup of living things for human purposes. Generally, the purpose of biotechnology is to create organisms that are useful to humans or to cure genetic disorders. For example, biotechnology may be used to create crops that resist insect pests or yield more food, or to create new treatments for human diseases.

Biotechnology: The Invisible Revolution can be seen at http://www.youtube.com/watch?v=OcG9q9cPqm4.

"What does biotechnology have to do with me?" is discussed in the following video: http://www.youtube.com/watch?v=rrT5BT_7HdI#38;feature=related(10:01).

Biotechnology Methods

Biotechnology uses a variety of techniques to achieve its aims. Two commonly used techniques are gene cloning and the polymerase chain reaction.

Gene Cloning

Gene cloning is the process of isolating and making copies of a gene. This is useful for many purposes. For example, gene cloning might be used to isolate and make copies of a normal gene for gene therapy. Gene cloning involves four steps: isolation, ligation, transformation, and selection. You can watch an interactive animation about gene cloning at this link: http://www.teachersdomain.org/asset/biot09_int_geneclone/.

a. In isolation, an enzyme is used to break DNA at a specific base sequence. This is done to isolate a gene.
b. During ligation, the enzyme DNA ligase combines the isolated gene with plasmid DNA from bacteria. (Plasmid DNA is circular DNA that is not part of a chromosome and can replicate independently.) Ligation is illustrated in **Figure** 8.14 . The DNA that results is called **recombinant DNA**.
c. In transformation, the recombinant DNA is inserted into a living cell, usually a bacterial cell. Changing an organism in this way is also called **genetic engineering**.
d. Selection involves growing transformed bacteria to make sure they have the recombinant DNA. This is a necessary step because transformation is not always successful. Only bacteria that contain the recombinant DNA are selected for further use.

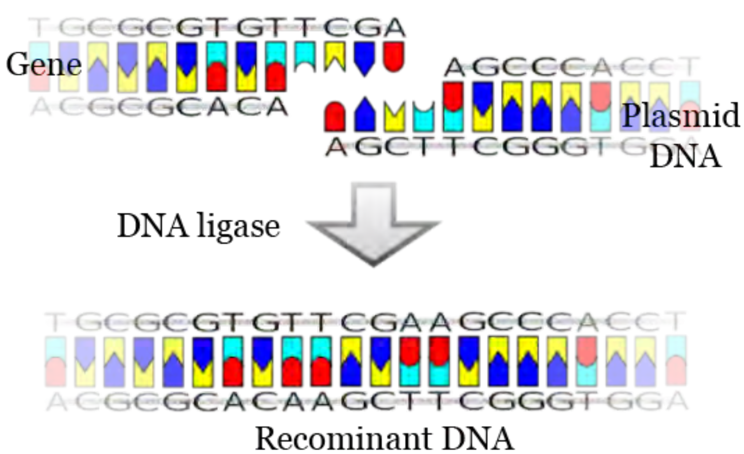


FIGURE 8.14
Ligation. DNA ligase joins together an isolated gene and plasmid DNA. This produces recombinant DNA.

Recombinant DNA technology is discussed in the following videos and animations: http://www.youtube.com/watch?v=x2jUMG2E-ic (4.36), http://www.youtube.com/watch?v=Jy15BWVxTC0 (0.50), http://www.youtube.com/watch?v=sjwNtQYLKeU#38;feature=related (7.20), http://www.youtube.com/watch?v=Fi63VjfhsfI (3:59).

Polymerase Chain Reaction

The **polymerase chain reaction (PCR)** makes many copies of a gene or other DNA segment. This might be done in order to make large quantities of a gene for genetic testing. PCR involves three steps: denaturing, annealing, and extension. The three steps are illustrated in **Figure** 8.15 . They are repeated many times in a cycle to make large quantities of the gene. You can watch animations of PCR at these links:

- http://www.dnalc.org/resources/3d/19-polymerase-chain-reaction.html
- http://www.teachersdomain.org/asset/biot09_int_pcr/.

a. Denaturing involves heating DNA to break the bonds holding together the two DNA strands. This yields two single strands of DNA.
b. Annealing involves cooling the single strands of DNA and mixing them with short DNA segments called primers. Primers have base sequences that are complementary to segments of the single DNA strands. As a result, bonds form between the DNA strands and primers.
c. Extension occurs when an enzyme (Taq polymerase or Taq DNA polymerase) adds nucleotides to the primers. This produces new DNA molecules, each incorporating one of the original DNA strands.

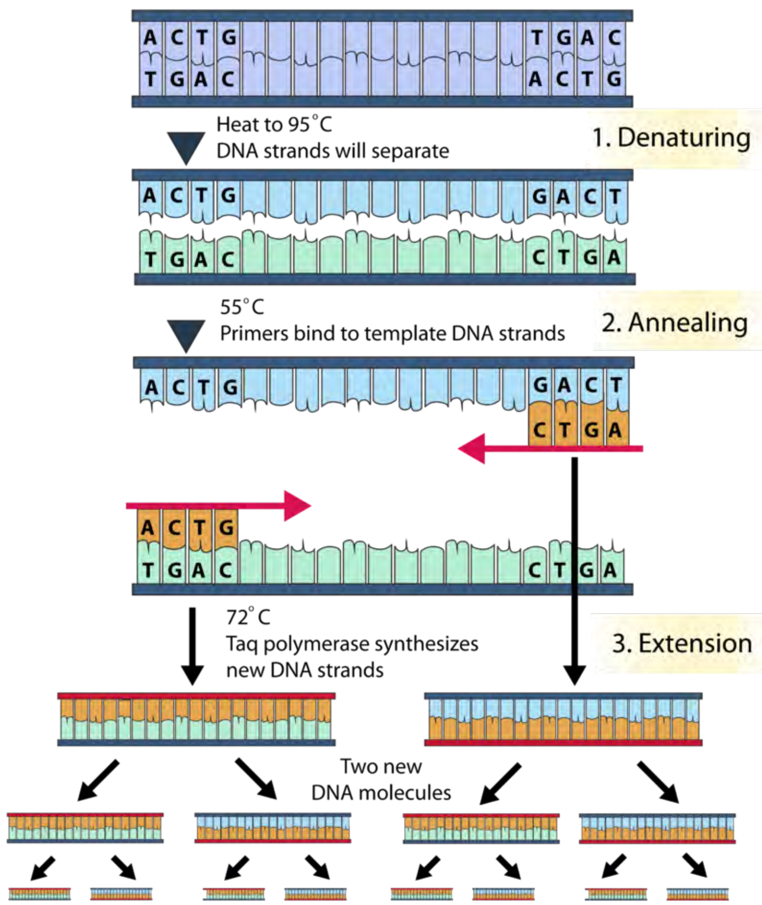


FIGURE 8.15
The Polymerase Chain Reaction. The polymerase chain reaction involves three steps. High temperatures are needed for the process to work. The enzyme Taq polymerase is used in step 3 because it can withstand high temperatures.

Applications of Biotechnology

Methods of biotechnology can be used for many practical purposes. They are used widely in both medicine and agriculture. To see how biotechnology can be used to solve crimes, watch the video *Justice DNA—Freeing the Innocent* at the following link: http://www.pubinfo.vcu.edu/secretsofthesequence/playlist_frame.asp.

Applications in Medicine

In addition to gene therapy for genetic disorders, biotechnology can be used to transform bacteria so they are able to make human proteins. **Figure** 8.16 shows how this is done. Proteins made by the bacteria are injected into people who cannot produce them because of mutations.

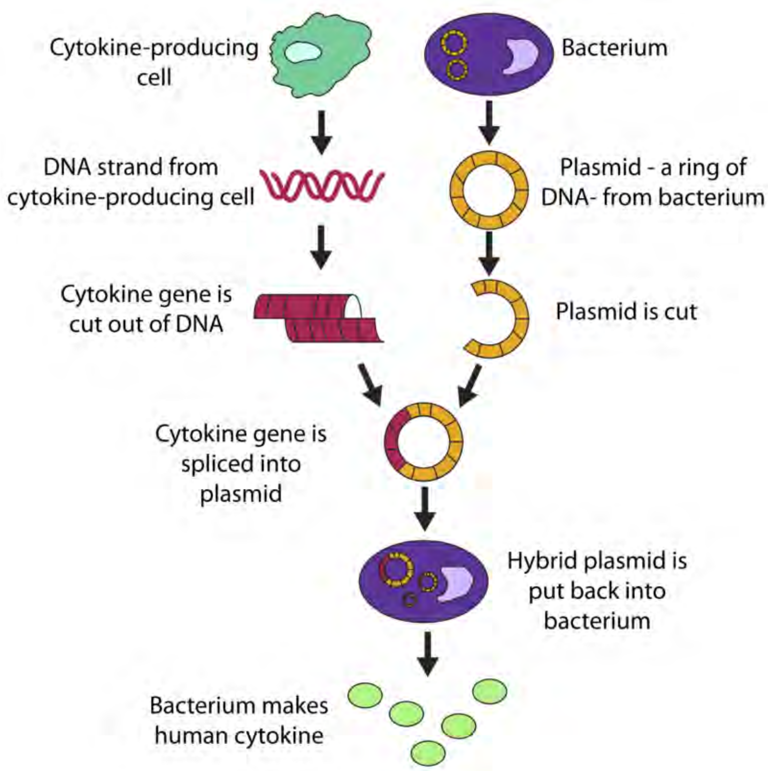


FIGURE 8.16

Genetically Engineering Bacteria to Produce a Human Protein. Bacteria can be genetically engineered to produce a human protein such as a cytokine. A cytokine is a small protein that helps fight infections.

Insulin was the first human protein to be produced in this way. Insulin helps cells take up glucose from the blood. People with type 1 diabetes have a mutation in the gene that normally codes for insulin. Without insulin, their blood glucose rises to harmfully high levels. At present, the only treatment for type 1 diabetes is the injection of insulin from outside sources. Until recently, there was no known way to make insulin outside the human body. The problem was solved by gene cloning. The human insulin gene was cloned and used to transform bacterial cells, which could then produce large quantities of human insulin.

KQED: Pharmacogenomics

As we have learned, we know that, thanks to our DNA, each of us is a little bit different. Some of those differences are obvious, like eye and hair color, but others are not so obvious, like how our bodies react to medication. Researchers are beginning to look at how to tailor medical treatments to our genetic profiles, in a relatively new field called **Pharmacogenomics.** Some of the biggest breakthroughs have been in cancer treatment. For additional information on this "personalized medicine," listen to http://www.kqed.org/quest/radio/personalized-medicine and see http://www.kqed.org/quest/blog/2009/09/11/reporters-notes-personalized-medicine/.

KQED: Synthetic Biology

Imagine living cells acting as memory devices; biofuels brewing from yeast, or a light receptor taken from algae that makes photographs on a plate of bacteria. The new field of **Synthetic Biology** is making biology easier to engineer so that new functions can be derived from living systems. Find out the tools that synthetic biologists are using and the exciting things they are building at http://www.kqed.org/quest/television/decoding-synthetic-biology and http://www.kqed.org/quest/television/web-extra-synthetic-biology-extended-interview.

MEDIA

Click image to the left for more content.

Applications in Agriculture

Biotechnology has been used to create transgenic crops. **Transgenic crops** are genetically modified with new genes that code for traits useful to humans. The diagram in **Figure** 8.17 shows how a transgenic crop is created. You can learn more about how scientists create transgenic crops with the interactive animation *Engineer a Crop—Transgenic Manipulation* at this link: http://www.pbs.org/wgbh/harvest/engineer/transgen.html.

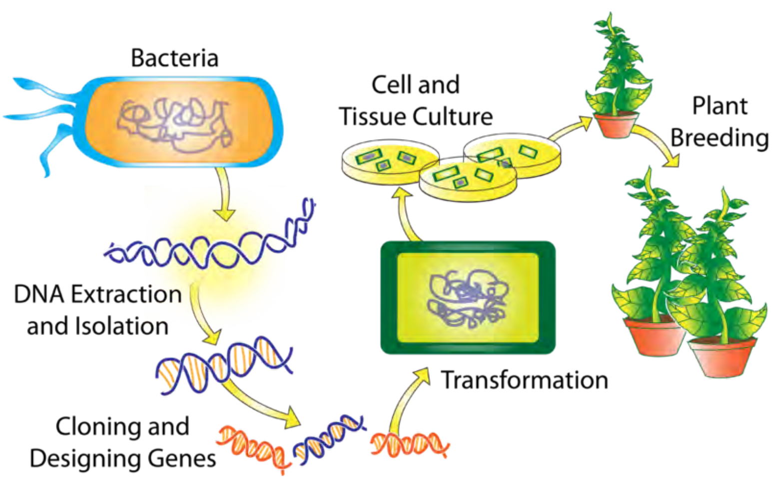


FIGURE 8.17

Creating a Transgenic Crop. A transgenic crop is genetically modified to be more useful to humans.

Transgenic crops have been created with a variety of different traits, such as yielding more food, tasting better, surviving drought, and resisting insect pests. Scientists have even created a transgenic purple tomato that contains a cancer-fighting compound (see **Figure** 8.18). To learn how scientists have used biotechnology to create plants that can grow in salty soil, watch the video *Salt of the Earth—Engineering Salt-Tolerant Plants* at this link: http://www.pubinfo.vcu.edu/secretsofthesequence/playlist_frame.asp.

Biotechnology in agriculture is discussed at http://www.youtube.com/watch?v=IY3mfgbe-0c (6:40).

FIGURE 8.18
Transgenic Purple Tomato. A purple tomato is genetically modified to contain a cancer-fighting compound. A gene for the compound was transferred into normal red tomatoes.

Ethical, Legal, and Social Issues

The use of biotechnology has raised a number of ethical, legal, and social issues. Here are just a few:

- Who owns genetically modified organisms such as bacteria? Can such organisms be patented like inventions?
- Are genetically modified foods safe to eat? Might they have unknown harmful effects on the people who consume them?
- Are genetically engineered crops safe for the environment? Might they harm other organisms or even entire ecosystems?
- Who controls a person's genetic information? What safeguards ensure that the information is kept private?
- How far should we go to ensure that children are free of mutations? Should a pregnancy be ended if the fetus has a mutation for a serious genetic disorder?

Addressing such issues is beyond the scope of this FlexBook. The following example shows how complex the issues may be:

A strain of corn has been created with a gene that encodes a natural pesticide. On the positive side, the transgenic corn is not eaten by insects, so there is more corn for people to eat. The corn also doesn't need to be sprayed with chemical pesticides, which can harm people and other living things. On the negative side, the transgenic corn has been shown to cross-pollinate nearby milkweed plants. Offspring of the cross-pollinated milkweed plants are now known to be toxic to monarch butterfly caterpillars that depend on them for food. Scientists are concerned that this may threaten the monarch species as well as other species that normally eat monarchs.

As this example shows, the pros of biotechnology may be obvious, but the cons may not be known until it is too late. Unforeseen harm may be done to people, other species, and entire ecosystems. No doubt the ethical, legal, and social issues raised by biotechnology will be debated for decades to come. For a recent debate about the ethics of applying biotechnology to humans, watch the video at the link below. In the video, a Harvard University professor of government and a Princeton University professor of bioethics debate the science of "perfecting humans." http://www.youtube.com/watch?v=-BPna-fSNOE

Lesson Summary

- Gene cloning is the process of isolating and making copies of a DNA segment such as a gene. The polymerase chain reaction makes many copies of a gene or other DNA segment.
- Biotechnology can be used to transform bacteria so they are able to make human proteins, such as insulin. It can also be used to create transgenic crops, such as crops that yield more food or resist insect pests.

- Biotechnology has raised a number of ethical, legal, and social issues. For example, are genetically modified foods safe to eat, and who controls a person's genetic information?

Lesson Review Questions

Recall

1. Define biotechnology.
2. What is recombinant DNA?
3. Identify the steps of gene cloning.
4. What is the purpose of the polymerase chain reaction?

Apply Concepts

5. Make a flow chart outlining the steps involved in creating a transgenic crop.

Think Critically

6. Explain how bacteria can be genetically engineered to produce a human protein.
7. Identify an ethical, legal, or social issue raised by biotechnology. State your view on the issue, and develop a logical argument to support your view.

Points to Consider

In this lesson, you read that bacteria can be transformed with human genes so they are able to make human proteins. This is possible because the genetic code is universal. Genetic information is encoded and read in the same way in all known species. This demonstrates that all life on Earth has a common evolutionary history, beginning with the earliest living things.

- How did the first living things on Earth arise? How and when might this have happened?
- What do you think the first living things were like?

CHAPTER 9 Life: From the First Organism Onward

CHAPTER OUTLINE

What alien planet is represented by this picture? Would it surprise you to learn that the picture represents Earth? After Earth first formed about 4.6 billion years ago, it may well have looked like this. Instead of rivers of water, rivers of molten rock flowed over its surface. Life as we know it could not have survived in such a place. How did this fiery hot planet become today's Earth, covered with water and teeming with life? The long and incredible story of Earth's history is told in this chapter.

9.1 Earth Forms and Life Begins

Lesson Objectives

- Explain how scientists learn about the history of life on Earth.
- Describe how and when planet Earth formed.
- Outline how the first organic molecules arose.
- Describe the characteristics of the first cells.
- Explain how eukaryotes are thought to have evolved.

Vocabulary

absolute dating carbon-14 or other method of dating fossils that gives an approximate age in years

extinction situation in which a species completely dies out and no members of the species remain

fossil preserved remains or traces of organisms that lived in the past

fossil record the record of life as told by the study and analysis of fossils

geologic time scale time line of Earth based on major events in geology, climate, and the evolution of life

Last Universal Common Ancestor (LUCA) hypothetical early cell (or group of cells) that gave rise to all subsequent life on Earth

molecular clock using DNA (or proteins) to measure how long it has been since related species diverged from a common ancestor

relative dating method of dating fossils by their location in rock layers; determines which fossils are older or younger but not their age in years

RNA world hypothesis hypothesis that RNA was the first organic molecule to evolve and that early life was based on RNA, rather than DNA or protein

Introduction

Earth formed 4.6 billion years ago, and life first appeared about 4 billion years ago. The first life forms were microscopic, single-celled organisms. From these simple beginnings, evolution gradually produced the vast complexity and diversity of life today. The evolution of life on Earth wasn't always smooth and steady—far from it. Living things had to cope with some astounding changes. Giant meteorites struck Earth's surface. Continents drifted and shifted. Ice ages buried the planet in snow and ice for millions of years at a time. At least five times, many, if not most, of Earth's living things went extinct. **Extinction** occurs when a species completely dies out and no members of the species remain. But life on Earth was persistent. Each time, it came back more numerous and diverse than before.

Earth in a Day

It's hard to grasp the vast amounts of time since Earth formed and life first appeared on its surface. It may help to think of Earth's history as a 24-hour day, as shown in **Figure** 9.1 . Humans would have appeared only during the last minute of that day. If we are such newcomers on planet Earth, how do we know about the vast period of time that went before us? How have we learned about the distant past?

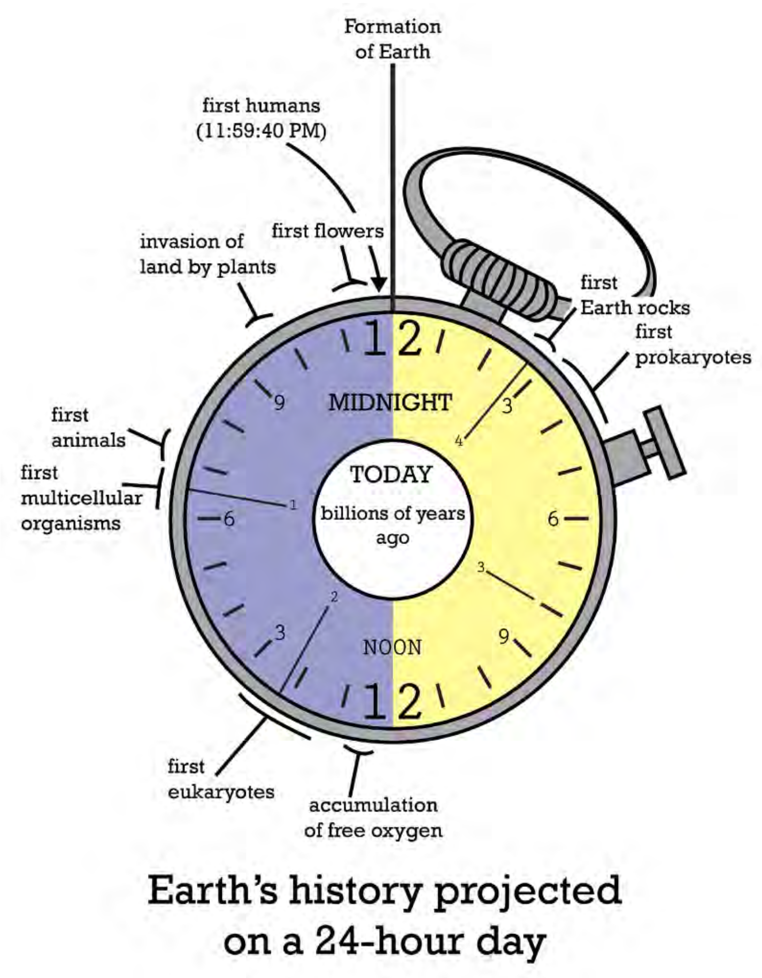


FIGURE 9.1

History of Earth in a Day. In this model of Earth&#8217 s history the planet formed at midnight. What time was it when the first prokaryotes evolved

Learning About the Past

Much of what we know about the history of life on Earth is based on the fossil record. Detailed knowledge of modern organisms also helps us understand how life evolved.

The Fossil Record

Fossils are the preserved remains or traces of organisms that lived in the past. The soft parts of organisms almost always decompose quickly after death. On occasion, the hard parts—mainly bones, teeth, or shells—remain long enough to mineralize and form fossils. An example of a complete fossil skeleton is shown in **Figure** 9.2 . The **fossil record** is the record of life that unfolded over four billion years and pieced back together through the analysis of fossils.

FIGURE 9.2

Extinct Lion Fossil. This fossilized skeleton represents an extinct lion species. It is rare for fossils to be so complete and well preserved as this one.

To be preserved as fossils, remains must be covered quickly by sediments or preserved in some other way. For example, they may be frozen in glaciers or trapped in tree resin, like the frog in **Figure** 9.3 . Sometimes traces of organisms—such as footprints or burrows—are preserved (see the fossil footprints in **Figure** 9.3). The conditions required for fossils to form rarely occur. Therefore, the chance of an organism being preserved as a fossil is very low. You can watch a video at the following link to see in more detail how fossils form: http://www.youtube.com/watch?v=A5i5Qrp6sJU.

In order for fossils to "tell" us the story of life, they must be dated. Then they can help scientists reconstruct how life changed over time. Fossils can be dated in two different ways: relative dating and absolute dating. Both are described below. You can also learn more about dating methods in the video at this link: http://www.youtube.com/watch?v=jM7vZ-9bBc0.

- **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 layers were laid down earlier, so they are assumed to contain older fossils. This is illustrated in **Figure** 9.4 .
- **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

FIGURE 9.3
The photo on the left shows an ancient frog trapped in hardened tree resin or amber. The photo on the right shows the fossil footprints of a dinosaur.

remains in a fossil. You can learn more about carbon-14 dating by watching the animation at this link: http://www.absorblearning.com/media/attachment.action?quick=bo#38;att=832.

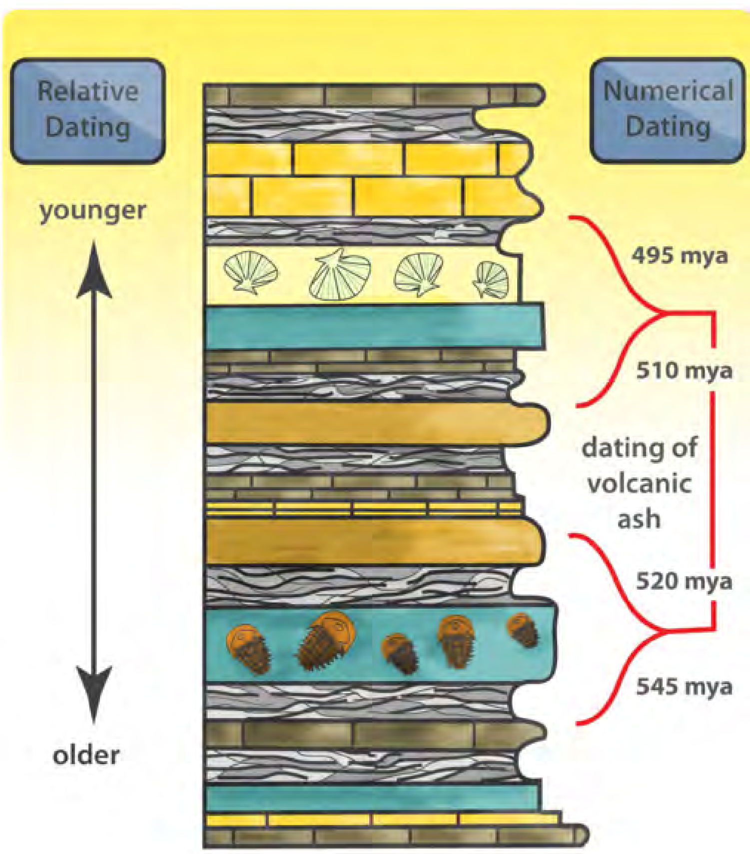


FIGURE 9.4
Relative Dating Using Rock Layers. Relative dating establishes which of two fossils is older than the other. It is based on the rock layers in which the fossils formed.

Molecular Clocks

Evidence from the fossil record can be combined with data from molecular clocks. A **molecular clock** uses DNA sequences (or the proteins they encode) to estimate how long it has been since related species diverged from a common ancestor. Molecular clocks are based on the assumption that mutations accumulate through time at a steady average rate for a given region of DNA. Species that have accumulated greater differences in their DNA sequences are assumed to have diverged from their common ancestor in the more distant past. Molecular clocks based on different regions of DNA may be used together for more accuracy. Consider the example in **Table** 9.1 . The table shows how similar the DNA of several animal species is to human DNA. Based on these data, which organism do you think shared the most recent common ancestor with humans?

TABLE 9.1: **Comparing DNA: Humans and Other Animals**

Organism	**Similarity with Human DNA (percent)**
Chimpanzee	98
Mouse	85
Chicken	60
Fruit Fly	44

Geologic Time Scale

Another tool for understanding the history of Earth and its life is the **geologic time scale**, shown in **Figure** 9.5 . The geologic time scale divides Earth's history into divisions (such as eons, eras, and periods) that are based on major changes in geology, climate, and the evolution of life. It organizes Earth's history and the evolution of life on the basis of important events instead of time alone. It also allows more focus to be placed on recent events, about which we know the most.

How Earth Formed: We Are Made of Stardust!

We'll start the story of life at the very beginning, when Earth and the rest of the solar system first formed. The solar system began as a rotating cloud of stardust. Then, a nearby star exploded and sent a shock wave through the dust cloud, increasing its rate of spin. As a result, most of the mass became concentrated in the middle of the disk, forming the sun. Smaller concentrations of mass rotating around the center formed the planets, including Earth. You can watch a video showing how Earth formed at this link: http://www.youtube.com/watch?v=-x8-KMR0nx8#38;feature=related. At first, Earth was molten and lacked an atmosphere and oceans. Gradually, the planet cooled and formed a solid crust. As the planet continued to cool, volcanoes released gases, which eventually formed an atmosphere. The early atmosphere contained ammonia, methane, water vapor, and carbon dioxide but only a trace of oxygen. As the atmosphere became denser, clouds formed and rain fell. Water from rain (and perhaps also from comets and asteroids that stuck Earth) eventually formed the oceans. The ancient atmosphere and oceans represented by the picture in **Figure** 9.6 would be toxic to today's life, but they set the stage for life to begin.

The First Organic Molecules

All living things consist of organic molecules. Therefore, it is likely that organic molecules evolved before cells, perhaps as long as 4 billion years ago. How did these building blocks of life first form? Scientists think that lightning sparked chemical reactions in Earth's early atmosphere. They hypothesize that this created a "soup" of organic molecules from inorganic chemicals. In 1953, scientists Stanley Miller and Harold Urey used their imaginations to

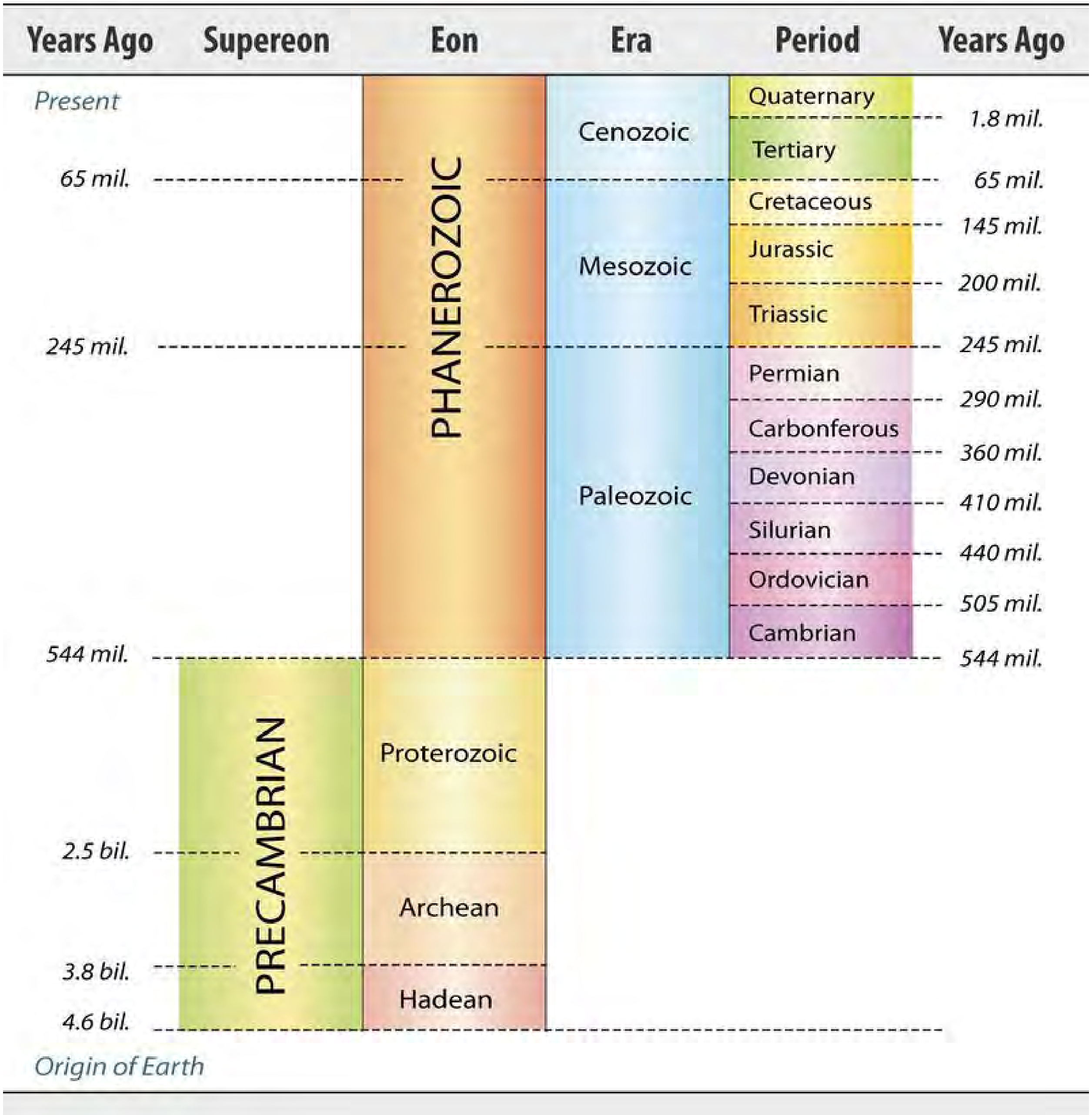


FIGURE 9.5

Geologic Time Scale. The geologic time scale divides Earth&#8217 s history into units that reflect major changes in Earth and its life forms. During which eon did Earth form What is the present era

FIGURE 9.6
Ancient Earth. This is how ancient Earth may have looked after its atmosphere and oceans formed.

test this hypothesis. They created a simulation experiment to see if organic molecules could arise in this way (see **Figure** 9.7). They used a mixture of gases to represent Earth's early atmosphere. Then, they passed sparks through the gases to represent lightning. Within a week, several simple organic molecules had formed. You can watch a dramatization of Miller and Urey's experiment at this link: http://www.youtube.com/watch?v=j9ZRHoawyOg.

Recently, the findings of Miller and Urey have come into question due to discrepancies in the composition of the early atmosphere, allowing a number of other ideas to surface on the formation of the first organic molecules. One idea states that the active volcanoes on early Earth gave the necessary materials for life. Despite the simplified account discussed above, the problem of the origin of the first organic compounds remains. Despite tremendous advances in biochemical analysis, answers to the problem remain. But whatever process did result in the first organic molecules, it was probably a spontaneous process, with elements coming together randomly to form small compounds, and small compounds reacting with other elements and other small compounds to make larger compounds. So, which organic molecule did come first?

Which Organic Molecule Came First?

Living things need organic molecules to store genetic information and to carry out the chemical work of cells. Modern organisms use DNA to store genetic information and proteins to catalyze chemical reactions. So, did DNA or proteins evolve first? This is like asking whether the chicken or the egg came first. DNA encodes proteins and proteins are needed to make DNA, so each type of organic molecule needs the other for its own existence. How could either of these two molecules have evolved before the other? Did some other organic molecule evolve first, instead of DNA or proteins?

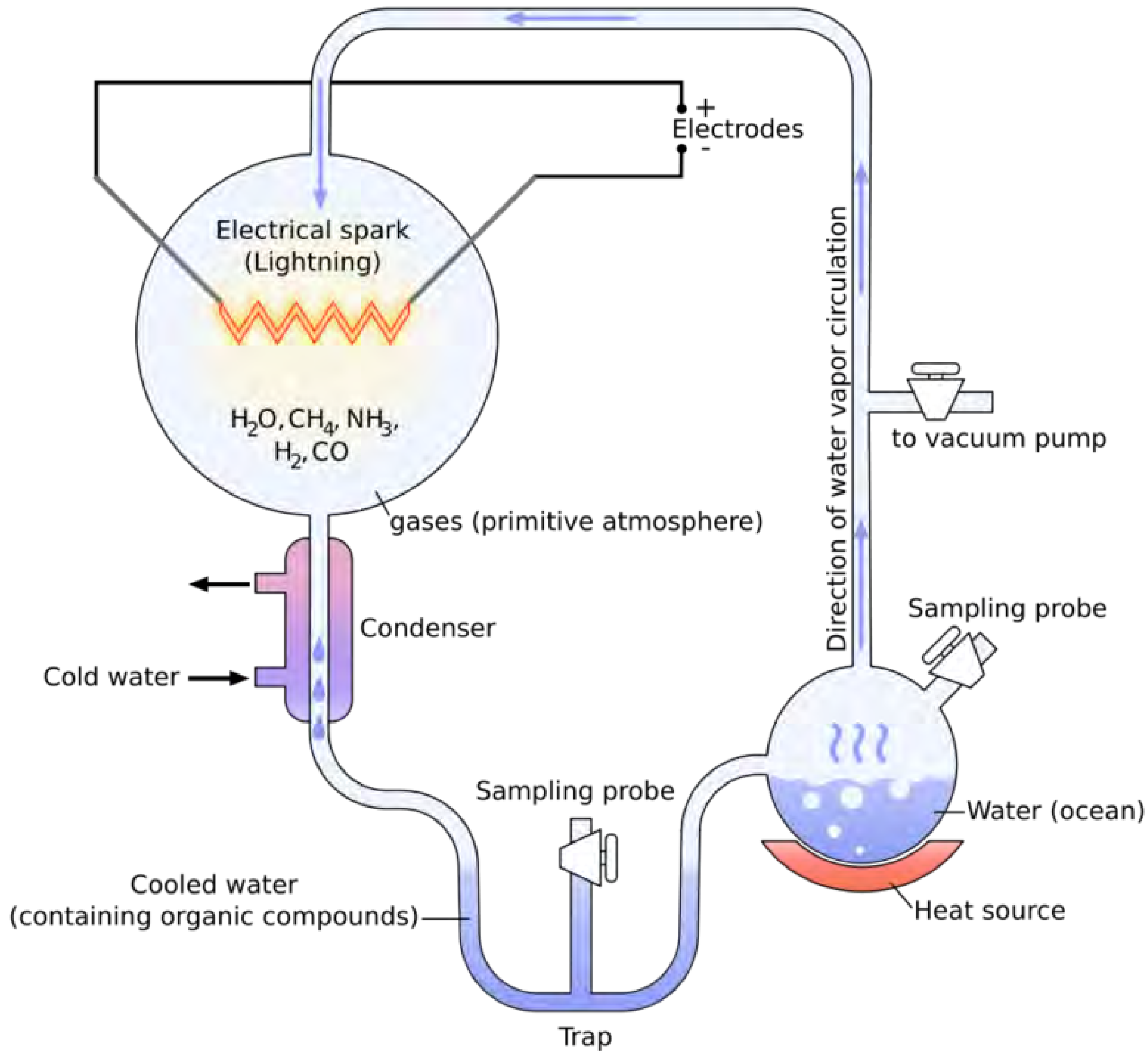


FIGURE 9.7

Miller and Urey&#8217 s Experiment. Miller and Urey demonstrated that organic molecules could form under simulated conditions on early Earth. What assumptions were their simulation based upon

RNA World Hypothesis

Some scientists speculate that RNA may have been the first organic molecule to evolve. In fact, they think that early life was based solely on RNA and that DNA and proteins evolved later. This is called the **RNA world hypothesis.** Why RNA? It can encode genetic instructions (like DNA), and some RNAs can carry out chemical reactions (like proteins). Therefore, it solves the chicken-and-egg problem of which of these two molecules came first. Other evidence also suggests that RNA may be the most ancient of the organic molecules. You can learn more about the RNA world hypothesis and the evidence for it at this link: http://www.youtube.com/watch?v=sAkgb3yNgqg.

The First Cells

How organic molecules such as RNA developed into cells is not known for certain. Scientists speculate that lipid membranes grew around the organic molecules. The membranes prevented the molecules from reacting with other molecules, so they did not form new compounds. In this way, the organic molecules persisted, and the first cells may have formed. **Figure** 9.8 shows a model of the hypothetical first cell.

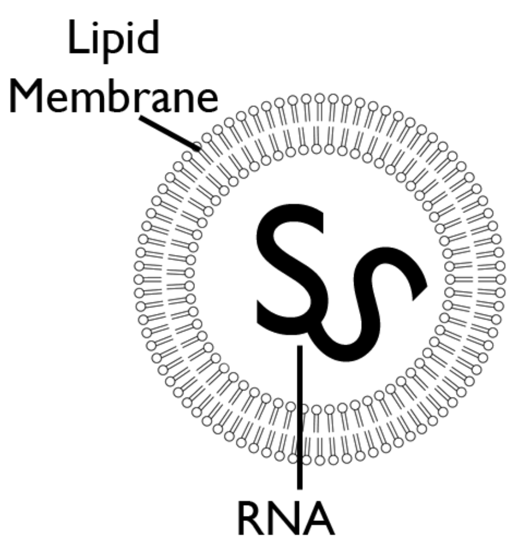


FIGURE 9.8
Hypothetical First Cell. The earliest cells may have consisted of little more than RNA inside a lipid membrane.

LUCA

No doubt there were many early cells of this type. However, scientists think that only one early cell (or group of cells) eventually gave rise to all subsequent life on Earth. That one cell is called the **Last Universal Common Ancestor (LUCA).** It probably existed around 3.5 billion years ago. LUCA was one of the earliest prokaryotic cells. It would have lacked a nucleus and other membrane-bound organelles. To learn more about LUCA and universal common descent, you can watch the video at the following link: http://www.youtube.com/watch?v=G0UGpcea8Zg.

Photosynthesis and Cellular Respiration

The earliest cells were probably heterotrophs. Most likely they got their energy from other molecules in the organic "soup." However, by about 3 billion years ago, a new way of obtaining energy evolved. This new way was photosynthesis. Through photosynthesis, organisms could use sunlight to make food from carbon dioxide and water. These organisms were the first autotrophs. They provided food for themselves and for other organisms that began to consume them. After photosynthesis evolved, oxygen started to accumulate in the atmosphere. This has been dubbed the "oxygen catastrophe." Why? Oxygen was toxic to most early cells because they had evolved in its absence. As a result, many of them died out. The few that survived evolved a new way to take advantage of the oxygen. This second major innovation was cellular respiration. It allowed cells to use oxygen to obtain more energy from organic molecules.

Evolution of Eukaryotes

The first eukaryotic cells probably evolved about 2 billion years ago. This is explained by endosymbiotic theory. As shown in **Figure** 9.9 , endosymbiosis came about when large cells engulfed small cells. The small cells were not digested by the large cells. Instead, they lived within the large cells and evolved into cell organelles.

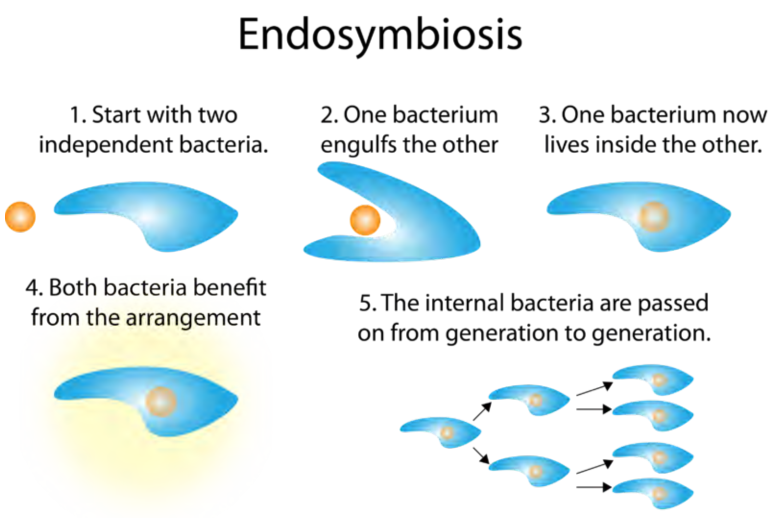


FIGURE 9.9
From Independent Cell to Organelle. The endosymbiotic theory explains how eukaryotic cells evolved.

The large and small cells formed a symbiotic relationship in which both cells benefited. Some of the small cells were able to break down the large cell's wastes for energy. They supplied energy not only to themselves but also to the large cell. They became the mitochondria of eukaryotic cells. Other small cells were able to use sunlight to make food. They shared the food with the large cell. They became the chloroplasts of eukaryotic cells. With their specialized organelles, eukaryotic cells were powerful and efficient. They would go on to evolve additional major adaptations. These adaptations include sexual reproduction, cell specialization, and multicellularity. Eventually, eukaryotic cells would evolve into the animals, plants, and fungi we know today.

Arsenic in Place of Phosphorus - New Biochemicals for Life?

In late 2010, NASA scientists proposed the notion that the elements essential for life - carbon, hydrogen, oxygen, nitrogen, phosphorus, and sulfur - may have additional members. Scientists have trained a bacterium to eat and grow on a diet of arsenic, in place of phosphorus. Phosphorus chains form the backbone of DNA, and ATP, with three phosphates, is the principal molecule in which energy is stored in the cell. Arsenic is directly under phosphorus in the Periodic Table, so the two elements have similar chemical bonding properties. This finding raises the possibility that organisms could exist on Earth or elsewhere in the universe using biochemicals not currently known to exist. These results expand the notion of what life could be and where it could be. It could be possible that life on other planets may have formed using biochemicals with elements different from the elements used in life on Earth.

In a classic example of the scientific community questioning controversial information, in the immediate six months after the original publication in the scientific journal *Nature*, the scientific community has raised various technical and theoretical issues concerning this finding. And as a response, the NASA team dismisses the criticism and stands by their data and interpretations.

See http://www.nytimes.com/2010/12/03/science/03arsenic.html?pagewanted=1#38;_r=3 and http://science.nasa.gov/science-news/science-at-nasa/2010/02dec_monolake/ for further information on this controversial finding.

Lesson Summary

- Much of what we know about the history of life on Earth is based on the fossil record. Molecular clocks are used to estimate how long it has been since two species diverged from a common ancestor. The geologic time scale is another important tool for understanding the history of life on Earth.
- Earth formed about 4.6 billion years ago. At first, Earth was molten and lacked an atmosphere and oceans. Gradually, the atmosphere formed, followed by the oceans.
- The first organic molecules formed about 4 billion years ago. This may have happened when lightning sparked chemical reactions in Earth's early atmosphere. RNA may have been the first organic molecule to form as well as the basis of early life.
- The first cells consisted of little more than an organic molecule such as RNA inside a lipid membrane. One cell (or group of cells), called the last universal common ancestor (LUCA), gave rise to all subsequent life on Earth. Photosynthesis evolved by 3 billion years ago and released oxygen into the atmosphere. Cellular respiration evolved after that to make use of the oxygen.
- Eukaryotic cells probably evolved about 2 billion years ago. Their evolution is explained by endosymbiotic theory. Eukaryotic cells would go on to evolve into the diversity of eukaryotes we know today.

Lesson Review Questions

Recall

1. What are fossils?

2. Describe how fossils form.

3. Give an overview of how Earth formed and how its atmosphere and oceans developed.

4. Describe Miller and Urey's experiment. What did it demonstrate?

5. State the RNA world hypothesis.

6. What was LUCA? What were its characteristics?

Apply Concepts

7. This table shows DNA sequence comparisons for some hypothetical species. Based on the data, describe evolutionary relationships between Species A and the other four species. Explain your answer.

TABLE 9.2: DNA Similarities

Species	DNA Similarity with Species A (%)
Species B	42
Species C	85
Species D	67
Species E	91

Think Critically

8. Compare and contrast relative and absolute dating.
9. Why could cellular respiration evolve only after photosynthesis had evolved?

Points to Consider

The earliest organisms lived in the ocean. Even after eukaryotes evolved, it was more than a billion years before organisms lived on land for the first time.

- What special challenges do you think organisms faced when they moved from water to land?
- How do you think they met these challenges? What adaptations might they have evolved?

9.2 The Evolution of Multicellular Life

Lesson Objectives

- Describe important events of the late Precambrian.
- Give an overview of evolution during the Paleozoic Era.
- Explain why the Mesozoic Era is called the age of the dinosaurs.
- Outline the main evolutionary events of the Cenozoic Era.

Vocabulary

Cambrian explosion spectacular burst of new life that occurred at the start of the Paleozoic Era

Cenozoic Era age of mammals that lasted from 65 million years ago to the present

mass extinction extinction event in which many if not most species abruptly disappear from Earth

Mesozoic Era age of dinosaurs that lasted from 245–65 million years ago

Paleozoic Era age of "old life" from 544–245 million years ago that began with the Cambrian explosion and ended with the Permian extinction

Permian extinction extinction at the end of the Paleozoic Period that was the biggest mass extinction the world had ever seen until then

Introduction

Nearly 80% of Earth's history passed before multicellular life evolved. Up until then, all organisms existed as single cells. Why did multicellular organisms evolve? What led up to this major step in the evolution of life? To put the evolution of multicellularity in context, let's return to what was happening on planet Earth during this part of its history.

Setting the Stage: The Late Precambrian

The late Precambrian is the time from about 2 billion to half a billion years ago. During this long span of time, Earth experienced many dramatic geologic and climatic changes.

- Continents drifted. They collided to form a gigantic supercontinent and then broke up again and moved apart. Continental drift changed climates worldwide and caused intense volcanic activity. To see an animation of continental drift, go to this link: http://www.ucmp.berkeley.edu/geology/anim1.html.
- Carbon dioxide levels in the atmosphere rose and fell. This was due to volcanic activity and other factors. When the levels were high, they created a greenhouse effect. More heat was trapped on Earth's surface, and the climate became warmer. When the levels were low, less heat was trapped and the planet cooled. Several times, cooling was severe enough to plunge Earth into an ice age. One ice age was so cold that snow and ice completely covered the planet (see **Figure** 9.10).

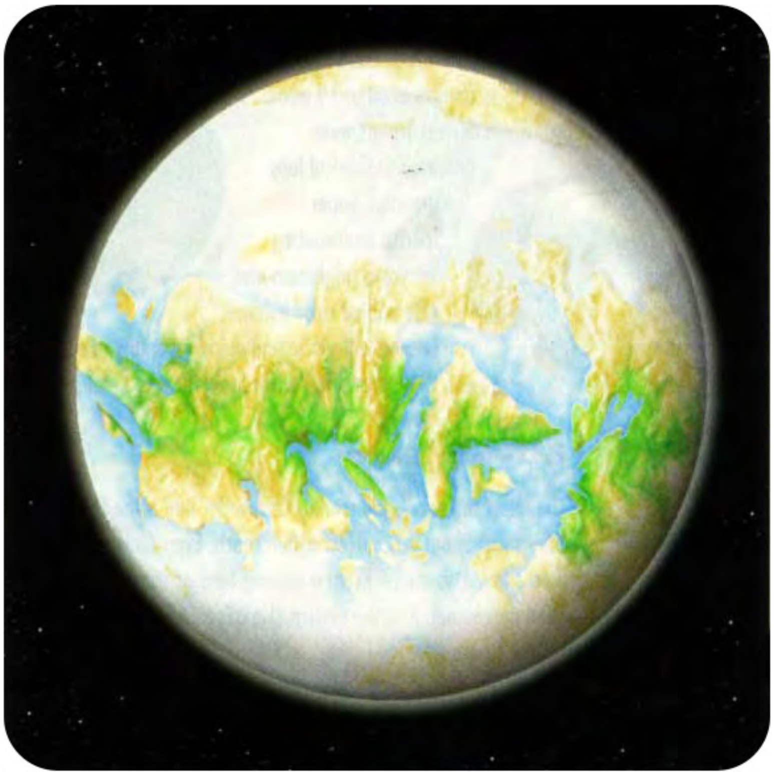


FIGURE 9.10
Snowball Earth. During the late Precambrian Earth grew so cold that it was covered with snow and ice. Earth during this ice age has been called &#8220 snowball Earth.&#8221

Life During the Late Precambrian

The dramatic changes of the late Precambrian had a major impact on Earth's life forms. Living things that could not adapt died out. They were replaced by organisms that evolved new adaptations. These adaptations included sexual reproduction, specialization of cells, and multicellularity.

- Sexual reproduction created much more variety among offspring. This increased the chances that at least some of them would survive when the environment changed. It also increased the speed at which evolution could occur.
- Some cells started to live together in colonies. In some colonies, cells started to specialize in doing different jobs. This made the cells more efficient as a colony than as individual cells.
- By 1 billion years ago, the first multicellular organisms had evolved. They may have developed from colonies of specialized cells. Their cells were so specialized they could no longer survive independently. However, together they were mighty. They formed an organism that was bigger, more efficient, and able to do much more than any single-celled organism ever could.

The Precambrian Extinction

At the close of the Precambrian 544 million years ago, a mass extinction occurred. In a **mass extinction**, many or even most species abruptly disappear from Earth. There have been five mass extinctions in Earth's history. Many scientists think we are currently going through a sixth mass extinction. What caused the Precambrian mass extinction? A combination of climatic and geologic events was probably responsible. No matter what the cause, the extinction paved the way for a burst of new life during the following Paleozoic Era.

Life During the Paleozoic

The **Paleozoic Era** is literally the era of "old life." It lasted from 544 to 245 million years ago and is divided into six periods. Major events in each period of the Paleozoic Era are described in **Figure** 9.11 . The era began with a spectacular burst of new life. This is called the **Cambrian explosion.** The era ended with the biggest mass extinction the world had ever seen. This is known as the **Permian extinction.** At the following link, you can watch a video about these and other events of the Paleozoic Era: http://www.youtube.com/watch?v=Bf2rrRmconU.

Paleozoic Era

The Cambrian Period: Following the Precambrian mass extinction, there was an explosion of new kinds of organisms in the Cambrian Period (544–505 million years ago). Many types of primitive animals called sponges evolved. Small ocean invertebrates called Trilobites became abundant.

The Ordovician Period: During the next period, the Ordovician Period (505–440 million years ago), the oceans became filled with invertebrates of many types. Also during this period, the first fish evolved and plants colonized the land for the first time. But animals still remained in the water.

The Silurian Period: During the Silurian Period (440–410 million years ago), corals appeared in the oceans, and fish continued to evolve. On land, vascular plants appeared. With special tissues to circulate water and other materials, these plants could grow larger than the earlier nonvascular plants.

The Devonian Period: During the Devonian Period (410–360 million years ago), the first seed plants evolved. Seeds have a protective coat and stored food to help them survive. Seed plants eventually became the most common type of land plants. In the oceans, fish with lobe fins evolved. They could breathe air when they raised their heads above water. Breathing would be necessary for animals to eventually colonize the land.

The Carboniferous Period: Next, during the Carboniferous Period (360–290 million years ago), widespread forests of huge plants left massive deposits of carbon that eventually turned to coal. The first amphibians evolved to move out of the water and colonize land, but they had to return to the water to reproduce. Soon after amphibians arose, the first reptiles evolved. They were the first animals that could reproduce on dry land.

The Permian Period: During the Permian Period (290–245 million years ago), all the major land masses collided to form a supercontinent called Pangaea. Temperatures were extreme, and the climate was dry. Plants and animals evolved adaptations to dryness, such as waxy leaves or leathery skin to prevent water loss. The Permian Period ended with a mass extinction.

In the mass extinction that ended the Permian, the majority of species went extinct. Many hypotheses have been offered to explain why this mass extinction occurred. These include huge meteorites striking Earth and enormous volcanoes spewing ashes and gases into the atmosphere. Both could have darkened the skies with dust for many months. This, in turn, would have shut down photosynthesis and cooled the planet. Despite the great loss of life, there was light at the end of the tunnel. The Permian extinction paved the way for another burst of new life at the start of the following Mesozoic Era. This included the evolution of the dinosaurs.

FIGURE 9.11

The Paleozoic Era includes the six periods described here.

FIGURE 9.12

Two representatives of more than fifty modern animal phyla from the Cambrian explosion are reef-building sponges *left* and early arthropods known as trilobites *right*. Both were abundant during the Cambrian and later became extinct however the phyla they represent persist to this day.

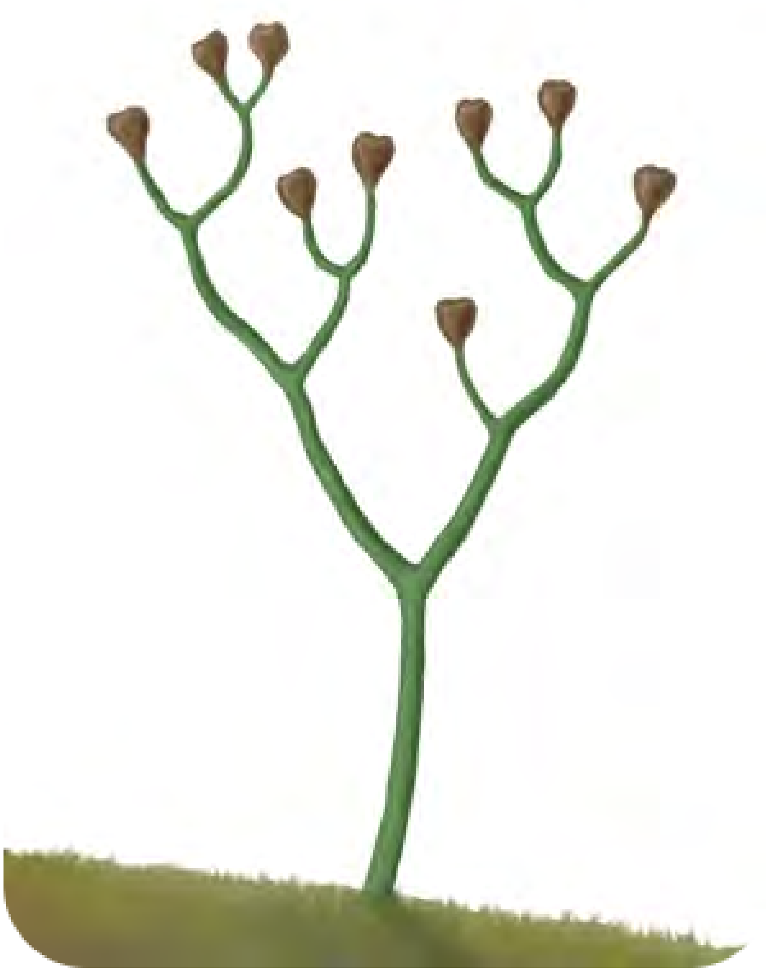


FIGURE 9.13

Cooksonia a branching vascular plant with sporangia at the tips of each branch. Cooksonia fossils measure just centimeters in height and date from the Silurian period.

FIGURE 9.14
On land clubmosses horsetails and ferns joined primitive seed plants and early trees to form the first forests.

FIGURE 9.15
The supercontinent Pangaea encompassed all of today&#8217 s continents in a single land mass. This configuration limited shallow coastal areas which harbor marine species and may have contributed to the dramatic event which ended the Permian - the most massive extinction ever recorded.

Mesozoic Era: Age of Dinosaurs

The **Mesozoic Era** is literally the era of "middle life." It is also known as the age of dinosaurs. It lasted from 245 to 65 million years ago and is divided into the three periods described in **Figure** 9.16 . The Mesozoic began with the supercontinent Pangaea. Then, during the era, Pangaea broke up and the continents drifted apart. The movement of continents changed climates. It also caused a lot of volcanic activity. Mass extinctions occurred at the end of the Triassic and Cretaceous Periods. The first extinction paved the way for a dinosaur takeover. In the second extinction, the dinosaurs finally disappeared. At the link below, you can watch a video about these and other exciting events during the age of dinosaurs. http://www.youtube.com/watch?v=watgb11LOHE

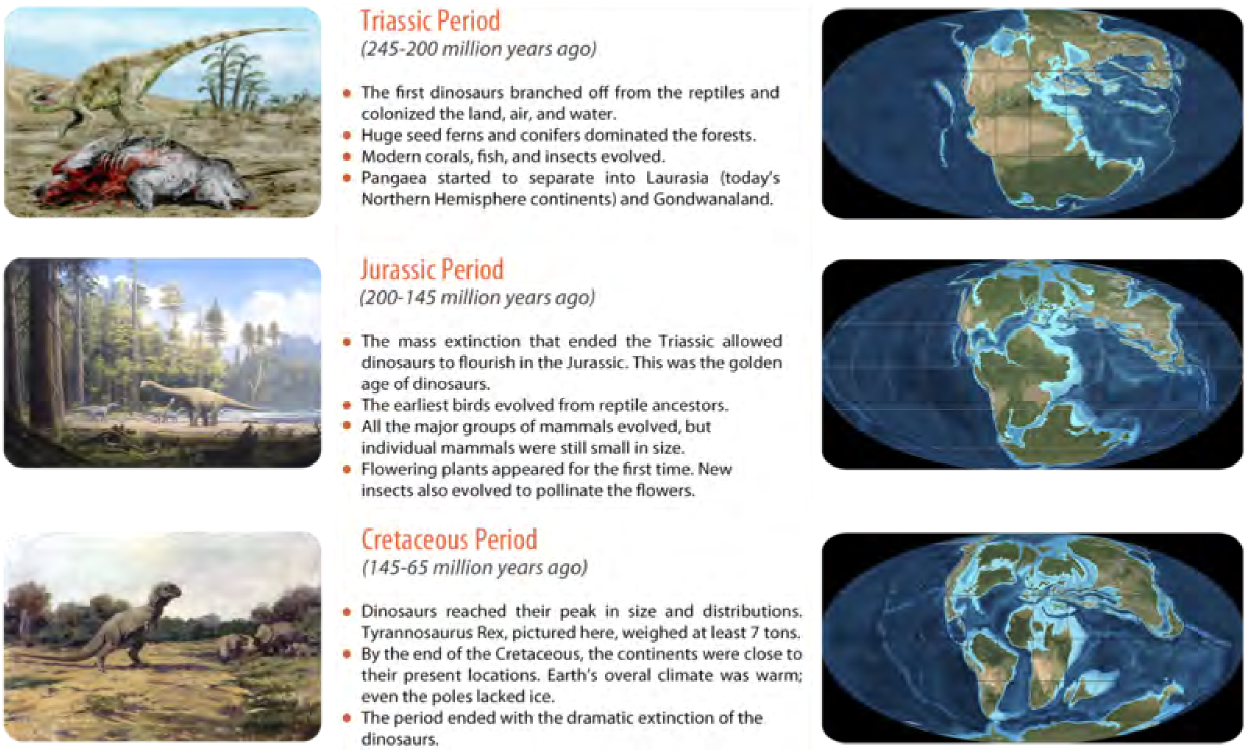


FIGURE 9.16

Mesozoic Era. The Mesozoic Era consists of the three periods described here.

The Triassic Period: During the Triassic Period (245–200 million years ago), the first dinosaurs branched off from the reptiles and colonized the land, air, and water. Huge seed ferns and conifers dominated the forests, and modern corals, fish, and insects evolved. The supercontinent Pangaea started to separate into **Laurasia** (today's Northern Hemisphere continents) and **Gondwanaland** (today's Southern Hemisphere continents). The Triassic Period ended with a mass extinction.

The Jurassic Period: The next period, the Jurassic Period (200–145 million years ago), began after the mass extinction that ended the Triassic Period. This mass extinction allowed dinosaurs to flourish in the Jurassic Period. This was the golden age of dinosaurs. Also during the Jurassic, the earliest birds evolved from reptile ancestors, and all the major groups of mammals evolved, but individual mammals were still small in size. Flowering plants appeared for the first time, and new insects also evolved to pollinate the flowers. The continents continued to move apart, and volcanic activity was especially intense.

The Cretaceous Period: During the Cretaceous Period (145–65 million years ago), dinosaurs reached their peak in size and distribution. *Tyrannosaurus Rex*, weighed at least 7 tons. By the end of the Cretaceous, the continents were close to their present locations. Earth's overall climate was warm; even the poles lacked ice. The period ended with the dramatic extinction of the dinosaurs.

What happened to the dinosaurs? Why did they go extinct at the end of the Cretaceous Period? Some scientists think a comet or asteroid may have collided with Earth, causing skies to darken, photosynthesis to shut down, and climates to change. A collision was probably at least a contributing factor. Without the dinosaurs, there were many opportunities for new organisms to exploit in the next era, the Cenozoic. Which living things do you think took over where the dinosaurs left off?

What happened to the dinosaurs? Why did they go extinct at the end of the Cretaceous Period? Some scientists think a comet or asteroid may have collided with Earth, causing skies to darken, photosynthesis to shut down, and climates to change. A collision was probably at least a contributing factor. Without the dinosaurs, there were many opportunities for new organisms to exploit in the next era, the Cenozoic. Which living things do you think took over where the dinosaurs left off?

Cenozoic Era: Age of Mammals

The **Cenozoic Era** literally means the era of "modern life." It is also called the age of mammals. Mammals took advantage of the extinction of the dinosaurs. They flourished and soon became the dominant animals on Earth. You can learn more about the evolution of mammals during the Cenozoic at the link below. The Cenozoic began 65 million years ago and continues to the present. It may be divided into the two periods described in **Figure** 9.17 . http://www.youtube.com/watch?v=H0uTGkCWXwQ

The Tertiary Period: During the Tertiary Period (65–1.8 million years ago), Earth's climate was generally warm and humid. Mammals evolved to fill virtually all niches vacated by dinosaurs. Many mammals increased in size. Mammals called **primates** evolved, including human ancestors. Modern rain forests and grasslands appeared, and flowering plants and insects were numerous and widespread.

The Quaternary Period: During the Quaternary Period (1.8 million years ago–present), Earth's climate cooled, leading to a series of ice ages. Sea levels fell because so much water was frozen in glaciers. This created land bridges between continents, allowing land animals to move to new areas. Some mammals, like the woolly mammoths adapted to the cold by evolving very large size and thick fur. Other animals moved closer to the equator or went extinct, along with many plants.

The last ice age ended about 12,000 years ago. By that time, our own species, *Homo sapiens*, had evolved. After that, we were witnesses to the unfolding of life's story. Although we don't know all the details of the recent past, it is far less of a mystery than the billions of years that preceded it.

KQED: The Last Ice Age

Imagine a vast grassy ecosystem covered with herds of elephants, bison and camels stretching as far as the eye can see. Africa? Maybe. But this also describes Northern California at the end of the last Ice Age. What happened to all this wildlife? Were they over hunted and killed off? Did global warming destroy their populations? Scientists are not sure, but this relatively recent loss of life does raise many interesting questions. See *Ice Age Bay Area* at http://www.kqed.org/quest/television/ice-age-bay-area2 for additional information.

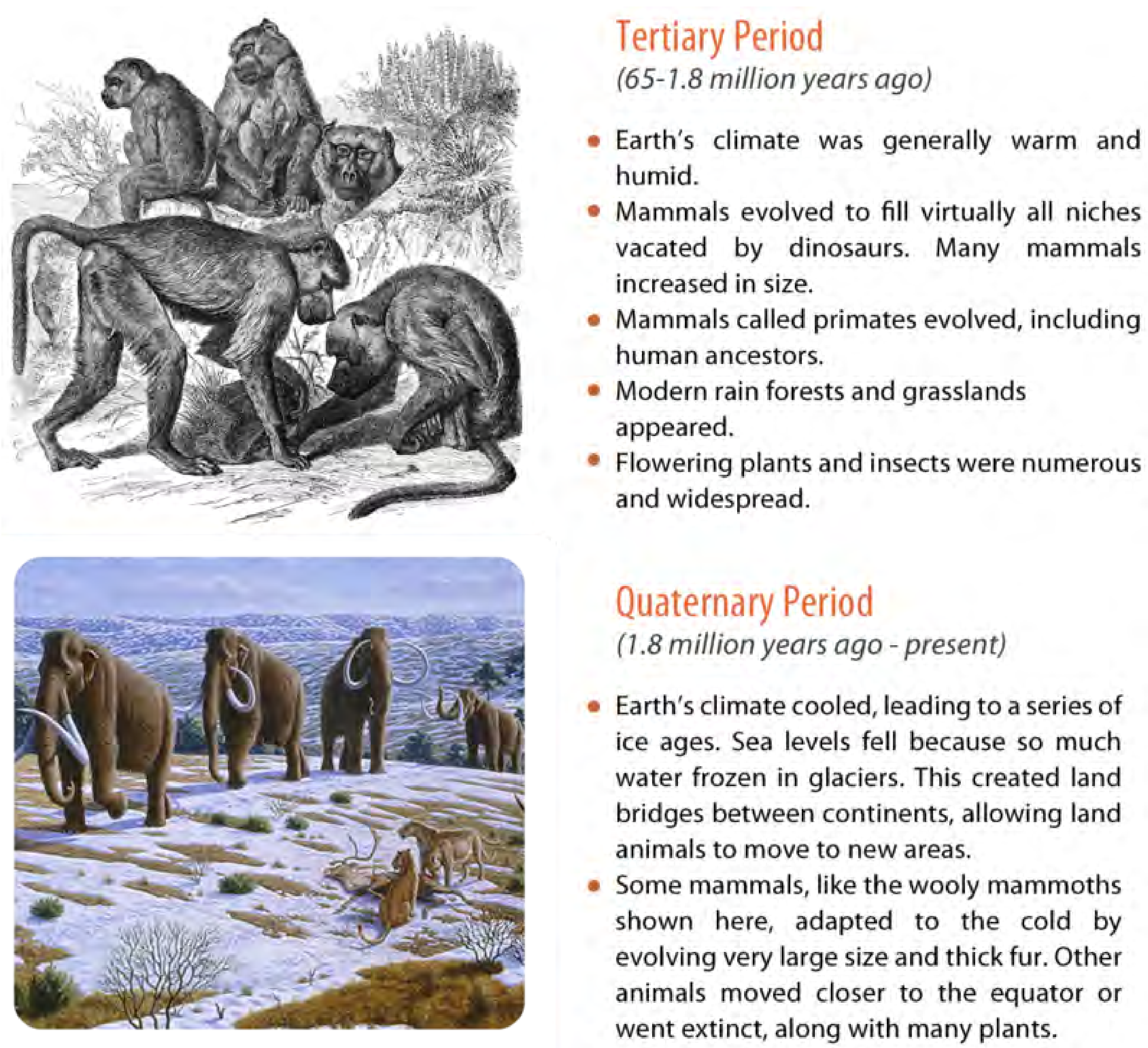


FIGURE 9.17

Cenozoic Era. One way of dividing the Cenozoic Era is into the two periods described here.

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Lesson Summary

- During the late Precambrian, continents drifted, carbon dioxide levels fluctuated, and climates changed. Many organisms could not survive the changes and died out. Others evolved important new adaptations. These include sexual reproduction, cell specialization, and multicellularity. The Precambrian ended with a mass extinction. It paved the way for the Cambrian explosion.
- The Paleozoic Era began with the Cambrian explosion. It ended with the Permian extinction. During the era, invertebrate animals diversified in the oceans. Plants, amphibians, and reptiles also moved to the land.
- The Mesozoic Era is the age of dinosaurs. They evolved from earlier reptiles to fill niches on land, in the water, and in the air. Mammals also evolved but were small in size. Flowering plants appeared for the first time. Dinosaurs went extinct at the end of the Mesozoic.
- The Cenozoic Era is the age of mammals. They evolved to fill virtually all the niches vacated by dinosaurs. The ice ages of the Quaternary Period of the Cenozoic led to many extinctions. The last ice age ended 12,000 years ago. By that time, *Homo sapiens* had evolved.

Lesson Review Questions

Recall

1. Describe geologic and climatic changes that occurred during the late Precambrian.
2. What is a mass extinction?
3. What is the relationship between the Precambrian extinction and the Cambrian explosion?
4. List several important evolutionary events that occurred during the Paleozoic Era.
5. Describe how the continents shifted during the Mesozoic Era.
6. What explains why mammals were able to flourish during Cenozoic Era?

Apply Concepts

7. Create a timeline of major evolutionary events during the Mesozoic and Cenozoic Eras. Include approximate dates in your timeline.

Think Critically

8. Explain the evolutionary advantages of sexual reproduction and multicellularity.
9. Relate the Permian, Triassic, and Cretaceous extinctions to the evolution and extinction of the dinosaurs.
10. Compare and contrast the Tertiary and Quaternary Periods of the Cenozoic Era.

Points to Consider

The human species evolved during the Cenozoic Era. The scientific name of the human species is *Homo sapiens*.

- Do you know what this name means? Do you know why species are given scientific names?
- What is a species? What determines whether a group of organisms is considered a species?

9.3 Classification

Lesson Objectives

- Outline the Linnaean classification, and define binomial nomenclature.
- Describe phylogenetic classification, and explain how it differs from Linnaean classification.

Vocabulary

binomial nomenclature method of naming species with two names, consisting of the genus name and species name

clade group of related organisms that includes an ancestor and all of its descendants

domain taxon in the revised Linnaean system that is larger and more inclusive than the kingdom

genus taxon above the species in the Linnaean classification system; group of closely related species

kingdom largest and most inclusive taxon in the original Linnaean classification system

Linnaean classification system system of classifying organisms based on observable physical traits; consists of a hierarchy of taxa, fro the kingdom to the species

phylogenetic tree diagram that shows how species are related to each other through common ancestors

phylogeny evolutionary history of a group of related organisms

species group of organisms that are similar enough to mate together and produce fertile offspring

taxa a grouping of organisms in a classification system such as the Linnaean system; for example, species or genus

taxonomy science of classifying organisms

Introduction

The evolution of life on Earth over the past 4 billion years has resulted in a huge variety of species. For more than 2,000 years, humans have been trying to classify the great diversity of life. The science of classifying organisms is called **taxonomy.** Classification is an important step in understanding the present diversity and past evolutionary history of life on Earth.

Linnaean Classification

All modern classification systems have their roots in the **Linnaean classification system.** It was developed by Swedish botanist Carolus Linnaeus in the 1700s. He tried to classify all living things that were known at his time. He grouped together organisms that shared obvious physical traits, such as number of legs or shape of leaves. For his contribution, Linnaeus is known as the "father of taxonomy." You can learn more about Linnaeus and his system of classification by watching the video at this link: http://teachertube.com/viewVideo.php?video_id=169889. The Linnaean system of classification consists of a hierarchy of groupings, called **taxa** (singular, taxon). Taxa range from the kingdom to the species (see **Figure** 9.18). The **kingdom** is the largest and most inclusive grouping. It consists of organisms that share just a few basic similarities. Examples are the plant and animal kingdoms. The **species** is the smallest and most exclusive grouping. It consists of organisms that are similar enough to produce fertile offspring together. Closely related species are grouped together in a **genus.**

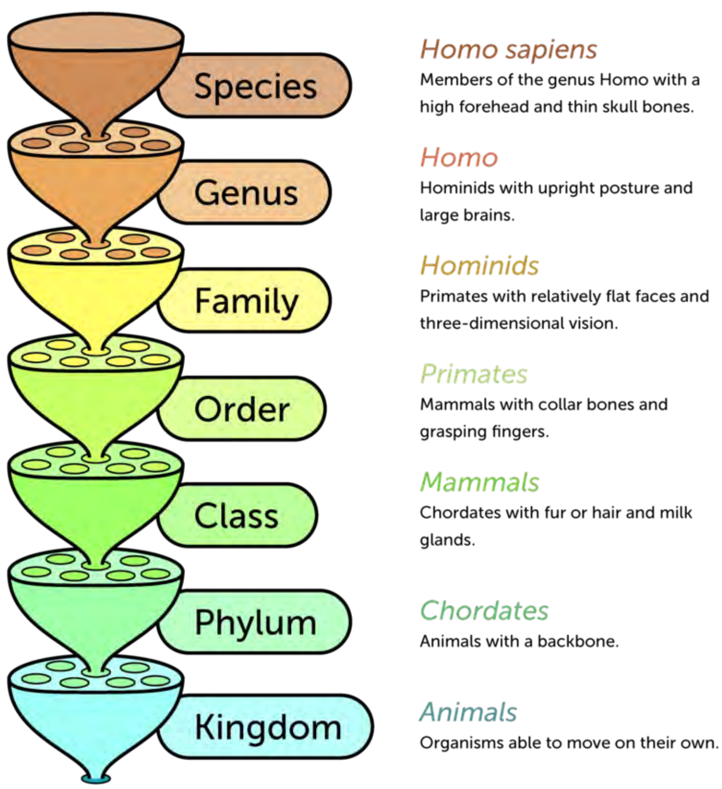

FIGURE 9.18
Linnaean Classification System Classification of the Human Species. This chart shows the taxa of the Linnaean classification system. Each taxon is a subdivision of the taxon below it in the chart. For example a species is a subdivision of a genus. The classification of humans is given in the chart as an example.

Binomial Nomenclature

Perhaps the single greatest contribution Linnaeus made to science was his method of naming species. This method, called **binomial nomenclature**, gives each species a unique, two-word Latin name consisting of the genus name and the species name. An example is *Homo sapiens*, the two-word Latin name for humans. It literally means "wise human." This is a reference to our big brains. Why is having two names so important? It is similar to people having a first and a last name. You may know several people with the first name Michael, but adding Michael's last name usually pins down exactly whom you mean. In the same way, having two names uniquely identifies a species.

Revisions in Linnaean Classification

Linnaeus published his classification system in the 1700s. Since then, many new species have been discovered. The biochemistry of organisms has also become known. Eventually, scientists realized that Linnaeus's system of classification needed revision. A major change to the Linnaean system was the addition of a new taxon called the domain. A **domain** is a taxon that is larger and more inclusive than the kingdom. Most biologists agree there are three domains of life on Earth: Bacteria, Archaea, and Eukaryota (see **Figure** 9.19). Both Bacteria and Archaea consist of single-celled prokaryotes. Eukaryota consists of all eukaryotes, from single-celled protists to humans. This domain includes the Animalia (animals), Plantae (plants), Fungi (fungi), and Protista (protists) kingdoms.

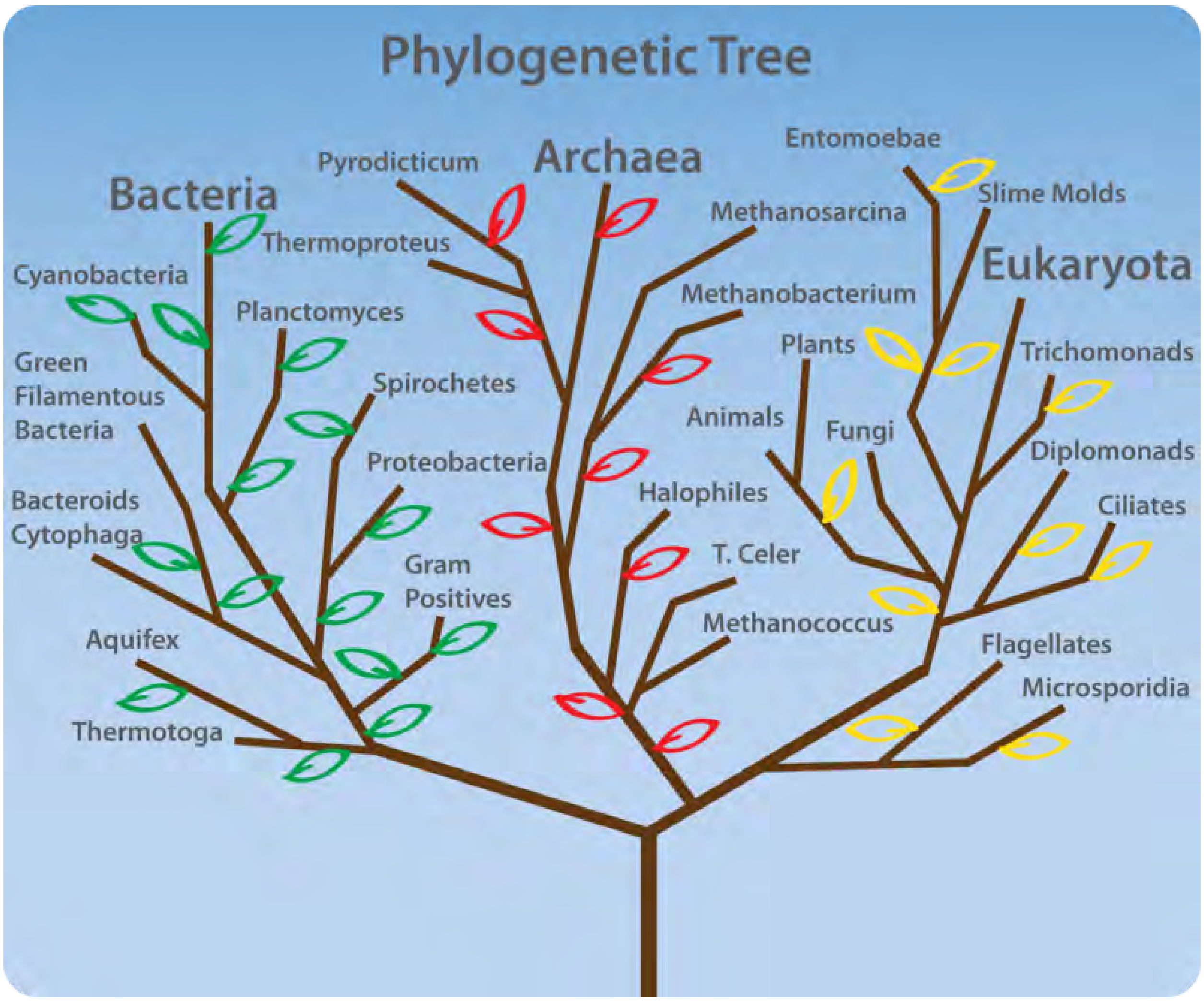

FIGURE 9.19

Three-Domain Classification. This diagram shows the three domains of organisms that currently live on Earth.

Phylogenetic Classification

Linnaeus classified organisms based on obvious physical traits. Basically, organisms were grouped together if they looked alike. After Darwin published his theory of evolution in the 1800s (discussed in the following chapter), scientists looked for a way to classify organisms that showed phylogeny. **Phylogeny** is the evolutionary history of a group of related organisms. It is represented by a **phylogenetic tree**, like the one in **Figure** 9.20 .

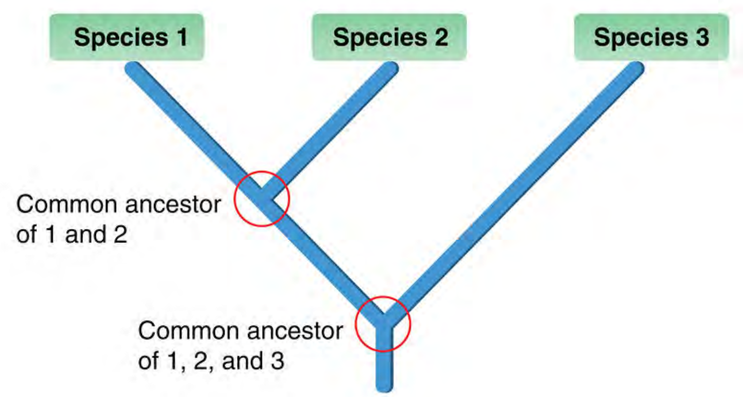

FIGURE 9.20
Phylogenetic Tree. This phylogenetic tree shows how three hypothetical species are related to each other through common ancestors. Do you see why Species 1 and 2 are more closely related to each other than either is to Species 3

One way of classifying organisms that shows phylogeny is by using the clade. A **clade** is a group of organisms that includes an ancestor and all of its descendants. Clades are based on cladistics. This is a method of comparing traits in related species to determine ancestor-descendant relationships. Clades are represented by cladograms, like the one in **Figure** 9.21 . This cladogram represents the mammal and reptile clades. The reptile clade includes birds. It shows that birds evolved from reptiles. Linnaeus classified mammals, reptiles, and birds in separate classes. This masks their evolutionary relationships.

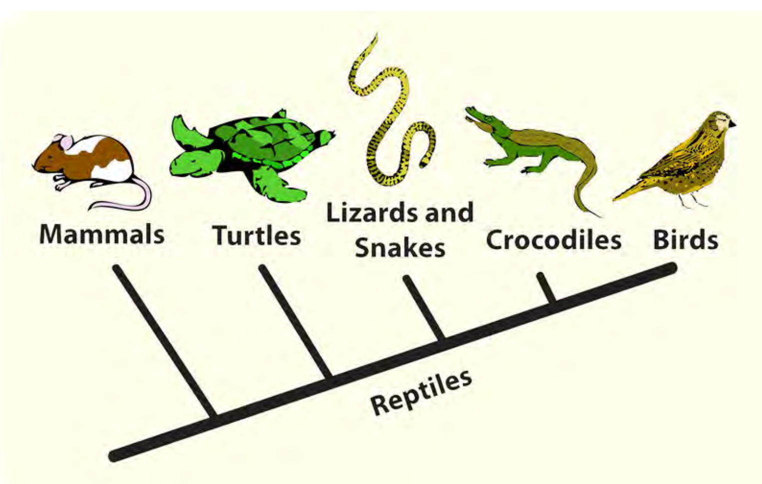

FIGURE 9.21
Mammal and Reptile Clades. This cladogram classifies mammals reptiles and birds in clades based on their evolutionary relationships.

Lesson Summary

- Classification is an important step in understanding life on Earth. All modern classification systems have their roots in the Linnaean classification system. The Linnaean system is based on similarities in obvious physical traits. It consists of a hierarchy of taxa, from the kingdom to the species. Each species is given a unique two-word Latin name. The recently added domain is a larger and more inclusive taxon than the kingdom.
- Phylogeny is the evolutionary history of group of related organisms. It is represented by a phylogenetic tree that shows how species are related to each other through common ancestors. A clade is a group of organisms that includes an ancestor and all of its descendants. It is a phylogenetic classification, based on evolutionary relationships.

Lesson Review Questions

Recall

1. What is taxonomy?

2. Define taxon and give an example.

3. What is binomial nomenclature? Why is it important?

4. What is a domain? What are the three domains of life on Earth?

5. What is cladistics, and what is it used for?

Apply Concepts

6. Create a taxonomy, modeled on the Linnaean classification system, for a set of common objects, such as motor vehicles, tools, or office supplies. Identify the groupings that correspond to the different taxa in the Linnaean system.

7. Dogs and wolves are more closely related to each other than either is to cats. Draw a phylogenetic tree to show these relationships.

Think Critically

8. Compare and contrast a Linnaean taxon, such as the family or genus, with the clade.

9. Explain why reptiles and birds are placed in the same clade.

Points to Consider

This chapter gives you a glimpse of 4 billion years of evolution on Earth. In the next chapter, you will read about the forces that bring about evolution. Natural selection is one of these forces. It generally results in a population or species becoming better adapted to its environment over time.

- How does natural selection work? How does it bring about evolutionary change?
- What might be the other forces of evolution?

CHAPTER 10 The Theory of Evolution

CHAPTER OUTLINE

The Grand Canyon, shown here, is an American icon and one of the wonders of the natural world. It's also a record of the past. Look at the rock layers in the picture. If you were to walk down a trail to the bottom of the canyon, with each step down you would be taking a step back in time. That's because lower layers of rock represent the more distant past. The rock layers and the fossils they contain show the history of Earth and its organisms over a 2-billion-year time span. Although Charles Darwin never visited the Grand Canyon, he saw rock layers and fossils in other parts of the world. They were one inspiration for his theory of evolution. Darwin's theory rocked the scientific world. In this chapter, you will read why.

10.1 Darwin and the Theory of Evolution

Lesson Objectives

- State Darwin's theory of evolution by natural selection.
- Describe observations Darwin made on the voyage of the *Beagle*.
- Identify influences on Darwin's development of evolutionary theory.
- Explain how a species can evolve through natural selection.

Vocabulary

artificial selection process in which organisms evolve traits useful to humans because people select which individuals are allowed to reproduce and pass on their genes to successive generations

fitness relative ability of an organism to survive and produce fertile offspring

Galápagos Islands group of 16 small volcanic islands in the Pacific Ocean 966 kilometers (600 miles) off the west coast of South America, where Darwin made some of his most important observations during his voyage on the *HMS Beagle*

inheritance of acquired characteristics mistaken idea of Jean Baptiste Lamarck that evolution occurs through the inheritance of traits that an organism develops in its own life time

Introduction

The Englishman Charles Darwin is one of the most famous scientists who ever lived. His place in the history of science is well deserved. Darwin's theory of evolution represents a giant leap in human understanding. It explains and unifies all of biology.

An overview of evolution can be seen at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/0/GcjgWov7mTM (17:39).

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Darwin's Theory at a Glance

Darwin's theory of evolution actually contains two major ideas:

a. One idea is that evolution occurs. In other words, organisms change over time. Life on Earth has changed as descendants diverged from common ancestors in the past.
b. 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 than others do. This results in changes in the traits of living things over time.

In Darwin's day, most people believed that all species were created at the same time and remained unchanged thereafter. They also believed that Earth was only 6,000 years old. Therefore, Darwin's ideas revolutionized biology. How did Darwin come up with these important ideas? It all started when he went on a voyage.

The Voyage of the

In 1831, when Darwin was just 22 years old, he set sail on a scientific expedition on a ship called the *HMS Beagle*. He was the naturalist on the voyage. As a naturalist, it was his job to observe and collect specimens of plants, animals, rocks, and fossils wherever the expedition went ashore. The route the ship took and the stops they made are shown in **Figure** 10.1 . You can learn more about Darwin's voyage at this link: http://www.aboutdarwin.com/voyage/voyage03.html.

FIGURE 10.1

Voyage of the Beagle. This map shows the route of Darwin&#8217 s 5-year voyage on the HMS Beagle. Each stop along the way is labeled. Darwin and the others on board eventually circled the globe.

Darwin was fascinated by nature, so he loved his job on the *Beagle.* He spent more than 3 years of the 5-year trip exploring nature on distant continents and islands. While he was away, a former teacher published Darwin's accounts of his observations. By the time Darwin finally returned to England, he had become famous as a naturalist.

Darwin's Observations

During the long voyage, Darwin made many observations that helped him form his theory of evolution. For example:

- He visited tropical rainforests and other new habitats where he saw many plants and animals he had never seen before (see **Figure** 10.2). This impressed him with the great diversity of life.

- He experienced an earthquake that lifted the ocean floor 2.7 meters (9 feet) above sea level. He also found rocks containing fossil sea shells in mountains high above sea level. These observations suggested that continents and oceans had changed dramatically over time and continue to change in dramatic ways.
- He visited rock ledges that had clearly once been beaches that had gradually built up over time. This suggested that slow, steady processes also change Earth's surface.
- He dug up fossils of gigantic extinct mammals, such as the ground sloth (see **Figure** 10.2). This was hard evidence that organisms looked very different in the past. It suggested that living things—like Earth's surface—change over time.

FIGURE 10.2

On his voyage Darwin saw giant marine iguanas and blue-footed boobies. He also dug up the fossil skeleton of a giant ground sloth like the one shown here. From left Giant Marine Iguana Blue-Footed Boobies and Fossil Skeleton of a Giant Ground Sloth

The Galápagos Islands

Darwin's most important observations were made on the **Galápagos Islands** (see map in **Figure** 10.3). This is a group of 16 small volcanic islands 966 kilometers (600 miles) off the west coast of South America.

Individual Galápagos islands differ from one another in important ways. Some are rocky and dry. Others have better soil and more rainfall. Darwin noticed that the plants and animals on the different islands also differed. For example, the giant tortoises on one island had saddle-shaped shells, while those on another island had dome-shaped shells (see **Figure** 10.4). People who lived on the islands could even tell the island a turtle came from by its shell. This started Darwin thinking about the origin of species. He wondered how each island came to have its own type of tortoise.

Influences on Darwin

Science, like evolution, always builds on the past. Darwin didn't develop his theory completely on his own. He was influenced by the ideas of earlier thinkers.

Earlier Thinkers Who Influenced Darwin

a. Jean Baptiste Lamarck (1744–1829) was an important French naturalist. He was one of the first scientists to propose that species change over time. However, Lamarck was wrong about how species change. His idea of the **inheritance of acquired characteristics** is incorrect. Traits an organism develops during its own life time cannot be passed on to offspring, as Lamarck believed.

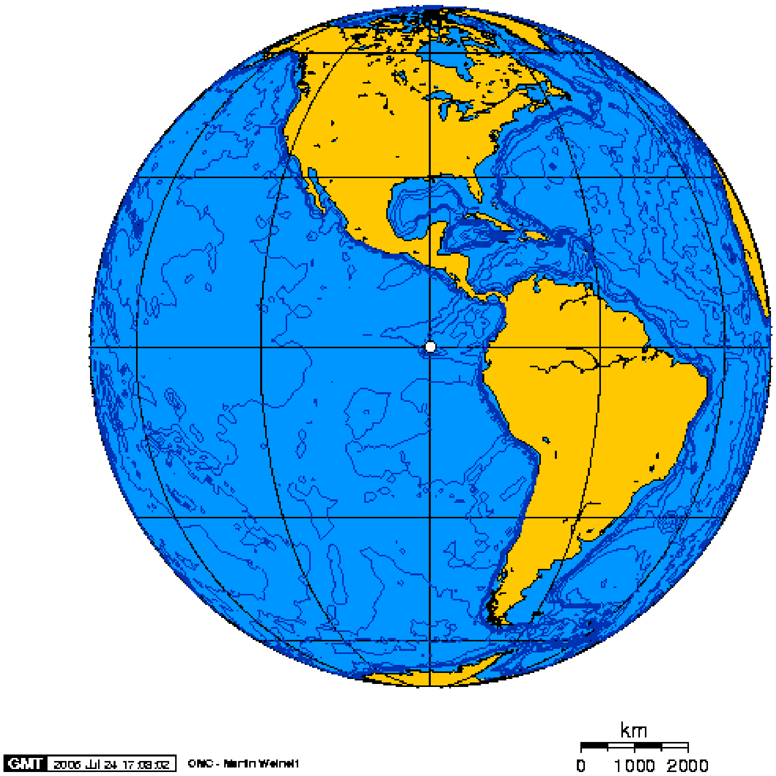


FIGURE 10.3

Gal&#225 pagos Islands. This map shows the location of the Gal&#225 pagos Islands that Darwin visited on his voyage.

Tortoise with saddle-shaped shell

Tortoise with dome-shaped shell

FIGURE 10.4

Gal&#225 pagos Tortoises. Gal&#225 pagos tortoises have differently shaped shells depending on which island they inhabit. Tortoises with saddle-shaped shells can reach up to eat plant leaves above their head. Tortoises with dome-shaped shells cannot reach up in this way. These two types of tortoises live on islands with different environments and food sources. How might this explain the differences in their shells

b. Charles Lyell (1797–1875) was a well-known English geologist. Darwin took his book, *Principles of Geology,* with him on the *Beagle*. In the book, Lyell argued that gradual geological processes have gradually shaped Earth's surface. From this, Lyell inferred that Earth must be far older than most people believed.
c. Thomas Malthus (1766–1834) was an English economist. He wrote an essay titled *On Population*. In the essay, Malthus argued that human populations grow faster than the resources they depend on. When populations become too large, famine and disease break out. In the end, this keeps populations in check by killing off the weakest members.

Artificial Selection

These weren't the only influences on Darwin. He was also aware that humans could breed plants and animals to have useful traits. By selecting which animals were allowed to reproduce, they could change an organism's traits. The pigeons in **Figure** 10.5 are good examples. Darwin called this type of change in organisms **artificial selection**. He used the word *artificial* to distinguish it from natural selection.

FIGURE 10.5

Artificial Selection in Pigeons. Pigeon hobbyists breed pigeons to have certain characteristics. All three of the pigeons in the bottom row were bred from the common rock pigeon.

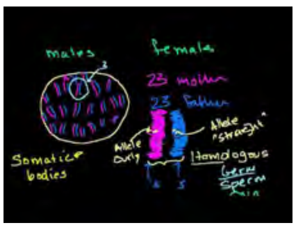
Wallace's Theory

Did you ever hear the saying that "great minds think alike?" It certainly applies to Charles Darwin and another English naturalist named Alfred Russel Wallace. Wallace lived at about the same time as Darwin. He also traveled to distant places to study nature. Wallace wasn't as famous as Darwin. However, he developed basically the same theory of evolution. While working in distant lands, Wallace sent Darwin a paper he had written. In the paper, Wallace explained his evolutionary theory. This served to confirm what Darwin already thought.

Darwin's Theory of Evolution by Natural Selection

Darwin spent many years thinking about the work of Lamarck, Lyell, and Malthus, what he had seen on his voyage, and artificial selection. What did all this mean? How did it all fit together? It fits together in Darwin's theory of evolution by natural selection. It's easy to see how all of these influences helped shape Darwin's ideas.

For a discussion of the underlying causes of natural selection and evolution see http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/5/DuArVnT1i-E (19:51).



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Evolution of Darwin's Theory

It took Darwin years to form his theory of evolution by natural selection. His reasoning went like this:

a. Like Lamarck, Darwin assumed that species can change over time. The fossils he found helped convince him of that.
b. From Lyell, Darwin saw that Earth and its life were very old. Thus, there had been enough time for evolution to produce the great diversity of life Darwin had observed.
c. From Malthus, Darwin knew that populations could grow faster than their resources. This "overproduction of offspring" led to a "struggle for existence," in Darwin's words.
d. From artificial selection, Darwin knew that some offspring have chance variations that can be inherited. In nature, offspring with certain variations might be more likely to survive the "struggle for existence" and reproduce. If so, they would pass their favorable variations to their offspring.
e. Darwin coined the term **fitness** to refer to an organism's relative ability to survive and produce fertile offspring. Nature selects the variations that are most useful. Therefore, he called this type of selection natural selection.
f. Darwin knew artificial selection could change domestic species over time. He inferred that natural selection could also change species over time. In fact, he thought that if a species changed enough, it might evolve into a new species.

Wallace's paper not only confirmed Darwin's ideas. They pushed him to finish his book, *On the Origin of Species.* Published in 1859, this book changed science forever. It clearly spelled out Darwin's theory of evolution by natural selection and provided convincing arguments and evidence to support it.

Applying Darwin's Theory

The following example applies Darwin's theory. It explains how giraffes came to have such long necks (see **Figure** 10.6).

- In the past, giraffes had short necks. But there was chance variation in neck length. Some giraffes had necks a little longer than the average.

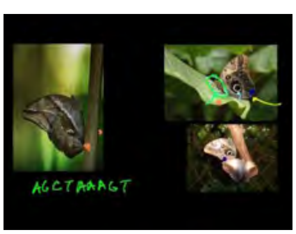
- Then, as now, giraffes fed on tree leaves. Perhaps the environment changed, and leaves became scarcer. There would be more giraffes than the trees could support. Thus, there would be a "struggle for existence."
- Giraffes with longer necks had an advantage. They could reach leaves other giraffes could not. Therefore, the long-necked giraffes were more likely to survive and reproduce. They had greater fitness.
- These giraffes passed the long-neck trait to their offspring. Each generation, the population contained more long-necked giraffes. Eventually, all giraffes had long necks.

FIGURE 10.6

African Giraffes. Giraffes feed on leaves high in trees. Their long necks allow them to reach leaves that other ground animals cannot.

As this example shows, chance variations may help a species survive if the environment changes. Variation among species helps ensure that at least one will be able to survive environmental change.

A summary of Darwin's ideas are presented in the *Natural Selection and the Owl Butterfly* video: http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/3/dR_BFmDMRaI (13:29).



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KQED: Chasing Beatles, Finding Darwin

It's been over 150 years since Charles Darwin published *On the Origin of Species*. Yet his ideas remain as central to scientific exploration as ever, and has been called the *unifying* concept of all biology. Is evolution continuing today? Of course it is.

QUEST follows researchers who are still unlocking the mysteries of evolution, including entomologist David Kavanaugh of the California Academy of Sciences, who predicted that a new beetle species would be found on the Trinity Alps of Northern California. See http://www.kqed.org/quest/television/chasing-beetles-finding-darwin2 for more information.

It's rare for a biologist to predict the discovery of a new species – even for someone like Kavanaugh, who has discovered many new species. For his prediction, Kavanaugh drew inspiration from Darwin's own 1862 prediction. When Darwin observed an orchid from Madagascar with a foot-long nectare, he predicted that a pollinator would be found with a tongue long enough to reach the nectar inside the orchid's very thin, elongated nectar "pouch," though he had never seen such a bird or insect. Darwin's prediction was based on his finding that all species are related to each other and that some of them evolve together, developing similar adaptations. His prediction came true in 1903, when a moth was discovered in Madagascar with a long, thin proboscis, which it uncurls to reach the nectar in the orchid's nectare. In the process of feeding from the orchid, the moth serves as its pollinator. The moth was given the scientific name *Xanthopan morganii praedicta*, in honor of Darwin's prediction.

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KQED: The California Academy of Sciences

Founded in 1853 as the first scientific institution in the western United States, the California Academy of Sciences' mission is to explore, explain, and protect the natural world. The California Academy of Sciences has the largest collection of biological reference materials west of the Mississippi River. Dating back over 100 years, the collection provides a treasure trove of biological information for scientists and researchers studying the natural world http://www.calacademy.org/.

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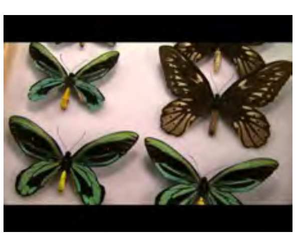
Norman Penny, collections manager of the entomology department of the California Academy of Sciences, gives QUEST viewers a peek at the California Academy of Sciences vast butterfly collection, and discusses the evolutionary importance of butterflies. See http://www.kqed.org/quest/television/cal-academy-butterfly-collection for additional information.



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KQED: The Farallon Islands: California's Galapagos

As one of 552 designated National Wildlife Refuges, the Farallon Islands are virtually uninhabited by humans. These islands are home to the largest seabird breeding colony in the contiguous United States. The Farallon Islands also have a rich diversity of marine life. They are the spawning grounds for numerous fish and invertebrate species, and at least 36 species of marine mammals have been observed in surrounding waters. This unique and fragile ecosystem has informally earned these islands the name *the Galapagos of California.*

Lying just 28 miles off the coast of California, the Farallon Islands sits amid one of the most productive marine food webs on the planet. Ventures out for a visit to learn what life is like on the islands and meet the scientists who call this incredibly wild place home at http://www.kqed.org/quest/television/the-farallon-islands–californias-galapagos.

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Lesson Summary

- Darwin's theory of evolution by natural selection states that living things with beneficial traits produce more offspring than others do. This produces changes in the traits of living things over time.
- During his voyage on the *Beagle*, Darwin made many observations that helped him develop his theory of evolution. His most important observations were made on the Galápagos Islands.
- Darwin was influenced by other early thinkers, including Lamarck, Lyell, and Malthus. He was also influenced by his knowledge of artificial selection.
- Wallace's paper on evolution confirmed Darwin's ideas. It also pushed him to publish his book, *On the Origin of Species.* The book clearly spells out his theory. It also provides evidence and logic to support it.

Lesson Review Questions

Recall

1. State Darwin's theory of evolution by natural selection.

2. Describe two observations Darwin made on his voyage on the *Beagle* that helped him develop his theory of evolution.

3. What is the inheritance of acquired characteristics? What scientist developed this mistaken idea?

4. What is artificial selection? How does it work?

5. How did Alfred Russel Wallace influence Darwin?

Apply Concepts

6. Apply Darwin's theory of evolution by natural selection to a specific case. For example, explain how Galápagos tortoises could have evolved saddle-shaped shells.

Think Critically

7. Why did Darwin's observations of Galápagos tortoises cause him to wonder how species originate?

8. Explain how the writings of Charles Lyell and Thomas Malthus helped Darwin develop his theory of evolution by natural selection.

Points to Consider

Darwin's book *On the Origin of Species* is a major milestone in science. It introduced biology's most important theory. It also provided an excellent example of how to think like a scientist. A scientist uses evidence and logic to understand the natural world. In this lesson, you read about some of the evidence Darwin used. This evidence included fossils and artificial selection.

- What other evidence might be used to show that evolution occurs? What about evidence based on molecules?
- Do you think it's possible to see evolution occurring? How might that happen?

10.2 Evidence for Evolution

Lesson Objectives

- Describe how fossils help us understand the past.
- Explain how evidence from living species gives clues about evolution.
- State how biogeography relates to evolutionary change.

Vocabulary

adaptive radiation process by which a single species evolves into many new species to fill available niches

analogous structure structure that is similar in unrelated organisms because it evolved to do the same job, not because it was inherited from a common ancestor

biogeography study of how and why plants and animals live where they do

comparative anatomy study of the similarities and differences in the structures of different species

comparative embryology study of the similarities and differences in the embryos of different species

homologous structure structure that is similar in related organisms because it was inherited from a common ancestor

paleontologist scientist who finds and studies fossils to learn about evolution and understand the past

vestigial structure structure such as the human tailbone or appendix that evolution has reduced in size because it is no longer used

Introduction

In his book *On the Origin of Species,* Darwin included a lot of evidence to show that evolution had taken place. He also made logical arguments to support his theory that evolution occurs by natural selection. Since Darwin's time, much more evidence has been gathered. The evidence includes a huge number of fossils. It also includes more detailed knowledge of living things, right down to their DNA.

Fossil Evidence

Fossils are a window into the past. They provide clear evidence that evolution has occurred. Scientists who find and study fossils are called **paleontologists**. How do they use fossils to understand the past? Consider the example of the horse, shown in **Figure** 10.7 . The fossil record shows how the horse evolved.

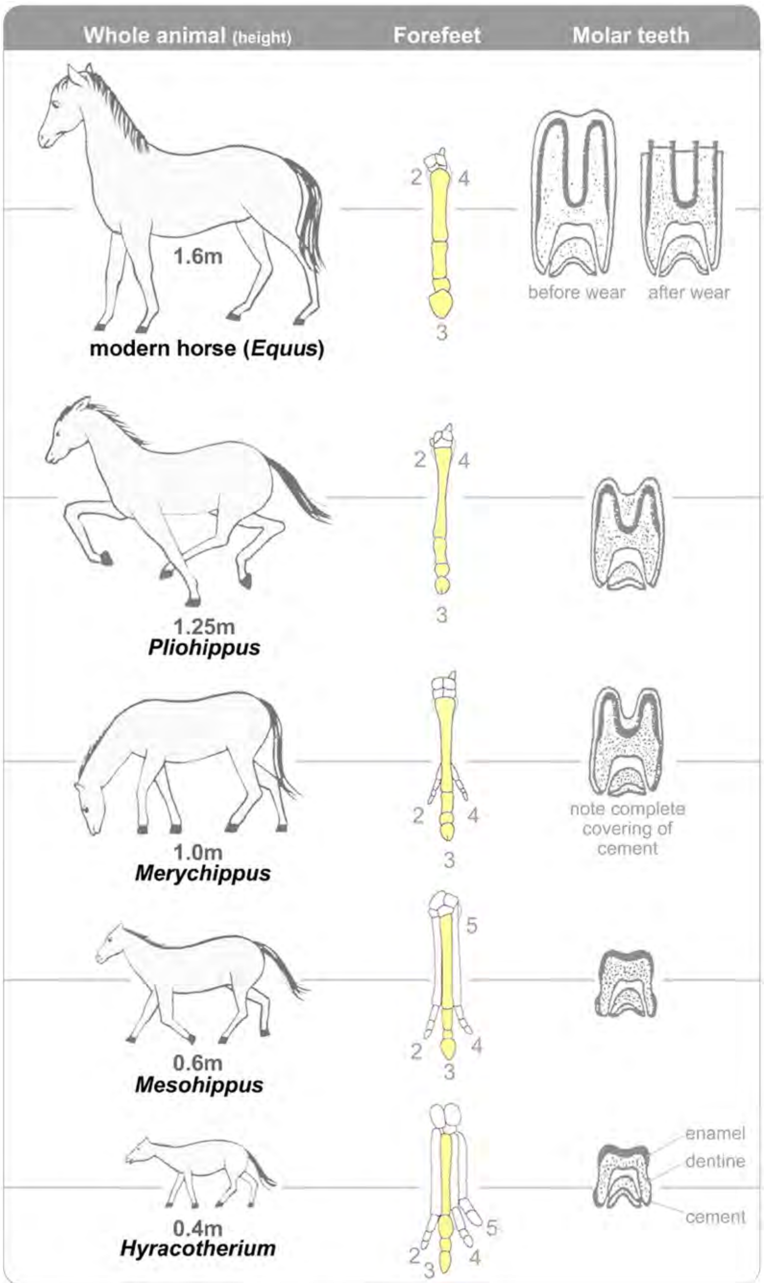


FIGURE 10.7
Evolution of the Horse. The fossil record reveals how horses evolved.

The oldest horse fossils show what the earliest horses were like. They were about the size of a fox, and they had four long toes. Other evidence shows they lived in wooded marshlands, where they probably ate soft leaves. Through time, the climate became drier, and grasslands slowly replaced the marshes. Later fossils show that horses changed as well.

- They became taller, which would help them see predators while they fed in tall grasses.
- They evolved a single large toe that eventually became a hoof. This would help them run swiftly and escape predators.
- Their molars (back teeth) became longer and covered with cement. This would allow them to grind tough grasses and grass seeds without wearing out their teeth.

Similar fossil evidence demonstrates the evolution of the whale, moving from the land into the sea. An animation of this process can be viewed at http://collections.tepapa.govt.nz/exhibitions/whales/Segment.aspx?irn=161.

Does The Fossil Record Support Evolution? This video can be seen at http://www.youtube.com/watch?v=QWVoXZPOCGk (9:20).

Evidence from Living Species

Just as Darwin did, today's scientists study living species to learn about evolution. They compare the anatomy, embryos, and DNA of modern organisms to understand how they evolved.

Comparative Anatomy

Comparative anatomy is the study of the similarities and differences in the structures of different species. Similar body parts may be homologies or analogies. Both provide evidence for evolution.

Homologous structures are structures that are similar in related organisms because they were inherited from a common ancestor. These structures may or may not have the same function in the descendants. **Figure** 10.8 shows the hands of several different mammals. They all have the same basic pattern of bones. They inherited this pattern from a common ancestor. However, their forelimbs now have different functions.

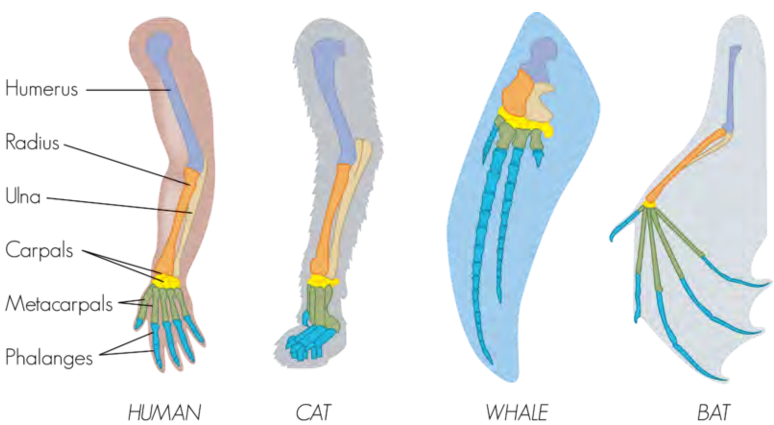


FIGURE 10.8
Hands of Different Mammals. The forelimbs of all mammals have the same basic bone structure.

Analogous structures are structures that are similar in unrelated organisms. The structures are similar because they evolved to do the same job, not because they were inherited from a common ancestor. For example, the wings of bats and birds, shown in **Figure** 10.9 , look similar on the outside. They also have the same function. However, wings evolved independently in the two groups of animals. This is apparent when you compare the pattern of bones inside the wings.

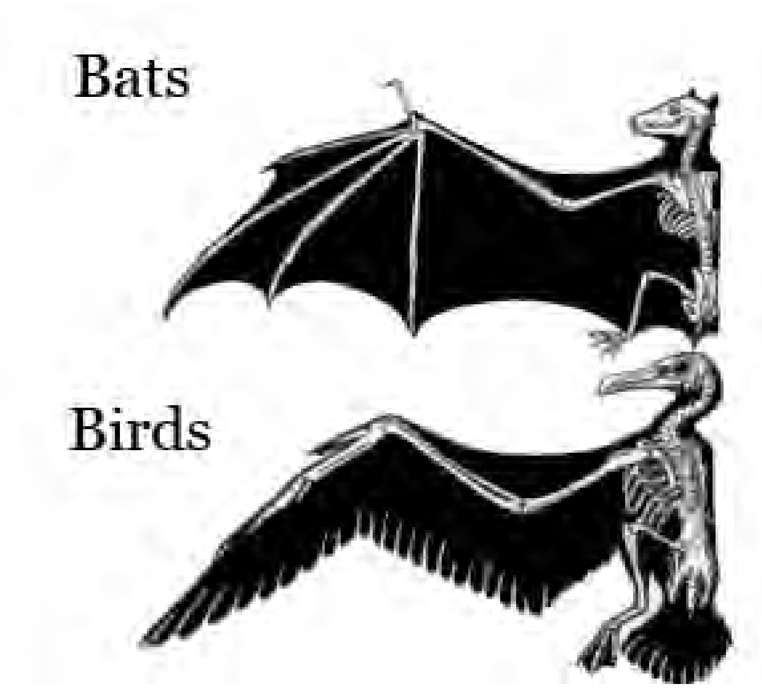


FIGURE 10.9
Wings of Bats and Birds. Wings of bats and birds serve the same function. Look closely at the bones inside the wings. The differences show they developed from different ancestors.

Comparative Embryology

Comparative embryology is the study of the similarities and differences in the embryos of different species. Similarities in embryos are evidence of common ancestry. All vertebrate embryos, for example, have gill slits and tails, as shown in **Figure** 10.10 . All of the animals in the figure, except for fish, lose their gill slits by adulthood. Some of them also lose their tail. In humans, the tail is reduced to the tail bone. Thus, similarities organisms share as embryos may be gone by adulthood. This is why it is valuable to compare organisms in the embryonic stage.

Vestigial Structures

Structures like the human tail bone are called **vestigial structures**. Evolution has reduced their size because the structures are no longer used. The human appendix is another example of a vestigial structure. It is a tiny remnant of a once-larger organ. In a distant ancestor, it was needed to digest food. It serves no purpose in humans today. Why do you think structures that are no longer used shrink in size? Why might a full-sized, unused structure reduce an organism's fitness?

Comparing DNA

Darwin could compare only the anatomy and embryos of living things. Today, scientists can compare their DNA. Similar DNA sequences are the strongest evidence for evolution from a common ancestor. Look at the cladogram in **Figure** 10.11 . It shows how humans and apes are related based on their DNA sequences.

Evolution and molecules are discussed at http://www.youtube.com/watch?v=nvJFI3ChOUU (3:52).

Using various types of information to understand evolutionary relationships is discussed in the following videos: http://www.youtube.com/watch?v=aZc1t2Os6UU (3:38), http://www.youtube.com/watch?v=6IRz85QNjz0 (6:45), http

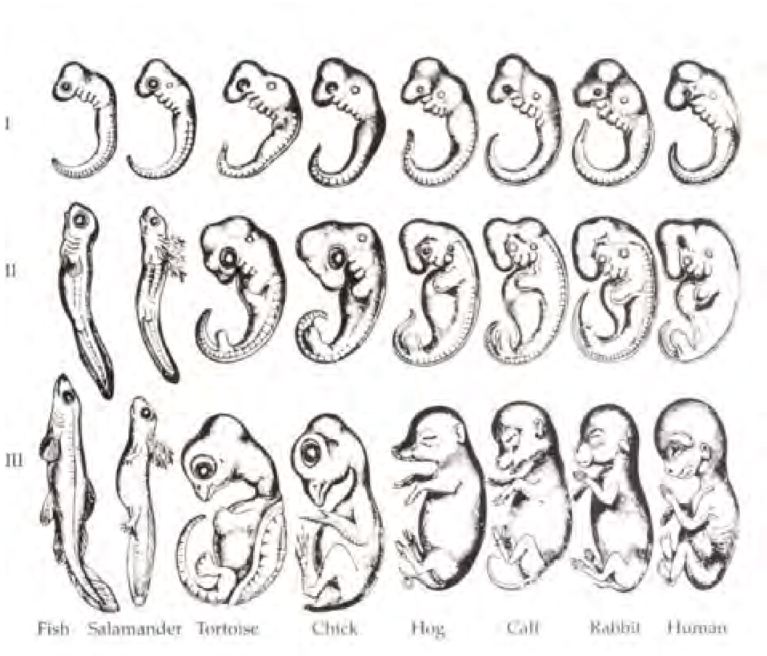


FIGURE 10.10

Vertebrate Embryos. Embryos of different vertebrates look much more similar than the adult organisms do.

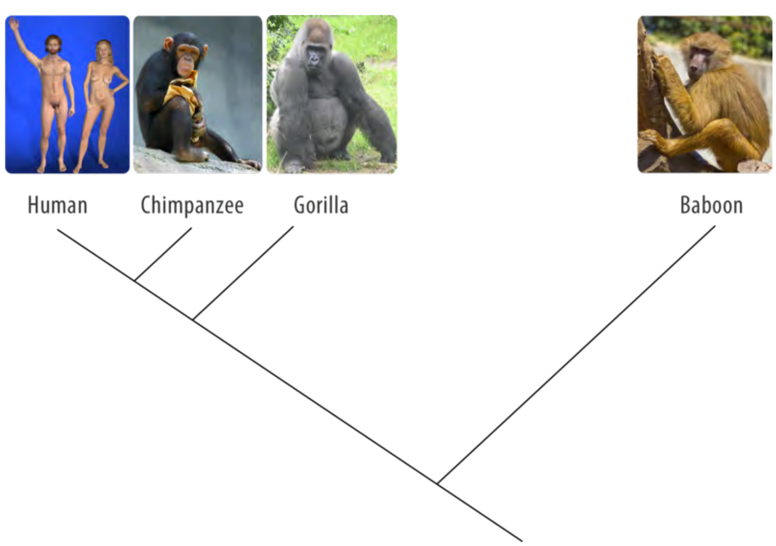


FIGURE 10.11

Cladogram of Humans and Apes. This cladogram is based on DNA comparisons. It shows how humans are related to apes by descent from common ancestors.

://www.youtube.com/watch?v=JgyTVT3dqGY#38;feature=related (10:51).

KQED: The Reverse Evolution Machine

In search of the common ancestor of all mammals, University of California Santa Cruz scientist David Haussler is pulling a complete reversal. Instead of studying fossils, he's comparing the genomes of living mammals to construct a map of our common ancestors' DNA. His technique holds promise for providing a better picture of how life evolved. See http://www.kqed.org/quest/television/the-reverse-evolution-machine for more information.

Evidence from Biogeography

Biogeography is the study of how and why plants and animals live where they do. It provides more evidence for evolution. Let's consider the camel family as an example.

Biogeography of Camels: An Example

Today, the camel family includes different types of camels. They are shown in **Figure** 10.12 . All of today's camels are descended from the same camel ancestors. These ancestors lived in North America about a million years ago.

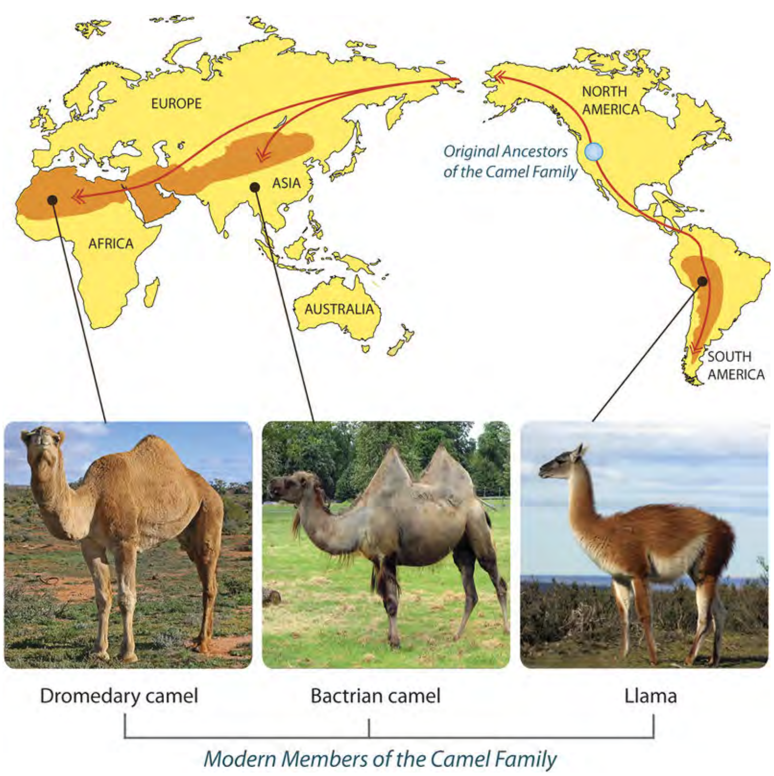


FIGURE 10.12
Camel Migrations and Present-Day Variation. Members of the camel family now live in different parts of the world. They differ from one another in a number of traits. However they share basic similarities. This is because they all evolved from a common ancestor. What differences and similarities do you see

Early North American camels migrated to other places. Some went to East Asia. They crossed a land bridge during the last ice age. A few of them made it all the way to Africa. Others went to South America. They crossed the Isthmus of Panama. Once camels reached these different places, they evolved independently. They evolved adaptations that suited them for the particular environment where they lived. Through natural selection, descendants of the original camel ancestors evolved the diversity they have today.

Island Biogeography

The biogeography of islands yields some of the best evidence for evolution. Consider the birds called finches that Darwin studied on the Galápagos Islands (see **Figure** 10.13). All of the finches probably descended from one bird that arrived on the islands from South America. Until the first bird arrived, there had never been birds on the islands. The first bird was a seed eater. It evolved into many finch species. Each species was adapted for a different type of food. This is an example of **adaptive radiation**. This is the process by which a single species evolves into many new species to fill available niches.

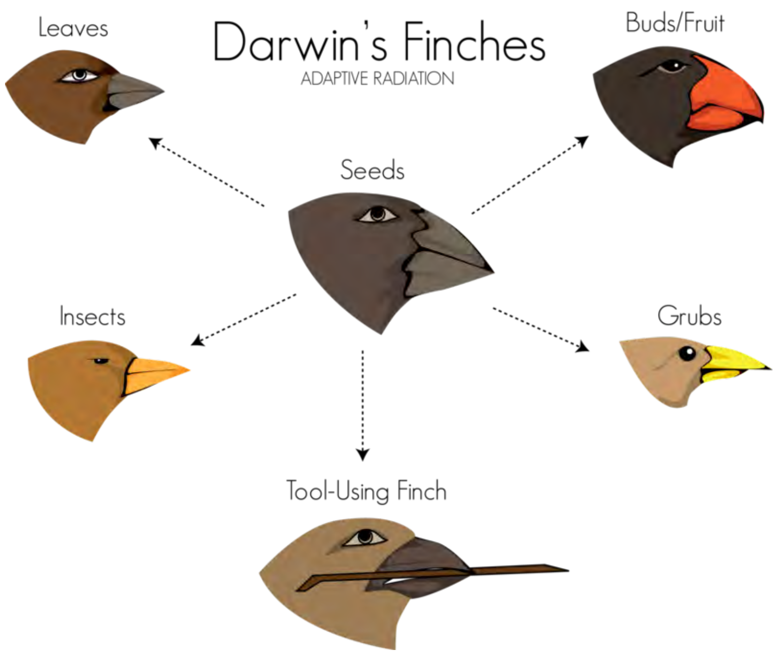


FIGURE 10.13
Gal&#225 pagos finches differ in beak size and shape depending on the type of food they eat.

Eyewitness to Evolution

In the 1970s, biologists Peter and Rosemary Grant went to the Galápagos Islands. They wanted to re-study Darwin's finches. They spent more than 30 years on the project. Their efforts paid off. They were able to observe evolution by natural selection actually taking place. While the Grants were on the Galápagos, a drought occurred. As a result, fewer seeds were available for finches to eat. Birds with smaller beaks could crack open and eat only the smaller seeds. Birds with bigger beaks could crack and eat seeds of all sizes. As a result, many of the small-beaked birds died in the drought. Birds with bigger beaks survived and reproduced (see **Figure** 10.14). Within 2 years, the average beak size in the finch population increased. Evolution by natural selection had occurred.

Lesson Summary

- Fossils provide a window into the past. They are evidence for evolution. Scientists who find and study fossils are called paleontologists.

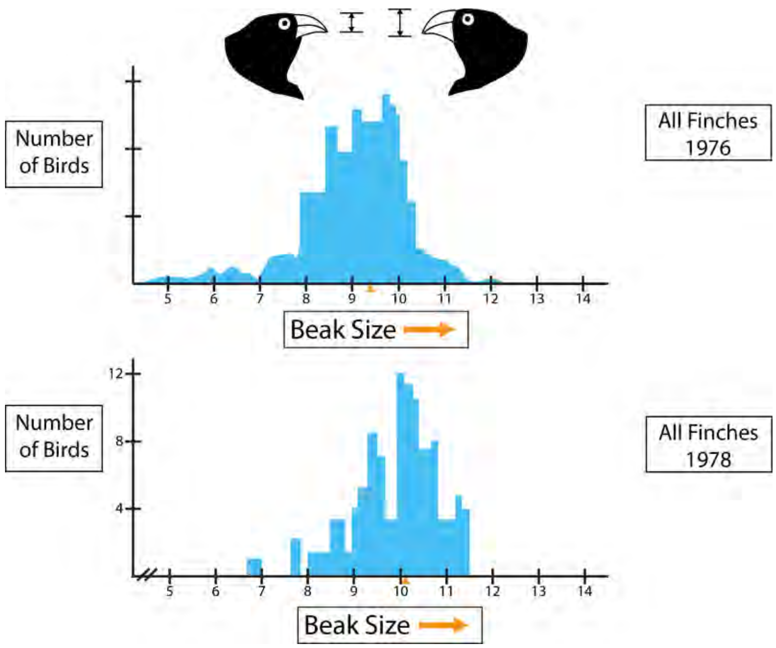


FIGURE 10.14

Evolution of Beak Size in Gal&#225 pagos Finches. The top graph shows the beak sizes of the entire finch population studied by the Grants in 1976. The bottom graph shows the beak sizes of the survivors in 1978. In just 2 years beak size increased.

- Scientists compare the anatomy, embryos, and DNA of living things to understand how they evolved. Evidence for evolution is provided by homologous structures. These are structures shared by related organisms that were inherited from a common ancestor. Other evidence is provided by analogous structures. These are structures that unrelated organisms share because they evolved to do the same job.
- Biogeography is the study of how and why plants and animals live where they do. It also provides evidence for evolution. On island chains, such as the Galápagos, one species may evolve into many new species to fill available niches. This is called adaptive radiation.

Lesson Review Questions

Recall

1. How do paleontologists learn about evolution?
2. Describe what fossils reveal about the evolution of the horse.
3. What are vestigial structures? Give an example.
4. Define biogeography.
5. Describe an example of island biogeography that provides evidence of evolution.

Apply Concepts

6. Humans and apes have five fingers they can use to grasp objects. Do you think these are analogous or homologous structures? Explain.

Think Critically

7. Compare and contrast homologous and analogous structures. What do they reveal about evolution?

8. Why does comparative embryology show similarities between organisms that do not appear to be similar as adults?

Points to Consider

The Grants saw evolution occurring from one generation to the next in a population of finches.

- What factors caused the short-term evolution the Grants witnessed? How did the Grants know that evolution had occurred?
- What other factors do you think might cause evolution to occur so quickly within a population?

10.3 Microevolution and the Genetics of Populations

Lesson Objectives

- Distinguish between microevolution and macroevolution.
- Define gene pool, and explain how to calculate allele frequencies.
- State the Hardy-Weinberg theorem
- Identify the four forces of evolution.

Vocabulary

allele frequency how often an allele occurs in a gene pool relative to the other alleles for that gene

directional selection type of natural selection for a polygenic trait in which one of two extreme phenotypes is selected for, resulting in a shift of the phenotypic distribution toward that extreme

disruptive selection type of natural selection for a polygenic trait in which phenotypes in the middle of the phenotypic distribution are selected against, resulting in two overlapping phenotypes, one at each end of the distribution

gene flow change in allele frequencies that occurs when individuals move into or out of a population

gene pool all the genes of all the members of a population

genetic drift a random change in allele frequencies that occurs in a small population

Hardy-Weinberg theorem founding principle of population genetics that proves allele and genotype frequencies do not change in a population that meets the conditions of no mutation, no migration, large population size, random mating, and no natural selection

macroevolution evolutionary change that occurs over geologic time above the level of the species

microevolution evolutionary change that occurs over a relatively short period of time within a population or species

population genetics science focusing on evolution within populations that is the area of overlap between evolutionary theory and Mendelian genetics

sexual dimorphism differences between the phenotypes of males and females of the same species

stabilizing selection type of natural selection for a polygenic trait in which phenotypes at both extremes of the phenotypic distribution are selected against, resulting in a narrowing of the range of phenotypic variation

Introduction

Darwin knew that heritable variations are needed for evolution to occur. However, he knew nothing about Mendel's laws of genetics. Mendel's laws were rediscovered in the early 1900s. Only then could scientists fully understand the process of evolution.

The Scale of Evolution

We now know that variations of traits are heritable. These variations are determined by different alleles. We also know that evolution is due to a change in alleles over time. How long a time? That depends on the scale of evolution.

- **Microevolution** occurs over a relatively short period of time within a population or species. The Grants observed this level of evolution in Darwin's finches.
- **Macroevolution** occurs over geologic time above the level of the species. The fossil record reflects this level of evolution. It results from microevolution taking place over many generations.

Genes in Populations

Individuals do not evolve. Their genes do not change over time. The unit of evolution is the population. A population consists of organisms of the same species that live in the same area. In terms of evolution, the population is assumed to be a relatively closed group. This means that most mating takes place within the population. The science that focuses on evolution within populations is **population genetics**. It is a combination of evolutionary theory and Mendelian genetics.

Gene Pool

The genetic makeup of an individual is the individual's genotype. A population consists of many genotypes. Altogether, they make up the population's gene pool. The **gene pool** consists of all the genes of all the members of the population. For each gene, the gene pool includes all the different alleles for the gene that exist in the population. For a given gene, the population is characterized by the frequency of the different alleles in the gene pool.

Allele Frequencies

Allele frequency is how often an allele occurs in a gene pool relative to the other alleles for that gene. Look at the example in **Table** 10.1 . The population in the table has 100 members. In a sexually reproducing species, each member of the population has two copies of each gene. Therefore, the total number of copies of each gene in the gene pool is 200. The gene in the example exists in the gene pool in two forms, alleles *A* and *a*. Knowing the genotypes of each population member, we can count the number of alleles of each type in the gene pool. The table shows how this is done.

TABLE 10.1: Number of Alleles in a Gene Pool

Genotype	Number of Individuals in the Population with that Genotype	Number of Allele *A* Contributed to the Gene Pool by that Genotype	Number of Allele *a* Contributed to the Gene Pool by that Genotype
AA	50	$50 \times 2 = 100$	$50 \times 0 = 0$

TABLE 10.1: (continued)

Genotype	Number of Individuals in the Population with that Genotype	Number of Allele *A* Contributed to the Gene Pool by that Genotype	Number of Allele *a* Contributed to the Gene Pool by that Genotype
Aa	40	$40 \times 1 = 40$	$40 \times 1 = 40$
aa	10	$10 \times 0 = 0$	$10 \times 2 = 20$
Totals	100	140	60

Let the letter p stand for the frequency of allele A. Let the letter q stand for the frequency of allele a. We can calculate p and q as follows:

- p = number of A alleles/total number of alleles = 140/200 = 0.7
- q = number of a alleles/total number of alleles = 60/200 = 0.3
- Notice that $p + q = 1$.

Evolution occurs in a population when allele frequencies change over time. What causes allele frequencies to change? That question was answered by Godfrey Hardy and Wilhelm Weinberg in 1908.

The Hardy-Weinberg Theorem

Hardy was an English mathematician. Weinberg was a German doctor. Each worked alone to come up with the founding principle of population genetics. Today, that principle is called the **Hardy-Weinberg theorem**. It shows that allele frequencies do not change in a population if certain conditions are met. Such a population is said to be in Hardy-Weinberg equilibrium. The conditions for equilibrium are:

a. No new mutations are occurring. Therefore, no new alleles are being created.
b. There is no migration. In other words, no one is moving into or out of the population.
c. The population is very large.
d. Mating is at random in the population. This means that individuals do not choose mates based on genotype.
e. There is no natural selection. Thus, all members of the population have an equal chance of reproducing and passing their genes to the next generation.

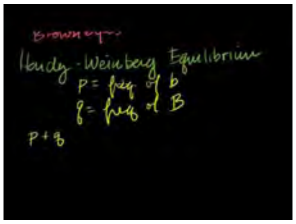
When all these conditions are met, allele frequencies stay the same. Genotype frequencies also remain constant. In addition, genotype frequencies can be expressed in terms of allele frequencies, as **Table** 10.2 shows. For a further explanation of this theorem, see http://khanexercises.appspot.com/video?v=4Kbruik_LOo.

TABLE 10.2: Genotype Frequencies in a Hardy-Weinberg Equilibrium Population

Genotype	Genotype Frequency
AA	p^2
Aa	$2pq$
aa	q^2

Hardy and Weinberg used mathematics to describe an equilibrium population (p = frequency of A, q = frequency of a): $p^2 + 2pq + q^2 = 1$. In **Table** 10.2 , if $p = 0.4$, what is the frequency of the AA genotype?

A video explanation of the Hardy-Weinberg model can be viewed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/14/4Kbruik_LOo (14:57).



MEDIA

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Forces of Evolution

The conditions for Hardy-Weinberg equilibrium are unlikely to be met in real populations. The Hardy-Weinberg theorem also describes populations in which allele frequencies are not changing. By definition, such populations are not evolving. How does the theorem help us understand evolution in the real world?

From the theorem, we can infer factors that cause allele frequencies to change. These factors are the forces of evolution. There are four such forces: mutation, gene flow, genetic drift, and natural selection.

Mutation

Mutation creates new genetic variation in a gene pool. It is how all new alleles first arise. In sexually reproducing species, the mutations that matter for evolution are those that occur in gametes. Only these mutations can be passed to offspring. For any given gene, the chance of a mutation occurring in a given gamete is very low. Thus, mutations alone do not have much effect on allele frequencies. However, mutations provide the genetic variation needed for other forces of evolution to act.

Gene Flow

Gene flow occurs when individuals move into or out of a population. If the rate of migration is high, this can have a significant effect on allele frequencies. Both the population they leave and the population they enter may change.

During the Vietnam War in the 1960s and 1970s, many American servicemen had children with Vietnamese women. Most of the servicemen returned to the United States after the war. However, they left copies of their genes behind in their offspring. In this way, they changed the allele frequencies in the Vietnamese gene pool. Was the gene pool of the American population also affected? Why or why not?

Genetic Drift

Genetic drift is a random change in allele frequencies that occurs in a small population. When a small number of parents produce just a few offspring, allele frequencies in the offspring may differ, by chance, from allele frequencies in the parents. This is like tossing a coin. If you toss a coin just a few times, you may, by chance, get more or less than the expected 50 percent heads or tails. In a small population, you may also, by chance, get different allele frequencies than expected in the next generation. In this way, allele frequencies may drift over time. There are two special conditions under which genetic drift occurs. They are called bottleneck effect and founder effect.

a. Bottleneck effect occurs when a population suddenly gets much smaller. This might happen because of a natural disaster such as a forest fire. By chance, allele frequencies of the survivors may be different from those of the original population.
b. Founder effect occurs when a few individuals start, or found, a new population. By chance, allele frequencies of the founders may be different from allele frequencies of the population they left. An example is described in **Figure** 10.15 .

FIGURE 10.15

Founder Effect in the Amish Population. The Amish population in the U.S. and Canada had a small number of founders. How has this affected the Amish gene pool

Natural Selection

Natural selection occurs when there are differences in fitness among members of a population. As a result, some individuals pass more genes to the next generation. This causes allele frequencies to change. The example of sickle-cell anemia is described in **Figure** 10.16 and **Table** 10.3 . It shows how natural selection can keep a harmful allele in a gene pool. You can also watch a video about natural selection and sickle-cell anemia at this link: http://www.pbs.org/wgbh/evolution/library/01/2/l_012_02.html.

TABLE 10.3: **Sickle Cell and Natural Selection**

Genotype	Phenotype	Fitness
AA	100% normal hemoglobin	Somewhat reduced fitness because of no resistance to malaria
AS	Enough normal hemoglobin to prevent sickle-cell anemia	Highest fitness because of resistance to malaria
SS	100% abnormal hemoglobin, causing sickle-cell anemia	Greatly reduced fitness because of sickle-cell anemia

Here's how natural selection can keep a harmful allele in a gene pool:

- The allele (*S*) for sickle-cell anemia is a harmful autosomal recessive. It is caused by a mutation in the normal allele (*A*) for hemoglobin (a protein on red blood cells).
- Malaria is a deadly tropical disease. It is common in many African populations.
- Heterozygotes (*AS*) with the sickle-cell allele are resistant to malaria. Therefore, they are more likely to survive and reproduce. This keeps the *S* allele in the gene pool.

The sickle-cell example shows that fitness depends on phenotypes. It also shows that fitness may depend on the environment. What do you think might happen if malaria was eliminated in an African population with a relatively high frequency of the *S* allele? How might the fitness of the different genotypes change? How might this affect the frequency of the *S* allele? Sickle-cell trait is controlled by a single gene. Natural selection for polygenic traits is more complex, unless you just look at phenotypes. Three ways that natural selection can affect phenotypes are

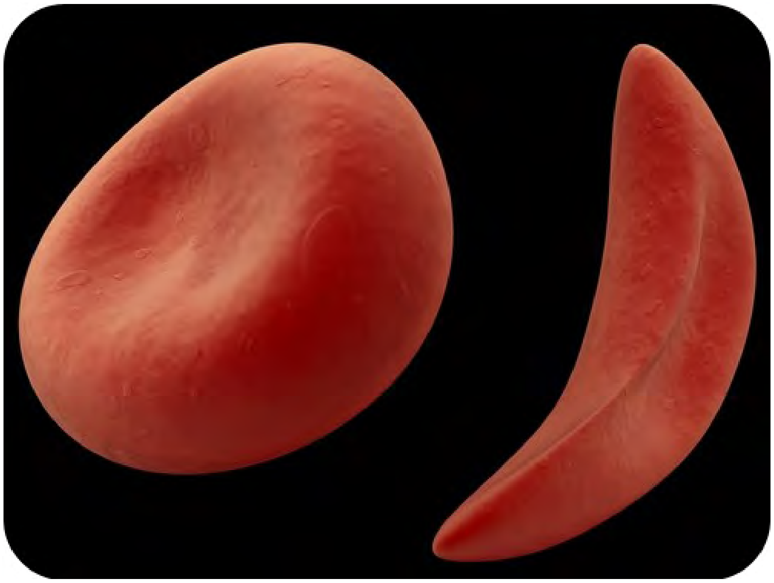


FIGURE 10.16
Sickle Cell and Natural Selection.

Lesson Summary

- Microevolution occurs over a short period of time in a population or species. Macroevolution occurs over geologic time above the level of the species.
- The population is the unit of evolution. A population's gene pool consists of all the genes of all the members of the population. For a given gene, the population is characterized by the frequency of different alleles in the gene pool.
- The Hardy-Weinberg theorem states that, if a population meets certain conditions, it will be in equilibrium. In an equilibrium population, allele and genotype frequencies do not change over time. The conditions that must be met are no mutation, no migration, very large population size, random mating, and no natural selection.
- There are four forces of evolution: mutation, gene flow, genetic drift, and natural selection. Natural selection for a polygenic trait changes the distribution of phenotypes. It may have a stabilizing, directional, or disruptive effect on the phenotype distribution.

Lesson Review Questions

Recall

1. Why are populations, rather than individuals, the units of evolution?

2. What is a gene pool?

3. Describe a Hardy-Weinberg equilibrium population. What conditions must it meet to remain in equilibrium?

4. Identify the four forces of evolution.

5. Why is mutation needed for evolution to occur, even though it usually has little effect on allele frequencies?

6. What is founder effect? Give an example.

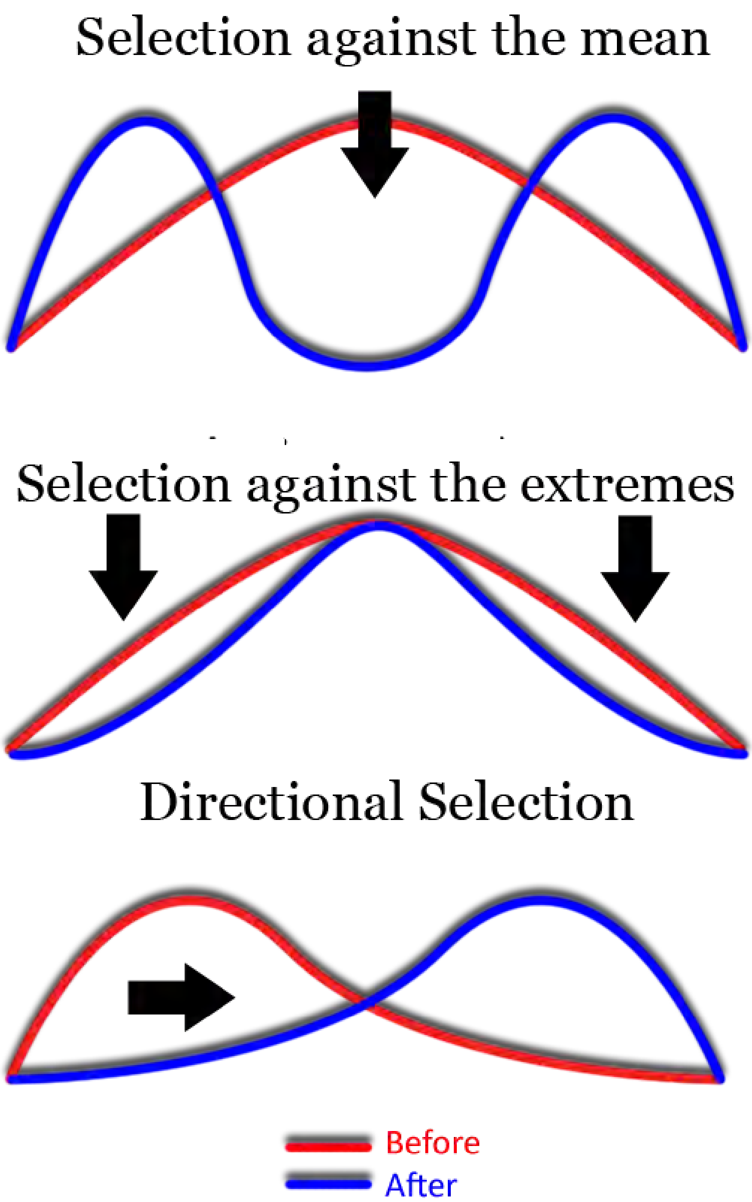


FIGURE 10.17
Natural Selection for a Polygenic Trait. Natural selection may affect the distribution of a polygenic trait. These graphs show three ways this can happen.

7. Identify three types of natural selection for a polygenic trait.

Apply Concepts

8. Assume that a population of 50 individuals has the following numbers of genotypes for a gene with two alleles, *B* and *b*: *BB* = 30, *Bb* = 10, and *bb* = 10. Calculate the frequencies of the two alleles in the population's gene pool.

9. Assume that a population is in Hardy-Weinberg equilibrium for a particular gene with two alleles, *A* and *a*. The frequency of *A* is *p*, and the frequency of *a* is *q*. Because these are the only two alleles for this gene, $p + q = 1.0$. If the frequency of homozygous recessive individuals (*aa*) is 0.04, what is the value of *q*? Based on the value of *q*, find *p*. Then use the values of *p* and *q* to calculate the frequency of the heterozygote genotype (*Aa*).

Think Critically

10. Compare and contrast microevolution and macroevolution. How are the two related?

11. Explain why genetic drift is most likely to occur in a small population.

Points to Consider

Disruptive selection for a polygenic trait results in two overlapping phenotypes. Theoretically, disruptive selection could lead to two new species forming.

- How might this happen? Can you describe how it could occur?
- How else might one species diverge into two?

10.4 Macroevolution and the Origin of Species

Lesson Objectives

- Describe two ways that new species may originate.
- Define coevolution, and give an example.
- Distinguish between gradualism and punctuated equilibrium.

Vocabulary

allopatric speciation evolution of a new species that occurs when some members of an original species become geographically separated from the rest of the species

coevolution process in which two interacting species evolve together, with each species influencing the other's evolution

gradualism model of the timing of evolution in which evolutionary change occurs at a slow and steady pace

punctuated equilibrium model of the timing of evolution in which long periods of little evolutionary change are interrupted by bursts of rapid evolutionary change

speciation process by which a new species evolves

sympatric speciation evolution of a new species that occurs when without geographic separation first occurring between members of an original species

Introduction

Macroevolution is evolution over geologic time above the level of the species. One of the main topics in macroevolution is how new species arise. The process by which a new species evolves is called **speciation**. How does speciation occur? How does one species evolve into two or more new species?

Origin of Species

To understand how a new species forms, it's important to review what a species is. A species is a group of organisms that can breed and produce fertile offspring together in nature. For a new species to arise, some members of a species must become reproductively isolated from the rest of the species. This means they can no longer interbreed with other members of the species. How does this happen? Usually they become geographically isolated first.

Allopatric Speciation

Assume that some members of a species become geographically separated from the rest of the species. If they remain separated long enough, they may evolve genetic differences. If the differences prevent them from interbreeding with members of the original species, they have evolved into a new species. Speciation that occurs in this way is called **allopatric speciation**. An example is described in **Figure** 10.18 .

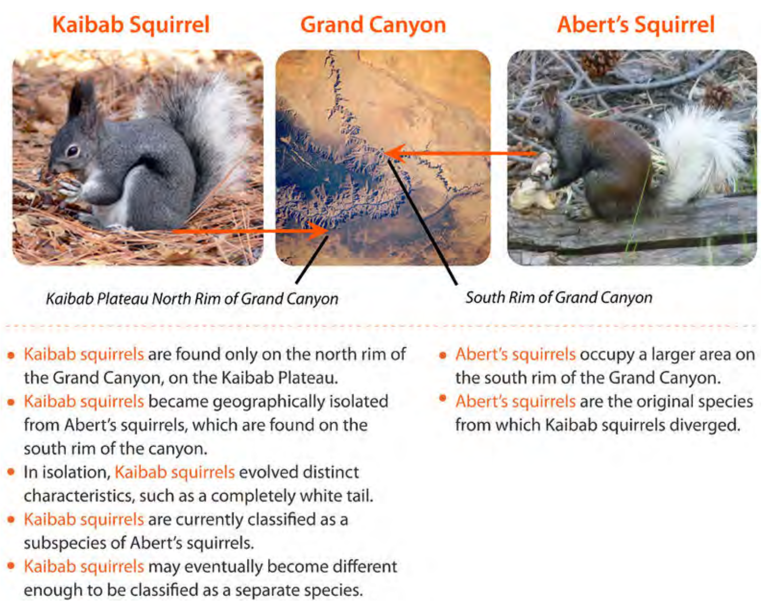


FIGURE 10.18

Allopatric Speciation in the Kaibab Squirrel. The Kaibab squirrel is in the process of becoming a new species.

Sympatric Speciation

Less often, a new species arises without geographic separation. This is called **sympatric speciation**. The following example shows one way this can occur.

a. Hawthorn flies lay eggs in hawthorn trees (see **Figure** 10.19). The eggs hatch into larvae that feed on hawthorn fruits. Both the flies and trees are native to the U.S.
b. Apple trees were introduced to the U.S. and often grow near hawthorn trees. Some hawthorn flies started to lay eggs in nearby apple trees. When the eggs hatched, the larvae fed on apples.
c. Over time, the two fly populations—those that fed on hawthorn trees and those that preferred apple trees—evolved reproductive isolation. Now they are reproductively isolated because they breed at different times. Their breeding season matches the season when the apple or hawthorn fruits mature.
d. Because they rarely interbreed, the two populations of flies are evolving other genetic differences. They appear to be in the process of becoming separate species.

Isolating mechanisms are discussed in the following video http://www.youtube.com/watch?v=-e64TfKeAXU (2:57).

Coevolution

Evolution occurs in response to a change in the environment. Environmental change often involves other species of organisms. In fact, species in symbiotic relationships tend to evolve together. This is called **coevolution**. As one

FIGURE 10.19
Sympatric Speciation in Hawthorn Flies. Hawthorn flies are diverging from one species into two. As this example shows behaviors as well as physical traits may evolve and lead to speciation.

species changes, the other species must also change in order to adapt.

Coevolution occurs in flowering plants and the species that pollinate them. The flower and bird in **Figure** 10.20 are a good example. They have evolved matching structures.

FIGURE 10.20
Results of Coevolution in a Flower and Its Pollinator. The very long mouth part of this hummingbird has coevolved with the tubular flower it pollinates. Only this species of bird can reach the nectar deep in the flower. What might happen to the flower if the bird species went extinct

Timing of Macroevolution

Is evolution slow and steady? Or does it occur in fits and starts? It may depend on what else is going on, such as changes in climate and geologic conditions.

- When geologic and climatic conditions are stable, evolution may occur gradually. This is how Darwin thought evolution occurred. This model of the timing of evolution is called **gradualism**.

- When geologic and climatic conditions are changing, evolution may occur more quickly. Thus, long periods of little change may be interrupted by bursts of rapid change. This model of the timing of evolution is called **punctuated equilibrium**. It is better supported by the fossil record than is gradualism.

Lesson Summary

- New species arise in the process of speciation. Allopatric speciation occurs when some members of a species become geographically separated. They then evolve genetic differences. If the differences prevent them from interbreeding with the original species, a new species has evolved. Sympatric speciation occurs without geographic separation.
- Coevolution occurs when species evolve together. This often happens in species that have symbiotic relationships. Examples include flowering plants and their pollinators.
- Darwin thought that evolution occurs gradually. This model of evolution is called gradualism. The fossil record better supports the model of punctuated equilibrium. In this model, long periods of little change are interrupted by bursts of rapid change.

Lesson Review Questions

Recall

1. Define speciation.

2. Describe how allopatric speciation occurs.

3. What is gradualism? When is it most likely to apply?

4. Describe the timing of evolutionary change according to the punctuated equilibrium model.

Apply Concepts

5. Apply the concepts of fitness and natural selection to explain how the insect and flower pictured in **Figure** 10.20 could have evolved their matching structures.

Think Critically

6. Why is sympatric speciation less likely to occur than allopatric speciation?

Points to Consider

You read in this chapter about adaptive radiation on the Galápagos Islands. A single finch species evolved into many new species to fill all available niches. For example, the species evolved adaptations for a variety of food sources.

- What is a species' niche? What do you think it might include besides the food a species eats?
- Niche is a term from ecology. What is ecology? How do you think knowledge of ecology might help scientists understand evolution?

CHAPTER 11 The Principles of Ecology

CHAPTER OUTLINE

These brilliant red “feathers” are actually animals called tube worms. They live in an extreme environment on the deep ocean floor, thousands of meters below the water’s surface. Their world is always very cold and completely dark. Without sunlight, photosynthesis is not possible. So what do organisms eat at these depths? Tube worms depend on chemosynthetic microorganisms that live inside them for food. In this and other ways, tube worms have adapted to the extreme conditions of their environment.

All organisms must adapt to their environment in order to survive. This is true whether they live in water or on land. Most environments are not as extreme as the deep ocean where tube worms live. But they all have conditions that require adaptations. In this chapter, you will read about a wide variety of environments and the organisms that live in them.

11.1 The Science of Ecology

Lesson Objectives

- Distinguish between abiotic and biotic factors.
- Define ecosystem and other ecological concepts.
- Describe how energy flows through ecosystems.
- Explain how food chains and webs model feeding relationships.
- Identify trophic levels in a food chain or web.

Vocabulary

abiotic factor nonliving aspect of the environment such as sunlight and soil

biomass total mass of organisms at a trophic level

biotic factor living aspects of the environment, including organisms of the same and different species

carnivore consumer that eats animals

chemoautotroph producer that uses energy from chemical compounds to make food by chemosynthesis

competitive exclusion principle principle of ecology stating that two different species cannot occupy the same niche in the same place for very long

decomposer organism that breaks down the remains of dead organisms and other organic wastes

detritivore decomposer that consumes detritus

detritus substance composed of dead leaves, other plant remains, and animal feces that collects on the soil or at the bottom of a body of water

ecology branch of biology that is the study of how living things interact with each other and with their environment

food chain diagram that represents a single pathway through which energy and matter flow through an ecosystem

food web diagram that represents multiple intersecting pathways through which energy and matter flow through an ecosystem

habitat physical environment in which a species lives and to which it has become adapted

herbivore consumer that eats producers such as plants or algae

niche role of a species in its ecosystem that includes all the ways the species interacts with the biotic and abiotic factors of the ecosystem

omnivore consumer that eats both plants and animals

photoautotroph producer that uses energy from sunlight to make food by photosynthesis

saprotroph decomposer such as a fungus or protozoan that feeds on any remaining organic matter that is left after other decomposers do their work

scavenger decomposer that consumers the soft tissues of dead animals

trophic level feeding position in a food chain or food web, such as producer, primary consumer, or secondary consumer

Introduction

Ecology is the study of how living things interact with each other and with their environment. It is a major branch of biology, but has areas of overlap with geography, geology, climatology, and other sciences. This lesson introduces fundamental concepts in ecology, beginning with organisms and the environment.

Organisms and the Environment

Organisms are individual living things. Despite their tremendous diversity, all organisms have the same basic needs: energy and matter. These must be obtained from the environment. Therefore, organisms are not closed systems. They depend on and are influenced by their environment. The environment includes two types of factors: abiotic and biotic.

a. **Abiotic factors** are the nonliving aspects of the environment. They include factors such as sunlight, soil, temperature, and water.
b. **Biotic factors** are the living aspects of the environment. They consist of other organisms, including members of the same and different species.

The Ecosystem

An ecosystem is a unit of nature and the focus of study in ecology. It consists of all the biotic and abiotic factors in an area and their interactions. Ecosystems can vary in size. A lake could be considered an ecosystem. So could a dead log on a forest floor. Both the lake and log contain a variety of species that interact with each other and with abiotic factors. Another example of an ecosystem is pictured in **Figure** 11.1 .

When it comes to energy, ecosystems are not closed. They need constant inputs of energy. Most ecosystems get energy from sunlight. A small minority get energy from chemical compounds. Unlike energy, matter is not constantly added to ecosystems. Instead, it is recycled. Water and elements such as carbon and nitrogen are used over and over again.

FIGURE 11.1
Desert Ecosystem. What are some of the biotic and abiotic factors in this desert ecosystem

Niche

One of the most important concepts associated with the ecosystem is the niche. A **niche** refers to the role of a species in its ecosystem. It includes all the ways that the species interacts with the biotic and abiotic factors of the environment. Two important aspects of a species' niche are the food it eats and how the food is obtained. Look at **Figure** 11.2 . It shows pictures of birds that occupy different niches. Each species eats a different type of food and obtains the food in a different way.

Habitat

Another aspect of a species' niche is its habitat. The **habitat** is the physical environment in which a species lives and to which it is adapted. A habitat's features are determined mainly by abiotic factors such as temperature and rainfall. These factors also influence the traits of the organisms that live there.

Competitive Exclusion Principle

A given habitat may contain many different species, but each species must have a different niche. Two different species cannot occupy the same niche in the same place for very long. This is known as the **competitive exclusion principle**. If two species were to occupy the same niche, what do you think would happen? They would compete with one another for the same food and other resources in the environment. Eventually, one species would be likely to outcompete and replace the other.

Flow of Energy

Energy enters ecosystems in the form of sunlight or chemical compounds. Some organisms use this energy to make food. Other organisms get energy by eating the food.

Producers

Producers are organisms that produce food for themselves and other organisms. They use energy and simple inorganic molecules to make organic compounds. The stability of producers is vital to ecosystems because all organisms

FIGURE 11.2

Bird Niches. Each of these species of birds has a beak that suits it for its niche. For example the long slender beak of the nectarivore allows it to sip liquid nectar from flowers. The short sturdy beak of the granivore allows it to crush hard tough grains.

need organic molecules. Producers are also called autotrophs. There are two basic types of autotrophs: photoautotrophs and chemoautotrophs.

a. **Photoautotrophs** use energy from sunlight to make food by photosynthesis. They include plants, algae, and certain bacteria (see **Figure** 11.3).
b. **Chemoautotrophs** use energy from chemical compounds to make food by chemosynthesis. They include some bacteria and also archaea. Archaea are microorganisms that resemble bacteria.

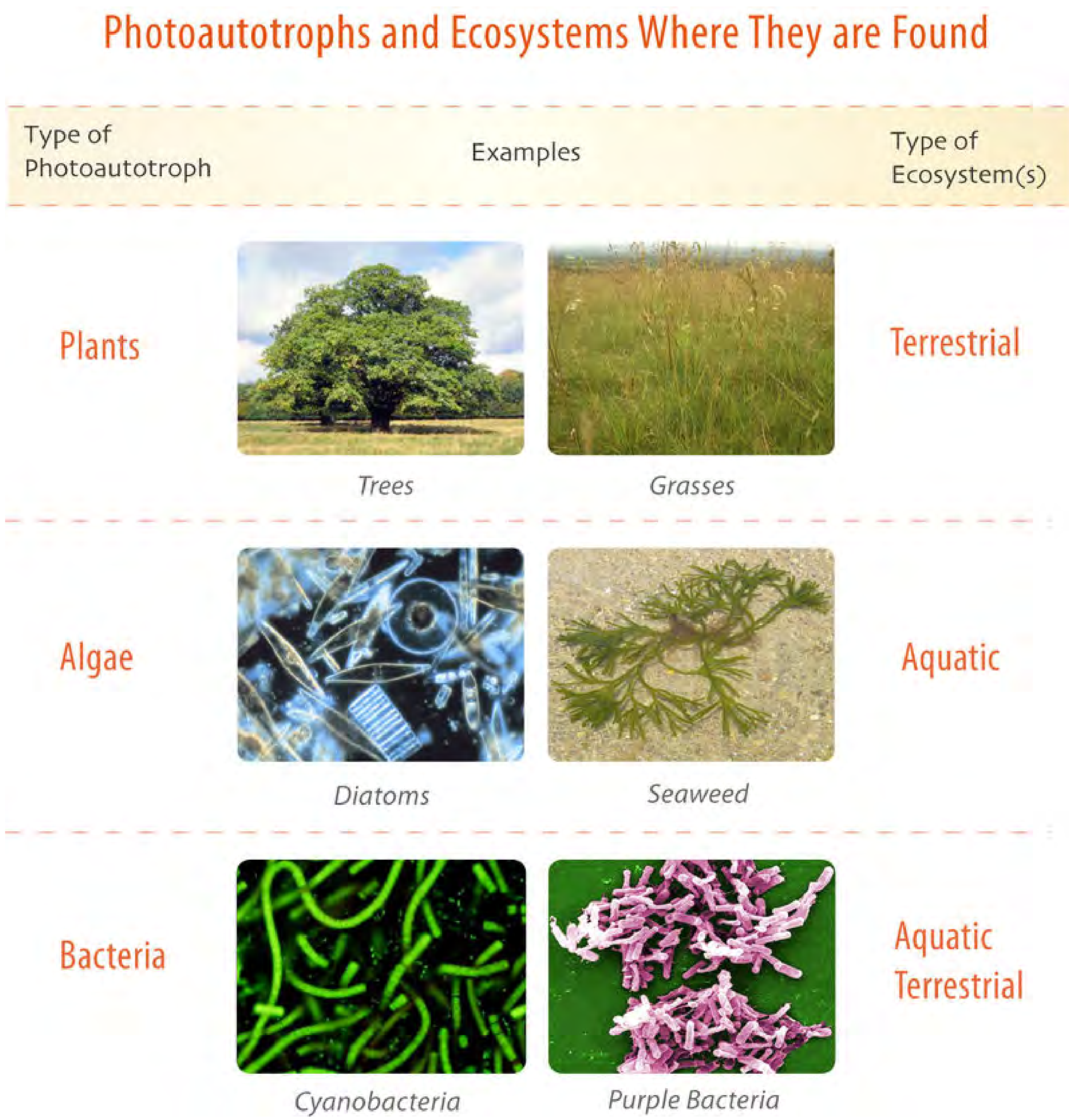


FIGURE 11.3
Different types of photoautotrophs are important in different ecosystems.

Consumers

Consumers are organisms that depend on other organisms for food. They take in organic molecules by essentially "eating" other living things. They include all animals and fungi. (Fungi don't really "eat"; they absorb nutrients from other organisms.) They also include many bacteria and even a few plants, such as the pitcher plant in **Figure** 11.4 . Consumers are also called heterotrophs. Heterotrophs are classified by what they eat:

- **Herbivores** consume producers such as plants or algae. They are a necessary link between producers and other consumers. Examples include deer, rabbits, and mice.
- **Carnivores** consume animals. Examples include lions, polar bears, hawks, frogs, salmon, and spiders. Carnivores that are unable to digest plants and must eat only animals are called obligate carnivores. Other carnivores can digest plants but do not commonly eat them.
- **Omnivores** consume both plants and animals. They include humans, pigs, brown bears, gulls, crows, and some species of fish.

FIGURE 11.4

Pitcher Plant. Virtually all plants are producers. This pitcher plant is an exception. It consumes insects. It traps them in a sticky substance in its &#8220 pitcher.&#8221 Then it secretes enzymes that break down the insects and release nutrients. Which type of consumer is a pitcher plant

Decomposers

When organisms die, they leave behind energy and matter in their remains. **Decomposers** break down the remains and other wastes and release simple inorganic molecules back to the environment. Producers can then use the molecules to make new organic compounds. The stability of decomposers is essential to every ecosystem. Decomposers are classified by the type of organic matter they break down:

- **Scavengers** consume the soft tissues of dead animals. Examples of scavengers include vultures, raccoons, and blowflies.

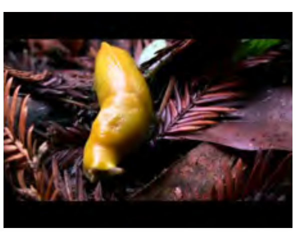
- **Detritivores** consume **detritus**—the dead leaves, animal feces, and other organic debris that collects on the soil or at the bottom of a body of water. On land, detritivores include earthworms, millipedes, and dung beetles (see **Figure** 11.5). In water, detritivores include "bottom feeders" such as sea cucumbers and catfish.
- **Saprotrophs** are the final step in decomposition. They feed on any remaining organic matter that is left after other decomposers do their work. Saprotrophs include fungi and single-celled protozoa. Fungi are the only organisms that can decompose wood.

FIGURE 11.5

Dung Beetle. This dung beetle is rolling a ball of feces to its nest to feed its young.

KQED: Banana Slugs: The Ultimate Recyclers

One of the most beloved and iconic native species within the old growth redwood forests of California is the Pacific Banana Slug. These slimy friends of the forest are the ultimate recyclers. Feeding on fallen leaves, mushrooms or even dead animals, they play a pivotal role in replenishing the soil. QUEST goes to Henry Cowell Redwoods State Park near Santa Cruz, California on a hunt to find *Ariolomax dolichophallus*, a bright yellow slug with a very big personality. See http://www.kqed.org/quest/television/science-on-the-spot-banana-slugs-unpeeled for more information.



MEDIA

Click image to the left for more content.

Food Chains and Food Webs

Food chains and food webs are diagrams that represent feeding relationships. They show who eats whom. In this way, they model how energy and matter move through ecosystems.

Food Chains

A **food chain** represents a single pathway through which energy and matter flow through an ecosystem. An example is shown in **Figure** 11.6 . Food chains are generally simpler than what really happens in nature. Most organisms consume—and are consumed by—more than one species.

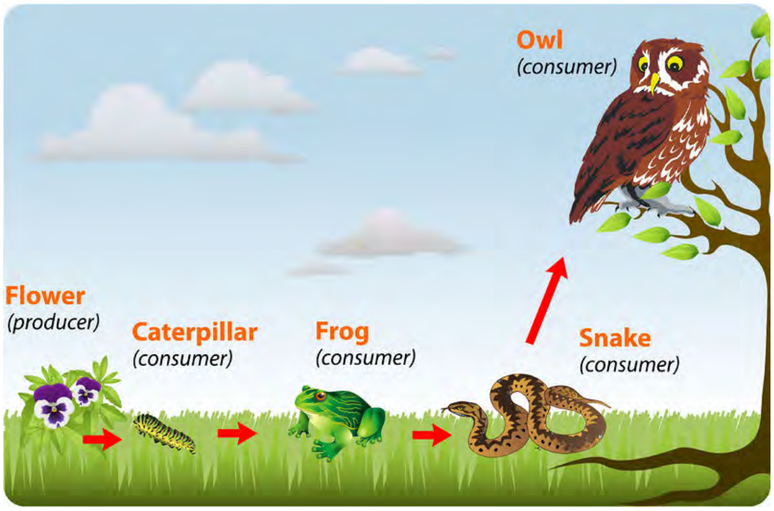


FIGURE 11.6
This food chain includes producers and consumers. How could you add decomposers to the food chain

A musical summary of food chains can be heard at http://www.youtube.com/watch?v=TE6wqG4nb3M (2:46).

Food Webs

A **food web** represents multiple pathways through which energy and matter flow through an ecosystem. It includes many intersecting food chains. It demonstrates that most organisms eat, and are eaten, by more than one species. An example is shown in **Figure** 11.7 .

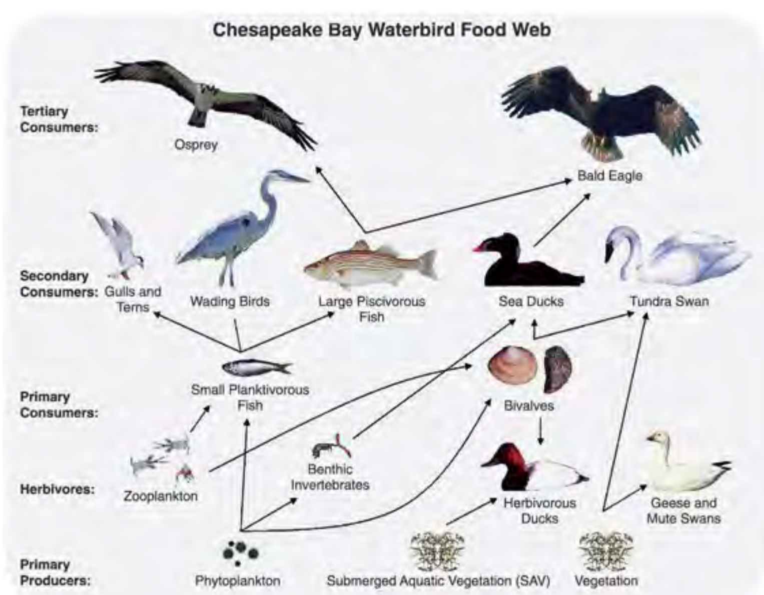


FIGURE 11.7
Food Web. This food web consists of several different food chains. Which organisms are producers in all of the food chains included in the food web

Trophic Levels

The feeding positions in a food chain or web are called **trophic levels**. The different trophic levels are defined in **Table** 11.1 . Examples are also given in the table. All food chains and webs have at least two or three trophic levels. Generally, there are a maximum of four trophic levels.

TABLE 11.1: **Trophic Levels**

Trophic Level	Where It Gets Food	Example
1st Trophic Level: Producer	Makes its own food	Plants make food
2nd Trophic Level: Primary Consumer	Consumes producers	Mice eat plant seeds
3rd Trophic Level: Secondary Consumer	Consumes primary consumers	Snakes eat mice
4th Trophic Level: Tertiary Consumer	Consumes secondary consumers	Hawks eat snakes

Many consumers feed at more than one trophic level. Humans, for example, are primary consumers when they eat plants such as vegetables. They are secondary consumers when they eat cows. They are tertiary consumers when they eat salmon.

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 available to the next level. This is represented by the pyramid in **Figure** 11.8 . What happens to the other 90 percent of energy? It 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. Sometimes there may be a fifth trophic level, but usually there's not enough energy left to support any additional levels.

Energy pyramids are discussed at http://www.youtube.com/watch?v=8T2nEMzk6_E#38;feature=related (1:44).

Trophic Levels and Biomass

With less energy at higher trophic levels, there are usually fewer organisms as well. Organisms tend to be larger in size at higher trophic levels, but their smaller numbers result in less biomass. **Biomass** is the total mass of organisms at a trophic level. The decrease in biomass from lower to higher levels is also represented by **Figure** 11.8 .

Lesson Summary

- Ecology is the study of how living things interact with each other and with their environment. The environment includes abiotic (nonliving) and biotic (living) factors.
- An ecosystem consists of all the biotic and abiotic factors in an area and their interactions. A niche refers to the role of a species in its ecosystem. A habitat is the physical environment in which a species lives and to which it is adapted. Two different species cannot occupy the same niche in the same place for very long.
- Ecosystems require constant inputs of energy from sunlight or chemicals. Producers use energy and inorganic molecules to make food. Consumers take in food by eating producers or other living things. Decomposers break down dead organisms and other organic wastes and release inorganic molecules back to the environment.

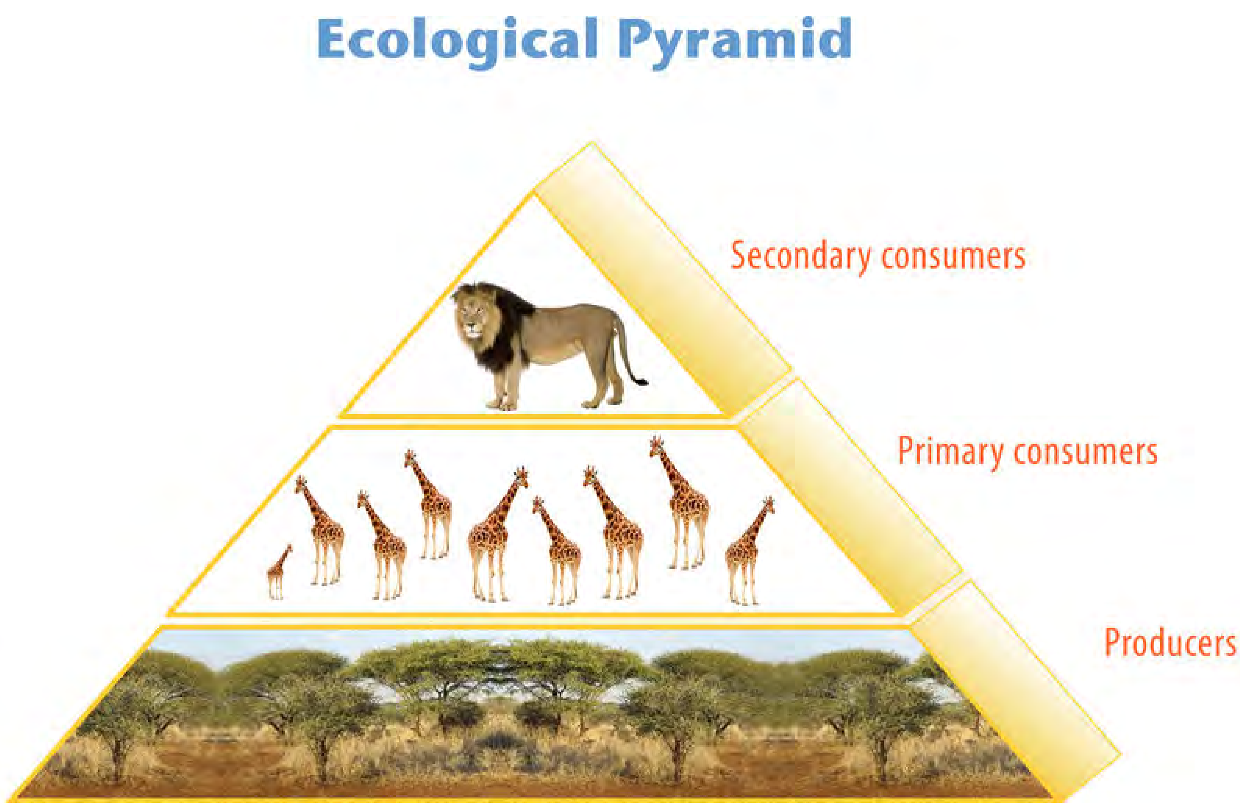


FIGURE 11.8

Ecological Pyramid. This pyramid shows how energy and biomass decrease from lower to higher trophic levels. Assume that producers in this pyramid have 1 000 000 kilocalories of energy. How much energy is available to primary consumers

- Food chains and food webs are diagrams that represent feeding relationships. They model how energy and matter move through ecosystems.
- The different feeding positions in a food chain or web are called trophic levels. Generally, there are no more than four trophic levels because energy and biomass decrease from lower to higher levels.

Lesson Review Questions

Recall

1. Define biotic and abiotic factors of the environment. Give an example of each.

2. How do ecologists define the term *ecosystem*?

3. State the competitive exclusion principle.

4. Identify three different types of consumers. Name an example of each type.

5. Describe the role of decomposers in food webs.

Apply Concepts

6. Draw a terrestrial food chain that includes four trophic levels. Identify the trophic level of each organism in the food chain.

Think Critically

7. Compare and contrast the ecosystem concepts of niche and habitat.

8. What can you infer about an ecosystem that depends on chemoautotrophs for food?

9. Explain how energy limits the number of trophic levels in a food chain or web.

Points to Consider

In this lesson, you learned how matter is transferred through food chains and webs. Producers make food from inorganic molecules. Other organisms consume the producers. When organisms die, decomposers break down their remains and release inorganic molecules that can be used again by producers. In this way, matter is recycled by the biotic factors in ecosystems.

- Do you think that abiotic factors in ecosystems might also play a role in recycling matter? In what way?
- What abiotic factors might be involved in recycling matter? For example, what abiotic factors might be involved in recycling water?

11.2 Recycling Matter

Lesson Objectives

- Define biogeochemical cycles.
- Describe the water cycle and its processes.
- Give an overview of the carbon cycle.
- Outline the steps of the nitrogen cycle.

Vocabulary

aquifer underground layer of rock that stores water

biogeochemical cycle interconnected pathways through which water or a chemical element such as carbon is continuously recycled through the biotic and abiotic components of the biosphere

carbon cycle interconnected pathways through which carbon is recycled through the biotic and abiotic components of the biosphere

condensation process in which water vapor changes to tiny droplets of liquid water

evaporation process in which liquid water changes to water vapor

exchange pool part of a biogeochemical cycle that holds an element or water for a short period of time

groundwater water that exists in the ground either in the soil or in rock layers below the surface

nitrogen cycle interconnected pathways through which nitrogen is recycled through the biotic and abiotic components of the biosphere

nitrogen fixation process of changing nitrogen gas to nitrates that is carried out by nitrogen-fixing bacteria in the soil or in the roots of legumes

precipitation water that falls from clouds in the atmosphere to Earth's in the form of rain, snow, sleet, hail, or freezing rain

reservoir part of a biogeochemical cycle that holds an element or water for a long period of time

runoff precipitation that falls on land and flows over the surface of the ground

sublimation process in which ice and snow change directly to water vapor

transpiration process in which plants give off water vapor from photosynthesis through tiny pores, called stomata, in their leaves

water cycle interconnected pathways through which water is recycled through the biotic and abiotic components of the biosphere

Introduction

Where does the water come from that is needed by your cells? Or the carbon and nitrogen that is needed to make your organic molecules? Unlike energy, matter is not lost as it passes through an ecosystem. Instead, matter is recycled. This recycling involves specific interactions between the biotic and abiotic factors in an ecosystem.

Biogeochemical Cycles

The chemical elements and water that are needed by organisms continuously recycle in ecosystems. They pass through biotic and abiotic components of the biosphere. That's why their cycles are called **biogeochemical cycles**. For example, a chemical 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 cycle.

- Part of a cycle that holds an element or water for a short period of time is called an **exchange pool**. For example, the atmosphere is an exchange pool for water. It usually holds water (in the form of water vapor) for just a few days.
- Part of a cycle that holds an element or water for a long period of time is called a **reservoir**. The ocean is a reservoir for water. The deep ocean may hold water for thousands of years.

The rest of this lesson describes three biogeochemical cycles: the water cycle, carbon cycle, and nitrogen cycle.

The Water Cycle

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** 11.9 .

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 in the water cycle.

Evaporation, Sublimation, and Transpiration

Water changes to a gas by three different processes:

a. **Evaporation** occurs when water on the surface changes to water vapor. The sun heats the water and gives water molecules enough energy to escape into the atmosphere.
b. **Sublimation** occurs when ice and snow change directly to water vapor. This also happens because of heat from the sun.

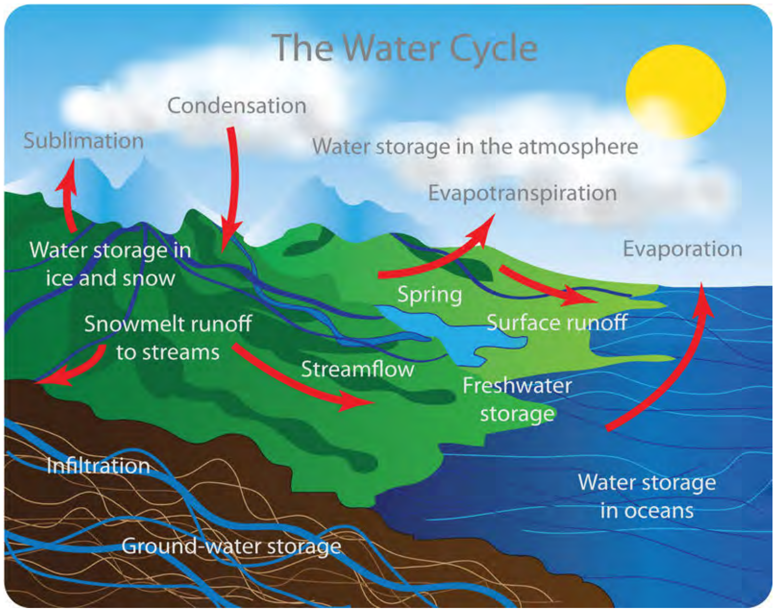


FIGURE 11.9
Like other biogeochemical cycles there is no beginning or end to the water cycle. It just keeps repeating.

c. **Transpiration** occurs when plants release water vapor through leaf pores called stomata (see **Figure** 11.10). The water is a product of photosynthesis.

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**—rain, snow, sleet, hail, or 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 longer.

Groundwater and Runoff

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 may soak into the ground, becoming **groundwater**. Groundwater may seep out of the ground at a spring or into a body of water such as the ocean. Some groundwater may be taken up by plant roots. Some may flow deeper underground to an **aquifer**. This is an underground layer of rock that stores water, sometimes for thousands of years.

The water cycle is demonstrated at http://www.youtube.com/watch?v=iohKd5FWZOE#38;feature=related (4:00).

The *Water Cycle Jump* can be viewed at http://www.youtube.com/watch?v=BayExatv8lE. (1:31).

KQED: Tracking Raindrops

We all rely on the water cycle, but how does it actually work? Scientists at University of California Berkeley are embarking on a new project to understand how global warming is affecting our fresh water supply. And they're

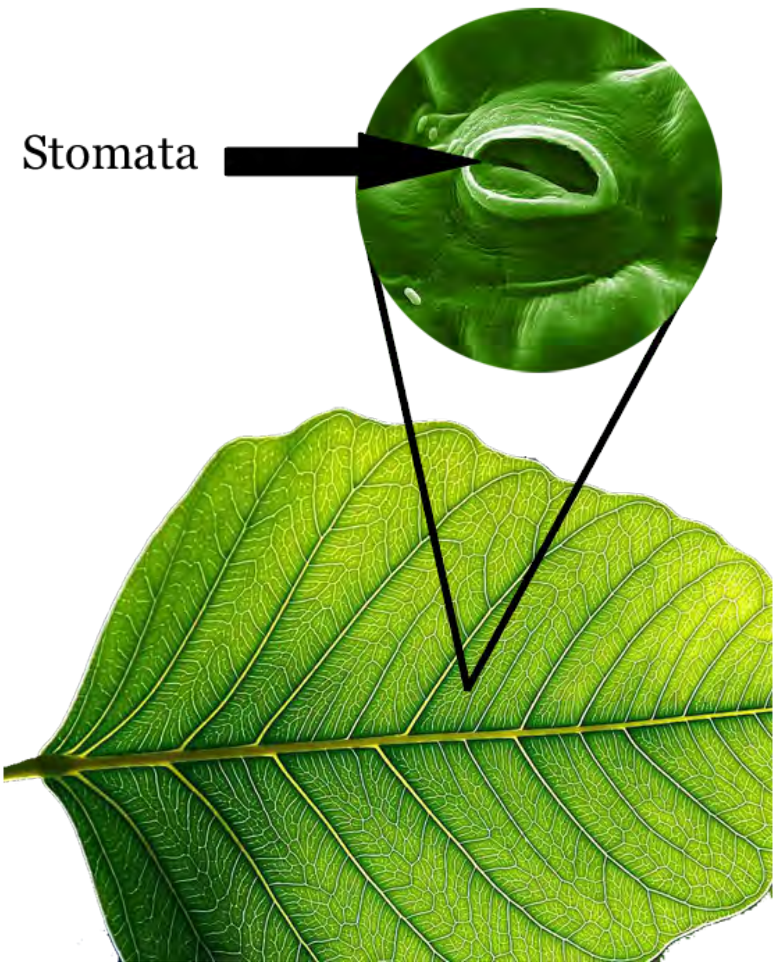


FIGURE 11.10
Plant leaves have many tiny stomata. They release water vapor into the air.

doing it by tracking individual raindrops in Mendocino and north of Lake Tahoe. See http://www.kqed.org/quest/television/tracking-raindrops for more information.

The Carbon Cycle

Flowing water can slowly dissolve carbon in sedimentary rock. Most of this carbon ends up in the ocean. The deep ocean can store carbon for thousands of years or more. Sedimentary rock and the ocean are major reservoirs of stored carbon. Carbon is also stored for varying lengths of time in the atmosphere, in living organisms, and as fossil fuel deposits. These are all parts of the **carbon cycle**, which is shown in **Figure** 11.11 .

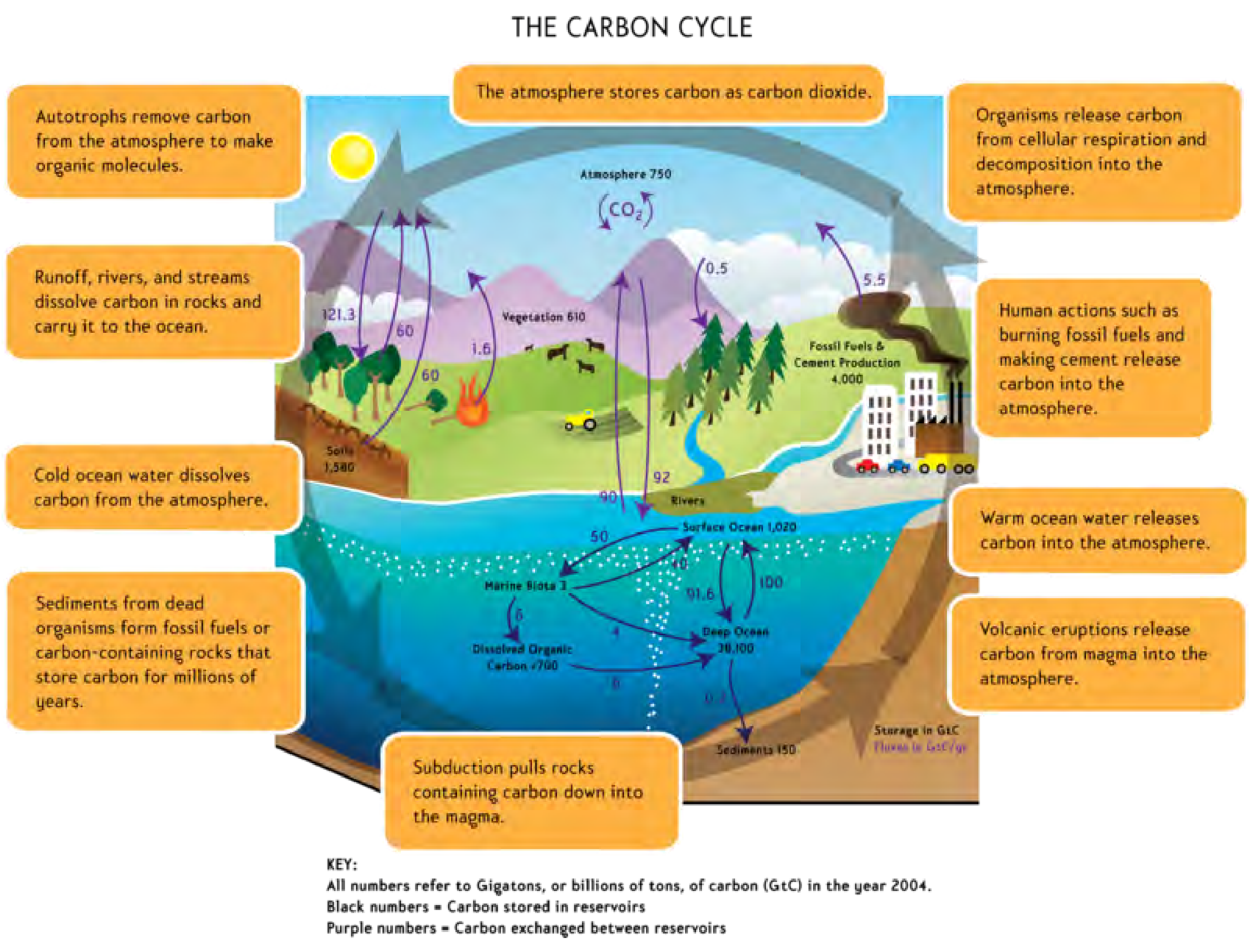


FIGURE 11.11

The Carbon Cycle. Carbon moves from one reservoir to another in the carbon cycle. What role do organisms play in this cycle

The carbon cycle is discussed in the following video: http://www.youtube.com/watch?v=0Vwa6qtEih8 (1:56).

Carbon cycles quickly between organisms and the atmosphere. Cellular respiration releases carbon into the atmosphere as carbon dioxide. Photosynthesis removes carbon dioxide from the atmosphere and uses it to make organic compounds. Carbon cycles far more slowly through geological processes such as sedimentation. Carbon may be stored in sedimentary rock for millions of years.

The Nitrogen Cycle

Nitrogen makes up 78 percent of Earth's atmosphere. It's also an important part of living things. Nitrogen is found in proteins, nucleic acids, and chlorophyll. The **nitrogen cycle** moves nitrogen through the abiotic and biotic parts of ecosystems. **Figure** 11.12 shows how nitrogen cycles through a terrestrial ecosystem. Nitrogen passes through a similar cycle in aquatic ecosystems.

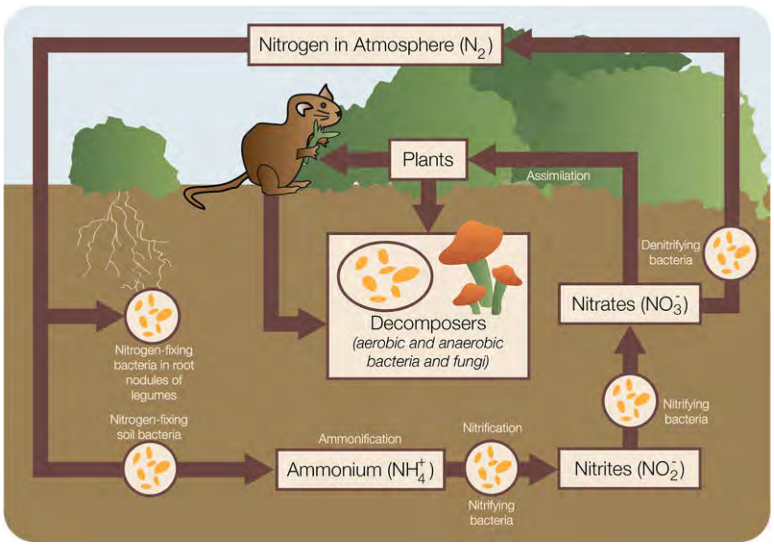


FIGURE 11.12
Nitrogen Cycle in a Terrestrial Ecosystem. Nitrogen cycles between the atmosphere and living things.

Plants cannot use nitrogen gas from the air to make organic compounds for themselves and other organisms. The nitrogen gas must be changed to a form called nitrates, which plants can absorb through their roots. The process of changing nitrogen gas to nitrates is called **nitrogen fixation**. It is carried out by nitrogen-fixing bacteria. The bacteria live in soil and roots of legumes, such as peas.

When plants and other organisms die, decomposers break down their remains. In the process, they release nitrogen in the form of ammonium ions. Nitrifying bacteria change the ammonium ions into nitrates. Some of the nitrates are used by plants. Some are changed back to nitrogen gas by denitrifying bacteria.

The nitrogen cycle is discussed at http://www.youtube.com/watch?v=pdY4I-EaqJA#38;feature=fvw (5:08).

Lesson Summary

- Chemical elements and water are recycled through biogeochemical cycles. The cycles include both biotic and abiotic parts of ecosystems.
- The water cycle takes place on, above, and below Earth's surface. In the cycle, water occurs as water vapor, liquid water, and ice. Many processes are involved as water changes state in the cycle. The atmosphere is an exchange pool for water. Ice masses, aquifers, and the deep ocean are water reservoirs.
- In the carbon cycle, carbon passes among sedimentary rocks, fossil fuel deposits, the ocean, the atmosphere, and living things. Carbon cycles quickly between organisms and the atmosphere. It cycles far more slowly through geological processes.
- The nitrogen cycle moves nitrogen back and forth between the atmosphere and organisms. Bacteria change nitrogen gas from the atmosphere to nitrogen compounds that plants can absorb. Other bacteria change nitrogen

compounds back to nitrogen gas, which re-enters the atmosphere.

Lesson Review Questions

Recall

1. What is a biogeochemical cycle? Name an example.
2. Identify and define two processes by which water naturally changes from a solid or liquid to a gas.
3. Define exchange pool and reservoir, and identify an example of each in the water cycle.
4. State three ways that carbon dioxide enters Earth's atmosphere.
5. List all the ways that a single tree may be involved in the carbon cycle.

Apply Concepts

6. Assume you are a molecule of water. Describe one way you could go through the water cycle, starting as water vapor in the atmosphere.

7. Read the following passage, then apply information from the lesson to explain why the farmer plants peas:

A farmer has three fields in which she grows corn for market. Every year, she plants one of the fields with peas, even though she cannot make as much money selling peas as she can selling corn. She rotates the fields she plants with peas so that each field is planted with peas every 3 years.

Think Critically

8. Compare and contrast biological and geological pathways of the carbon cycle.
9. Explain why bacteria are essential parts of the nitrogen cycle.

Points to Consider

In this lesson, you read how matter is recycled through ecosystems. Ecosystems vary in the amount of matter they can recycle. For example, rainforests can recycle more matter than deserts.

- Consider the abiotic and biotic factors of a rainforest and desert. How might they be different?
- Why do you think a rainforest can recycle more matter than a desert?

11.3 Biomes

Lesson Objectives

- Identify and describe terrestrial biomes.
- Give an overview of aquatic biomes.

Vocabulary

aphotic zone area in aquatic biomes deeper than 200 meters

aquatic biome water-based biomes, defined by the availability of sunlight and the concentration of dissolved oxygen and nutrients in the water

climate average weather in an area over a long period of time

dormancy state in which a plant slows down cellular activity and may shed its leaves

estuary a partly enclosed coastal body of water with one or more rivers or streams flowing into it, and with a free connection to the ocean

freshwater biome aquatic biome such as a pond, lake, stream, or river in which the water contains little or no salt

growing season period of time each year when it is warm enough and wet enough for plants to grow

intertidal zone in marine biomes, the narrow strip along the coastline that is covered by water at high tide and exposed to air at low tide

marine biome aquatic biome in the salt water of the ocean

photic zone area in an aquatic biome that extends to a maximum depth of 200 meters

phytoplankton bacteria and algae that use sunlight to make food

terrestrial biome a biome of or pertaining to land, as in terrestrial ecosystem

wetland area that is saturated with water or covered by water for at least one season of the year

zooplankton tiny animals that feed on phytoplankton

Introduction

If you look at the two pictures in **Figure** 11.13 , you will see very few similarities. The picture on the left shows a desert in Africa. The picture on the right shows a rainforest in Australia. The desert doesn't have any visible plants, whereas the rainforest is densely packed with trees. What explains these differences?

FIGURE 11.13

Sahara Desert in northern Africa *left*. Rainforest in northeastern Australia *right*. Two very different biomes are pictured here. Both are found at roughly the same distance from the equator.

The two pictures in **Figure** 11.13 represent two different biomes. A biome is a group of similar ecosystems with the same general abiotic factors and primary producers. Biomes may be terrestrial or aquatic.

Terrestrial Biomes

Terrestrial biomes include all the land areas on Earth where organisms live. The distinguishing features of terrestrial biomes are determined mainly by climate. Terrestrial biomes include tundras, temperate forests and grasslands, chaparral, temperate and tropical deserts, and tropical forests and grasslands.

Terrestrial Biomes and Climate

Climate is the average weather in an area over a long period of time. Weather refers to the conditions of the atmosphere from day to day. Climate is generally described in terms of temperature and moisture. Temperature falls from the equator to the poles. Therefore, major temperature zones are based on latitude. They include tropical, temperate, and arctic zones (see **Figure** 11.14). However, other factors besides latitude may also influence temperature. For example, land near the ocean may have cooler summers and warmer winters than land farther inland. This is because water gains and loses heat more slowly than does land, and the water temperature influences the temperature on the coast. Temperature also falls from lower to higher altitudes. That's why tropical zone mountain tops may be capped with snow.

In terms of moisture, climates can be classified as arid (dry), semi-arid, humid (wet), or semi-humid. The amount of moisture depends on both precipitation and evaporation. Precipitation increases moisture. Evaporation decreases moisture.

- The global pattern of precipitation is influenced by movements of air masses. For example, there is a global belt of dry air masses and low precipitation at about 30° N and 30° S latitude.
- Precipitation is also influenced by temperature. Warm air can hold more moisture than cold air, so tropical areas receive more rainfall than other parts of the world.
- Nearness to the ocean and mountain ranges may also influence the amount of precipitation an area receives. This is explained in **Figure** 11.15 .

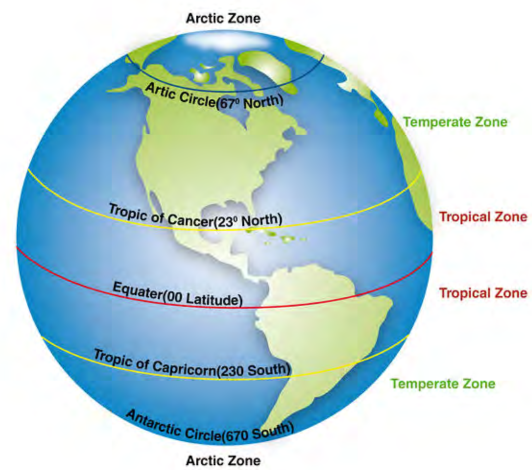


FIGURE 11.14
Temperature Zones. Temperature zones are based on latitude. What temperature zone do you live in

- Evaporation of moisture is greatest where it is hot and sunny. Therefore, cold climates with low precipitation may not be as dry as warm climates with the same amount of precipitation.
- Moist air from the ocean rises up over the mountain range.
- As the air rises, it cools and its water vapor condenses. Precipitation falls on the windward side of the mountain range.
- The air is dry when it reaches the leeward side of the mountain range, so there is little precipitation there. This creates a "rain shadow."

Climate and Plant Growth

Plants are the major producers in terrestrial biomes. They have five basic needs: air, warmth, sunlight, water, and nutrients. How well these needs are met in a given location depends on the growing season and soil quality, both of which are determined mainly by climate.

- The **growing season** is the period of time each year when it is warm and wet enough for plants to grow. The growing season may last all year in a hot, wet climate but just a few months in a cooler or drier climate.
- Plants grow best in soil that contains plenty of nutrients and organic matter. Both are added to soil when plant litter and dead organisms decompose. Decomposition occurs too slowly in cold climates and too quickly in hot, wet climates for nutrients and organic matter to accumulate. Temperate climates usually have the best soil for plant growth.

Climate and Biodiversity

Because climate determines plant growth, it also influences the number and variety of other organisms in a terrestrial biome. Biodiversity generally increases from the poles to the equator. It is also usually greater in more humid climates. This is apparent from the desert and rainforest biomes pictured in **Figure** 11.13 .

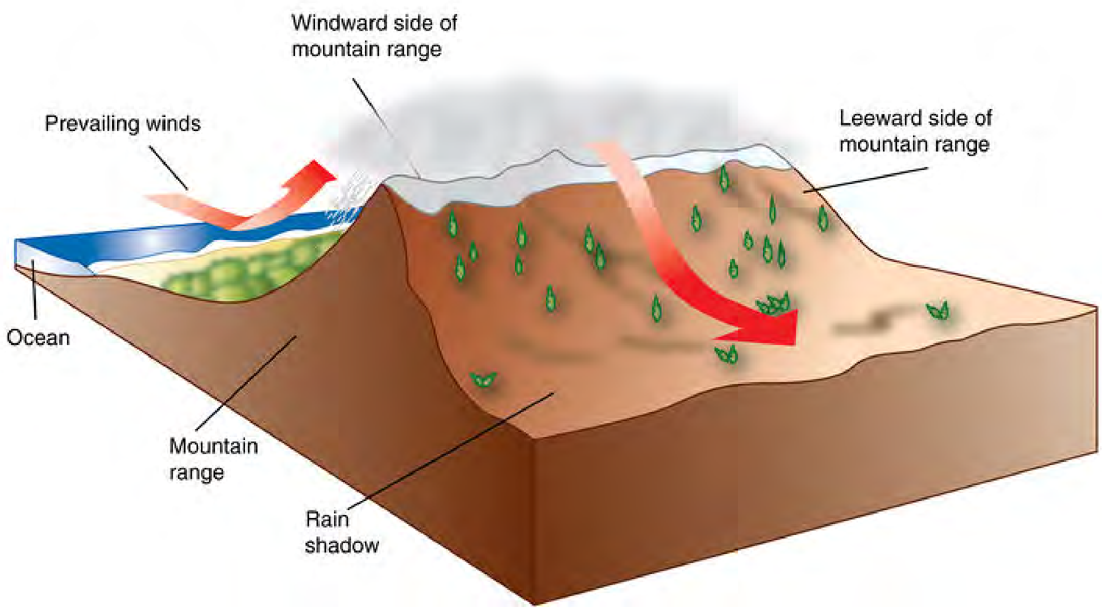


FIGURE 11.15

This diagram shows how precipitation is affected by the ocean and a mountain range.

Climate and Adaptations

Organisms evolve adaptations that help them survive in the climate of the biome where they live. For example, in biomes with arid climates, plants may have special tissues for storing water (see **Figure** 11.16). The desert animals pictured in **Figure** 11.17 also have adaptations for a dry climate.

FIGURE 11.16
Aloe Plant and Barrel Cactus. The aloe plant on the left stores water in its large hollow leaves. The cactus plant on the right stores water in its stout barrel-shaped stems.

FIGURE 11.17
Gila Monster and Kangaroo Rat. The Gila monster&#8217 s fat tail is an adaptation to its dry climate. It serves as a storage depot for water. The kangaroo rat has very efficient kidneys. They produce concentrated urine thus reducing the amount of water lost from the body.

In biomes with cold climates, plants may adapt by becoming dormant during the coldest part of the year. **Dormancy** is a state in which a plant slows down cellular activities and may shed its leaves. Animals also adapt to cold temperatures. One way is with insulation in the form of fur and fat. This is how the polar bears in **Figure** 11.18 stay warm.

Survey of Terrestrial Biomes

Terrestrial biomes are classified by climatic factors and types of primary producers. The world map in **Figure** 11.19 shows where 13 major terrestrial biomes are found. **Figure** 11.20 summarizes their basic features.

FIGURE 11.18

Polar Bears. Thick fur and a layer of blubber keep polar bears warm in their Arctic ecosystem. Why do you think their fur is white Why might it be an adaptation in an Arctic biome

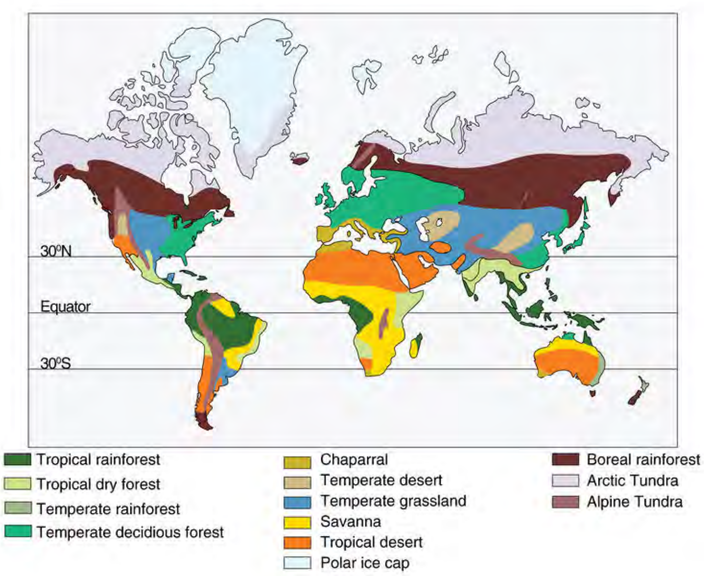
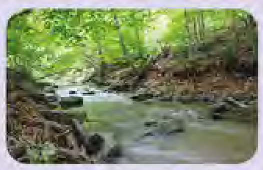
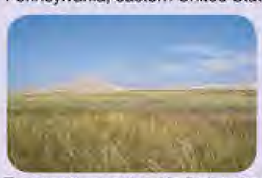


FIGURE 11.19

Worldwide Distribution of Terrestrial Biomes. This map shows the locations of Earth&#8217 s major terrestrial biomes.

Biome: Other Name(s)	Type of Climate, Growing Season, Soil Quality	Biodiversity, Common Plants, Common Animals
Tundra: Artic tundra (high latitudes) Alpine tundra (high altitudes)	*Type of climate*: arctic, arid *Growing season:* very short *Soil quality:* Very poor	 Alpine tundra in the Alps Mountains of Switzerland in Europe  Arctic tundra on the northern coast of Alaska in the United States *Biodiversity:* very low *Plants*: mosses, grasses, and lichens; few herbaceous plants; no trees *Animals:* insects; birds (summer only); no amphibians or reptiles; mammals such as rodents, arctic hares, arctic foxes, polar bears; caribou (summer only); mountain goats and chinchillas (alpine tundra only)
Boreal Forest: Taiga Northern conifer forest	*Climate:* subarctic, semi-arid *Growing season:* short *Soil quality:* Poor	*Biodiversity:* low *Plants:* conifers such as cedar, spruce, pine, and fir; mosses and lichens *Animals:* insects; birds (mainly in summer); no amphibians or reptiles; mammals such as rodents, rabbits, minks, raccoons, bears, and moose; caribou (winter only)  Boreal forest in central (inland) Alaska, United States
Temperate Deciduous Forest: Temperate hardwood forest Temperate broadleaf forest	*Climate:* temperate, semi-humid *Growing season:* medium *Soil quality:* good *Climate:* temperate, semi-arid *Growing season:* medium *Soil quality:* excellent	 Temperate deciduous forest in Pennsylvania, eastern United States *Biodiversity*: high *Plants*: broadleaf deciduous trees such as beech, maple, oak, and hickory; ferns, mosses, and shrubs; many herbaceous plants *Animals*: insects, amphibians, reptiles, and birds; mammals such as mice, chipmunks, squirrels, raccoons, foxes, deer, black bears, bobcats, and wolves  Temperate grassland in Nebraska, midwestern United States *Biodiversity*: medium–high *Plants*: grasses; other herbaceous plants; no trees *Animals*: invertebrates such as worms and insects; amphibians, reptiles, and birds; mammals such as mice, prairie dogs, rabbits, foxes, wolves, coyotes, bison, and antelope; kangaroo (only in Australia)
Chaparral Mediterranean scrub forest	*Climate:* temperate, semi-arid *Growing season:* medium *Soil quality:* poor	*Biodiversity*: low–medium *Plants:* shrubs and small trees such as scrub oak and scrub pine *Animals:* insects, reptiles, and birds; mammals such as rodents and deer  Chaparral in southern California, United States
Desert	*Climate:* temperate or tropical, arid *Growing season:* varies *Soil quality:* very poor	*Biodiversity:* none–low *Plants:* plants adapted to dryness, such as cacti, sage-brush, and mesquite; virtually no plants if extremely arid *Animals*: insects, reptiles, and birds; mammals such as rodents and coyotes  Desert in southern California, United States
Tropical Rainforest	*Climate:* tropical, humid *Growing season:* year-round *Soil quality:* excellent	*Biodiversity*: very high *Plants*: tall flowering, broadleaf evergreen trees; vines and epiphytes; few plants on forest floor *Animals:* insects, amphibians, reptiles, and birds; mammals such as monkeys, sloths, leopards, jaguars, pigs, and tigers  Tropical rainforest in Ecuador, South America
Tropical Grassland	*Climate*: tropical, semi-arid *Growing season:*	*Biodiversity*: low–medium *Plants*: grasses; scattered clumps of trees 

Aquatic Biomes

Terrestrial organisms are generally limited by temperature and moisture. Therefore, terrestrial biomes are defined in terms of these abiotic factors. Most aquatic organisms do not have to deal with extremes of temperature or moisture. Instead, their main limiting factors are the availability of sunlight and the concentration of dissolved oxygen and nutrients in the water. These factors vary from place to place in a body of water and are used to define **aquatic biomes**.

Aquatic Biomes and Sunlight

In large bodies of standing water, including the ocean and lakes, the water can be divided into zones based on the amount of sunlight it receives:

a. The **photic zone** extends to a maximum depth of 200 meters (656 feet) below the surface of the water. This is where enough sunlight penetrates for photosynthesis to occur. Algae and other photosynthetic organisms can make food and support food webs.
b. The **aphotic zone** is water deeper than 200 meters. This is where too little sunlight penetrates for photosynthesis to occur. As a result, food must be made by chemosynthesis or else drift down from the water above.

These and other aquatic zones in the ocean are identified in **Figure** 11.21 .

Aquatic Biomes and Dissolved Substances

Water in lakes and the ocean also varies in the amount of dissolved oxygen and nutrients it contains:

a. Water near the surface of lakes and the ocean usually has more dissolved oxygen than does deeper water. This is because surface water absorbs oxygen from the air above it.
b. Water near shore generally has more dissolved nutrients than water farther from shore. This is because most nutrients enter the water from land. They are carried by runoff, streams, and rivers that empty into a body of water.
c. Water near the bottom of lakes and the ocean may contain more nutrients than water closer to the surface. When aquatic organisms die, they sink to the bottom. Decomposers near the bottom of the water break down the dead organisms and release their nutrients back into the water.

Aquatic Organisms

Aquatic organisms generally fall into three broad groups: plankton, nekton, and benthos. They vary in how they move and where they live.

a. Plankton are tiny aquatic organisms that cannot move on their own. They live in the photic zone. They include phytoplankton and zooplankton. **Phytoplankton** are bacteria and algae that use sunlight to make food. **Zooplankton** are tiny animals that feed on phytoplankton.
b. Nekton are aquatic animals that can move on their own by "swimming" through the water. They may live in the photic or aphotic zone. They feed on plankton or other nekton. Examples of nekton include fish and shrimp.
c. Benthos are aquatic organisms that crawl in sediments at the bottom of a body of water. Many are decomposers. Benthos include sponges, clams, and anglerfish like the one in **Figure** 11.22 . How has this fish adapted to a life in the dark?

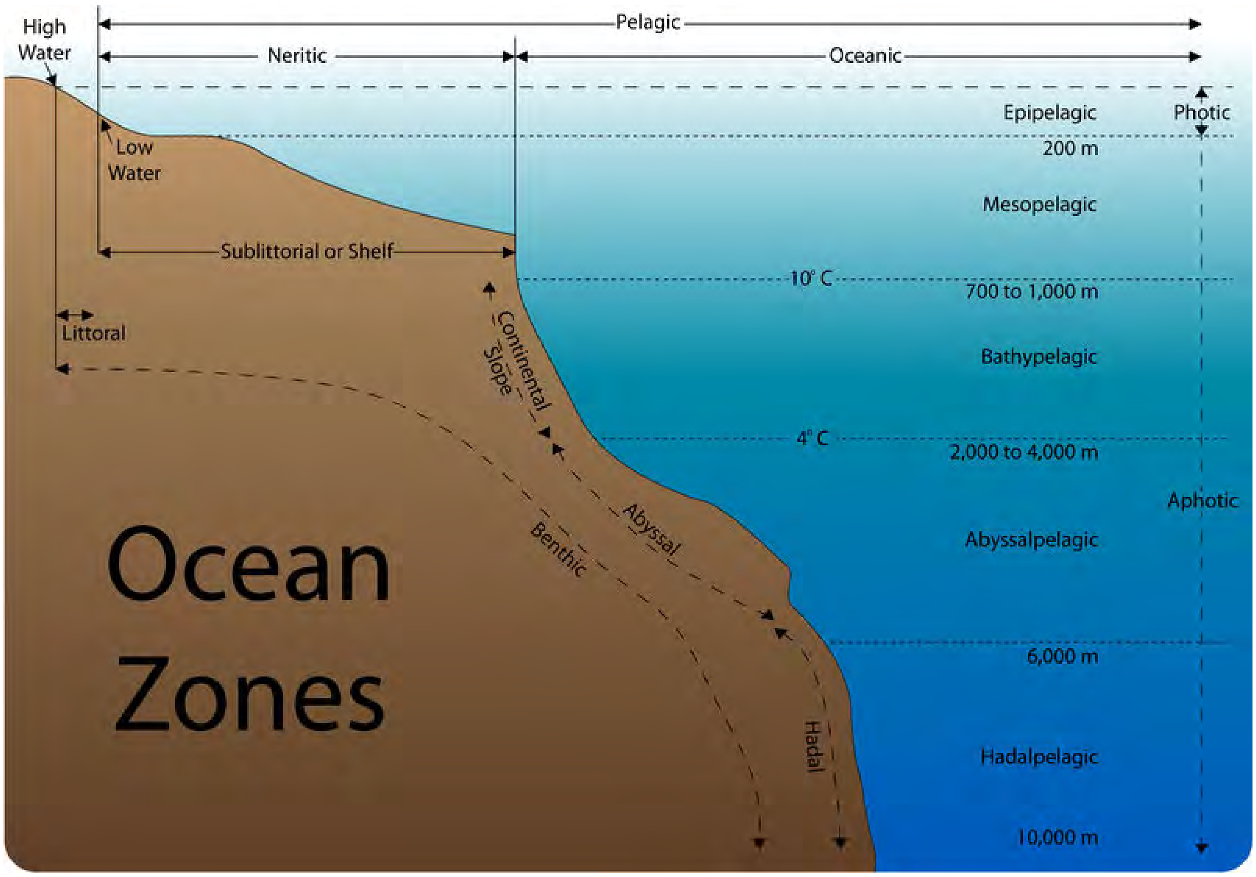


FIGURE 11.21
The ocean is divided into many different zones depending on distance from shore and depth of water.

FIGURE 11.22
Anglerfish. This anglerfish lives between 1000 and 4000 meters below sea level. No sunlight penetrates to this depth. The rod-like structure on its face has a glow-in-the-dark tip. It is covered with microorganisms that give off their own light. The fish wiggles the structure like a worm to attract prey. In the darkness only the rod-like worm is visible.

Marine Biomes

Anglerfish live in the ocean. Aquatic biomes in the ocean are called **marine biomes**. Organisms that live in marine biomes must be adapted to the salt in the water. For example, many have organs for excreting excess salt. Two ocean zones are particularly challenging to marine organisms: the intertidal zone and the deep ocean. The **intertidal zone** is the narrow strip along the coastline that is covered by water at high tide and exposed to air at low tide (see **Figure** 11.23). There are plenty of nutrients and sunlight in the intertidal zone. However, the water is constantly moving in and out, and the temperature keeps changing. These conditions requires adaptations in the organisms that live there, such as the barnacles in **Figure** 11.24 .

FIGURE 11.23
These pictures show the intertidal zone of the Bay of Fundy on the Atlantic coast in Maine. Can you identify the intertidal zone from the pictures

FIGURE 11.24
Barnacles. Barnacles secrete a cement-like substance that anchors them to rocks in the intertidal zone.

Organisms that live deep in the ocean must be able to withstand extreme water pressure, very cold water, and complete darkness. However, even here, thriving communities of living things can be found. Organisms cluster around hydrothermal vents in the ocean floor. The vents release hot water containing chemicals that would be toxic to most other living things. The producers among them are single-celled chemoautotrophs. They make food using energy stored in the chemicals. The tube worms in this chapter's opening photo depend on these chemoautotrophs for food.

Freshwater Biomes

Freshwater biomes have water that contains little or no salt. They include standing and running freshwater biomes. Standing freshwater biomes include ponds and lakes. Lakes are generally bigger and deeper than ponds. Some of the water in lakes is in the aphotic zone where there is too little sunlight for photosynthesis. Plankton and plants (such as the duckweed in **Figure** 11.25) are the primary producers in standing freshwater biomes.

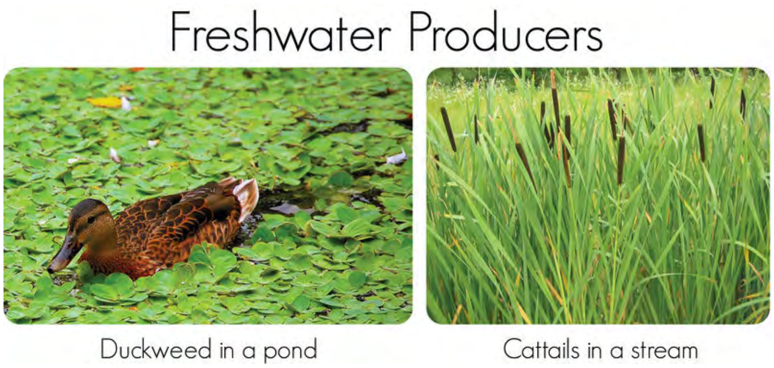


FIGURE 11.25
The pond on the left has a thick mat of duckweed plants. They cover the surface of the water and use sunlight for photosynthesis. The cattails on the right grow along a stream bed. They have tough slender leaves that can withstand moving water.

Running freshwater biomes include streams and rivers. Rivers are usually larger than streams. Streams may start with runoff or water seeping out of a spring. The water runs downhill and joins other running water to become a stream. A stream may flow into a river that empties into a lake or the ocean. Running water is better able to dissolve oxygen and nutrients than standing water. However, the moving water is a challenge to many living things. Algae and plants (such as the cattails in **Figure** 11.25) are the primary producers in running water biomes.

Wetlands

A **wetland** is an area that is saturated with water or covered by water for at least one season of the year. The water may be freshwater or salt water. Wetlands are extremely important biomes for several reasons:

- They store excess water from floods.
- They slow down runoff and help prevent erosion.
- They remove excess nutrients from runoff before it empties into rivers or lakes.
- They provide a unique habitat that certain communities of plants need to survive.
- They provide a safe, lush habitat for many species of animals, so they have high biodiversity.

KQED: Restoring Wetlands

More than 100,000 acres of wetlands are being restored in the Northern California Bay Area, but how exactly do we know what to restore them to? Historical ecologists are recreating San Francisco Bay wetlands that existed decades ago. To learn more, see http://www.kqed.org/quest/television/view/416.

For more than 100 years, south San Francisco Bay has been a center for industrial salt production. Now federal and state biologists are working to restore the ponds to healthy wetlands for fish and other wildlife. Salt marshes are rich habitats that provide shelter and food for many species, some of which are endangered or threatened.

See http://www.kqed.org/quest/television/from-salt-ponds-to-wetlands for additional information.

KQED: San Francisco Bay: A Unique Estuary

An **estuary** is a partly enclosed coastal body of water with one or more rivers or streams flowing into it, and with a free connection to the ocean. Estuaries can be thought of as the most biologically productive regions on Earth, with very high biodiversity. Estuaries are zones where land and sea come together, and where fresh and salt water meet.

The San Francisco Bay is one of the great estuaries of the world. See http://www.youtube.com/watch?v=clZz2OjE5n0#38;playnext=1#38;list=PL0AAA2B9B3E9F6AB3 for further information.

MEDIA

Click image to the left for more content.

KQED: Studying Aquatic Animals

Oceans cover more than 70 percent of our planet yet they make up one of the least explored regions on Earth. Who better to unlock the mysteries of the ocean than marine animals themselves? Marine scientists have been tagging and tracking sharks, leatherback turtles and other sea life to learn more about marine ecosystems. Through the Tagging of Pacific Predators program (TOPP), scientists hope to both assess and explain the migration routes, ecosystems and diversity of our oceans' species.

Beginning in 2000, scientists from the National Oceanic and Atmospheric Administration, Stanford University and the University of California, Santa Cruz combined to form TOPP. As part of TOPP, researchers attach satellite tags to elephant seals, white sharks, giant leatherback turtles, bluefin tuna, swordfish and other marine animals. The tags collect information, such as how deep each animal dives, the levels of ambient light (to help determine an animal's location) and interior and exterior body temperature. Some tags also collect information about the temperature, salinity and depth of the water surrounding an animal to help scientists identify ocean currents. The tags send the data to a satellite, which in turn sends the data the scientists. They use this information to create maps of migration patterns and discover new information about different marine ecosystems. The information collected by TOPP offers rare insights into the lives of marine animals. Without TOPP, that information would otherwise remain unknown. With TOPP, scientists are developing a working knowledge of the particular migration routes animals take, as well as the locations of popular breeding grounds and the environmental dangers faced by different species. TOPP has shed light on how we can better protect the leatherback turtle and other endangered species.

See http://www.kqed.org/quest/television/tagging-pacific-predators- for more information.

MEDIA

Click image to the left for more content.

Lesson Summary

- Terrestrial biomes are determined mainly by climate. Climate influences plant growth, biodiversity, and adaptations of land organisms. Terrestrial biomes include tundras, temperate forests and grasslands, chaparral, temperate and tropical deserts, and tropical forests and grasslands.
- Aquatic biomes are determined mainly by sunlight and concentrations of dissolved oxygen and nutrients in the water. Aquatic organisms are either plankton, nekton, or benthos. Marine biomes are found in the salt water of the ocean. Freshwater biomes include standing and running water biomes. Wetlands are extremely important biomes. They may have freshwater or salt water.

Lesson Review Questions

Recall

1. What is climate? How does it differ from weather?

2. What is a rain shadow?

3. How does climate influence plant growth?

4. Identify two types of tundra and where they are found.

5. In which biome are you most likely to find grasses, zebras, and lions?

6. What is the photic zone of the ocean?

Apply Concepts

7. Compare the data for Seattle and Denver in **Table** 11.2 . Seattle is farther north than Denver. Why is Seattle warmer?

TABLE 11.2: **short caption**

City, State	Latitude (° N)	Altitude (ft above sea level)	Location (relative to ocean)	Average Low Temperature in January (° F)
Seattle, Washington	48	429	Coastal	33
Denver, Colorado	41	5183	Interior	15

8. If you were to design a well-adapted desert animal, what adaptations would you give it to help it survive in its desert biome?

Think Critically

9. Explain the relationship between biodiversity and climate in terrestrial biomes.

10. Compare and contrast plankton, nekton, and benthos.

11. A developer wants to extend a golf course into a wetland. Outline environmental arguments you could make against this plan.

Points to Consider

You read in this lesson that wetlands have high biodiversity.

- In general, what abiotic factors do you think contribute to high biodiversity?
- Do you think Earth's biodiversity is increasing or decreasing? Why?

Opening image courtesy of the National Science Foundation, http://www.nsf.gov/news/overviews/earth-environ/assets/interact06.jpg, and under the public domain.

Chapter 12 Communities and Populations

Chapter Outline

If you saw the movie *Finding Nemo,* then you probably recognize this fish. It's known as a clownfish, and it's swimming near the tentacles of an animal called a sea anemone. The sea anemone kills prey by injecting poison with its tentacles. For some reason, the anemone doesn't harm the clownfish, perhaps because the fish has a coating of mucus that helps disguise it. But why does the clownfish "hang out" with the sea anemone? One reason is for the food. The clownfish eats the remains of the anemone's prey after it finishes feeding. Another reason is safety. The clownfish is safe from predators when it's near the anemone. Predators are scared away by the anemone's poison tentacles. In return, the clownfish helps the anemone catch food by attracting prey with its bright colors. Its feces also provide nutrients to the anemone. The clownfish and anemone are just one example of the diverse ways that living things may help each other in nature. You will learn more about species interactions such as this when you read this chapter.

12.1 Community Interactions

Lesson Objectives

- Define community as the term is used in ecology.
- Describe predation and its effects on population size and evolution.
- Explain why interspecific competition leads to extinction or greater specialization.
- Compare and contrast mutualism, commensalism, and parasitism.
- Outline primary and secondary succession, and define climax community.

Vocabulary

climax community final stable stage of ecological succession that may be reached in an undisturbed community

commensalism symbiotic relationship in which one species benefits while the other species is not affected

ecological succession changes through time in the numbers and types of species that make up the community of an ecosystem

host species that is harmed in a parasitic relationship

interspecific competition relationship between organisms of different species that strive for the same resources in the same place

intraspecific competition relationship between organisms of the same species that strive for the same resources in the same place

keystone species species that plays an especially important role in its community so that major changes in its numbers affect the populations of many other species in the community

mutualism type of symbiotic relationship in which both species benefit

parasite species that benefits in a parasitic relationship

parasitism symbiotic relationship in which one species benefits while the other species is harmed

pioneer species type of species that first colonizes a disturbed area

predation relationship in which members of one species consume members of another species

predator species that consumes another in a predator-prey relationship

prey species that is consumed by another in a predator-prey relationship

primary succession change in the numbers and types of species that live in a community that occurs in an area that has never before been colonized

secondary succession change in the numbers and types of species that live in a community that occurs in an area that was previously colonized but has been disturbed

specialization evolution of different adaptations in competing species, which allows them to live in the same area without competing

Introduction

Biomes as different as deserts and wetlands share something very important. All biomes have populations of interacting species. Species also interact in the same basic ways in all biomes. For example, all biomes have some species that prey on others for food. The focus of study of species interactions is the community.

What Is a Community?

A community is the biotic part of an ecosystem. It consists of all the populations of all the species in the same area. It also includes their interactions. Species interactions in communities are important factors in natural selection. They help shape the evolution of the interacting species. There are three major types of community interactions: predation, competition, and symbiosis.

Predation

Predation is a relationship in which members of one species (the **predator**) consume members of another species (the **prey**). The lions and buffalo in **Figure** 12.1 are classic examples of predators and prey. In addition to the lions, there is another predator in this figure. Can you spot it? The other predator is the buffalo. Like the lion, it consumes prey species, in this case species of grass. However, unlike the lions, the buffalo does not kill its prey. Predator-prey relationships such as these account for most energy transfers in food chains and food webs.

Predation and Population

A predator-prey relationship tends to keep the populations of both species in balance. This is shown by the graph in **Figure** 12.2 . As the prey population increases, there is more food for predators. So, after a slight lag, the predator population increases as well. As the number of predators increases, more prey are captured. As a result, the prey population starts to decrease. What happens to the predator population then?

FIGURE 12.1
Predators and Their Prey. Two lions feed on the carcass of a South African cape buffalo.

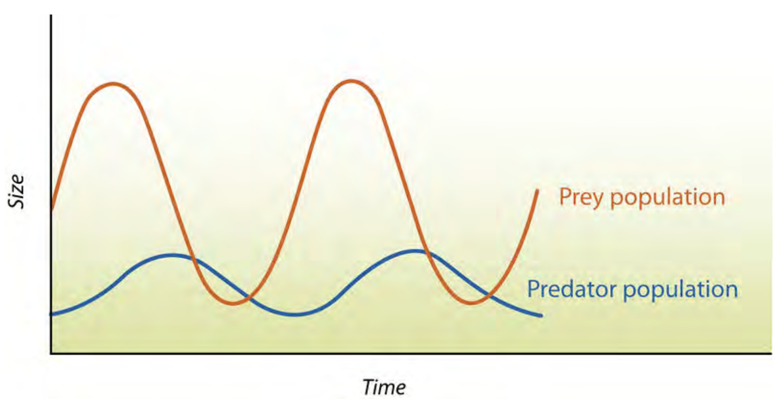


FIGURE 12.2
Predator-Prey population Dynamics. As the prey population increases why does the predator population also increase

Keystone Species

Some predator species are known as keystone species. A **keystone species** is one that plays an especially important role in its community. Major changes in the numbers of a keystone species affect the populations of many other species in the community. For example, some sea star species are keystone species in coral reef communities. The sea stars prey on mussels and sea urchins, which have no other natural predators. If sea stars were removed from a coral reef community, mussel and sea urchin populations would have explosive growth. This, in turn, would drive out most other species. In the end, the coral reef community would be destroyed.

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 is camouflage. Several examples are shown in **Figure** 12.3 . Camouflage in prey helps them hide from predators. Camouflage in predators helps them sneak up on prey.

FIGURE 12.3

Camouflage in Predator and Prey Species. Can you see the crab in the photo on the left It is camouflaged with algae. The preying mantis in the middle photo looks just like the dead leaves in the background. Can you tell where one zebra ends and another one begins This may confuse a predator and give the zebras a chance to run away.

Competition

Competition is a relationship between organisms that strive for the same resources in the same place. The resources might be food, water, or space. There are two different types of competition:

a. **Intraspecific competition** occurs between members of the same species. For example, two male birds of the same species might compete for mates in the same area. This type of competition is a basic factor in natural selection. It leads to the evolution of better adaptations within a species.
b. **Interspecific competition** occurs between members of different species. For example, predators of different species might compete for the same prey.

Interspecific Competition and Extinction

Interspecific competition often leads to extinction. The species that is less well adapted may get fewer of the resources that both species need. As a result, members of that species are less likely to survive, and the species may go extinct.

Interspecific Competition and Specialization

Instead of extinction, interspecific competition may lead to greater specialization. **Specialization** occurs when competing species evolve different adaptations. For example, they may evolve adaptations that allow them to use different food sources. **Figure** 12.4 describes an example.

FIGURE 12.4

Specialization in Anole Lizards. Specialization lets different species of anole lizards live in the same area without competing.

Symbiotic Relationships

Symbiosis is a close relationship between two species in which at least one species benefits. For the other species, the relationship may be positive, negative, or neutral. There are three basic types of symbiosis: mutualism, commensalism, and parasitism.

Mutualism

Mutualism is a symbiotic relationship in which both species benefit. An example of mutualism involves goby fish and shrimp (see **Figure** 12.5). The nearly blind shrimp and the fish spend most of their time together. The shrimp maintains a burrow in the sand in which both the fish and shrimp live. When a predator comes near, the fish touches the shrimp with its tail as a warning. Then, both fish and shrimp retreat to the burrow until the predator is gone. From their relationship, the shrimp gets a warning of approaching danger. The fish gets a safe retreat and a place to lay its eggs.

FIGURE 12.5
The multicolored shrimp in the front and the green goby fish behind it have a mutualistic relationship.

Commensalism

Commensalism is a symbiotic relationship in which one species benefits while the other species is not affected. One species typically uses the other for a purpose other than food. For example, mites attach themselves to larger flying insects to get a "free ride." Hermit crabs use the shells of dead snails for homes.

Parasitism

Parasitism is a symbiotic relationship in which one species (the **parasite**) benefits while the other species (the **host**) is harmed. Many species of animals are parasites, at least during some stage of their life. Most species are also hosts to one or more parasites. Some parasites live on the surface of their host. Others live inside their host. They may enter the host through a break in the skin or in food or water. For example, roundworms are parasites of mammals, including humans, cats, and dogs (see **Figure** 12.6). The worms produce huge numbers of eggs, which are passed in the host's feces to the environment. Other individuals may be infected by swallowing the eggs in contaminated food or water.

Some parasites kill their host, but most do not. It's easy to see why. If a parasite kills its host, the parasite is also likely to die. Instead, parasites usually cause relatively minor damage to their host.

Ecological Succession

Communities are not usually static. The numbers and types of species that live in them generally change through time. This is called **ecological succession**. Important cases of succession are primary and secondary succession.

FIGURE 12.6
Canine Roundworm. The roundworm above found in a puppyś intestine might eventually fill a dog&#8217 s intestine unless it gets medical treatment.

Primary Succession

Primary succession occurs in an area that has never before been colonized. Generally, the area is nothing but bare rock. This type of environment may come about when

- lava flows from a volcano and hardens into rock.
- a glacier retreats and leaves behind bare rock.
- a landslide uncovers an area of bare rock.

The first species to colonize a disturbed area such as this are called **pioneer species** (see **Figure** 12.7) They change the environment and pave the way for other species to come into the area. Pioneer species are likely to include bacteria and lichens that can live on bare rock. Along with wind and water, they help weather the rock and form soil. Once soil begins to form, plants can move in. At first, the plants include grasses and other species 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.

Secondary Succession

Secondary succession occurs in a formerly inhabited area that was disturbed. The disturbance could be a fire, flood, or human action such as farming. This type of succession is faster because the soil is already in place. In this case, the pioneer species are plants such as grasses, birch trees, and fireweed. Organic matter from the pioneer species improves the soil. This lets other plants move into the area. An example of this type of succession is shown in **Figure** 12.8 .

Climax Communities

Many early ecologists thought that a community always goes through the same series of stages during succession. They also assumed that succession always ends with a final stable stage. They called this stage the **climax community**. Today, most ecologists no longer hold these views. They believe that continued change is normal in most ecosystems. They think that most communities are disturbed too often to become climax communities.

FIGURE 12.7

Primary Succession. On an island near New Zealand bare rocks from a volcanic eruption are slowly being colonized by pioneer species.

FIGURE 12.8

Secondary Succession. This formerly plowed field in Poland is slowly changing back to forest.

Lesson Summary

- A community is the biotic part of an ecosystem. It consists of all the populations of all the species that live in the same area. It also includes their interactions.
- Predation is a relationship in which members of one species (the predator) consume members of another species (the prey). A predator-prey relationship keeps the populations of both species in balance.
- Competition is a relationship between organisms that strive for the same resources in the same place. Intraspecific competition occurs between members of the same species. It improves the species' adaptations. Interspecific competition occurs between members of different species. It may lead to one species going extinct or both becoming more specialized.
- Symbiosis is a close relationship between two species in which at least one species benefits. Mutualism is a symbiotic relationship in which both species benefit. Commensalism is a symbiotic relationship in which one species benefits while the other species is not affected. Parasitism is a symbiotic relationship in which one species (the parasite) benefits while the other species (the host) is harmed.
- Ecological succession is the process in which a community changes through time. Primary succession occurs in an area that has never before been colonized. Secondary succession occurs in a formerly inhabited area that was disturbed.

Lesson Review Questions

Recall

1. List the three major types of community interactions.
2. Describe the relationship between a predator population and the population of its prey.
3. What is a keystone species? Give an example.
4. Define mutualism and commensalism.
5. What is a climax community?
6. Summarize how ideas about ecological succession and climax communities have changed.

Apply Concepts

7. In 1980, a massive volcanic eruption of Mount St. Helen's in Washington State covered a large area with lava and ash. By 2010, plants were growing in the area, including some small trees. What type of ecological succession had occurred? How do you know? Describe how living things colonized the bare rock.

Think Critically

8. Compare and contrast the evolutionary effects of intraspecific and interspecific competition.
9. Explain why most parasites do not kill their host. Why is it in their own best interest to keep their host alive?

Points to Consider

Communities consist of populations of different species. The size and growth of populations in a community are influenced by species interactions. For example, predator-prey relationships control the growth of both predator and prey populations.

- How might populations grow without these influences? What other factors do you think might affect population growth?
- What factors do you think may have affected the growth of the human population?

12.2 Characteristics of Populations

Lesson Objectives

- Define population size, density, and dispersion.
- Relate population pyramids and survivorship curves to population structure.
- Identify factors that determine population growth rate.
- Compare and contrast exponential and logistic growth.

Vocabulary

age-sex structure number of individuals of each sex and age in a population

carrying capacity (K) largest population size that can be supported in an area without harming the environment

dispersal movement of offspring away from their parents

emigration movement of individuals out of a population

exponential growth pattern of population growth in which a population starts out growing slowly but grows faster and faster as population size increases

immigration movement of individuals into a population

species in which population growth is controlled by density-dependent factors and population size is generally at or near carrying capacity

logistic growth pattern of population growth in which growth slows and population size levels off as the population approaches the carrying capacity

migration regular movement of individuals or populations each year during certain seasons, usually to find food, mates, or other resources

population density average number of individuals in a population per unit of area or volume

population distribution describes how the individuals are distributed, or spread throughout their habitat

population growth rate (r) how fast a population changes in size over time

population pyramid bar graph that represents the age-structure of a population species in which population growth is rapid but death rates are high so population size is generally below the carrying capacity

survivorship curve graph that represents the individuals still alive at each age in a population

Introduction

Communities are made up of populations of different species. In biology, a population is a group of organisms of the same species that live in the same area. The population is the unit of natural selection and evolution. How large a population is and how fast it is growing are often used as measures of its health.

Population Size, Density, and Distribution

Population size is the number of individuals in a population. For example, a population of insects might consist of 100 individual insects, or many more. Population size influences the chances of a species surviving or going extinct. Generally, very small populations are at greatest risk of extinction. However, the size of a population may be less important than its density.

Population Density

Population density is the average number of individuals in a population per unit of area or volume. For example, a population of 100 insects that live in an area of 100 square meters has a density of 1 insect per square meter. If the same population lives in an area of only 1 square meter, what is its density? Which population is more crowded? How might crowding affect the health of a population?

Population Distribution

Population density just gives the average number of individuals per unit of area or volume. Often, individuals in a population are not spread out evenly. Instead, they may live in clumps or some other pattern (see **Figure** 12.9). The pattern may reflect characteristics of the species or its environment. **Population distribution** describes how the individuals are distributed, or spread throughout their habitat.

Population Structure

Population growth is the change in the size of the population over time. An important factor in population growth is **age-sex structure**. This is the number of individuals of each sex and age in the population. The age-sex structure influences population growth. This is because younger people are more likely to reproduce, while older people have higher rates of dying.

Population Pyramids

Age-sex structure is represented by a **population pyramid**. This is a bar graph, like the one **Figure** 12.10 . In this example, the bars become narrower from younger to older ages. Can you explain why?

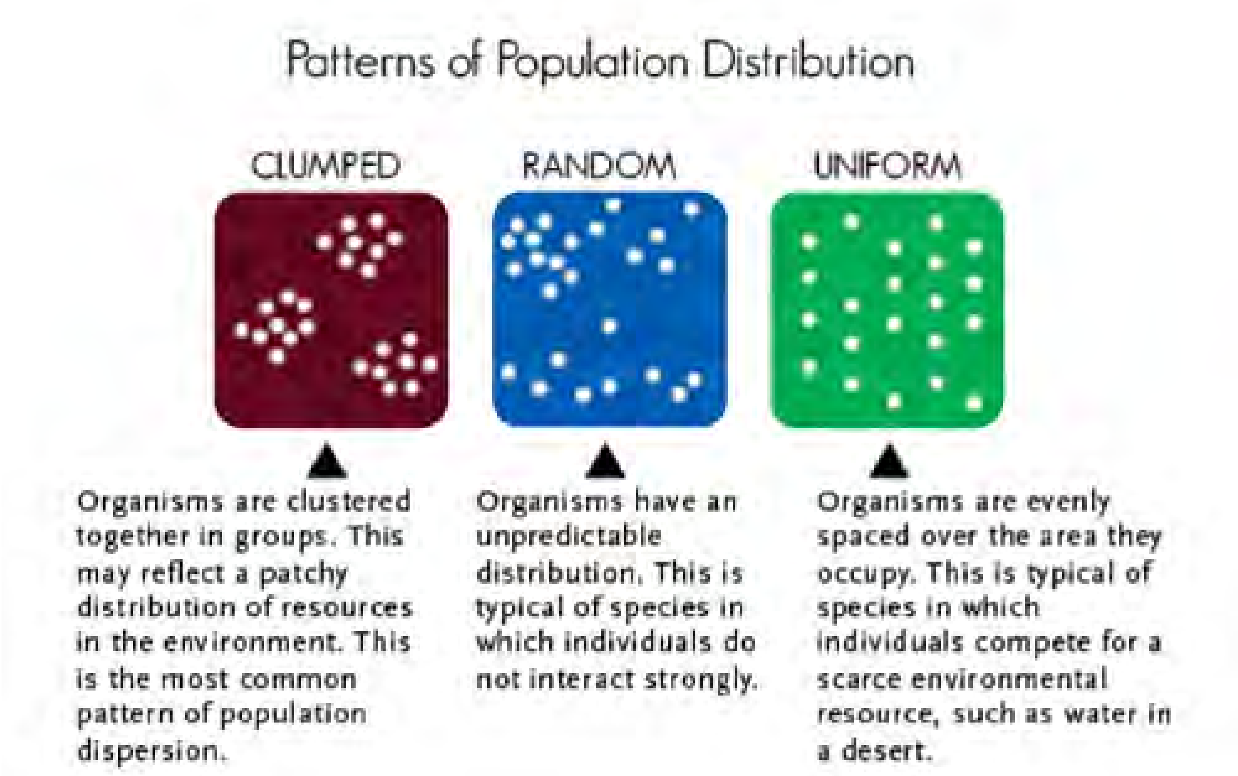


FIGURE 12.9

Patterns of Population Distribution. What factors influence the pattern of a population over space

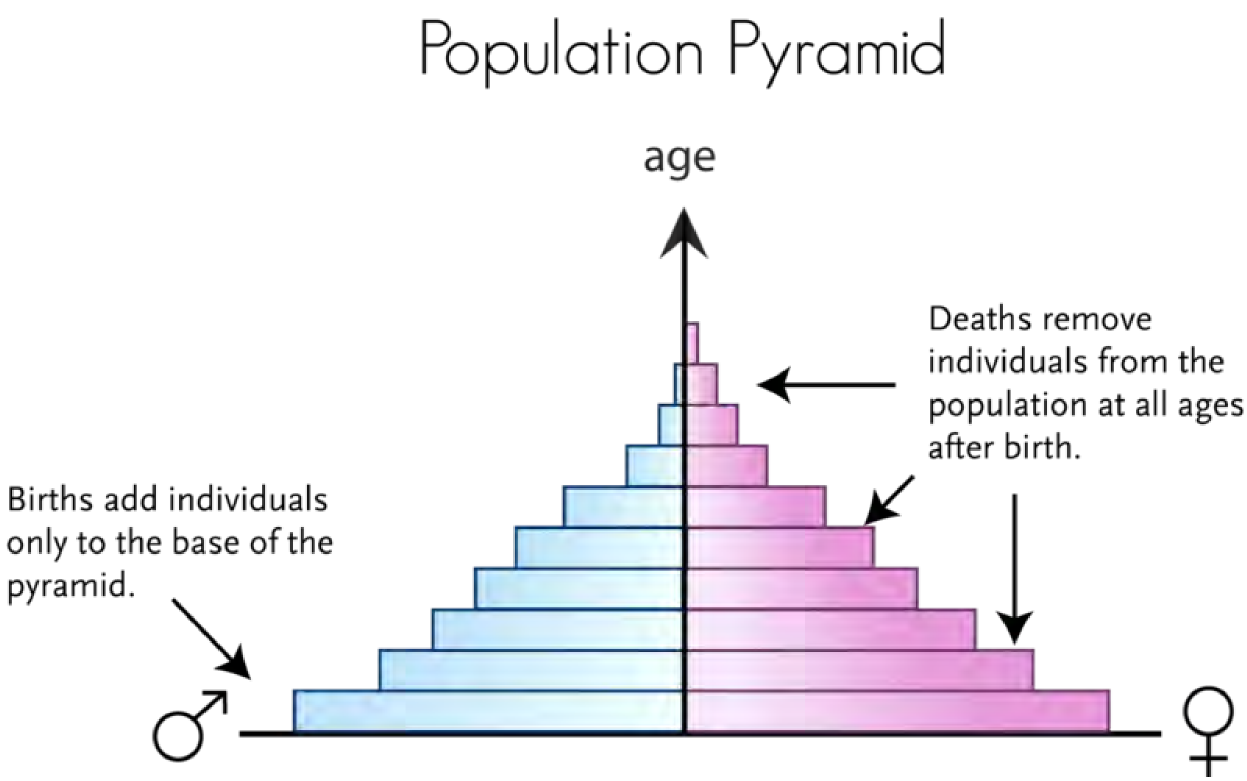


FIGURE 12.10
Population Pyramid. A population pyramid represents the age-sex structure of a population.

Survivorship Curves

Another way to show how deaths affect populations is with **survivorship curves**. These are graphs that represent the number of individuals still alive at each age. Examples are shown in **Figure** 12.11 .

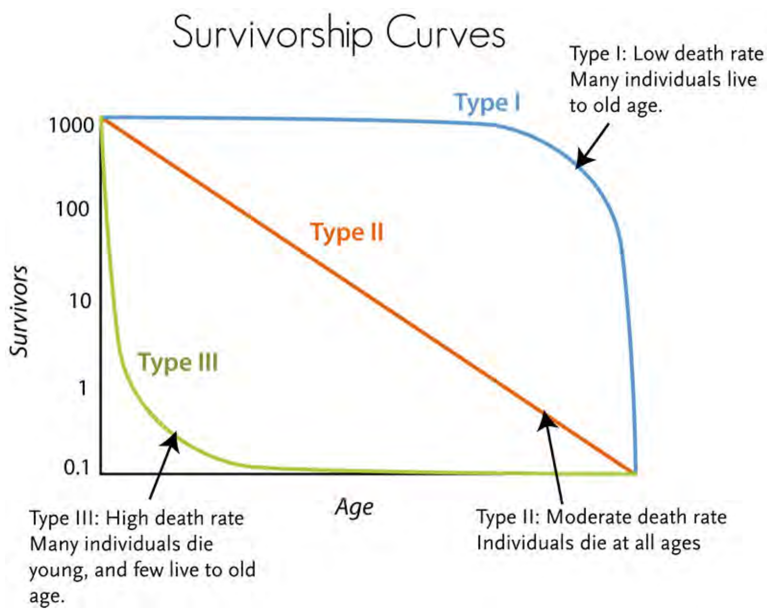


FIGURE 12.11

Survivorship Curves. Survivorship curves reflect death rates at different ages.

The three types of curves shown in the figure actually represent different strategies species use to adapt to their environment:

- Type I: Parents produce relatively few offspring and provide them with a lot of care. As a result, most of the offspring survive to adulthood so they can reproduce. This pattern is typical of large animals, including humans.
- Type II: Parents produce moderate numbers of offspring and provide some parental care. Deaths occur more uniformly throughout life. This pattern occurs in some birds and many asexual species.
- Type III: Parents produce many offspring but provide them with little or no care. As a result, relatively few offspring survive to adulthood. This pattern is typical of plants, invertebrates, and many species of fish.

The type I strategy occurs more often in stable environments. The Type III strategy is more likely in unstable environments. Can you explain why?

Population Growth

Populations gain individuals through births and immigration. They lose individuals through deaths and emigration. These factors together determine how fast a population grows.

Population Growth Rate

Population growth rate (*r*) is how fast a population changes in size over time. A positive growth rate means a population is increasing. A negative growth rate means it is decreasing. The two main factors affecting population growth are the birth rate (*b*) and death rate (*d*). Population growth may also be affected by people coming into the population from somewhere else (**immigration**, *i*) or leaving the population for another area (**emigration**, *e*). The formula for population growth takes all these factors into account.

$r = (b + i) - (d + e)$

- r = population growth rate
- b = birth rate
- i = immigration rate
- d = death rate
- e = emigration rate

Two lectures on demography are available at http://www.youtube.com/watch?v=3diw1Hu3auk (50:36) and http://www.youtube.com/watch?v=Wg3ESbyKbic (49:38).

Dispersal and Migration

Other types of movements may also affect population size and growth. For example, many species have some means of **dispersal**. This refers to offspring moving away from their parents. This prevents the offspring from competing with the parents for resources such as light or water. For example, dandelion seeds have "parachutes." They allow the wind to carry the seeds far from the parents (see **Figure** 12.12).

FIGURE 12.12
Dandelion Seeds. These dandelion seeds may disperse far from the parent plant. Why might this be beneficial to both parents and offspring

Migration is another type of movement that changes population size. **Migration** is the regular movement of individuals or populations each year during certain seasons. The purpose of migration usually is to find food, mates, or other resources. For example, many Northern Hemisphere birds migrate thousands of miles south each fall. They go to areas where the weather is warmer and more resources are available (see **Figure** 12.13). Then they return north in the spring to nest. Some animals, such as elk, migrate vertically. They go up the sides of mountains in spring as snow melts. They go back down the mountain sides in fall as snow returns.

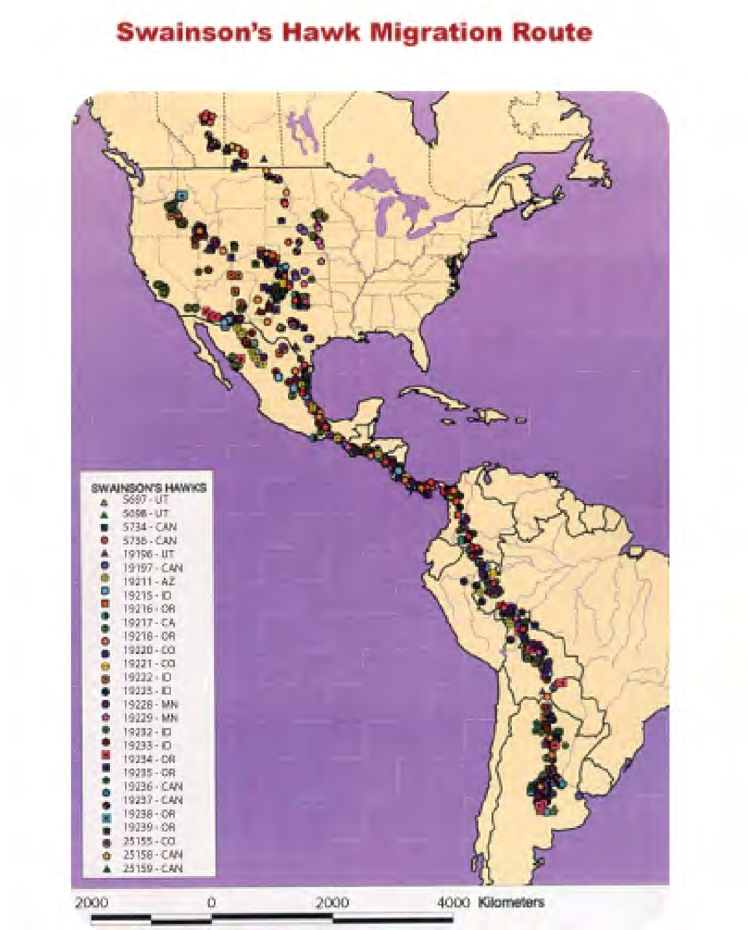


FIGURE 12.13

Swainson&#8217 s hawks migrate from North to South America and back again each year. This map shows where individual hawks have been identified during their migration.

Patterns of Population Growth

Populations may show different patterns of growth. The growth pattern depends partly on the conditions under which a population lives.

Exponential Growth

Under ideal conditions, populations of most species can grow at exponential rates. Curve A in **Figure** 12.14 represents **exponential growth**. The population starts out growing slowly. As population size increases, the growth rate also increases. The larger the population becomes, the faster it grows.

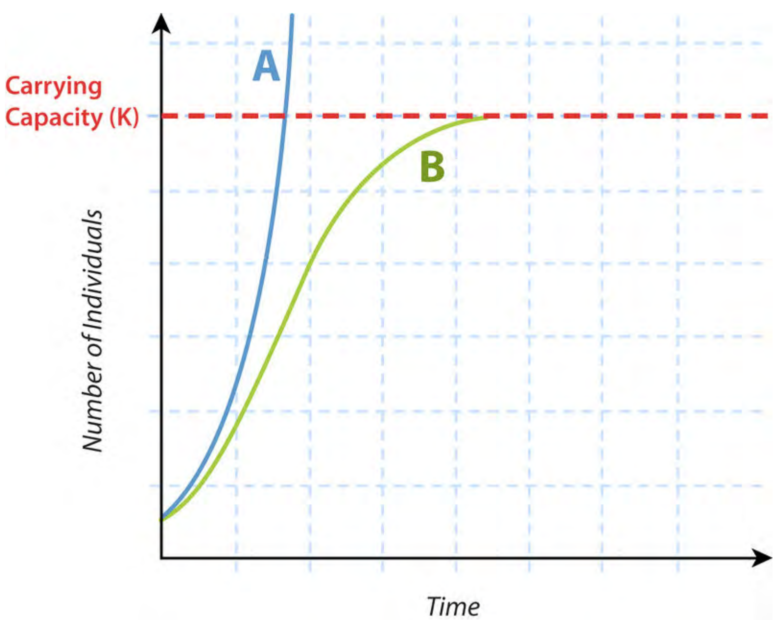


FIGURE 12.14
Exponential and Logistic Growth. Curve A shows exponential growth. Curve B shows logistic growth.

Logistic Growth

Most populations do not live under ideal conditions. Therefore, most do not grow exponentially. Certainly, no population can keep growing exponentially for very long. Many factors may limit growth. Often, the factors are density dependent. These are factors that kick in when the population becomes too large and crowded. For example, the population may start to run out of food or be poisoned by its own wastes. As a result, population growth slows and population size levels off. Curve B in **Figure** 12.14 represents this pattern of growth, which is called **logistic growth**.

At what population size does growth start to slow in the logistic model of growth? That depends on the population's carrying capacity (see **Figure** 12.14). The **carrying capacity (K)** is the largest population size that can be supported in an area without harming the environment. Population growth hits a ceiling at that size in the logistic growth model.

Species can be divided into two basic types when it comes to how their populations grow.

- Species that live in stable environments are likely to be ***K*-selected**. Their population growth is controlled by density-dependent factors. Population size is generally at or near the carrying capacity. These species are represented by curve B in **Figure** 12.14 .
- Species that live in unstable environments are likely to ***r*-selected**. Their potential population growth is rapid. For example, they have large numbers of offspring. However, individuals are likely to die young. Thus, population size is usually well below the carrying capacity. These species are represented by the lower part of curve A in **Figure** 12.14 .

Lesson Summary

- Population size is the number of individuals in a population. Population density is the average number of individuals per unit of area or volume. The pattern of spacing of individuals in a population may be affected by characteristics of a species or its environment.
- The age-sex structure of a population is the number of individuals of each sex and age in the population. Age-sex structure influences population growth. It is represented by a population pyramid. The number of survivors at each age is plotted on a survivorship curve.
- Population growth rate is how fast a population changes in size over time. It is determined by rates of birth, death, immigration, and emigration.
- Under ideal conditions, populations can grow exponentially. The growth rate increases as the population gets larger. Most populations do not live under ideal conditions and grow logistically instead. Density-dependent factors slow population growth as population size nears the carrying capacity.

Lesson Review Questions

Recall

1. What is population density?

2. Define immigration and emigration.

3. What is migration? Give an example.

4. Write the formula for the population growth rate. Identify all the variables.

5. State why dispersal of offspring away from their parents might be beneficial.

6. Describe exponential population growth.

7. What are K-selected and r-selected species?

Apply Concepts

8. A population of 820 insects lives in a 1.2-acre area. They gather nectar from a population of 560 flowering plants. The plants live in a 0.2-acre area. Which population has greater density, the insects or the plants?

9. Assume that a population pyramid has a very broad base. What does that tell you about the population it represents?

Think Critically

10. What can you infer about a species that has a random pattern of distribution over space? A uniform pattern?
11. Compare and contrast Type I and Type III survivorship curves.

Points to Consider

Human populations have an interesting history that you will read about in the next lesson. You just read about population dispersion and growth. Make some predictions about dispersion and growth in human populations:

- Do you think human populations have a clumped, random, or uniform dispersion?
- How fast do human populations grow? What might limit their growth?

12.3 Human Population Growth

Lesson Objectives

- Describe early human population growth.
- Outline the stages of the demographic transition.
- Explain trends in recent human population growth.
- Summarize the human population problem and possible solutions to the problem.

Vocabulary

demographic transition changes in population that occurred in Europe and North America beginning in the 18^{th} century, in which death rates fell and population growth rates increased, followed by birth rates falling and population growth rates decreasing

Introduction

Humans have been called the most successful "weed species" Earth has ever seen. Like weeds, human populations are fast growing. They also disperse rapidly. They have colonized habitats from pole to pole. Overall, the human population has had a pattern of exponential growth, as shown in **Figure** 12.15 . The population increased very slowly at first. As it increased in size, so did its rate of growth.

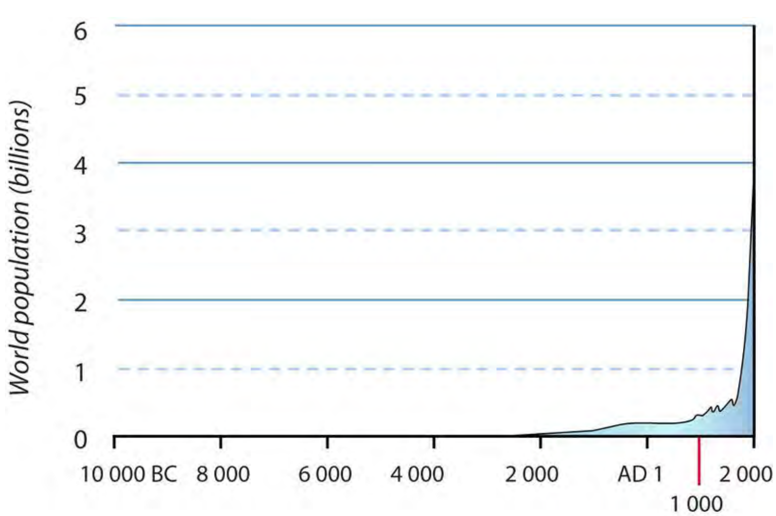


FIGURE 12.15

Growth of the Human Population. This graph gives an overview of human population growth since 10 000 BC. It took until about 1800 AD for the number of humans to reach 1 billion. It took only a little over 100 years for the number to reach 2 billion. Today the human population is rapidly approaching the 7 billion mark Why do you think the human population began growing so fast

Early Population Growth

Homo sapiens arose about 200,000 years ago in Africa. Early humans lived in small populations of nomadic hunters and gatherers. They first left Africa about 40,000 years ago. They soon moved throughout Europe, Asia, and Australia. By 10,000 years ago, they had reached the Americas. During this long period, birth and death rates were both fairly high. As a result, population growth was slow. Humans invented agriculture about 10,000 years ago. This provided a bigger, more dependable food supply. It also let them settle down in villages and cities for the first time. The death rate increased because of diseases associated with domestic animals and crowded living conditions. The birth rate increased because there was more food and settled life offered other advantages. The combined effect was continued slow population growth.

Demographic Transition

Major changes in the human population first began during the 1700s in Europe and North America. First death rates fell, followed somewhat later by birth rates.

Death Rates Fall

Several advances in science and technology led to lower death rates in 18^{th} century Europe and North America:

- New scientific knowledge of the causes of disease led to improved water supplies, sewers, and personal hygiene.
- Better farming techniques and machines increased the food supply.
- The Industrial Revolution of the 1800s led to new sources of energy, such as coal and electricity. This increased the efficiency of the new agricultural machines. It also led to train transport, which improved the distribution of food.

For all these reasons, death rates fell, especially in children. This allowed many more children to survive to adulthood, so birth rates increased. As the gap between birth and death rates widened, the human population grew faster.

Birth Rates Fall

It wasn't long before birth rates started to fall as well in Europe and North America. People started having fewer children because large families were no longer beneficial for several reasons.

- As child death rates fell and machines did more work, farming families no longer needed to have as many children to work in the fields.
- Laws were passed that required children to go to school. Therefore, they could no longer work and contribute to their own support. They became a drain on the family's income.

Eventually, birth rates fell to match death rates. As a result, population growth slowed to nearly zero.

Stages of the Demographic Transition

These changes in population that occurred in Europe and North America have been called the **demographic transition**. The transition can be summarized in the following four stages, which are illustrated in **Figure** 12.16 :

- Stage 1—High birth and death rates lead to slow population growth.
- Stage 2—The death rate falls but the birth rate remains high, leading to faster population growth.
- Stage 3—The birth rate starts to fall, so population growth starts to slow.
- Stage 4—The birth rate reaches the same low level as the death rate, so population growth slows to zero.

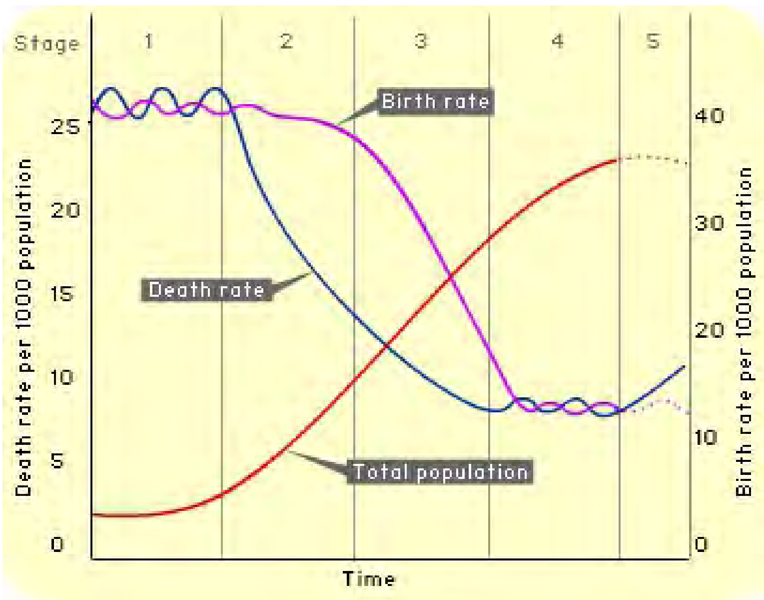


FIGURE 12.16

Stages of the Demographic Transition. In the demographic transition the death rate falls first. After a lag the birth rate also falls. How do these changes affect the rate of population growth over time

Recent Population Growth

At one time, scientists predicted that all human populations would pass through the same demographic transition as Europe and North America. Now, they are not so sure. Death rates have fallen throughout the world. No country today remains in Stage 1 of the transition. However, birth rates are still high in many poor countries. These populations seem to be stuck in Stage 2. An example is the African country of Angola. Its population pyramid for 2005 is shown in **Figure** 12.17 . The wide base of the pyramid base reflects the high birth rate of this population.

Many other countries have shifted to Stage 3 of the transition. Birth rates have started to fall. As a result, population growth is slowing. An example is Mexico. Its population pyramid for 1998 is shown in **Figure** 12.18 . It reflects a recent fall in the birth rate.

Most developed nations have entered Stage 4. Sweden is an example (see **Figure** 12.19). The birth rate has been low for many years in Sweden. Therefore, the rate of population growth is near zero.

In some countries, birth rates have fallen even lower than death rates. As result, their population growth rates are negative. In other words, the populations are shrinking in size. These populations have top-heavy population pyramids, like the one for Italy shown in **Figure** 12.20 . This is a new stage of the demographic transition, referred to as Stage 5. You might think that a negative growth rate would be a good thing. In fact, it may cause problems. For example, growth-dependent industries decline. Supporting the large aging population is also a burden for the shrinking younger population of workers.

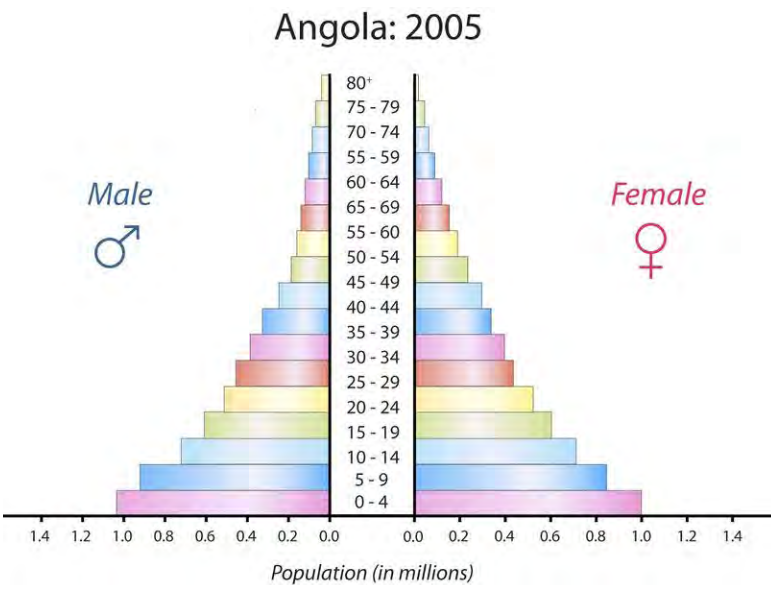


FIGURE 12.17

Angola&#8217 s population pyramid is typical of Stage 2 of the demographic transition.

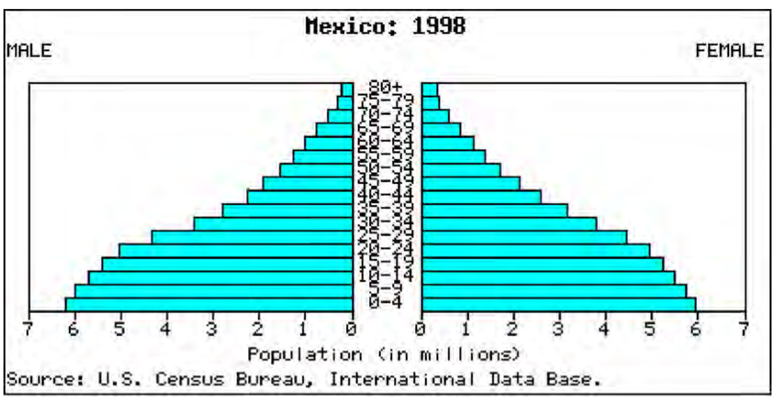


FIGURE 12.18

Mexico&#8217 s 1998 population pyramid is typical of Stage 3 population. How can you tell that the birth rate has started to fall

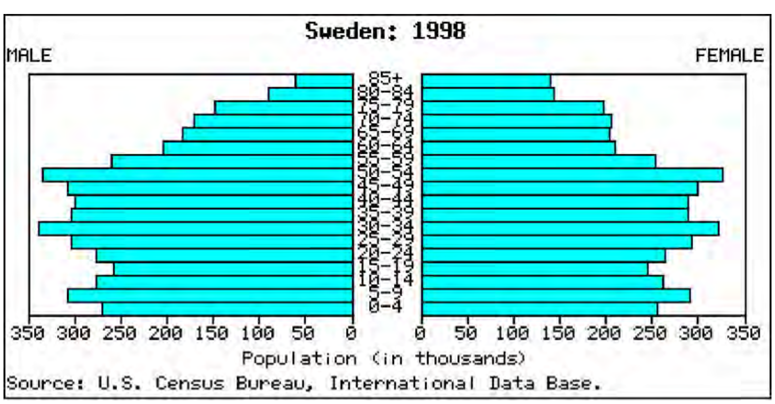


FIGURE 12.19

Sweden&#8217 s 1998 population pyramid shows a population in Stage 4.

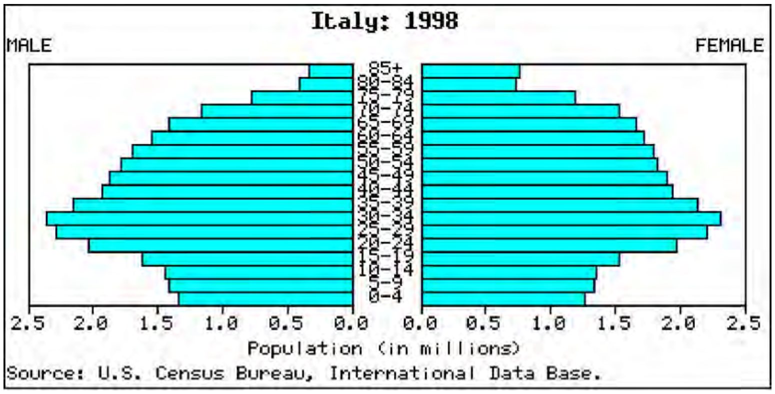


FIGURE 12.20

This 1998 population pyramid for Italy represents a Stage 5 population.

Future Population Growth

The human population is now growing by more than 200,000 people a day. At this rate, there will be more than 9 billion people by 2050. The human population may well be close to its carrying capacity. It has already harmed the environment. An even larger human population may cause severe environmental problems. This could lead to outbreaks of disease, starvation, and global conflict. There are three potential solutions:

a. Use technology to make better use of resources to support more people.
b. Change behaviors to reduce human numbers and how much humans consume.
c. Distribute resources more fairly among all the world's people.

Which solution would you choose?

Census Update: What the World Will Look like in 2050

On June 30, 2011, Time.com published *Census Update: What the World Will Look like in 2050* (http://www.time.com/time/nation/article/0,8599,2080404,00.html). According to the U.S Census Bureau, in 2050, there will be 9.4 billion people:

- India will be the most populous nation, surpassing China sometime around 2025.
- The U.S. will remain the third most populous nation, with a population of 423 million (up from 308 million in 2010).
- Declining birth rates Japan and Russia will cause them to fall from their current positions as the 9th and 10th most populous nations, respectively, to 16th and 17th.
- Nigeria will have a population of 402 million, up from 166 million people.
- Ethiopia's population will likely triple, from 91 million to 278 million, making the East African nation one of the top 10 most populous countries in the world.

So what does all this mean?

- The African continent is expected to experience significant population growth in the coming decades, which could compound the already-problematic food-supply issues in some African nations.
- Immigration and differing birth rates among races will change the ethnic composition of the U.S.
- Population booms in Africa and India, the decline of Russia and the expected plateau of China will all change the makeup of the estimated 9.4 billion people who will call Earth home in 2050.

Lesson Summary

- Early humans lived in small populations of nomadic hunters and gatherers. Both birth and death rates were fairly high. As a result, human population growth was very slow. The invention of agriculture increased both birth and death rates. The population continued to grow slowly.
- Major changes in the human population first began during the 1700s. This occurred in Europe and North America. First, death rates fell while birth rates remained high. This led to rapid population growth. Later, birth rates also fell. As a result, population growth slowed.
- Other countries have completed a similar demographic transition. However, some countries seem stalled at early stages. They have high birth rates and rapidly growing populations.
- The total human population may have to stop growing eventually. Even if we reduce our use of resources and distribute them more fairly, at some point the carrying capacity will be reached.

Lesson Review Questions

Recall

1. How did the invention of agriculture affect human birth and death rates? How did it affect human population growth?

2. Outline the four stages of the demographic transition as it occurred in Europe and North America.

3. State two reasons why death rates fell in Europe and North America, starting in the 1700s.

4. Why did birth rates fall in Europe and North America during the demographic transition?

5. Why was a fifth stage added to the demographic transition model? Describe a population at this stage.

Apply Concepts

6. Which stage of the demographic transition is represented by the population pyramid 12.21 ?

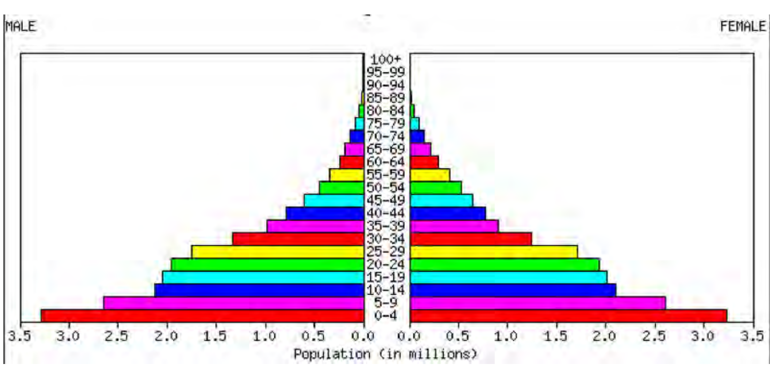


FIGURE 12.21

7. Assume you will add a line to the graph in **Figure** 12.16 to represent the population growth rate (r). Describe what the line would like.

Think Critically

8. Evaluate how well the original demographic transition model represents human populations today.

9. What is the human population problem? What are some potential solutions? Which solution do you think is best? Present a logical argument to support your choice.

Points to Consider

The human population may already be larger than its carrying capacity.

- What evidence might show that there are too many people on Earth today?
- How does human overpopulation affect the environment? How does it affect the populations of other species?

12.4 The Biodiversity Crisis

Lesson Objectives

- Define biodiversity.
- Identify economic benefits and ecosystem services of biodiversity.
- Relate human actions to the sixth mass extinction.

Vocabulary

exotic species species that is introduced (usually by human actions) into a new habitat where it may lack local predators and out-compete native species

habitat loss destruction or disruption of Earth's natural habitats, most often due to human actions such as agriculture, forestry, mining, and urbanization

sixth mass extinction current mass extinction caused primarily by habitat loss due to human actions

Introduction

One of the effects of human overpopulation is the loss of other species. The rapidly growing human population has reduced Earth's biodiversity.

What Is Biodiversity?

Biodiversity refers to the variety of life and its processes, including the variety of living organisms, the genetic differences among them, and the communities and ecosystems in which they occur. Scientists have identified about 1.9 million species alive today. They are divided into the six kingdoms of life shown in **Figure** 12.22 . Scientists are still discovering new species. Thus, they do not know for sure how many species really exist today. Most estimates range from 5 to 30 million species.

A discussion of biodiversity is available at http://www.youtube.com/watch?v=vGxJArebKoc (6:12).

Millions of Unseen Species

A study released in August 2011 estimates that Earth has almost 8.8 million animal, plant and fungi species, but we've only discovered less than a quarter of them. So far, only 1.9 million species have been found. Recent newly discovered species have been very diverse: a psychedelic frogfish, a lizard the size of a dime and even a blind hairy

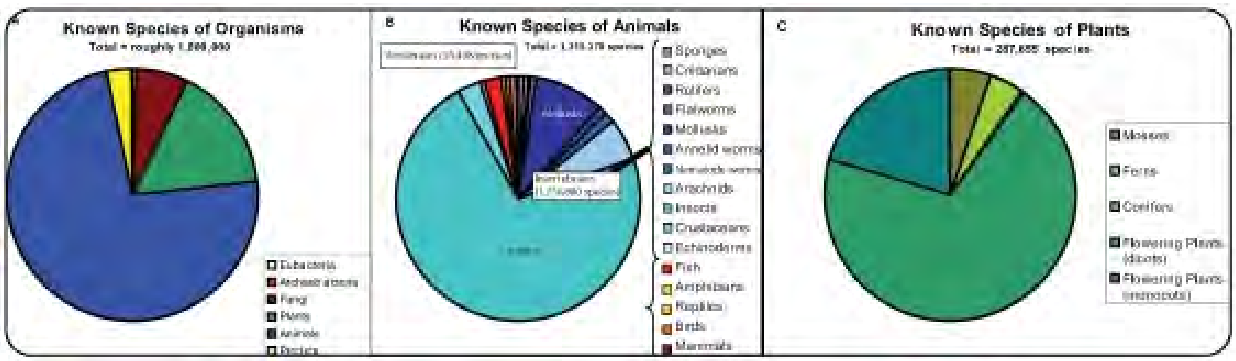


FIGURE 12.22

Known species represent only a fraction of all species that exist on Earth.

mini-lobster at the bottom of the ocean. There are potential benefits from these undiscovered species, which need to be found before they disappear from the planet. The study estimates that of the 8.8 million species, about 6.5 million would be on land and 2.2 million in the ocean. The research estimates that animals rule with 7.8 million species, followed by fungi with 611,000 and plants with just shy of 300,000 species. See http://news.yahoo.com/wild-world-millions-unseen-species-fill-earth-210051661.html for additional information.

Why Is Biodiversity Important?

Human beings benefit in many ways from biodiversity. Biodiversity has direct economic benefits. It also provides services to entire ecosystems.

Economic Benefits of Biodiversity

The diversity of species provides humans with a wide range of economic benefits:

- Wild plants and animals maintain a valuable pool of genetic variation. This is important because domestic species are genetically uniform. This puts them at great risk of dying out due to disease.
- Other organisms provide humans with many different products. Timber, fibers, adhesives, dyes, and rubber are just a few.
- Certain species may warn us of toxins in the environment. When the peregrine falcon nearly went extinct, for example, it warned us of the dangers of DDT.
- More than half of the most important prescription drugs come from wild species. Only a fraction of species have yet been studied for their medical potential.
- Other living things provide inspiration for engineering and technology. For example, the car design in **Figure** 12.23 was based on a fish.

Ecosystem Services of Biodiversity

Biodiversity generally increases the productivity and stability of ecosystems. It helps ensure that at least some species will survive environmental change. It also provides many other ecosystem services. For example:

FIGURE 12.23
From flowers to fish biodiversity benefits humans in many ways.

- Plants and algae maintain the atmosphere. During photosynthesis, they add oxygen and remove carbon dioxide.
- Plants help prevent soil erosion. They also improve soil quality when they decompose.
- Microorganisms purify water in rivers and lakes. They also return nutrients to the soil.
- Bacteria fix nitrogen and make it available to plants. Other bacteria recycle the nitrogen from organic wastes and remains of dead organisms.
- Insects and birds pollinate flowering plants, including crop plants.
- Natural predators control insect pests. They reduce the need for expensive pesticides, which may harm people and other living things.

Human Actions and the Sixth Mass Extinction

Over 99 percent of all species that ever lived on Earth have gone extinct. Five mass extinctions are recorded in the fossil record. They were caused by major geologic and climatic events. Evidence shows that a **sixth mass extinction** is occurring now. Unlike previous mass extinctions, the sixth extinction is due to human actions.

Some scientists consider the sixth extinction to have begun with early hominids during the Pleistocene. They are blamed for over-killing big mammals such as mammoths. Since then, human actions have had an ever greater impact on other species. The present rate of extinction is between 100 and 100,000 species per year. In 100 years, we could lose more than half of Earth's remaining species.

Causes of Extinction

The single biggest cause of extinction today is **habitat loss**. Agriculture, forestry, mining, and urbanization have disturbed or destroyed more than half of Earth's land area. In the U.S., for example, more than 99 percent of tall-grass prairies have been lost. Other causes of extinction today include:

- **Exotic species** introduced by humans into new habitats. They may carry disease, prey on native species, and disrupt food webs. Often, they can out-compete native species because they lack local predators. An example is described in **Figure** 12.24 .
- Over-harvesting of fish, trees, and other organisms. This threatens their survival and the survival of species that depend on them.
- Global climate change, largely due to the burning of fossil fuels. This is raising Earth's air and ocean temperatures. It is also raising sea levels. These changes threaten many species.
- Pollution, which adds chemicals, heat, and noise to the environment beyond its capacity to absorb them. This causes widespread harm to organisms.
- Human overpopulation, which is crowding out other species. It also makes all the other causes of extinction worse.

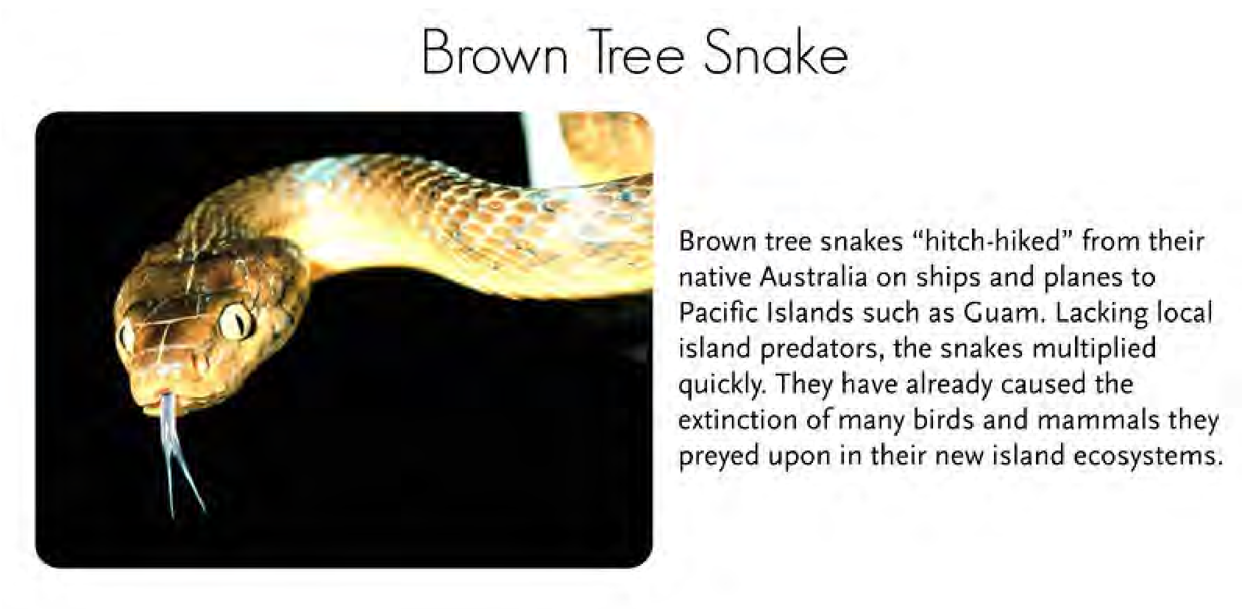


FIGURE 12.24
Brown Tree Snake. The brown tree snake is an exotic species that has caused many extinctions on Pacific islands such as Guam.

Effects of Extinction

The results of a study released in the summer of 2011 have shown that the decline in the numbers of large predators like sharks, lions and wolves is disrupting Earth's ecosystem in all kinds of unusual ways. The study, conducted by scientists from 22 different institutions in six countries, confirmed the sixth mass extinction. The study states that this mass extinction differs from previous ones because it is entirely driven by human activity through changes in land use, climate, pollution, hunting, fishing and poaching. The effects of the loss of these large predators can be seen in the oceans and on land.

- Fewer cougars in the western US state of Utah led to an explosion of the deer population. The deer ate more vegetation, which altered the path of local streams and lowered overall biodiversity.

- In Africa, where lions and leopard are being lost to poachers, there is a surge in the numbers of olive baboons who are transferring intestinal parasites to human who live nearby.
- In the oceans, industrial whaling led a change in the diets of killer whales, who eat more sea lion, seals and otters and dramatically lowered those population counts.

The study concludes that the loss of big predators has likely driven many of the pandemics, population collapses and ecosystem shifts the Earth has seen in recent centuries. See http://news.yahoo.com/loss-big-predators-disrupts-earth-ecosystem-study-181200945.html for additional information.

KQED: Disappearing Frogs

Around the world, frogs are declining at an alarming rate due to threats like pollution, disease and climate change. Frogs bridge the gap between water and land habitats, making them the first indicators of ecosystem changes. Meet the California researchers working to protect frogs across the state and across the world at http://www.kqed.org/quest/television/disappearing-frogs. Learn about the plight of the yellow-legged frog at http://www.kqed.org/quest/radio/plight-of-the-yellowlegged-frog.

MEDIA
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KQED: Nonnative Species

Scoop a handful of critters out of the San Francisco Bay and you'll find many organisms from far away shores. Invasive kinds of mussels, fish and more are choking out native species, challenging experts around the state to change the human behavior that brings them here. See http://www.kqed.org/quest/television/san-francisco-bay-invaders for more information.

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How You Can Help Protect Biodiversity

There are many steps you can take to help protect biodiversity. For example:

- Consume wisely. Reduce your consumption wherever possible. Re-use or recycle rather than throw out and buy new. When you do buy new, choose products that are energy efficient and durable.
- Avoid plastics. Plastics are made from petroleum and produce toxic waste.
- Go organic. Organically grown food is better for your health. It also protects the environment from pesticides and excessive nutrients in fertilizers.
- Save energy. Unplug electronic equipment and turn off lights when not in use. Take mass transit instead of driving.

See http://www.youtube.com/watch?v=GnK7gNXxb3c for an outstanding *60 Minutes* video of the Great Migration in Kenya, and the issues facing these animals.

KQED: Lost Salmon

Because of a sharp decline in their numbers, the entire salmon fishing season in the ocean off California and Oregon was canceled in both 2008 and 2009. At no other time in history has this salmon fishery been closed. The species in the most danger is the California coho salmon. Examine efforts to protect the coho in Northern California and explores the important role salmon play in the native ecosystem at http://www.kqed.org/quest/television/californias-lost-salmon and http://www.kqed.org/quest/television/coho-salmon-in-muir-woods.

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The Encyclopedia of Life

Encyclopedia of Life

The **Encyclopedia of Life** (EOL) is a free, online collaborative encyclopedia intended to document all of the 1.9+ million living species known to science. It is compiled from existing scientific databases, and from contributions by experts and non-experts world-wide. Its goal is to build one *infinitely expandable* page for each species, including videos, sound, images, graphics, and text. As the discovery of new species is expected to continue (the current rate is about 20,000 new species identified per year), EOL will grow continuously. As taxonomy finds new ways to include species identified by molecular techniques, the rate of new species additions will increase - in particular with respect to the microbial world of (eu)bacteria, archaebacteria and viruses. EOL went live on February 26, 2008 with 30,000 entries.

The EOL has developed web-based tools and services that provide visitors enhanced capability to use EOL content for their own purposes and to contribute to the site and become part of a growing international community interested in biodiversity.

See http://www.eol.org/ and http://www.youtube.com/watch?v=6NwfGA4cxJQ for additional information.

MEDIA

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In addition, *Understanding Biodiversity,* the CK-12 and EOL biodiversity-themed resource currently under development, is an expanding library of biodiversity information aimed at the secondary-level biology classroom. *Understanding Biodiversity* pages will provide information for each species relevant to the high school biology curriculum: cell biology, genetics, evolution, ecology, and physiology. If you would like to submit a species page to *Understanding Biodiversity,* email a proposal for contributions to teachers-requests@ck12.org.

Field Guides

http://education.eol.org/ideas/tools/fieldguide

Field Guides pull selected content from EOL species pages into a format that is easier to view and use for particular projects. Rather than sorting through all 1.9 million species pages and all of the *Table of Contents* information, users will see information for just the organisms and information they select. Users are able to customize and edit the content in their field guide.

You can try creating a field guide for the organisms found in your schoolyard or for the organisms discussed in another chapter of this FlexBook. See what information is found in EOL and what is missing. Is there anything you can contribute to EOL, such as an image or class research information?

EOL Podcasts

http://education.eol.org/podcast

Lend an ear and discover the wonders of nature—right outside your back door and halfway around the world. EOL audio broadcasts are aimed at learning about life-from organisms as small as yeast to as big as a bowhead whale. Hear people's stories about nature and hone your backyard observation skills. Explore the diversity of life—five minutes and *One Species at a Time*. Listen to the podcasts online, or download them and take them with you on your own exploration of the world around you.

One Species at a Time

The audio series *One Species at a Time* is a tribute to life on Earth http://education.eol.org/podcast/one-species-time. Each episode is a story, a mystery, a riddle, or an exploration of a different creature pulsing, fluttering, surging, respiring, and galloping on this planet. Biodiversity is center stage, from scurrying invasive beetles in Oregon to the threatened cedar trees of Lebanon to Ediacaran fauna from 580 million years ago. There are associated *Extras* and a *Meet the Scientist* section with each podcast. Some have associated educational materials. Some have associated educational materials. All podcasts are freely available and can be used in other projects.

The Biodiversity Heritage Library

http://www.biodiversitylibrary.org/

Twelve major natural history museum libraries, botanical libraries, and research institutions have joined to form the **Biodiversity Heritage Library**. The participating libraries have over two million volumes of biodiversity literature collected over 200 years to support the work of scientists, researchers, and students in their home institutions and throughout the world.

The Biodiversity Heritage Library (BHL) consortium cooperates to digitize and make accessible the biodiversity literature held in their collections and to make that literature available for open access and responsible use as a part of a global "biodiversity commons." Because of the BHL's success in digitizing a significant mass of biodiversity literature, the scientific documentation of the study of living organisms since the time of Linnaeus has became easily accessible.

Anyone can access the BHL website directly or link to it from any EOL species page. When on a species page, scroll down through the Table of Contents on the left hand side of the page to the "References and More Information" section and click on "Biodiversity Heritage Library." BHL literature directly related to the species under consideration will be shown.

The published literature on biological diversity has limited global distribution; much of it is available in only a few select libraries in the developed world. These collections are of exceptional value because the domain of systematic biology depends - more than any other science - upon historic literature. Yet, this wealth of knowledge is available only to those few who can gain direct access to significant library collections. Literature about the *life* that exists in developing countries is often not available within their borders. Biologists have long considered that access to the published literature is one of the chief impediments to the efficiency of research in the field. Among other results, free global access to digitized versions of the literature would make available information about the Earth's species to all parts of the world. Many of the texts digitized by the BHL have until now only been held in a few European or North American libraries. Now, with this resource, scientists and student in the developing world have access to them, thereby accelerating biodiversity research.

Since 2009, the BHL has expanded globally. The European Commission's eContentPlus program has recently funded the BHL-Europe project, with 28 institutions, to assemble the European language literature. Additionally, the Chinese Academy of Sciences, the Atlas of Living Australia, Brazil, and the Bibliotheca Alexandrina have created regional BHL sites. These projects will work together to share content, protocols, services, and digital preservation practices.

Lesson Summary

- Biodiversity refers to the number of species in an ecosystem or the biosphere as a whole.
- Biodiversity has direct economic benefits. It also provides services to entire ecosystems.
- Evidence shows that a sixth mass extinction is occurring. The single biggest cause is habitat loss caused by human actions. There are many steps you can take to help protect biodiversity. For example, you can use less energy.
- The Encyclopedia of Life is a free, online collaborative encyclopedia intended to document all of the 1.9+ million living species known to science.

Lesson Review Questions

Recall

1. What is biodiversity?

2. List three economic benefits of biodiversity.

3. Identify ecosystem services of biodiversity.

4. How is human overpopulation related to the sixth mass extinction?

Apply Concepts

5. Create a poster that conveys simple tips for protecting biodiversity.

6. Why might the brown tree snake or the peregrine falcon serve as "poster species" for causes of the sixth mass extinction?

Think Critically

7. Predict what would happen to other organisms in an ecosystem in which all the decomposers went extinct?

8. Describe a hypothetical example showing how rising sea levels due to global warming might cause extinction.

Points to Consider

All species depend on the environment to provide them with the resources they need. As populations grow, resources may be used up. Just using the resources can create more problems.

- What resources do you depend on?
- Does using the resources pollute the environment? Are the resources running out?

12.5 Natural Resources and Climate Change

Lesson Objectives

- Distinguish between renewable and nonrenewable resources.
- Describe threats to soil and water resources.
- Identify the causes and effects of air pollution.
- Explain global climate change.

Vocabulary

acid rain low-pH precipitation that forms with air pollution combines with water

air pollution chemical substances and particles released into the air mainly by human actions such as burning fossil fuels

algal bloom excessive growth of algae in bodies of water because of high levels of nutrients, usually from fertilizer in runoff

dead zone area in the ocean or other body of water where low oxygen levels from excessive growth of algae have killed all aquatic organisms

global warming recent rise in Earth's average surface temperature generally attributed to an increased greenhouse effect

greenhouse effect natural feature of Earth's atmosphere that occurs when gases in the atmosphere radiate the sun's heat back down to Earth's surface, making Earth's temperature far warmer than it otherwise would be

natural resource something supplied by nature that helps support life

nonrenewable resource natural resource that exists in a fixed amount and can be used up

ozone hole hole in the ozone layer high in the atmosphere over Antarctica caused by air pollution destroying ozone

renewable resource natural resource that can be replenished by natural processes as quickly as humans use it

soil mixture of eroded rock, minerals, organic matter, and other materials that is essential for plant growth and forms the foundation of terrestrial ecosystems

sustainable use use of resources in a way that meets the needs of the present and also preserves the resources for the use of future generations

Introduction

A **natural resource** is something supplied by nature that helps support life. When you think of natural resources, you may think of minerals and fossil fuels. However, ecosystems and the services they provide are also natural resources. Biodiversity is a natural resource as well.

Renewable and Nonrenewable Resources

From the human point of view, natural resources can be classified as renewable or nonrenewable.

Renewable Resources

Renewable resources can be replenished by natural processes as quickly as humans use them. Examples include sunlight and wind. They are in no danger of being used up (see **Figure** 12.25). Metals and other minerals are renewable too. They are not destroyed when they are used and can be recycled.

FIGURE 12.25
Wind is a renewable resource. Wind turbines like this one harness just a tiny fraction of wind energy.

Living things are considered to be renewable. This is because they can reproduce to replace themselves. However, they can be over-used or misused to the point of extinction. To be truly renewable, they must be used sustainably. **Sustainable use** is the use of resources in a way that meets the needs of the present and also preserves the resources for future generations.

Nonrenewable Resources

Nonrenewable resources are natural resources that exist in fixed amounts and can be used up. Examples include fossil fuels such as petroleum, coal, and natural gas. These fuels formed from the remains of plants over hundreds of millions of years. We are using them up far faster than they could ever be replaced. At current rates of use, petroleum will be used up in just a few decades and coal in less than 300 years. Nuclear power is also considered to be a nonrenewable resource because it uses up uranium, which will sooner or later run out. It also produces harmful wastes that are difficult to dispose of safely.

Soil and Water Resources

Theoretically, soil and water are renewable resources. However, they may be ruined by careless human actions.

Soil

Soil is a mixture of eroded rock, minerals, partly decomposed organic matter, and other materials. It is essential for plant growth, so it is the foundation of terrestrial ecosystems. Soil is important for other reasons as well. For example, it removes toxins from water and breaks down wastes.

Although renewable, soil takes a very long to form—up to hundreds of millions of years. So, for human purposes, soil is a nonrenewable resource. It is also constantly depleted of nutrients through careless use and eroded by wind and water. For example, misuse of soil caused a huge amount of it to simply blow away in the 1930s during the Dust Bowl (see **Figure** 12.26). Soil must be used wisely to preserve it for the future. Conservation practices include contour plowing and terracing. Both reduce soil erosion. Soil also must be protected from toxic wastes.

FIGURE 12.26

The Dust Bowl occurred between 1933 and 1939 in Oklahoma and other southwestern U.S. states. Plowing had exposed prairie soil. Drought turned the soil to dust. Intense dust storms blew away vast quantities of the soil. Much of the soil blew all the way to the Atlantic Ocean.

Water

Water is essential for all life on Earth. For human use, water must be fresh. Of all the water on Earth, only 1 percent is fresh, liquid water. Most of the rest is either salt water in the ocean or ice in glaciers and ice caps.

Although water is constantly recycled through the water cycle, it is in danger. Over-use and pollution of freshwater threaten the limited supply that people depend on. Already, more than 1 billion people worldwide do not have adequate freshwater. With the rapidly growing human population, the water shortage is likely to get worse.

KQED: Are We in Danger of Running Out of Water?

California's population is growing by 600,000 people a year, but much of the state receives as much annual rainfall as Morocco. With fish populations crashing, global warming, and the demands of the country's largest agricultural industry, the pressures on our water supply are increasing. Are we in danger of running out of water? See http://www.kqed.org/quest/television/state-of-thirst-californias-water-future for additional information.

MEDIA

Click image to the left for more content.

Too Much of a Good Thing

Water pollution comes from many sources. One of the biggest sources is runoff. Runoff picks up chemicals such as fertilizer from agricultural fields, lawns, and golf courses. It carries the chemicals to bodies of water. The added nutrients from fertilizer often cause excessive growth of algae, creating **algal blooms** (see **Figure** 12.27). The algae use up oxygen in the water so that other aquatic organisms cannot survive. This has occurred over large areas of the ocean, creating **dead zones**, where low oxygen levels have killed all ocean life. A very large dead zone exists in the Gulf of Mexico. Measures that can help prevent these problems include cutting down on fertilizer use. Preserving wetlands also helps because wetlands filter runoff.

The Atmosphere

The atmosphere plays an important part in maintaining Earth's freshwater supply. It is part of the water cycle. It refills lakes and rivers with precipitation. The atmosphere also provides organisms with gases needed for life. It contains oxygen for cellular respiration and carbon dioxide for photosynthesis.

Air Pollution

Earth's atmosphere is vast. However, it has been seriously polluted by human activities. **Air pollution** consists of chemical substances and particles released into the atmosphere, mainly by human actions. The major cause of outdoor air pollution is the burning of fossil fuels. Power plants, motor vehicles, and home furnaces all burn fossil fuels and contribute to the problem (see **Table** 12.1). Ranching and using chemicals such as fertilizers also cause air pollution. Erosion of soil in farm fields and construction sites adds dust particles to the air as well. Fumes from building materials, furniture, carpets, and paint add toxic chemicals to indoor air.

TABLE 12.1: Pollutant Problems

Pollutant	Example/Major Source	Problem
Sulfur oxides (SO_x)	Coal-fired power plants	Acid Rain
Nitrogen oxides (NO_x)	Motor vehicle exhaust	Acid Rain
Carbon monoxide (CO)	Motor vehicle exhaust	Poisoning
Carbon dioxide (CO_2)	All fossil fuel burning	Global Warming
Particulate matter (smoke, dust)	Wood and coal burning	Respiratory disease, Global Dimming

TABLE 12.1: (continued)

Pollutant	Example/Major Source	Problem
Mercury	Coal-fired power plants, medical waste	Neurotoxicity
Smog	Coal burning	Respiratory problems; eye irritation
Ground-level ozone	Motor vehicle exhaust	Respiratory problems; eye irritation

In humans, air pollution causes respiratory and cardiovascular problems. In fact, more people die each year from air pollution than automobile accidents. Air pollution also affects ecosystems worldwide by causing acid rain, ozone depletion, and global warming. Ways to reduce air pollution from fossil fuels include switching to nonpolluting energy sources (such as solar energy) and using less energy. What are some ways you could use less energy?

Acid Rain

All life relies on a relatively narrow range of pH, or acidity. That's because protein structure and function is very sensitive to pH. Air pollution can cause precipitation to become acidic. Nitrogen and sulfur oxides—mainly from motor vehicle exhaust and coal burning—create acids when they combine with water in the air. The acids lower the pH of precipitation, forming **acid rain**. If acid rain falls on the ground, it may damage soil and soil organisms. If it falls on plants, it may kill them (see **Figure** 12.28). If it falls into lakes, it lowers the pH of the water and kills aquatic organisms.

Ozone Depletion

There are two types of ozone. You can think of them as bad ozone and good ozone. Both are affected by air pollution.

- Bad ozone forms near the ground when sunlight reacts with pollutants in the air. Ground-level ozone is harmful to the respiratory systems of humans and other animals.
- Good ozone forms in a thin layer high up in the atmosphere, between 15 and 35 kilometers above Earth's surface. This ozone layer shields Earth from most of the sun's harmful UV radiation. It plays an important role in preventing mutations in the DNA of organisms.

Unfortunately, the layer of good ozone is being destroyed by air pollution. The chief culprits are chlorine and bromine gases. They are released in aerosol sprays, coolants, and other products. Loss of ozone has created an **ozone hole** over Antarctica. Ozone depletion results in higher levels of UV radiation reaching Earth. In humans, this increases skin cancers and eye cataracts. It also disturbs the nitrogen cycle, kills plankton, and disrupts ocean food webs. The total loss of the ozone layer would be devastating to most life. It's rate of loss has slowed with restrictions on pollutants, but it is still at risk.

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 natural greenhouse effect. This raises the temperature of Earth's surface.

What Is the Greenhouse Effect?

The **greenhouse effect** is a natural feature of Earth's atmosphere. It occurs when gases in the atmosphere radiate the sun's heat back down to Earth's surface (see **Figure** 12.29). Otherwise, the heat would escape into space. Without

FIGURE 12.27

Algal Bloom. Nutrients from fertilizer in runoff caused this algal bloom.

FIGURE 12.28
Effects of Acid Rain. These trees in a European forest were killed by acid rain.

the greenhouse effect, Earth's surface temperature would be far cooler than it is. In fact, it would be too cold to support life as we know it.

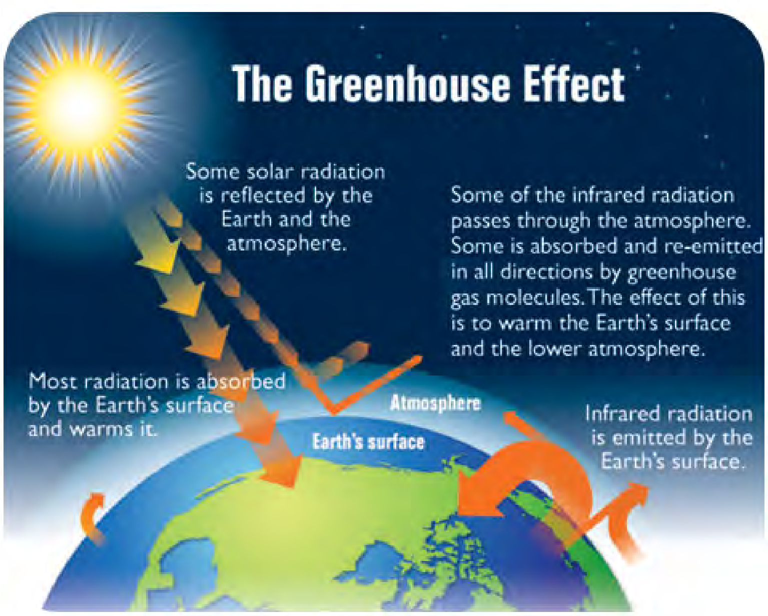


FIGURE 12.29
The Greenhouse Effect. Without greenhouse gases most of the sun&#8217 s energy would be radiated from Earth&#8217 s surface back out to space.

Global Warming

Global warming refers to a recent increase in Earth's average surface temperature (see **Figure** 12.30). During the past century, the temperature has risen by almost 1°C (about 1.3°F). That may not seem like much. But consider that just 10°C is the difference between an ice-free and an ice-covered Earth.

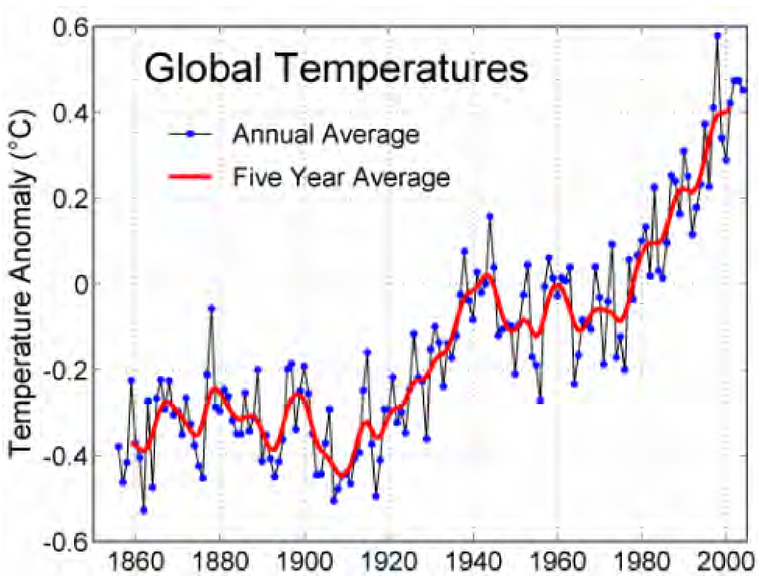


FIGURE 12.30
The average annual temperature on Earth has been rising for the past 100 years.

Most scientists agree that global warming is caused by more carbon dioxide in the atmosphere (see **Figure** 12.31). This increases the greenhouse effect. There is more carbon dioxide mainly because of the burning of fossil fuels. Destroying forests is another cause. With fewer forests, less carbon dioxide is removed from the atmosphere by photosynthesis.

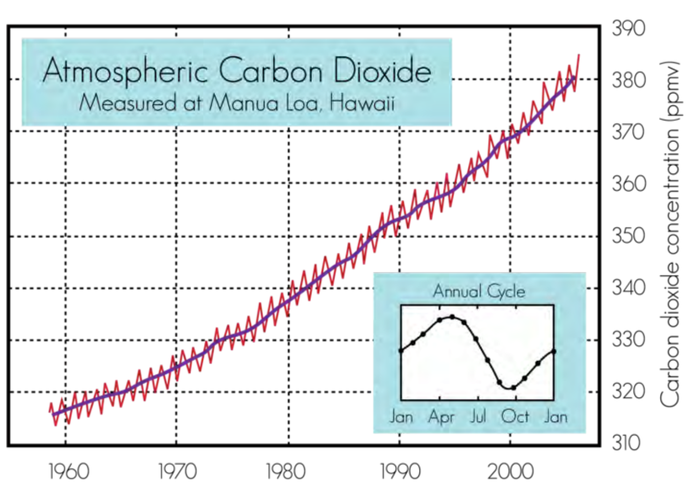


FIGURE 12.31
This graph shows the recent trend in carbon dioxide in the atmosphere.

Effects of Climate Change

How has global warming affected Earth and its life? Some of its effects include:

- Decline in cold-adapted species such as polar bears.
- Melting of glaciers and rising sea levels.
- Coastal flooding and shoreline erosion.
- Heat-related human health problems.
- More droughts and water shortages.
- Changing patterns of precipitation.
- Increasing severity of storms.
- Major crop losses.

These two videos discuss some of the consequences from changes in ecosystems: http://www.youtube.com/watch?v=jHWgWxDWhsA (7:47) and http://www.youtube.com/watch?v=5qblwORXwrg (2:26).

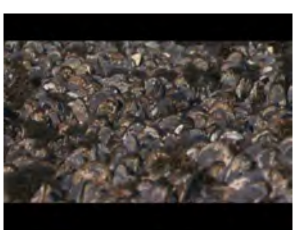
KQED: Climate Watch: California at the Tipping Point

The world's climate is changing and California is now being affected in both dramatic and subtle ways. In 2008, scientists determined that California's temperatures increased by more than 2.1°F during the last century. What's more, the data showed that human activity has played a significant role in that climate change. "What's just 2 degrees?" you may wonder. But, as the science shows, just 2 degrees is extremely significant.

What does all this temperature change mean? For starters, declining mountain snowpack and prolonged drought conditions could pose a threat to limited water supplies. Heat waves are projected to be longer, bringing increased danger from wildfires and heat-related deaths. Rising sea levels due to temperature shifts jeopardize life in coastal areas, both for human communities and the plants and animals that rely on intertidal and rich wetland ecosystems. Also, more precipitation is expected to fall as rain rather than snow, thereby increasing the risk of floods. And, as heat increases the formation of smog, poor air quality could get even worse.

Climate change may also profoundly affect the economy in California and elsewhere. Shorter ski seasons and damage to the marine ecosystem mean a reduction in tourism. Water shortages mean issues with the commercial and recreational fishing industry, and higher temperatures will affect crop growth and quality, weakening the agricultural industry, to name just a few of the economic issues associated with climate change.

Get an in-depth look at the science behind climate change at http://www.kqed.org/quest/television/climate-watch-california-at-the-tipping-point-part-one.



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KQED: Giant Redwoods and Global Warming

Forest ecologist Steve Sillett is leading a team of scientists as they climb and measure every branch of some of the last and tallest old growth redwoods in California. Their goal is to learn how these ancient giants have historically responded to climatic shifts and to monitor how they are being impacted today by global warming. See http://www.kqed.org/quest/television/science-on-the-spot-measuring-redwood-giants for additional information.

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KQED: Acidic Seas

Melting glaciers, rising temperatures and droughts are all impacts of global warming. But how does global warming actually affect the oceans? The sea, it turns out, absorbs carbon dioxide emissions. The ocean acts like a giant sponge, absorbing carbon dioxide emissions from the air. And as we add more and more carbon dioxide to air by burning fossil fuels, the ocean is absorbing it. On one level, it's done us a big favor. Scientists say that we would be experiencing much more extreme climate change were it not for the ocean's ability to remove the heat-trapping gas. However, these emissions are causing the oceans to become more acidic. Changing pH levels threaten entire marine food webs, from coral reefs to salmon. See http://www.kqed.org/quest/radio/acidic-seas for additional information.

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What Can Be Done?

Efforts to reduce future global warming mainly involve energy use. We need to use less energy, for example, by driving more fuel-efficient cars. We also need to switch to energy sources that produce less carbon dioxide, such as solar and wind energy. At the same time, we can increase the amount of carbon dioxide that is removed from air. We can stop destroying forests and plant new ones.

KQED: Earth Day

Earth Day Network's mission is to broaden, diversify and activate the environmental movement worldwide, driving action year-round through a combination of education, public policy, and consumer campaigns. See http://www.earthday.org/ for additional information.

Each year, April 22 marks the anniversary of what many consider the birth of the modern environmental movement in 1970. The idea came to Earth Day founder Gaylord Nelson, then a U.S. Senator from Wisconsin, after witnessing the ravages of the 1969 massive oil spill in Santa Barbara, California. On the 22nd of April, 20 million Americans took to the streets, parks, and auditoriums to demonstrate for a healthy, sustainable environment in massive coast-to-coast rallies. Thousands of colleges and universities organized protests against the deterioration of the environment. Groups that had been fighting against oil spills, polluting factories and power plants, raw sewage, toxic dumps, pesticides, freeways, the loss of wilderness, and the extinction of wildlife suddenly realized they shared common values.

As 1990 approached, a group of environmental leaders organized another big campaign. This time, Earth Day went global, mobilizing 200 million people in 141 countries and lifting environmental issues onto the world stage. Earth

Day 1990 gave a huge boost to recycling efforts worldwide and helped pave the way for the 1992 United Nations Earth Summit in Rio de Janeiro.

As the year 2000 approached, 5,000 environmental groups in a record 184 countries reached out to hundreds of millions of people. Earth Day 2000 used the Internet to organize activists, but also featured a talking drum chain that traveled from village to village in Gabon, Africa, and hundreds of thousands of people gathered on the National Mall in Washington, DC. Earth Day 2000 sent world leaders the loud and clear message that citizens around the world wanted quick and decisive action on clean energy.

In 2010, the Earth Day Network reestablished Earth Day as a powerful focal point around which people could demonstrate their commitment. The Earth Day Network brought 225,000 people to the National Mall for a Climate Rally, amassed 40 million environmental service actions toward its 2012 goal of *A Billion Acts of Green*, launched an international, 1-million tree planting initiative with *Avatar* director James Cameron, and tripled its online base to over 900,000 members. The fight for a clean environment continues in a climate of increasing urgency, as the ravages of climate change become more manifest every day.

See http://www.kqed.org/quest/television/earth-day-tv-special-where-weve-been-where-were-headed for more information on California's environmental movement.

Lesson Summary

- Renewable resources can be replaced by natural processes as quickly as humans use them. Examples include sunlight and wind. Nonrenewable resources exist in fixed amounts. They can be used up. Examples include fossil fuels such as coal.
- Soil and water are renewable resources but may be ruined by careless human actions. Soil can be depleted of nutrients. It can also be eroded by wind or water. Over-use and pollution of freshwater threaten the limited supply that people depend on.
- Air pollution consists of chemical substances and particles released into the air, mainly by human actions. The major cause of outdoor air pollution is the burning of fossil fuels. Indoor air can also be polluted. Air pollution, in turn, causes acid rain, ozone depletion, and global warming.
- Gases such as carbon dioxide from the burning of fossil fuels increase the natural greenhouse effect. This is raising the temperature of Earth's surface, and is called global warming.

Lesson Review Questions

Recall

1. Define natural resource.

2. Distinguish between renewable and nonrenewable resources and give examples.

3. Summarize the environmental effects of burning fossil fuels.

4. How does air pollution contribute to global warming?

Apply Concepts

5. How could you create a three-dimensional model of the greenhouse effect? What processes would you demonstrate with your model? What materials would you use?

6. Apply lesson concepts to explain the relationship between the graphs in **Figure** 12.30 and **Figure** 12.31

Think Critically

7. Infer factors that determine whether a natural resource is renewable or nonrenewable.
8. Why would you expect a dead zone to start near the mouth of a river, where the river flows into a body of water?
9. Explain how air pollution is related to acid rain and ozone depletion.

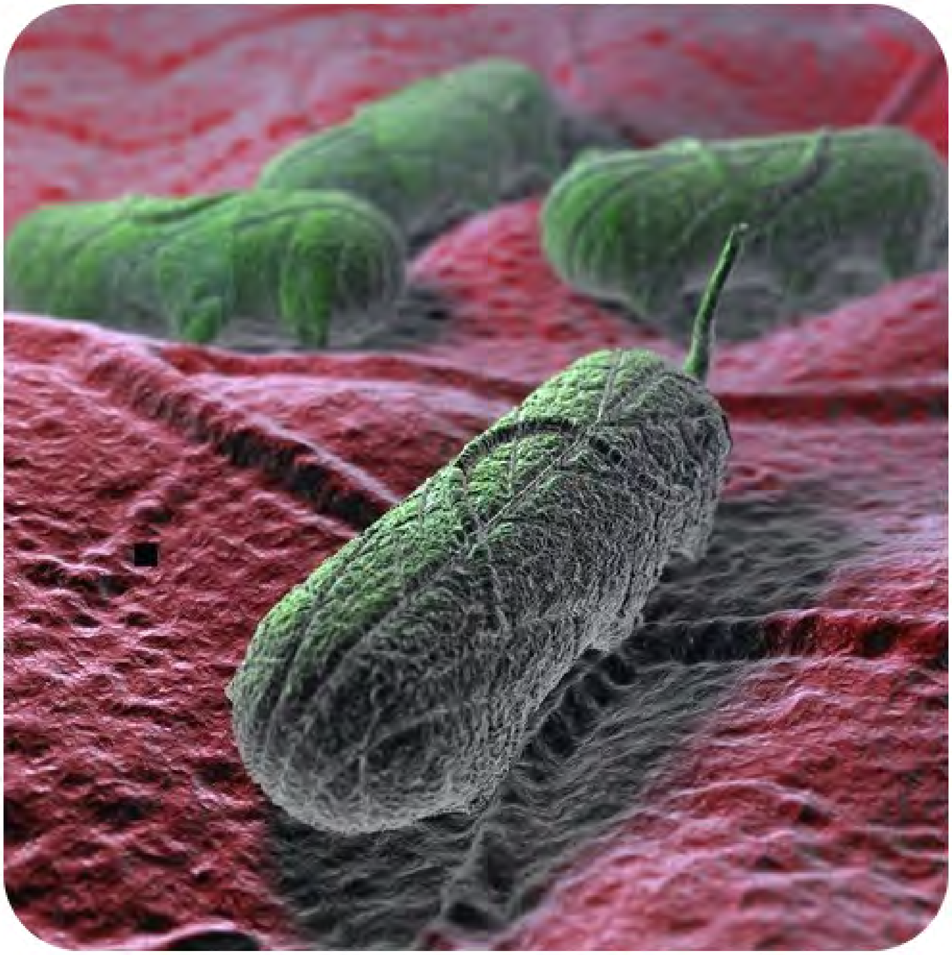
Points to Consider

Microorganisms such as bacteria are important living resources in all ecosystems. They recycle nutrients and other matter.

- What do you know about microorganisms? Besides bacteria, are there other types of microorganisms?
- Are viruses microorganisms? Are they living things?

CHAPTER 13 Microorganisms: Prokaryotes and Viruses

CHAPTER OUTLINE



Can you guess what organisms are pictured here? Are they fat green worms on a red leaf? Here's a clue: There are more organisms like these than any other on Earth. Here's another clue: Each organisms consists of a single cell without a nucleus.

The organisms are bacteria called *Salmonella.* If the word Salmonella rings a bell, that's probably because *Salmonella* causes human diseases such as 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 will learn why when you read this chapter.

13.1 Prokaryotes

Lesson objectives

- Outline the classification and evolution of prokaryotes.
- Describe the structure of prokaryotes.
- Identify different types of metabolism found in prokaryotes.
- Describe the range of prokaryote habitats.
- Explain how prokaryotes reproduce.
- Identify important relationships between bacteria and humans.

Vocabulary

antibiotic drug drug that kills bacteria and cures bacterial infections and diseases

antibiotic resistance ability to withstand antibiotic drugs that has evolved in some bacteria

Archaea one of two prokaryote domains that includes organisms that live in extreme environments

Bacteria domain of prokaryotes, some of which cause human diseases

biofilm colony of prokaryotes that is stuck to a surface such as a rock or a host's tissue

cyanobacteria Gram-positive blue-green photosynthetic bacteria of the type that added oxygen to Earth's early atmosphere and evolved into chloroplasts of eukaryotic cells

endospore spores that form inside prokaryotic cells when they are under stress, enclosing the DNA and helping it survive conditions that may kill the cell

extremophile any type of Archaea that lives in an extreme environment, such as a very salty, hot, or acidic environment

flagella long, thin protein extensions of the plasma membrane in most prokaryotic cells that help the cells move

genetic transfer method of increasing genetic variation in prokaryotes that involves cells "grabbing" stray pieces of DNA from their environment or exchanging DNA directly with other cells

Gram-negative bacteria type of bacteria that stain red with Gram stain and have a thin cell wall with an outer membrane

Gram-positive bacteria type of bacteria that stain purple with Gram stain and have a thick cell wall without an outer membrane

plasmid small, circular piece of DNA in a prokaryotic cell

vector organism such as an insect that spreads pathogens from host to host

Introduction

No doubt you've had a sore throat before, and you've probably eaten cheese or yogurt. If so, then you've encountered the fascinating world of prokaryotes. Prokaryotes are single-celled organisms that lack a nucleus. They also lack other membrane-bound organelles. Prokaryotes are tiny and sometimes bothersome, but they are the most numerous organisms on Earth. Without them, the world would be a very different place.

An overview of bacteria can be seen at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/16/TDoGrbpJJ14.

MEDIA

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Evolution and Classification of Prokaryotes

Prokaryotes are currently placed in two domains. A domain is the highest taxon, just above the kingdom. The prokaryote domains are **Bacteria** and **Archaea** (see **Figure** 13.1). The third domain is Eukarya. It includes all eukaryotes. Unlike prokaryotes, eukaryotes have a nucleus in their cells.

Prokaryote Evolution

It's not clear how the three domains 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 (see **Table** 13.1). How can this be explained? One hypothesis is that Eukarya arose when an Archaean cell fused with a Bacterial cell. The two cells became the nucleus and cytoplasm of a new Eukaryan cell. How well does this hypothesis fit the evidence in **Table** 13.1 ?

TABLE 13.1: Comparison of Bacteria, Archaea, and Eukarya

Characteristic	Bacteria	Archaea	Eukarya
Flagella	Unique to Bacteria	Unique to Archaea	Unique to Eukarya
Cell Membrane	Unique to Bacteria	Like Bacteria and Eukarya	Unique to Eukarya
Protein Synthesis	Unique to Bacteria	Like Eukarya	Like Archaea
Introns	Absent in most	Present	Present

TABLE 13.1: (continued)

Characteristic	Bacteria	Archaea	Eukarya
Peptidoglycan (in cell wall)	Present	Absent in most	Absent

Domain Bacteria

Bacteria are the most diverse and abundant group of organisms on Earth. They live in almost all environments. They are found in the ocean, the soil, and the 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 5×10^{30}, or five million trillion trillion. You have more bacteria in and on your body than you have body cells!

Bacteria called **cyanobacteria** are very important. They are bluish green in color (see **Figure** 13.2) because they contain chlorophyll. They make food through photosynthesis and release oxygen into the air. These bacteria were probably responsible for adding oxygen to the air on early Earth. This changed the planet's atmosphere. It also changed the direction of evolution. Ancient cyanobacteria also may have evolved into the chloroplasts of plant cells.

Thousands of species of bacteria have been discovered, and many more are thought to exist. The known species can be classified on the basis of various traits. One classification is based on differences in their cell walls and outer membranes. It groups bacteria into **Gram-positive** and **Gram-negative** bacteria, as described in **Figure** 13.3 .

Domain Archaea

Scientists still know relatively little about Archaea. This is partly because they are hard to grow in the lab. Many live inside the bodies of animals, including humans. However, none are known for certain to cause disease.

Archaea were first discovered in extreme environments. For example, some were found in hot springs. Others were found around deep sea vents. Such Archaea are called **extremophiles**, or "lovers of extremes." **Figure** 13.4 describes three different types of Archaean extremophiles. The places where some of them live are thought to be similar to the environment on ancient Earth. This suggests that they may have evolved very early in Earth's history.

Archaea are now known to live just about everywhere on Earth. They are particularly numerous in the ocean. Archaea in plankton may be one of the most abundant types of organisms on the planet. Archaea are also thought to play important roles in the carbon and nitrogen cycles. For these reasons, Archaea are now recognized as a major aspect of life on Earth.

Prokaryote Structure

Most prokaryotic cells are much smaller than eukaryotic cells. Although they are tiny, prokaryotic cells can be distinguished by their shapes. The most common shapes are helices, spheres, and rods (see **Figure** 13.5).

Plasma Membrane and Cell Wall

Like other cells, prokaryotic cells have a plasma membrane (see **Figure** 13.6). It controls what enters and leaves the cell. It is also the site of many metabolic reactions. For example, cellular respiration and photosynthesis take place in the plasma membrane.

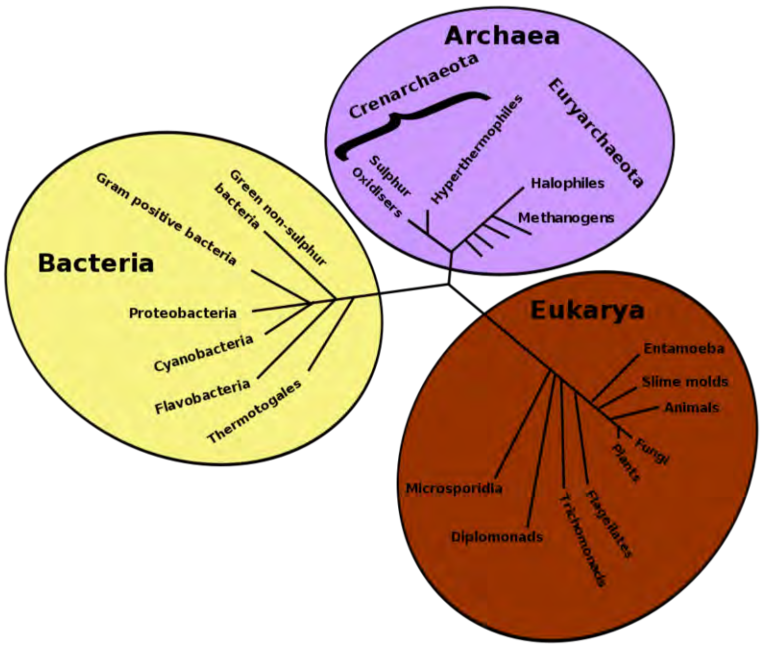


FIGURE 13.1

The Three Domains of Life. All living things are grouped in three domains. The domains Bacteria and Archaea consist of prokaryotes. The Eukarya domain consists of eukaryotes.

FIGURE 13.2

Cyanobacteria Bloom. The green streaks in this lake consist of trillions of cyanobacteria. Excessive nutrients in the water led to overgrowth of the bacteria.

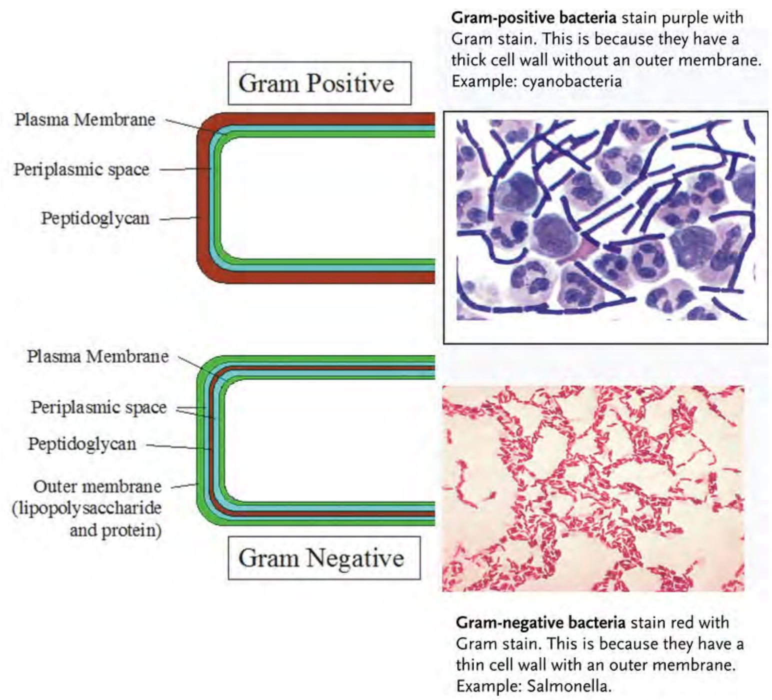


FIGURE 13.3

Classification of Bacteria. Different types of bacteria stain a different color when stained with Gram stain. This makes them easy to identify.

Most prokaryotes also have a cell wall. It lies just outside the plasma membrane. It gives strength and rigidity to the cell. Bacteria and Archaea differ in the makeup of their cell wall. The cell wall of Bacteria contains peptidoglycan (composed of sugars and amino acids). The cell wall of most Archaea lacks peptidoglycan.

Cytoplasm and Cell Structures

Inside the plasma membrane of prokaryotic cells is the cytoplasm. It contains several structures, including ribosomes, a cytoskeleton, and genetic material. Ribosomes are sites where proteins are made. The cytoskeleton helps the cell keeps its shape. The genetic material is usually a single loop of DNA. There may also be small, circular pieces of DNA, called **plasmids**. (see **Figure** 13.7). The cytoplasm may contain microcompartments as well. These are tiny structures enclosed by proteins. They contain enzymes and are involved in metabolic processes.

Extracellular Structures

Many prokaryotes have an extra 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. Because of this, many prokaryotes can form biofilms, like the one shown in **Figure** 13.8 . A **biofilm** is a colony of prokaryotes that is stuck to a surface such as 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 bacteria.

Most prokaryotes also have long, thin protein structures called **flagella** (singular, flagellum). They extend from the plasma membrane. Flagella help prokaryotes move. They spin around a fixed base, causing the cell to roll and tumble. As shown in **Figure** 13.9 , prokaryotes may have one or more flagella.

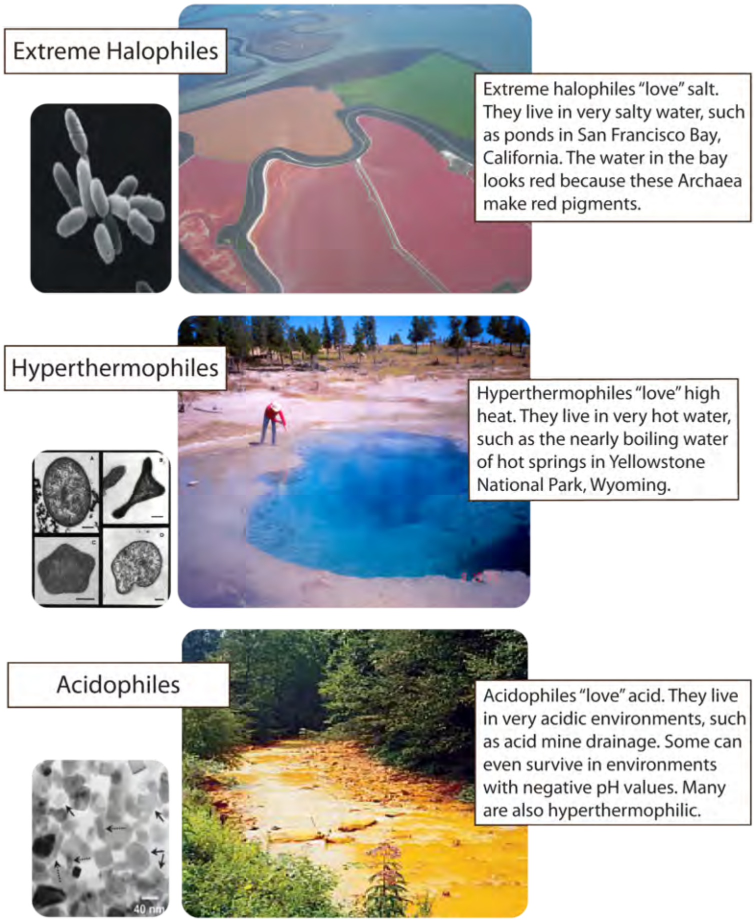


FIGURE 13.4

Extremophile Archaea. Many Archaea are specialized to live in extreme environments. Just three types are described here.

FIGURE 13.5

Prokaryotic Cell Shapes. The three most common prokaryotic cell shapes are shown here.

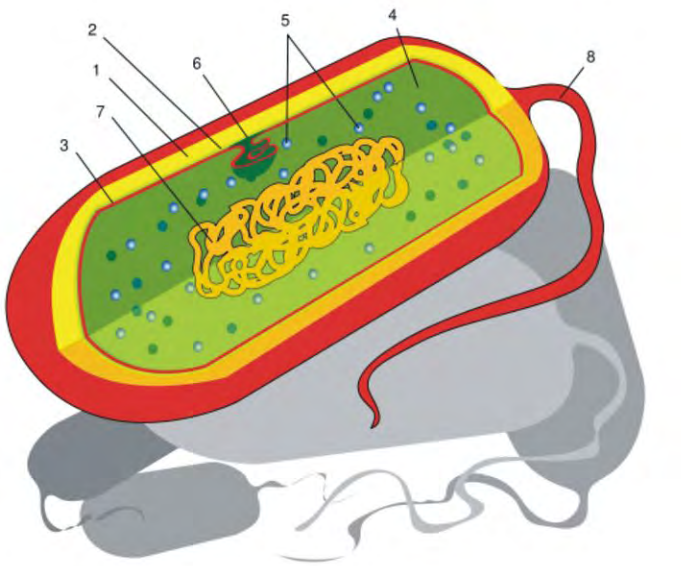


FIGURE 13.6

Prokaryotic Cell. The main parts of a prokaryotic cell are shown in this diagram. The structure called a mesosome was once thought to be an organelle. More evidence has convinced most scientists that it is not a true cell structure at all. Instead it seems to be an artifact of cell preparation. This is a good example of how scientific knowledge is revised as more evidence becomes available.

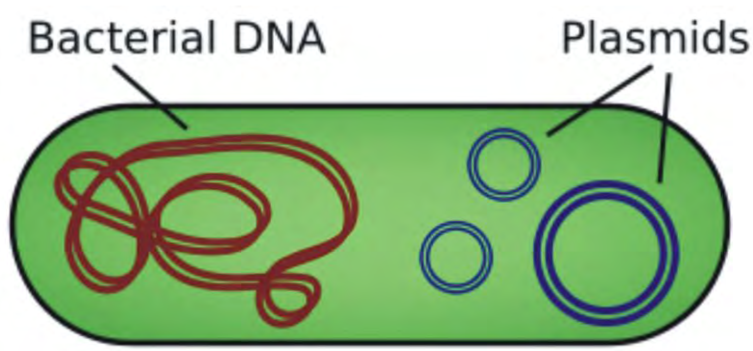


FIGURE 13.7

Prokaryotic DNA. The DNA of a prokaryotic cell is in the cytoplasm because the cell lacks a nucleus.

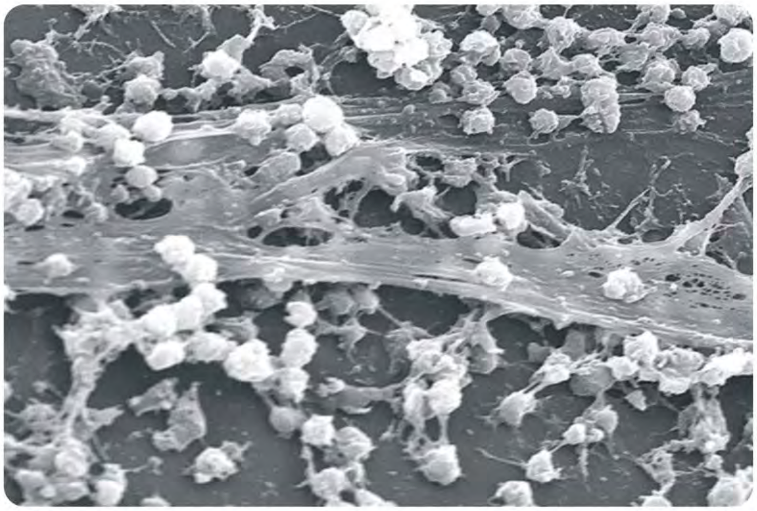


FIGURE 13.8
Bacterial Biofilm. The greatly magnified biofilm shown here was found on a medical catheter *tubing* removed from a patient&#8217 s body.

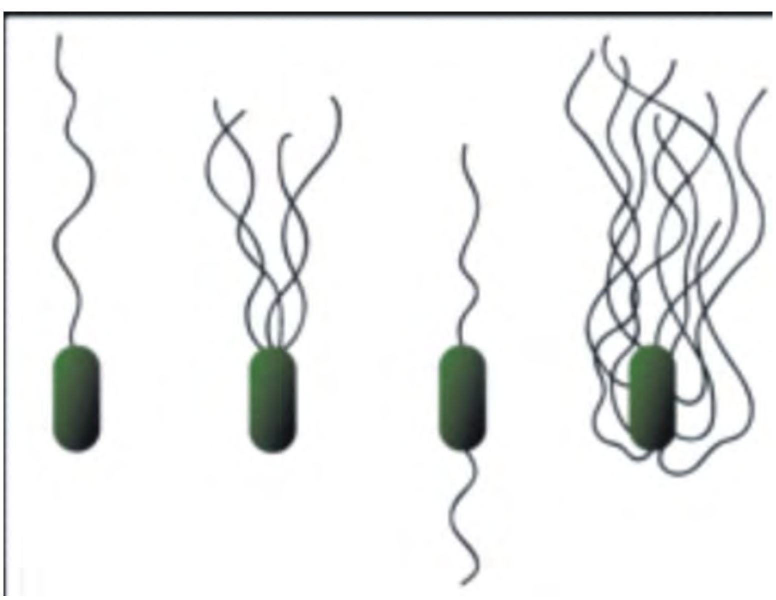


FIGURE 13.9
Variations in the Flagella of Bacteria. Flagella in prokaryotes may be located at one or both ends of the cell or all around it. They help prokaryotes move toward food or away from toxins.

Endospores

Many organisms form spores for reproduction. Some prokaryotes form spores for survival. Called **endospores**, they form inside prokaryotic cells when they are under stress (see **Figure** 13.10). The stress could be UV radiation, high temperatures, or harsh chemicals. Endospores enclose the DNA and help it survive under conditions that may kill the cell. Endospores are commonly found in soil and water. They may survive for long periods of time.

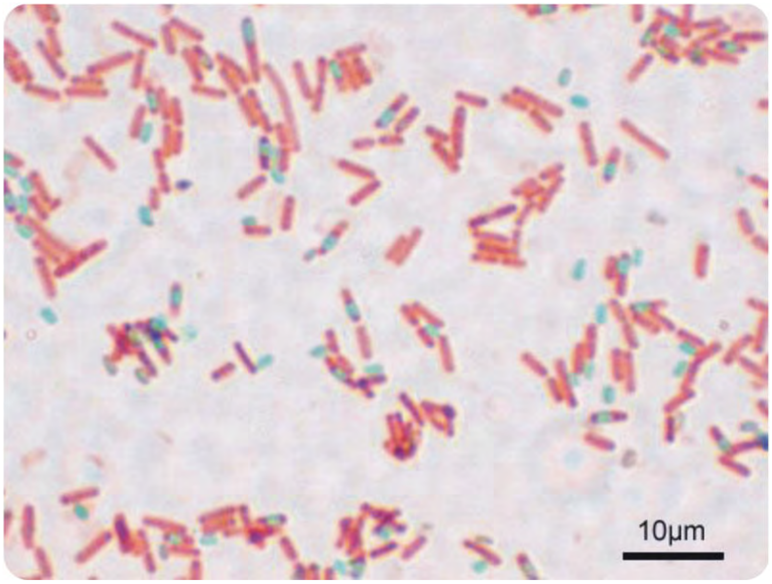


FIGURE 13.10
Prokaryotic Endospores. The red shapes are bacterial cells. The blue-green shapes are endospores.

Prokaryote Metabolism

Like all living things, prokaryotes need energy and carbon. They meet these needs in a variety of ways. In fact, prokaryotes have just about every possible type of metabolism. They may get energy from light (photo) or chemical compounds (chemo). They may get carbon from carbon dioxide (autotroph) or other living things (heterotroph). **Table** 13.2 shows all the possible types of metabolism. Which types of prokaryotes are producers? Which types are consumers?

TABLE 13.2: Metabolism in Prokaryotes

Type of Energy	Source of Carbon: carbon dioxide	Source of Carbon: other organisms
Light	Photoautotroph	Photoheterotroph
Chemical Compounds	Chemoautotroph	Chemoheterotroph

Most prokaryotes are chemoheterotrophs. They depend on other organisms for both energy and carbon. Many break down organic wastes and the remains of dead organisms. They play vital roles as decomposers and help recycle carbon and nitrogen. Photoautotrophs are important producers. They are especially important in aquatic ecosystems.

Prokaryote Habitats

Prokaryote habitats can be classified on the basis of oxygen or temperature. These factors are important to most organisms.

- Aerobic prokaryotes need oxygen. They use it for cellular respiration. An example is the bacterium that causes the disease tuberculosis (TB). It infects human lungs.
- Anaerobic prokaryotes do not need oxygen. They use fermentation or other methods of respiration that don't require oxygen. In fact, some cannot tolerate oxygen. An example is a bacterium that infects wounds and kills tissues, causing a condition called gangrene.

Temperature

Like most organisms, prokaryotes live and grow best within certain temperature ranges. Prokaryotes can be classified by their temperature preferences, as shown in **Table** 13.3 . Which type of prokaryote would you expect to find inside the human body?

TABLE 13.3: Classification of Prokaryotes by Temperature

Type of Prokaryote	Preferred Temperature	Where It Might Be Found
Thermophile	above 45°C (113°F)	in compost
Mesophile	about 37°C (98°F)	inside animals
Psychrophile	below 20°C (68°F)	in the deep ocean

Reproduction in Prokaryotes

Prokaryote cells grow to a certain size. Then they divide through binary fission. For a discussion of exponential growth and bacteria see http://www.youtube.com/watch?v=-3MI0ZX5WRc (10:43).

Binary Fission

Binary fission is a type of asexual reproduction. It occurs when a parent cell splits into two identical daughter cells. This can result in very rapid population growth. For example, under ideal conditions, bacterial populations can double every 20 minutes. Such rapid population growth is an adaptation to an unstable environment. Can you explain why?

Genetic Transfer

In asexual reproduction, all the offspring are exactly the same. This is the biggest drawback of this type of reproduction. Why? Lack of genetic variation increases the risk of extinction. Without variety, there may be no organisms that can survive a major change in the environment.

Prokaryotes have a different way to increase genetic variation. It's called **genetic transfer**. It can occur in two ways. One way is when cells "grab" stray pieces of DNA from their environment. The other way is when cells directly exchange DNA (usually plasmids) with other cells. Genetic transfer makes bacteria very useful in biotechnology. It can be used to create bacterial cells that carry new genes.

Bacteria and Humans

Bacteria and humans have many important relationships. Bacteria make our lives easier in a number of ways. In fact, we could not survive without them. On the other hand, bacteria can also make us sick.

Benefits of Bacteria

Bacteria provide vital ecosystem services. They are important decomposers. They are also needed for the carbon and nitrogen cycles. There are billions of bacteria inside the human intestines. They help digest food, make vitamins, and play other important roles. Humans also use bacteria in many other ways, including:

- Creating products, such as ethanol and enzymes.
- Making drugs, such as antibiotics and vaccines.
- Making biogas, such as methane.
- Cleaning up oil spills and toxic wastes.
- Killing plant pests.
- Transferring normal genes to human cells in gene therapy.
- Fermenting foods (see **Figure** 13.11).

FIGURE 13.11

Fermented Foods. Fermentation is a type of respiration that doesn&#8217 t use oxygen. Fermentation by bacteria is used in brewing and baking. It is also used to make the foods pictured here.

Bacteria and Disease

You have ten times as many bacteria as human cells in your body. Most of these bacteria are harmless. However, bacteria can also cause disease. Examples of bacterial diseases include tetanus, syphilis, and food poisoning. Bacteria may spread directly from one person to another. For example, they can spread through touching, coughing, or sneezing. They may also spread via food, water, or objects.

Another way bacteria and other pathogens can spread is by vectors. A **vector** is an organism that spreads pathogens from host to host. Insects are the most common vectors of human diseases. **Figure** 13.12 shows two examples.

Humans have literally walked into some new bacterial diseases. When people come into contact with wild populations, they may become part of natural cycles of disease transmission. Consider Lyme disease. It's caused by

FIGURE 13.12

Bacterial Disease Vectors. Ticks spread bacteria that cause Lyme disease. Deerflies spread bacteria that cause tularemia.

bacteria that normally infect small, wild mammals, such as mice. A tick bites a mouse and picks up the bacteria. The tick may then bite a human who invades the natural habitat. Through the bite, the bacteria are transmitted to the human host.

Controlling Bacteria

Bacteria in food or water usually can be killed by heating it to a high temperature (generally, at least 71°C, or 160°F). Bacteria on many surfaces can be killed with chlorine bleach or other disinfectants. Bacterial infections in people can be treated with **antibiotic drugs**. For example, if you ever had "strep" throat, you were probably treated with an antibiotic.

Antibiotics have saved many lives. However, misuse and over-use of the drugs have led to **antibiotic resistance** in bacteria. **Figure** 13.13 shows how antibiotic resistance evolves. Some strains of bacteria are now resistant to most common antibiotics. These infections are very difficult to treat.

Lesson Summary

- Prokaryotes include Bacteria and Archaea. An individual prokaryote consists of a single cell without a nucleus. Bacteria live in virtually all environments on Earth. Archaea live everywhere on Earth, including extreme environments.
- Most prokaryotic cells are much smaller than eukaryotic cells. They have a cell wall outside their plasma membrane. Prokaryotic DNA consists of a single loop. Some prokaryotes also have small, circular pieces of DNA called plasmids.
- Prokaryotes fulfill their carbon and energy needs in various ways. They may be photoautotrophs, chemoautotrophs, photoheterotrophs, or chemoheterotrophs.
- Aerobic prokaryotes live in habitats with oxygen. Anaerobic prokaryotes live in habitats without oxygen. Prokaryotes may also be adapted to habitats that are hot, moderate, or cold in temperature.
- Prokaryotic cells grow to a certain size. Then they divide by binary fission. This is a type of asexual reproduction. It produces genetically identical offspring. Genetic transfer increases genetic variation in prokaryotes.
- Bacteria and humans have many important relationships. Bacteria provide humans with a number of services. They also cause human diseases.

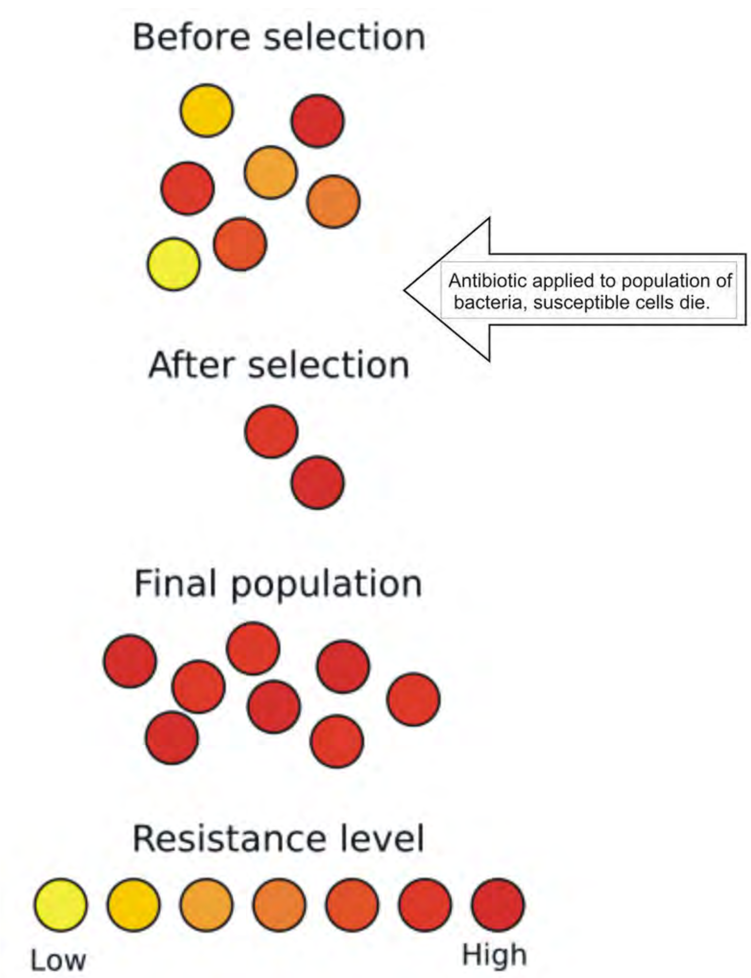


FIGURE 13.13

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

Lesson Review Questions

Recall

1. What are prokaryotes?

2. Distinguish between Gram-positive and Gram-negative bacteria, and give an example of each.

3. Summarize the evolutionary significance of cyanobacteria.

4. What are extremophiles? Name three types.

5. Identify the three most common shapes of prokaryotic cells.

6. Describe a typical prokaryotic cell.

7. What are the roles of flagella and endospores in prokaryotes?

8. List several benefits of bacteria.

Apply Concepts

9. Assume that a certain prokaryote is shaped like a ball, lives deep under the water on the ocean floor, and consumes dead organisms. What traits could you use to classify it?

10. Apply lesson concepts to explain why many prokaryotes are adapted for living at the normal internal temperature of the human body.

Think Critically

11. Compare and contrast Archaea and Bacteria.

12. Why might genetic transfer be important for the survival of prokaryote species?

13. Why might genetic transfer make genetic comparisons of prokaryotes difficult to interpret in studies of their evolution?

Points to Consider

In this lesson, you read that some bacteria cause human diseases. Many other human diseases are caused by viruses.

- What are viruses? Do they belong in one of the three domains of life?
- Can you name any diseases that are caused by viruses? Do you know how viruses spread from one person to another?

13.2 Viruses

Lesson Objectives

- Describe the structure of viruses.
- Outline the discovery and origins of viruses.
- Explain how viruses replicate.
- Explain how viruses cause human disease.
- Describe how viruses can be controlled.
- Identify how viruses are used in research and medicine.

Vocabulary

capsid protein coat that surrounds the DNA or RNA of a virus particle

latency period of dormancy of a virus inside a living body that may last for many years

vaccine substance containing modified pathogens that does not cause disease but provokes an immune response and results in immunity to the pathogen

virion individual virus particle that consists of nucleic acid within a protein capsid

Introduction

At the end of the last lesson, you were asked which of the three domains of life do viruses belong to. Did you figure it out? None. Why? Viruses are usually considered to be nonliving. Viruses do not meet most of the criteria of life. They are not even cells.

An overview of viruses can be seen at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/17/0h5Jd7sgQWY.

MEDIA

Click image to the left for more content.

Characteristics of Viruses

An individual virus is called a **virion.** It is a tiny particle much smaller than a prokaryotic cell. Because viruses do not consist of cells, they also lack cell membranes, cytoplasm, ribosomes, and other cell organelles. Without these structures, they are unable to make proteins or even reproduce on their own. Instead, they must depend on a host cell to synthesize their proteins and to make copies of themselves. Viruses infect and live inside the cells of living organisms. When viruses infect the cells of their host, they may cause disease. For example, viruses cause AIDS, influenza (flu), chicken pox, and the common cold.

Although viruses are not classified as living things, they share two important traits with living things. They have genetic material, and they can evolve. This is why the classification of viruses has been controversial. It calls into question just what it means to be alive. What do you think? How would you classify viruses?

Structure and Classification of Viruses

Viruses vary in their structure. The structure of a virus is one trait that determines how it is classified.

Structure of Viruses

A virus particle consists of DNA or RNA within a protective protein coat called a **capsid.** The shape of the capsid may vary from one type of virus to another, as shown in **Figure** 13.14 .

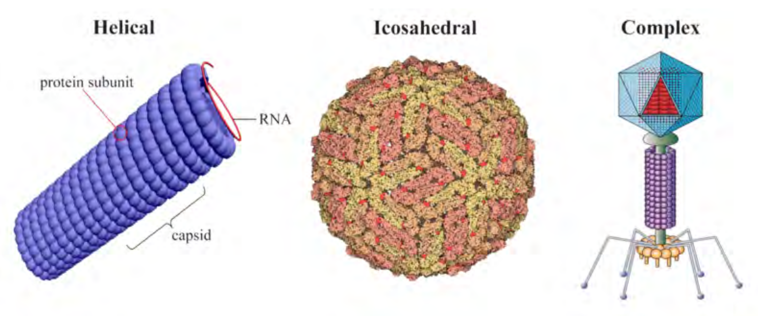


FIGURE 13.14
Capsid Shapes in Viruses. Three shapes of viral capsids are shown here. They are helical $spiral$ icosahedral $20-sided$ and complex. Viruses with complex shapes may have extra structures such as protein tails.

Some viruses have an envelope of phospholipids and proteins. The envelope is made from portions of the host's cell membrane. It surrounds the capsid and helps protect the virus from the host's immune system. The envelope may also have receptor molecules that can bind with host cells. They make it easier for the virus to infect the cells.

Classification of Viruses

Viruses are classified on the basis of several traits. For example, they may be classified by capsid shape, presence or absence of an envelope, and type of nucleic acid. Most systems of classifying viruses identify at least 20 virus families. **Table** 13.4 shows four examples of virus families and their traits. Have any of these viruses made you sick?

TABLE 13.4: Virus Classification: Four Examples

Virus Family	Capsid Shape	Envelope Present?	Type of Nucleic Acid	Disease Caused by a Virus in this Family
Adenovirus	icosahedral	no	DNA	acute respiratory disease
Herpesviruses	icosahedral	yes	DNA	chicken pox
Orthomyxoviruses	helical	yes	RNA	influenza
Coronaviruses	complex	yes	RNA	common cold

Discovery and Origin of Viruses

Viruses are so small that they can be seen only with an electron microscope. Before electron microscopes were invented, scientists knew viruses must exist. How did they know? They had demonstrated that particles smaller than bacteria cause disease.

Discovery of Viruses

Researchers used special filters to remove bacteria from tissues that were infected. If bacteria were causing the infection, the filtered tissues should no longer be able to make other organisms sick. However, the filtered tissues remained infective. This meant that something even smaller than bacteria was causing the infection.

Scientists did not actually see viruses for the first time until the 1930s. That's when the electron microscope was invented. The virus shown in **Figure** 13.15 was the first one to be seen.

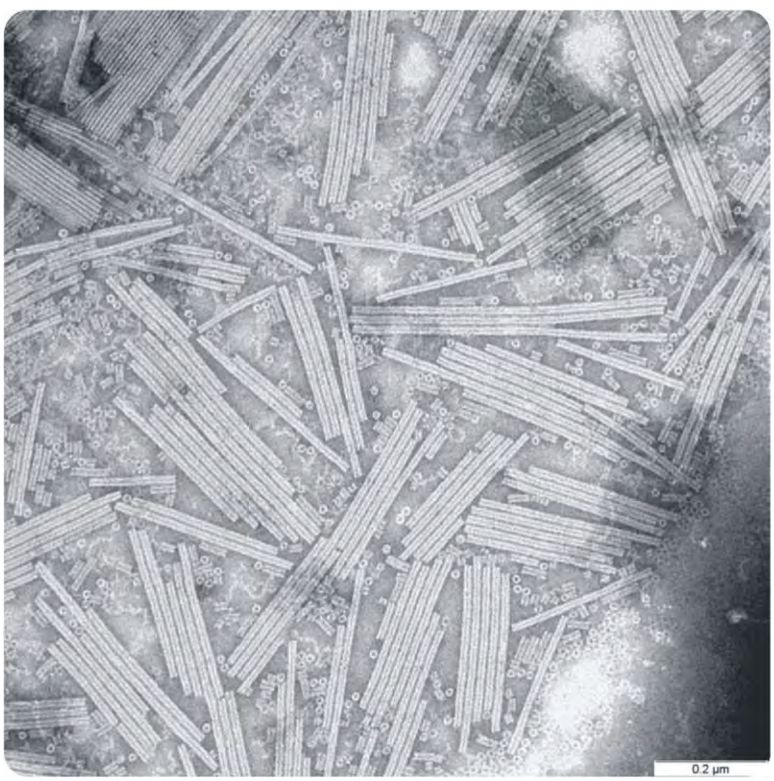


FIGURE 13.15

Tobacco Mosaic Virus. This tobacco mosaic virus was the first virus to be discovered. It was first seen with an electron microscope in 1935.

Origin of Viruses

Where did viruses come from? How did the first viruses arise? The answers to these questions are not known for certain. Several hypotheses have been proposed. The two main hypotheses are stated below. Both may be valid and explain the origin of different viruses.

- Small viruses started as runaway pieces of nucleic acid that originally came from living cells such as bacteria.
- Large viruses were once parasitic cells inside bigger host cells. Over time, genes needed to survive and reproduce outside host cells were lost.

Replication of Viruses

Populations of viruses do not grow through cell division because they are not cells. Instead, they use the machinery and metabolism of a host cell to produce new copies of themselves. After infecting a host cell, a virion uses the cell's ribosomes, enzymes, ATP, and other components to replicate. Viruses vary in how they do this. For example:

- Some RNA viruses are translated directly into viral proteins in ribosomes of the host cell. The host ribosomes treat the viral RNA as though it were the host's own mRNA.
- Some DNA viruses are first transcribed in the host cell into viral mRNA. Then the viral mRNA is translated by host cell ribosomes into viral proteins.

In either case, the newly made viral proteins assemble to form new virions. The virions may then direct the production of an enzyme that breaks down the host cell wall. This allows the virions to burst out of the cell. The host cell is destroyed in the process. The newly released virus particles are free to infect other cells of the host.

Viruses and Human Disease

Viruses cause many human diseases. In addition to the diseases mentioned above, viruses cause rabies, measles, diarrheal diseases, hepatitis, polio, and cold sores (see **Figure** 13.16). Viral diseases range from mild to fatal. One way viruses cause disease is by causing host cells to burst open and die. Viruses may also cause disease without killing host cells. They may cause illness by disrupting homeostasis in host cells.

Some viruses live in a dormant state inside the body. This is called **latency**. For example, the virus that causes chicken pox may infect a young child and cause the short-term disease chicken pox. Then the virus may remain latent in nerve cells within the body for decades. The virus may re-emerge later in life as the disease called shingles. In shingles, the virus causes painful skin rashes with blisters (see **Figure** 13.17).

Some viruses can cause cancer. For example, human papillomavirus (HPV) causes cancer of the cervix in females. Hepatitis B virus causes cancer of the liver. A viral cancer is likely to develop only after a person has been infected with a virus for many years.

Control of Viruses

Viral diseases can be difficult to treat. They live inside the cells of their host, so it is hard to destroy them without killing host cells. Antibiotics also have no effect on viruses. Antiviral drugs are available, but only for a limited number of viruses.

FIGURE 13.16
Cold Sore. Cold sores are caused by a herpes virus.

FIGURE 13.17
Shingles. Shingles is a disease caused by the same virus that causes chicken pox.

Many viral diseases can be prevented by giving people vaccines (see **Figure** 13.18). A **vaccine** is a substance that contains pathogens such as viruses. The pathogens have been changed in some way so they no longer cause disease. However, they can still provoke a response from the host's immune system. This results in immunity, or the ability to resist the pathogen. Vaccines have been produced for the viruses that cause measles, chicken pox, mumps, polio, and several other diseases.

FIGURE 13.18

Vaccination. A child receives a vaccine to prevent a viral disease. How does the vaccine prevent the disease

Viruses in Research and Medicine

Viruses are important tools in scientific research and medicine. Viral research has increased our understanding of fundamental biological processes involving DNA, RNA, and proteins. Viruses that infect cancer cells are being studied for their use in cancer treatment. Viruses are also being used in gene therapy to treat genetic disorders, as explained in **Figure** 13.19 .

Lesson Summary

- Viruses are tiny particles, smaller than prokaryotic cells. They are not cells and cannot replicate without help, but they have nucleic acids and can evolve.
- Viruses can be classified on the basis of capsid shape, presence or absence of an envelope, and type of nucleic acid.
- Viruses were assumed to exist before they were first seen with an electron microscope in the 1930s. Multiple hypotheses for viral origins have been proposed.
- After infecting a host cell, a virus uses the cell's machinery and metabolism to produce new copies of itself.
- Viruses cause many human diseases by killing host cells or disturbing their homeostasis. Viruses are not affected by antibiotics. Several viral diseases can be treated with antiviral drugs or prevented with vaccines.
- Viruses are useful tools in scientific research and medicine. Viruses help us understand molecular biology. They are also used in gene therapy.

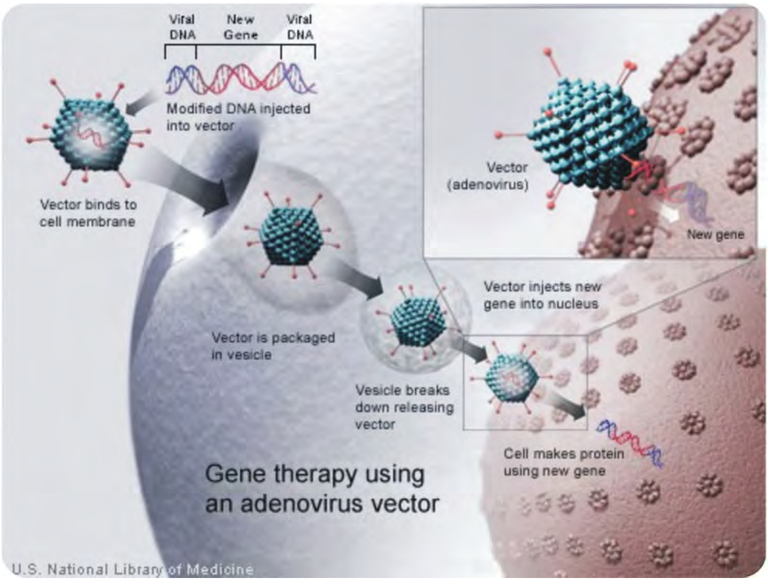


FIGURE 13.19
Using a Virus in Gene Therapy. A normal human gene is inserted into a virus. The virus carries the gene into a human host cell. The gene enters the nucleus and becomes part of the DNA. The normal gene can then be used to make normal proteins. It can also be copied and passed to daughter cells in the host.

Lesson Review Questions

Recall

1. How do viruses differ from living things? How are they similar to living things?
2. Describe variation in capsid shape in viruses.
3. State two hypotheses for the origin of viruses.
4. Describe how viruses replicate.
5. How do viruses cause human disease?

Apply Concepts

6. Apply lesson concepts to decide how strep throat and flu can be treated or prevented. Create a chart to summarize your ideas.
7. Viruses often infect bacteria. Some of them destroy the bacterial cells they infect. How could this information be applied to finding a cure for bacterial infections?

Think Critically

8. Why did scientists think viruses must exist even before they ever saw them with an electron microscope?
9. Why are viruses especially useful tools for understanding molecular biology? What might scientists learn by studying how viruses invade and use host cells?

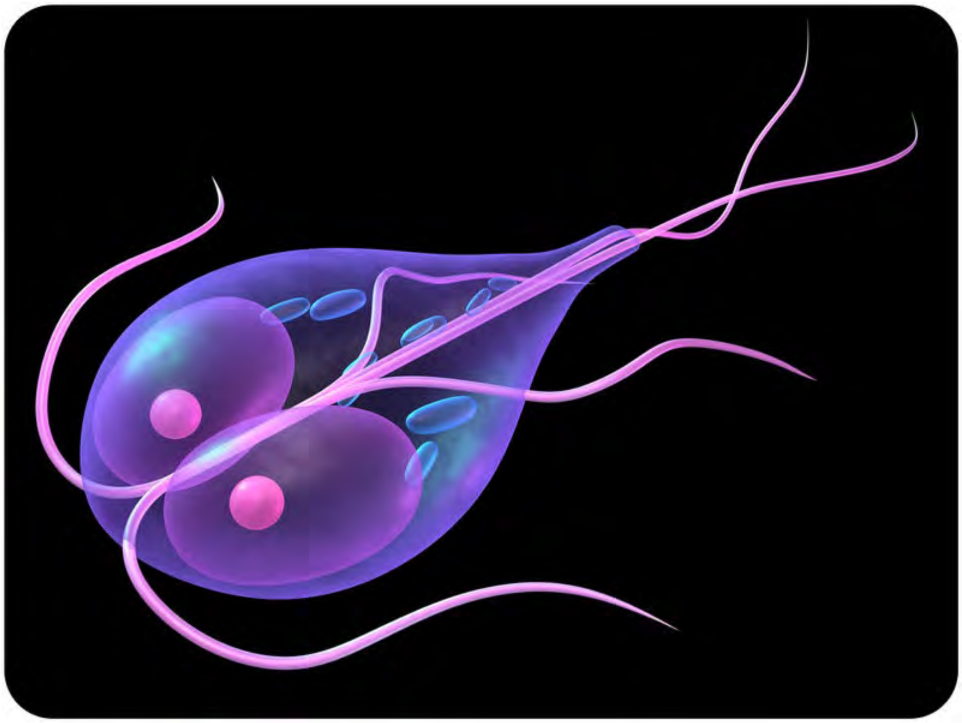
Points to Consider

In this chapter, you read about two of the three domains of life: Bacteria and Archaea. The next chapter introduces the simplest, smallest members of the third domain, the Eukarya.

- Some Eukarya are single-celled organisms. What do you think they are?
- How might single-celled eukaryotes differ from single-celled prokaryotes? How might they be the same?

CHAPTER 14 Eukaryotes: Protists and Fungi

CHAPTER OUTLINE



This organism consists of a single cell with several flagella. Is it a prokaryote, such as a bacterium? Actually, it's larger than a prokaryotic cell, and it also has a nucleus. Therefore, this organism belongs to the domain Eukarya, the domain that includes humans. This particular eukaryote is one of the smallest, simplest organisms in the domain, called a protist. It's scientific name is *Giardia lamblia.* As a human parasite, it can make us sick.

In this chapter, you'll read more about protists like *Giardia lamblia.* You'll discover that protists have a wide diversity of traits and ways of life. And only some of them make us sick.

14.1 Introduction to Protists

Lesson Objectives

- Describe the protist kingdom.
- Outline the evolution of protists.
- Identify protist characteristics.

Vocabulary

cilia (singular, cilium) short, hairlike projections, similar to flagella, that allow some cells to move

motility the ability to move

protist kingdom in the domain Eukarya that includes all eukaryotes except plants, animals, and fungi

pseudopod temporary, foot-like extension of the cytoplasm that some cells use for movement or feeding

Introduction

Protists are the simplest eukaryotes. They are easiest to define by what they are not. Protists are not animals, plants, or fungi.

Kingdom Protista

The protist kingdom is sometimes called the "trash can" kingdom. It includes all eukaryotes that don't fit in one of the other three eukaryote kingdoms: Animalia, Plantae, or Fungi. There are thought to be between 60,000 and 200,000 protist species. Many have yet to be identified. The protist kingdom is very diverse, as shown in **Figure** 14.1 .

Evolution of Protists

Scientists think that protists are the oldest eukaryotes. If so, they must have evolved from prokaryotic cells. How did this happen? The endosymbiotic theory provides the most widely-accepted explanation. That's because it is well supported by evidence.

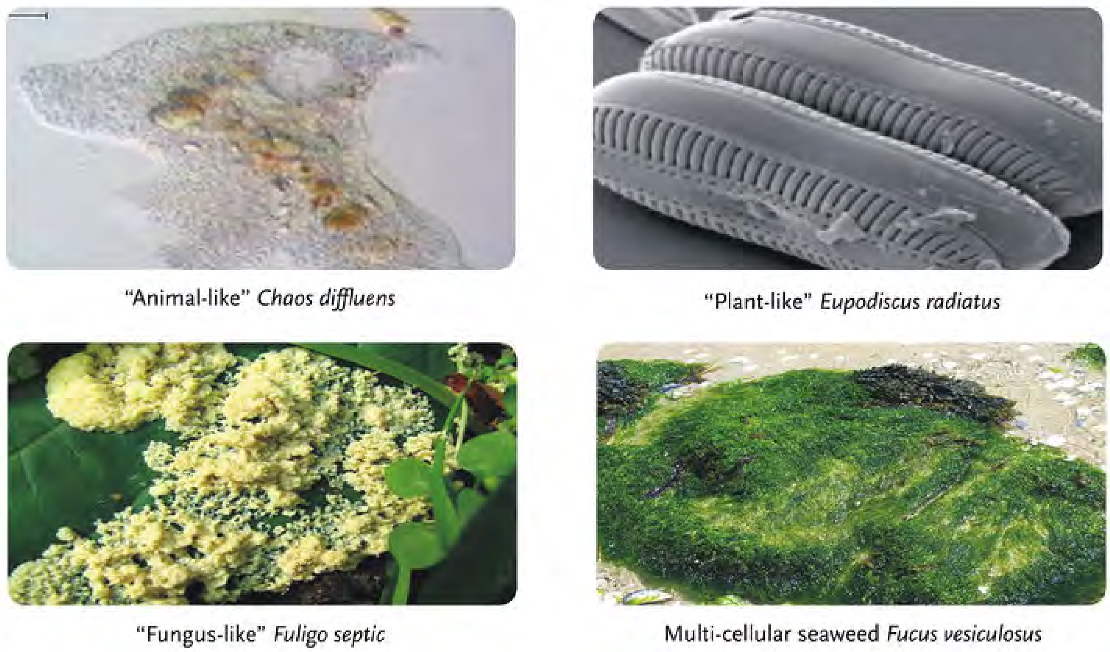


FIGURE 14.1
Protists range from single-celled amoebas to multicellular seaweed. Protists may be similar to animals plants or fungi.

The First Eukaryotic Cells

According to the endosymbiotic theory, the first eukaryotic cells evolved from a symbiotic relationship between two or more prokaryotic cells. Smaller prokaryotic cells were engulfed by (or invaded) larger prokaryotic cells. The small cells (now called endosymbionts) benefited from the relationship by getting a safe home and nutrients. The large cells (now called hosts) benefited by getting some of the organic molecules or energy released by the endosymbionts. Eventually, the endosymbionts evolved into organelles of the host cells. After that, neither could live without the other.

As shown in **Figure** 14.2 , some of the endosymbionts were aerobic bacteria. They were specialized to break down chemicals and release energy. They evolved into the mitochondria of eukaryotic cells. Some of the small cells were cyanobacteria. They were specialized for photosynthesis. They evolved into the chloroplasts of eukaryotic cells.

Evidence for the Endosymbiotic Theory

Many pieces of evidence support the endosymbiotic theory. For example:

- Mitochondria and chloroplasts contain DNA that is different from the DNA found in the cell nucleus. Instead, it is similar to the circular DNA of bacteria.
- Mitochondria and chloroplasts are surrounded by their own plasma membranes, which are similar to bacterial membranes.
- New mitochondria and chloroplasts are produced through a process similar to binary fission. Bacteria also reproduce through binary fission.
- The internal structure and biochemistry of chloroplasts is very similar to that of cyanobacteria.

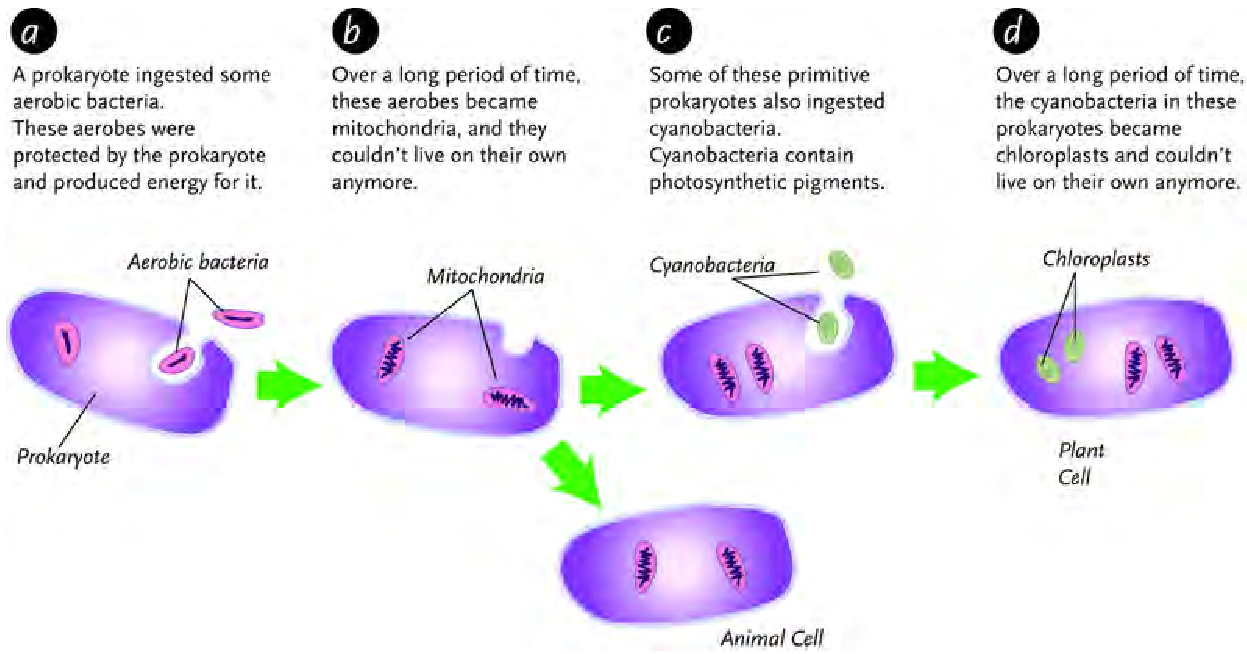


FIGURE 14.2

Endosymbiotic theory explains how eukaryotic cells arose.

Characteristics of Protists

Like all other eukaryotes, protists have a nucleus containing their DNA. They also have other membrane-bound organelles, such as mitochondria. Most protists are single-celled. Some are multicellular. Because the protist kingdom is so diverse, their ways of getting food and reproducing vary widely.

Protist Habitats

Most protists are aquatic organisms. They need a moist environment to survive. They are found mainly in damp soil, marshes, puddles, lakes, and the ocean. Some protists are free-living organisms. Others are involved in symbiotic relationships. They live in or on other organisms, including humans.

Motility of Protists

Most protists have **motility**. This is the ability to move. Protists have three types of appendages for movement. As shown in **Figure** 14.3 , they may have flagella, **cilia**, or **pseudopods** ("false feet"). There may be one or more whip-like flagella. Cilia are similar to flagella, except they are shorter and there are more of them. They may completely cover the surface of the protist cell. Pseudopods are temporary, foot-like extensions of the cytoplasm.

Protist Reproduction

Protists have complex life cycles. Many have both asexual and sexual reproduction. An example is a protist called *Spirogyra*, a type of algae, shown **Figure** 14.4 . It usually exists as haploid cells that reproduce by binary fission. In

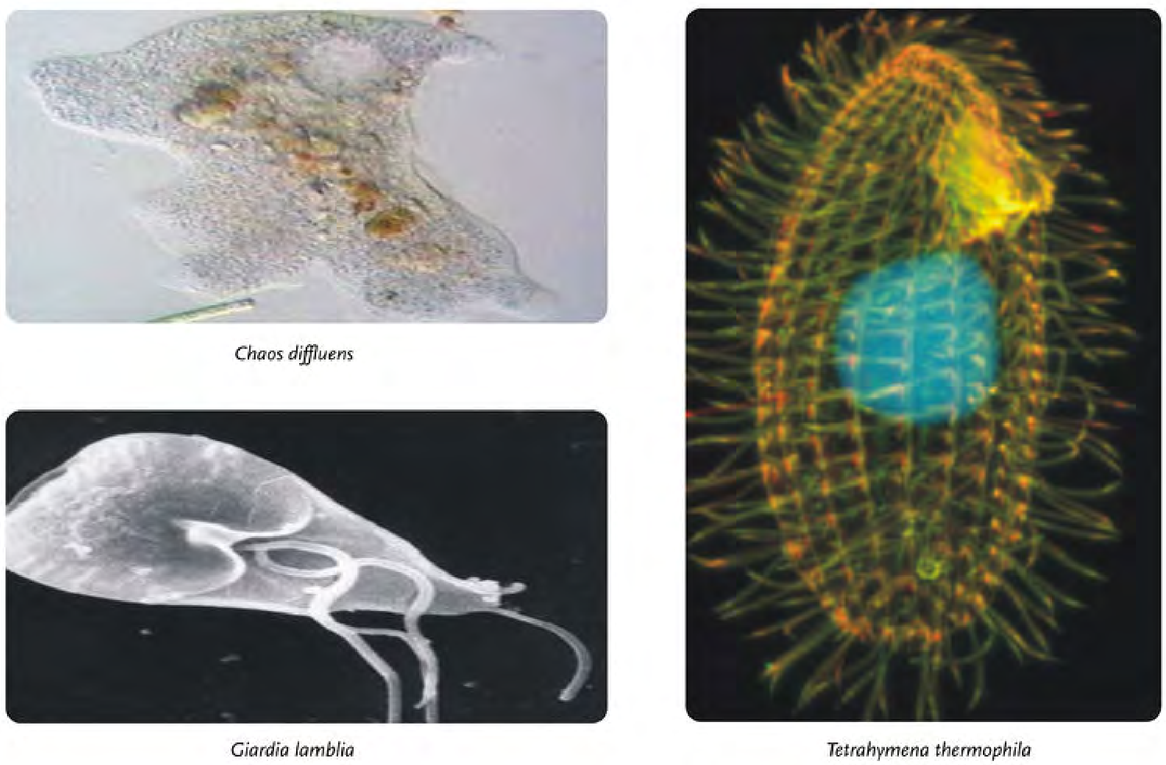


FIGURE 14.3

Protists use flagella cilia or pseudopods to move.

a stressful environment, such as one that is very dry, *Spirogyra* may produce tough spores that can withstand harsh conditions. Spores are reproductive cells produced by protists (and other organisms). If two protist spores are close together, they can fuse to form a diploid zygote. This is a type of sexual reproduction. The zygote then undergoes meiosis, producing haploid cells that repeat the cycle.

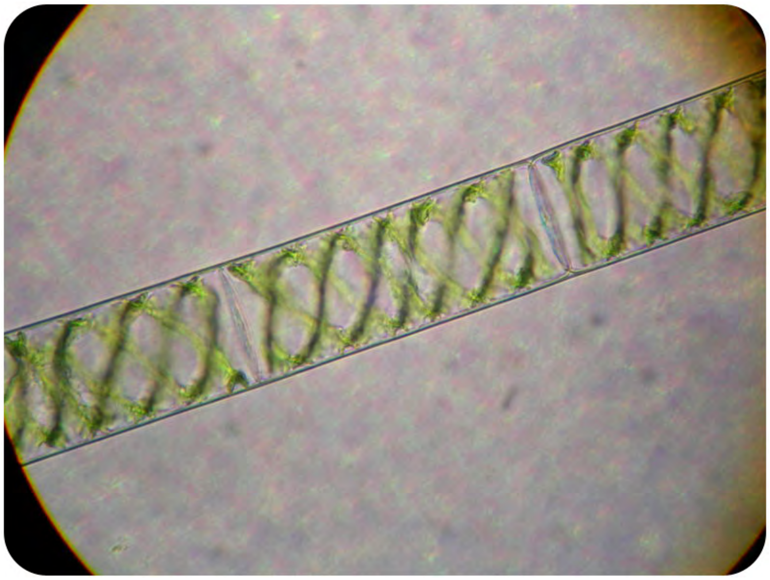


FIGURE 14.4
Spirogyra is a genus of algae with a complex life cycle. Each organism consists of rectangular cells connected end-to-end in long filaments.

Protist Nutrition

Protists get food in one of three ways. They may ingest, absorb, or make their own organic molecules.

- Ingestive protists ingest, or engulf, bacteria and other small particles. They extend their cell wall and cell membrane around the food item, forming a food vacuole. Then enzymes digest the food in the vacuole.

- Absorptive protists absorb food molecules across their cell membranes. This occurs by diffusion. These protists are important decomposers.
- Photosynthetic protists use light energy to make food. They are major producers in aquatic ecosystems.

Lesson Summary

- Kingdom Protista includes all eukaryotes that are not animals, plants, or fungi. It is a very diverse kingdom. It consists of both single-celled and multicellular organisms.
- Scientists think that protists are the oldest eukaryotes. They most likely evolved from prokaryotic cells, as explained by the endosymbiotic theory. This theory is well-supported by evidence.
- Protists have nuclear membranes around their DNA. They also have other membrane-bound organelles. Many live in aquatic habitats, and most are motile, or able to move. Protists have complex life cycles that may include both sexual and asexual reproduction. They get food through ingestion, absorption, or photosynthesis.

Lesson Review Questions

Recall

1. What are protists?
2. How did the first eukaryotic cells evolve, according to endosymbiotic theory?
3. Identify three structures that protists use to move.
4. Describe three ways that protists get food.

Apply Concepts

5. A mystery organism consists of one cell. It could be a protist or a prokaryote. What single fact about the mystery cell would allow you to determine which type of organism it is? Explain your answer.

Think Critically

6. Identify one piece of evidence for endosymbiotic theory. Explain how this evidence supports the theory.
7. Compare and contrast asexual and sexual reproduction in protists.

Points to Consider

Protists are traditionally classified as animal-like, plant-like, or fungi-like. You will read more about each of these types of protists in the next lesson.

- Based on what you already know about animals, plants, and fungi (such as mushrooms), how might the three types of protists differ?
- Why do you think these protists are not classified with the organisms they resemble? For example, why aren't animal-like protists classified as animals? What sets protists apart from other eukaryotes?

14.2 Types of Protists

Lesson Objectives

- Describe animal-like protists.
- Give an overview of plant-like protists.
- Identify types of fungus-like protists.

Vocabulary

algae (singular, alga) plant-like protists such as diatoms and seaweeds

amoeboid type of protozoa, such as *Amoeba,* that moves with pseudopods

ciliate type of protozoa, such as *Paramecium,* that moves with cilia

flagellate type of protozoa, such as *Giardia,* that moves with flagella

kelp multicellular seaweed that may grow as large as a tree and occurs in forests found throughout the ocean in temperate and arctic climates

protozoa (singular, protozoan) animal-like protists such as *Amoeba* and *Paramecium*

slime mold fungus-like protist commonly found on rotting logs and other decaying organic matter

sporozoa (singular, sporozoan) type of protozoa that cannot move as adults

water mold fungus-like protist commonly found in moist soil and surface water

Introduction

Protists are often classified based on how similar they are to other eukaryotes—animals, plants, and fungi. This lesson describes protists that resemble each of these other eukaryote kingdoms.

Animal-Like Protists: Protozoa

Animal-like protists are commonly called **protozoa** (singular, protozoan). Most protozoa consist of a single cell. They are animal-like because they are heterotrophs, and are capable of moving. Although protozoa are not animals, they are thought to be the ancestors of animals.

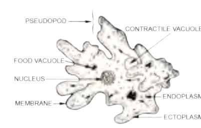
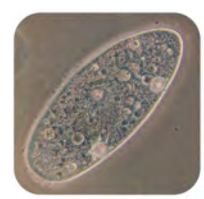
Ecology of Protozoa

Protozoa generally feed by engulfing and digesting other organisms. As consumers, they have various roles in food chains and webs. Some are predators. They prey upon other single-celled organisms, such as bacteria. In fact, protozoa predators keep many bacterial populations in check. Other protozoa are herbivores. They graze on algae. Still others are decomposers. They consume dead organic matter. There are also parasitic protozoa that live in or on living hosts. For example, the protozoan that causes malaria lives inside a human host. For their part, protozoa are important food sources for many larger organisms, including insects and worms.

Classification of Protozoa

Protozoa can be classified on the basis of how they move. As shown in **Table** 14.1 , protozoa move in three different ways. Only sporozoa cannot move. Note that this classification is based only on differences in movement. It does not represent phylogenetic relationships.

TABLE 14.1: Classification of Protozoa Based on Movement

Type of Protozoa	How It Moves	Example (Genus)
Amoeboid	pseudopods	*Amoeba* 
Ciliate	cilia	*Paramecium* 
Flagellate	flagella	*Giardia* 
Sporozoan	does not move (as adult)	*Plasmodium* 

Plant-Like Protists: Algae

Plant-like protists are called **algae** (singular, alga). They are a large and diverse group. Some algae, diatoms, are single-celled. Others, such as seaweed, are multicellular (see **Figure** 14.5).

FIGURE 14.5
Diatoms are single-celled algae. Other forms of algae are multicellular.

Why are algae considered plant-like? The main reason is that they contain chloroplasts and produce food through photosynthesis. However, they lack many other structures of true plants. For example, algae do not have roots, stems, or leaves. Some algae also differ from plants in being motile. They may move with pseudopods or flagella. Although not plants themselves, algae were probably the ancestors of plants.

Ecology of Algae

Algae play significant roles as producers in aquatic ecosystems. Microscopic forms live suspended in the water column. They are the main component of phytoplankton. As such, they contribute to the food base of most marine ecosystems.

Multicellular seaweeds called **kelp** may grow as large as trees. They are the food base of ecosystems called kelp forests (see **Figure** 14.6). Kelp forests are found throughout the ocean in temperate and arctic climates. They are highly productive ecosystems.

Classification of Algae

Types of algae include red and green algae, euglenids, and dinoflagellates (see **Table** 14.2 for examples). Scientists think that red and green algae evolved from endosymbiotic relationships with cyanobacteria. Their chloroplasts have two membranes because the cell membranes of the cyanobacteria became additional plasma membranes of the chloroplasts. Scientists think that euglenids and dinoflagellates evolved later, from endosymbiotic relationships with green and red algae. This is why their chloroplasts have three membranes. Differences in the types of chlorophyll in the four types of algae also support the hypothesized evolutionary relationships.

FIGURE 14.6
Kelp Forest. This kelp forest supports a large community of many other types of organisms.

TABLE 14.2: Types of Algae

Type of Algae	Origin of Chloroplast	Type of Chloroplast
Red algae 	cyanobacteria	two membranes, chlorophyll like the majority of cyanobacteria
Green algae 	cyanobacteria	two membranes, chlorophyll like a minority of cyanobacteria
Euglenids 	green algae	three membranes, chlorophyll like green algae

TABLE 14.2: (continued)

Type of Algae	Origin of Chloroplast	Type of Chloroplast
Dinoflagellates 	red algae	three membranes, chlorophyll like red algae

Reproduction of Algae

Algae have varied life cycles. Two examples are shown in **Figure** 14.7 . Both cycles include phases of asexual reproduction (haploid, *n*) and sexual reproduction (diploid, *2n*). Why go to so much trouble to reproduce? Asexual reproduction is fast, but it doesn't create new genetic variation. Sexual reproduction is more complicated and risky, but it creates new gene combinations. Each strategy may work better under different conditions. Rapid population growth is adaptive when conditions are favorable. Genetic variation helps ensure that some organisms will survive if the environment changes.

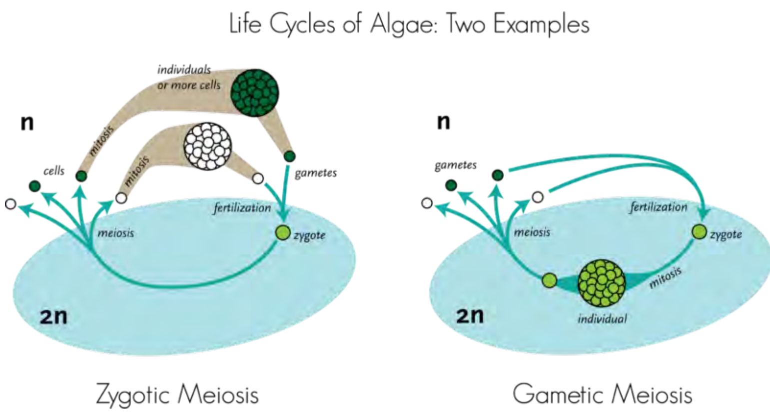


FIGURE 14.7

Life Cycles of Algae Two Examples - Zygotic meiosis and Gametic meiosis. In life cycle A $left$ diploid $2n$ zygotes undergo meiosis and produce haploid n gametes. The gametes undergo mitosis and produce many additional copies of themselves. How is life cycle B *right* different from life cycle A

KQED: Algae Power

QUEST explores the potential of algae-–once considered nothing more than pond scum—to become the fuel of the future. Entrepreneurs from throughout California are working to create the next generation of biofuels from algae. But will you ever be able to run your car off it? See http://www.kqed.org/quest/television/algae-power for additional information.

MEDIA

Click image to the left for more content.

Fungus-Like Protists: Molds

Fungus-like protists are molds. They are absorptive feeders on decaying organic matter. They resemble fungi, and they reproduce with spores as fungi do. However, in other ways, they are quite different from fungi and more like other protists. For example, they have cell walls made of cellulose, whereas fungi have cell walls made of chitin. Like other protists, they have complicated life cycles with both asexual and sexual reproduction. They are motile cells during some stages of their life cycle. Two major types of fungus-like protists are slime molds and water molds.

Slime Molds

Slime molds are fungus-like protists commonly found on rotting logs and compost. They move very slowly in search of decaying matter to eat. When food is scarce, individual cells swarm together to form a blob-like mass, like the "dog vomit" slime mold in **Figure** 14.8 . The mass glides along on its own secretions, engulfing decaying organic matter as it moves over it.

FIGURE 14.8
&#8220 Dog Vomit&#8221 Slime Mold. This slime mold looks like its name.

There are two types of slime molds when it comes to how they swarm: acellular and cellular.

- When acellular slime molds swarm, they fuse together to form a single cell with many nuclei.
- When cellular slime molds swarm, they remain as distinct cells.

Cellular slime molds are used as model organisms in molecular biology and genetics. They may be the key to how multicellular organisms evolved. Can you explain why?

Water Molds

Water molds are commonly found in moist soil and surface water. Many are plant pathogens that destroy crops. They infect plants such as grapes, lettuce, corn, and potatoes. Some water molds are parasites of fish and other aquatic organisms, such as the mold in **Figure** 14.9 .

FIGURE 14.9
Water mold is growing on this fly larva.

Lesson Summary

- Animal-like protists are called protozoa. Most consist of a single cell. Like animals, they are heterotrophic and capable of moving. Examples of protozoa include amoebas and paramecia.
- Plant-like protists are called algae. They include single-celled diatoms and multicellular seaweed. Like plants, they contain chlorophyll and make food by photosynthesis. Types of algae include red and green algae, euglenids, and dinoflagellates.
- Fungus-like protists are molds. They are absorptive feeders, found on decaying organic matter. They resemble fungi and reproduce with spores as fungi do. Examples of fungus-like protists include slime molds and water molds.

Lesson Review Questions

Recall

1. How are protozoa similar to animals?

2. What roles do protozoa play in food chains and webs?

3. State pros and cons of asexual and sexual reproduction in algae.

4. How are fungus-like protists similar to fungi? What is one way they are different?

Apply Concepts

5. Assume that a new species of organism has been discovered and it's your job to classify it. The organism consists of a single cell with a nucleus. It has cilia and obtains food by consuming other single-celled organisms. Name a genus that the new species could possibly be placed in. Explain your answer.

Think Critically

6. Compare and contrast algae and plants.

7. Explain why dinoflagellates and euglenids have chloroplasts with three membranes instead of two.

8. Why might cellular slime molds—but not acellular slime molds—be the key to how multicellular organisms evolved?

Points to Consider

In this lesson you read about slime molds and water molds. These aren't the only kinds of molds. In fact, you are probably more familiar with molds that are classified as fungi. The next lesson introduces the fungi.

- How do you think fungi might be different from fungi-like protists? (*Hint:* Fungi are also eukaryotes, but they belong to a different kingdom than protists.)
- What types of molds might be fungi rather than protists?

14.3 Introduction to Fungi

Lesson Objectives

- Identify what fungi are.
- Describe habitats of fungi.
- Outline the structure of fungi.
- Describe fungi reproduction.
- Summarize the evolution of fungi.
- Give an overview of fungi classification.

Vocabulary

budding type of asexual reproduction in yeasts in which an offspring cell pinches off from the parent cell

chitin tough carbohydrate that makes up the cell walls of fungi and the exoskeletons of insects and other arthropods

fungi (singular, fungus) kingdom in the domain Eukarya that includes molds, mushrooms, and yeasts

hyphae (singular, hypha) thread-like filaments that make up the body of a fungus and consist of one or more cells surrounded by a tubular cell wall

mycelium body of a fungus that consists of a mass of threadlike filaments called hyphae

zygospore diploid spore in fungi that is produced by the fusion of two haploid parent cells

Introduction

Do you see the organisms growing on the bread in **Figure** 14.10 ? They belong to the Kingdom Fungi. Molds growing on foods are some of the most common fungi in our everyday lives. These organisms may seem useless, gross, and costly. But fungi play very important roles in almost every terrestrial ecosystem on Earth.

What Are Fungi?

Fungi (singular, fungus) are a kingdom in the domain Eukarya. The fungi kingdom may contain more than a million species, but fewer than 100,000 have been identified. As shown in **Figure** 14.11 , fungi include mushrooms and yeasts in addition to molds.

FIGURE 14.10
The mold growing on this bread is a common fungus.

FIGURE 14.11
Several examples of fungi are pictured here.

Most fungi are multicellular, but some exist as single cells. Fungi spend most of their life cycle in the haploid state. They form diploid cells only during sexual reproduction. Like the cells of protists and plants, the cells of fungi have cell walls. But fungi are unique in having cell walls made of chitin instead of cellulose. **Chitin** is a tough carbohydrate that also makes up the exoskeleton (outer skeleton) of insects and related organisms.

Habitats of Fungi

You probably already know where some species of fungi live. No doubt, you've seen them growing on rotting logs and moist soil. In fact, most fungi live on dead matter or soil. However, some fungi are aquatic. Others live in or on other organisms in symbiotic relationships.

Structure of Fungi

Except for yeasts, which grow as single cells, most fungi grow as thread-like filaments, like those shown in **Figure** 14.12 . The filaments are called **hyphae** (singular, hypha). Each hypha consists of one or more cells surrounded by a tubular cell wall. A mass of hyphae make up the body of a fungus, which is called a **mycelium** (plural, mycelia).

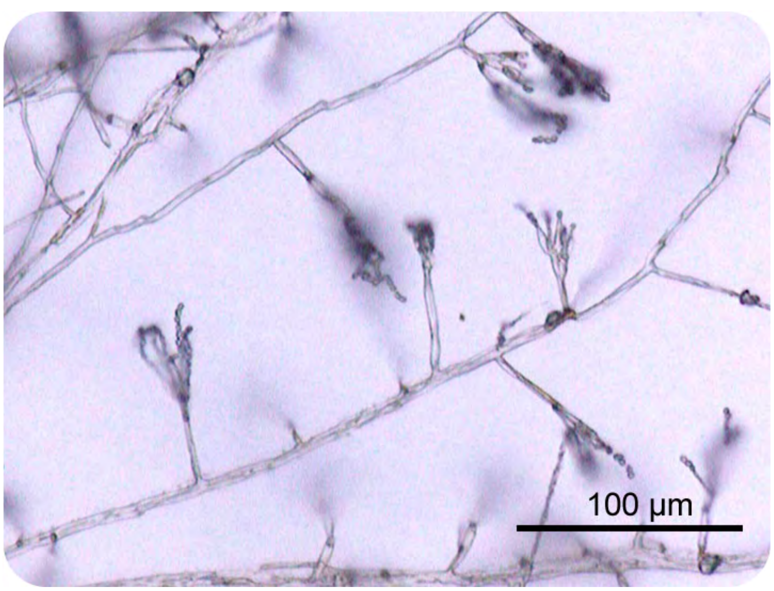


FIGURE 14.12

These branches are hyphae or filaments of a mold called Penicillium.

A mycelium may range in size from microscopic to very large. In fact, one of the largest living organisms on Earth is the mycelium of a single fungus. A small part of a similar fungus is pictured in **Figure** 14.13 . The giant fungus covers 8.9 square kilometers (3.4 square miles) in an Oregon forest. That's about the size of a small city. The fungus didn't grow that large over night. It's estimated to be 2,400 years old—and it's still growing!

FIGURE 14.13

The fungus shown here has been dubbed the &#8220 humongous fungus&#8221 because it covers such a large area.

Reproduction of Fungi

The majority of fungi can reproduce both asexually and sexually. This allows them to adjust to conditions in the environment. They can spread quickly through asexual reproduction when conditions are stable. They can increase their genetic variation through sexual reproduction when conditions are changing and variation may help them survive.

Asexual Reproduction

Almost all fungi reproduce asexually by producing spores. A fungi spore is a haploid cell produced by mitosis from a haploid parent cell. It is genetically identical to the parent cell. Fungi spores can develop into new haploid individuals without being fertilized.

Spores may be dispersed by moving water, wind, or other organisms. Some fungi even have "cannons" that "shoot" the spores far from the parent organism. This helps to ensure that the offspring will not have to compete with the parents for space or other resources. You are probably familiar with puffballs, like the one in **Figure** 14.14 . They release a cloud of spores when knocked or stepped on. Wherever the spores happen to land, they do not germinate until conditions are favorable for growth. Then they develop into new hyphae.

Yeasts do not produce spores. Instead, they reproduce asexually by budding. **Budding** is the pinching off of an offspring from the parent cell. The offspring cell is genetically identical to the parent. Budding in yeast is pictured in **Figure** 14.15 .

Sexual Reproduction

Sexual reproduction also occurs in virtually all fungi. This involves mating between two haploid hyphae. During mating, two haploid parent cells fuse, forming a diploid spore called a **zygospore**. The zygospore is genetically different from the parents. After the zygospore germinates, it can undergo meiosis, forming haploid cells that develop into new hyphae.

FIGURE 14.14

Puffballs release spores when disturbed.

FIGURE 14.15

Yeast reproduce asexually by budding.

Evolution of Fungi

DNA evidence suggests that almost all fungi have a single common ancestor. The earliest fungi may have evolved about 600 million years ago or even earlier. They were probably aquatic organisms with a flagellum. Fungi first colonized the land at least 460 million years ago, around the same time as plants. Fossils of terrestrial fungi date back almost 400 million years (see **Figure** 14.16). Starting about 250 million years ago, the fossil record shows fungi were abundant in many places. They may have been the dominant life forms on Earth at that time.

FIGURE 14.16
This rock contains fossilized fungi. The fungi lived 396 million years ago in what is now Scotland. They were preserved when they were covered with lava from a volcano. The lava cooled and hardened into rock.

Classification of Fungi

For a long time, scientists considered fungi to be members of the plant kingdom because they have obvious similarities with plants. Both fungi and plants are immobile, have cell walls, and grow in soil. Some fungi, such as lichens, even look like plants (see **Figure** 14.17).

The Kingdom Fungi

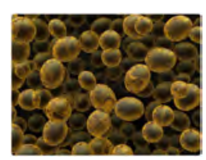
Today, fungi are no longer classified as plants. We now know that they have unique physical, chemical, and genetic traits that set them apart from plants (and other eukaryotes). For example, the cell walls of fungi are made of chitin, not cellulose. Also, fungi absorb nutrients from other organisms, whereas plants make their own food. These are just a few of the reasons fungi are now placed in their own kingdom.

Fungal Phyla

Classification of fungi below the level of the kingdom is controversial. There is no single, widely-accepted system of fungal classification. Most classifications include several phyla (the next major taxon below the kingdom). Three of the most common phyla are compared in **Table** 14.3 .

FIGURE 14.17
Moss *Plant* and Lichen Growing on Tree Bark. Both fungi and moss are growing on this tree. Can you tell them apart

TABLE 14.3: Three Common Phyla of Fungi

Phylum	Description	Example
Zygomycota	mainly terrestrial, live in soil and compost and on foods such as bread	black bread mold 
Basidiomycota	have many different shapes, considerable variation exists even within species	button mushrooms 
Ascomycota	found in all terrestrial ecosystems world-wide, even in Antarctica, often involved in symbiotic relationships	baker's yeast 

Lesson Summary

- Fungi are a kingdom in the domain Eukarya that includes molds, mushrooms, and yeasts. Most fungi are multicellular. They are unique in having cell walls made of chitin.
- Most fungi live on dead matter or soil. Some live in aquatic habitats. Many are involved in symbiotic relationships.
- Most fungi grow as thread-like filaments called hyphae. A mass of hyphae make up the body of a fungus, called a mycelium.
- The majority of fungi can reproduce both asexually and sexually. This allows them to adjust to conditions in the environment. Yeast reproduce asexually by budding. Other fungi reproduce asexually by producing

2. List several habitats where fungi live.
3. Describe the general structure of multicellular fungi.
4. Identify ways that fungi spores may be dispersed.
5. Summarize the evolution of fungi.
6. State why fungi were once classified as plants.

Apply Concepts

7. Create a diagram to show the life cycle of a multicellular fungus.

Think Critically

8. Explain the significance of the chitin cell wall of fungi.
9. Compare and contrast a fungi spore and zygospore.

Points to Consider

In this lesson, you read that fungi differ from plants in major ways. For example, unlike plants, fungi do not make their own food by photosynthesis.

- How do you think fungi obtain food? What organisms might they consume?
- What roles do you think fungi might play in food chains and webs?

14.4 Ecology of Fungi

Lesson Objectives

- Describe the role of fungi as decomposers.
- Identify symbiotic relationships of fungi.
- List human uses of fungi.

Vocabulary

lichen mutualistic relationship between a fungus and a cyanobacterium or green alga

mycorrhiza mutualistic relationship between a plant and a fungus that grows in or on its roots

Introduction

Fungi lack chlorophyll, so they cannot make food by photosynthesis as plants can. Instead, they are heterotrophs, like animals. But they don't have a mouth or teeth. So how do fungi "eat"? They 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. They are decomposers called saprotrophs. A saprotroph feeds on any remaining organic matter after other decomposers do their work. Fungi use enzymes to digest organic remains and then absorb the resulting organic compounds. As decomposers, fungi are vital for the health of ecosystems. They break down nonliving organic matter and release the nutrients into the soil. Plants can then use the nutrients and pass them on to herbivores and other consumers.

Bacteria are also major decomposers, but they can grow and feed only on the exposed surfaces of organic matter. In contrast, fungi can use their hyphae to penetrate deep into organic matter. Fungi are also the only decomposers that can break down tough plant substances, including lignin (in wood) and cellulose (in plant cell walls). They have special enzymes to do this work. The enzymes are released by the tips of the hyphae. Because of these abilities, fungi are the primary decomposers in forests (see **Figure** 14.18).

FIGURE 14.18
Forest Decomposers. These forest mushrooms may look fragile but they do a powerful job. They decompose dead wood and other tough plant material.

Symbiotic Relationships of Fungi

Not all fungi feed on dead organisms. Many are involved in symbiotic relationships, including parasitism and mutualism.

Fungi as Parasites

In a parasitic relationship, the parasite benefits while the host is harmed. Parasitic fungi live in or on other organisms and get their nutrients from them. Fungi have special structures for penetrating a host. They also produce enzymes that break down the host's tissues.

Parasitic fungi often cause illness and may eventually kill their host. They are the major cause of disease in agricultural plants. Fungi also parasitize animals, such as the insect pictured in **Figure** 14.19 . Fungi even parasitize humans. Did you ever have athelete's foot? If so, you were the host of a parasitic fungus. You can read more about fungi and human disease in the last lesson of this chapter.

Mutualism in Fungi

Fungi have several mutualistic relationships with other organisms. In mutualism, both organisms benefit from the relationship. Two common mutualistic relationships involving fungi are mycorrhiza and lichen.

- A **mycorrhiza** is a mutualistic relationship between a fungus and a plant. The fungus grows in or on the plant roots. The fungus benefits from the easy access to food made by the plant. The plant benefits because the fungus puts out mycelia that help absorb water and nutrients. Scientists think that a symbiotic relationship such as this may have allowed plants to first colonize the land.
- A **lichen** is a mutualistic relationship between a fungus and a photosynthetic organism. The other organism is usually a cyanobacterium or green alga. The fungus grows around the bacterial or algal cells. The fungus

FIGURE 14.19
Parasitic Fungus and Insect Host. The white parasitic fungus named Cordyceps is shown here growing on its host&#8212 a dark brown moth.

benefits from the constant supply of food produced by the photosynthesizer. The photosynthesizer benefits from the water and nutrients absorbed by the fungus. **Figure** 14.20 shows lichen growing on a rock.

FIGURE 14.20
Lichen Growing on Rock. Unlike plants lichen can grow on bare rocks because they don&#8217 t have roots. That&#8217 s why lichens are often pioneer species in primary ecological succession. How do lichen get water and nutrients without roots

Some fungi have mutualistic relationships with insects. For example:

- Leafcutter ants grow fungi on beds of leaves in their nests. The fungi get a protected place to live. The ants feed the fungi to their larvae.
- Ambrosia beetles bore holes in tree bark and "plant" fungal spores in the holes. The holes in the bark give the fungi an ideal place to grow. The beetles harvest fungi from their "garden."

Human Uses of Fungi

Whenever you eat pizza, you eat fungi, even if you don't like your pizza with mushrooms. That's because pizza dough contains yeast. Do you know other foods that are made with fungi?

Fungi for Food

Humans have collected and grown mushrooms for food for thousands of years. **Figure** 14.21 shows some of the many types of mushrooms that people eat. Yeasts are used in bread baking and brewing alcoholic beverages. Other fungi are used in fermenting a wide variety of foods, including soy sauce, tempeh, and cheeses. Blue cheese has its distinctive appearance and flavor because of the fungus growing though it (see **Figure** 14.22).

FIGURE 14.21
These are just a few of the many species of edible mushrooms consumed by humans.

Fungi for Pest Control

Harmless fungi can be used to control pathogenic bacteria and insect pasts on crops. Fungi compete with bacteria for nutrients and space, and they parasitize insects that eat plants. Fungi reduce the need for pesticides and other toxic chemicals.

Other Uses of Fungi

Fungi are useful for many other reasons.

- They are a major source of citric acid (vitamin C).
- They produce antibiotics such as penicillin, which has saved countless lives.
- They can be genetically engineered to produce insulin and other human hormones.
- They are model research organisms. To see how one lab is using yeast in cancer research, watch the video at this link: http://college.usc.edu/news/stories/727/yeast-unleashed/.

FIGURE 14.22

Blue Cheese. The dark blue strands running through this cheese are a fungus. In fact this cheese is moldy The fungus is Penicillium roqueforti a type of mold.

Lesson Summary

- Most fungi are decomposers called saprotrophs. They feed on decaying organic matter and return nutrients to the soil for plants to use. Fungi are the only decomposers that can break down wood and the cellulose in plant cell walls, so they are the primary decomposers in forests.
- Many fungi are involved in symbiotic relationships. Some are parasites. They are specialized to penetrate a host and break down the host's tissues. Parasitic fungi often cause illness and may eventually kill their host. Two common mutualistic relationships involving fungi are mycorrhiza (fungi and plant roots) and lichen (fungi and either cyanobacteria or green algae). Some fungi also have mutualistic relationships with insects.
- Humans use fungi for many purposes, including as food or in the preparation of food. Humans also use fungi for pest control. In addition, fungi can be used to produce citric acid, antibiotics, and human hormones. Fungi are model research organisms as well.

Lesson Review Questions

Recall

1. How do fungi obtain organic compounds from dead organisms?
2. Why are fungi the primary decomposers in forests?
3. How significant are fungi as plant parasites?

4. Describe an example of a mutualistic relationship between fungi and insects.

5. List several ways that humans use fungi.

Apply Concepts

6. Assume that you notice a fungus growing on a plant. What possible relationships might exist between the fungus and the plant? What type of evidence might help you identify which is the correct relationship?

Think Critically

7. Compare and contrast mycorrhiza and lichen.

8. Explain how fungi might have allowed early plants to colonize the land.

Points to Consider

You read in this lesson that many fungi are parasites, and they make their hosts sick. An example in humans is athlete's foot.

- Do you know any other human diseases caused by fungi?
- Besides parasitism, how else might fungi make people sick?

14.5 Protists, Fungi, and Human Disease

Lesson Objectives

- Explain how protists cause human disease.
- Identify three ways fungi can make humans sick.

Vocabulary

athlete's foot infection of the skin between the toes by the fungus *Trichophyton*

candidiasis infection of the mouth or of the vagina in females that is caused by the yeast *Candida*

giardiasis disease caused by *Giardia* protozoa that spreads through contaminated food or water

malaria disease caused by *Plasmodium* protozoa and transmitted by mosquitoes in tropical and subtropical regions of the world

ringworm skin infection caused by the fungus *Trichophyton* that causes a characteristic ring-shaped rash

Introduction

Protists and fungi may seem defenseless, but they can be deadly. Both are important causes of disease and death in other living things—including humans.

Protists and Human Disease

Most protist diseases in humans are caused by animal-like protists, or protozoa. Protozoa make us sick when they become human parasites. Three examples of parasitic protozoa are described below.

Members of the genus *Trypanosoma* are flagellate protozoa that cause sleeping sickness, which is common in Africa. They also cause Chagas disease, which is common in South America. The parasites are spread by insect vectors. The vector for Chagas disease is shown in **Figure** 14.23 . *Trypanosoma* parasites enter a person's blood when the vector bites. Then they spread to other tissues and organs. The diseases may be fatal without medical treatment.

FIGURE 14.23
Vector for Chagas Disease. In Chagas disease the Trypanosoma parasite is spread by an insect commonly called the &#8220 kissing bug.&#8221 A bite from this bug could be the kiss of death.

The discovery of Chagas disease is unique in the history of medicine. That's because a single researcher—a Brazilian physician named Carlos Chagas—single-handedly identified and explained the new infectious disease. In the early 1900s, Chagas did careful lab and field studies. He determined the pathogen, vector, host, symptoms, and mode of transmission of the disease that is now named for him.

Giardia are flagellate protozoa that cause **giardiasis**. The parasites enter the body through food or water that has been contaminated by feces of infected people or animals. The protozoa attach to the lining of the host's small intestine, where they prevent the host from fully absorbing nutrients. They may also cause diarrhea, abdominal pain, and fever. A picture of a *Giardia* protozoan opens this chapter.

Plasmodium protozoa cause **malaria**. The parasites are spread by a mosquito vector. Parasites enter a host's blood through the bite of an infected mosquito. The parasites infect the host's red blood cells, causing symptoms such as fever, joint pain, anemia, and fatigue.

Malaria is common in tropical and subtropical climates throughout the world (see **Figure** 14.24). In fact, malaria is one of the most common infectious diseases on the planet. Malaria is also a very serious disease. It kills several million people each year, most of them children.

Fungi and Human Disease

Fungi cause human illness in three different ways: poisonings, parasitic infections, and allergic reactions.

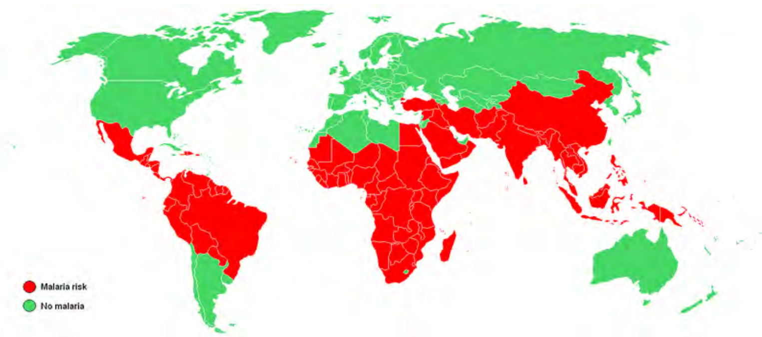


FIGURE 14.24
Worldwide Distribution of Malaria. This map shows where malaria is found. The area is determined by the mosquito vector. The mosquito can live year-round only in the red-shaded areas.

Fungal Poisoning

Many fungi protect themselves from parasites and predators by producing toxic chemicals. If people eat toxic fungi, they may experience digestive problems, hallucinations, organ failure, and even death. Most cases of mushroom poisoning are due to mistaken identity. That's because many toxic mushrooms look very similar to safe, edible mushrooms. An example is shown in **Figure** 14.25 .

FIGURE 14.25
Poisonous or Edible The destroying angel mushroom on the left causes liver and kidney failure. The puffball mushroom on the right is tasty and harmless. Do you think you could tell these two species of mushrooms apart

Fungal Parasites

Some fungi cause disease when they become human parasites. Two examples are fungi in the genera *Candida* and *Trichophyton.*

- *Candida* are yeast that cause **candidiasis**, commonly called a "yeast infection." The yeast can infect the mouth or the vagina (in females). If yeast enter the blood, they cause a potentially life threatening illness. However, this is rare, except in people with a depressed immune system.
- *Trichophyton* are fungi that cause **ringworm**. This is a skin infection characterized by a ring-shaped rash. The rash may occur on the arms, legs, head, neck, or trunk. The same fungi cause **athlete's foot** when they infect

the skin between the toes. Athlete's foot is the second most common skin disease in the U.S.

Figure 14.26 shows signs of these two infections.

FIGURE 14.26
Ringworm produces a ring-shaped rash but it isn&#8217 t caused by a worm. It&#8217 s caused by the same fungus that causes athlete&#8217 s foot.

Fungal Allergies

Mold allergies are very common. They are caused by airborne mold spores. When the spores enter the respiratory tract, the immune system responds to them as though they were harmful microbes. Symptoms may include sneezing, coughing, and difficulty breathing. The symptoms are likely to be more severe in people with asthma or other respiratory diseases. Long-term exposure to mold spores may also weaken the immune system.

Molds grow indoors as well as out. Indoors, they grow in showers, basements, and other damp places. Homes damaged in floods and hurricanes may have mold growing just about everywhere (see **Figure** 14.27). Indoor mold may cause more health problems than outdoor mold because of the closed, confined space. Most people also spend more time indoors than out.

FIGURE 14.27
The mold growing on the walls and ceiling of this storm-damaged home may be harmful to human health.

Lesson Summary

- Most protist diseases in humans are caused by protozoa. Protozoa make humans sick when they become human parasites. *Trypanosoma* protozoa cause Chagas disease and sleeping sickness. *Giardia* protozoa cause giardiasis, and *Plasmodium* protozoa cause malaria.
- Fungi cause three different types of human illness: poisonings, parasitic infections, and allergies. Many poisonous mushrooms are eaten by mistake because they look like edible mushrooms. Parasitic yeasts cause candidiasis, ringworm, and athlete's foot. Mold allergies are very common.

Lesson Review Questions

Recall

1. Describe how the protozoa that cause Chagas disease are spread to human hosts.
2. State why malaria is commonly found only in tropical and subtropical regions of the world.
3. How does mold cause allergies?
4. State why indoor mold may cause more health problems than outdoor mold.

Apply Concepts

5. Terri lost her water bottle while hiking in Canada. It was a hot day, so she drank water from a stream to stay hydrated. A few days later, Terri became ill with abdominal pain, fever, and diarrhea. Her doctor thinks she has a protozoan infection. Which type of protozoa do you think is most likely responsible for Terri's illness? How do you think Terri became infected?

Think Critically

6. Explain why you should never eat mushrooms you find in the woods unless you know for certain which type of mushrooms they are.
7. Compare and contrast ringworm and athlete's foot.

Points to Consider

In this chapter you learned about two kingdoms of Eukarya, the protists and fungi. In the next chapter, you'll learn about another kingdom of Eukarya, the plants.

- Plants are a very diverse kingdom. How many different kinds of plants can you think of?
- What traits do you think might distinguish plants from other eukaryotes? What do you already know about plants that might help you answer this question?

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CHAPTER 15 Plant Evolution and Classification

CHAPTER OUTLINE

If you take a walk in a damp wooded area in the spring, you might smell this interesting plant before you notice its striking yellow hood. The hood surrounds a stalk covered with tiny flowers. It's an intriguing sight—but don't get too close! It grows on a plant called the skunk cabbage. It's aptly named for its unpleasant odor, which smells like rotten meat. The plant stores food in its fleshy roots all winter so it can grow the hood and flowers in the spring. They emerge from the soil so early that there may still be snow on the ground, but the plant produces enough heat to melt the snow.

Why does the skunk cabbage put so much energy into producing its unusual, smelly flowers? As you will read in this chapter, flowering plants have devised many ways to attract pollinators to their flowers so they can reproduce. The skunk cabbage is no exception. What pollinators do you think its stinky flowers might attract?

15.1 Introduction to the Plant Kingdom

Lesson Objectives

- Identify traits of plants.
- Explain the importance of plants.
- Give an overview of the plant life cycle.
- Outline major events in plant evolution.
- Describe how plants are classified.

Vocabulary

alternation of generations change back and forth from one generation to the next between haploid gametophyte and diploid sporophyte stages in the life cycle of plants

angiosperm type of seed plant that produces seeds in the ovary of a flower

cone structure consisting of scales that bear naked seeds in the type of seed plants called gymnosperms

flower structure in angiosperms consisting of male and female reproductive structures that attracts animal pollinators

fruit structure in many flowering plants that develops from the ovary and contains seeds

gametophyte haploid generation in the life cycle of a plant that results from asexual reproduction with spores and that produces gametes for sexual reproduction

germination early growth and development of a plant embryo in a seed

gymnosperm type of seed plant that produces bare seeds in cones

lignin tough, hydrophobic carbohydrate molecule that stiffens and waterproofs vascular tissues of plants

ovary one of two female reproductive organs that produces eggs and secretes estrogen

plant multicellular eukaryote with chloroplasts, cell walls made of cellulose, and specialized reproductive organs

rhizoid hair-like structure in a nonvascular plant that absorbs water and minerals and anchors the plant to a surface

seed structure produced by a seed plant that contains an embryo and food supply enclosed within a tough coat

sporophyte diploid generation in the life cycle of a plant that results from sexual reproduction with gametes and that produces spores for asexual reproduction

vascular tissue type of tissue in plants that transports fluids through the plant; includes xylem and phloem

vegetative reproduction asexual reproduction in plants using nonreproductive tissues such as leaves, stems, or roots

weed plant that is growing where people do not want it

Introduction

Like the skunk cabbage, most of the plants you are familiar with produce flowers. However, plants existed for hundreds of millions of years before they evolved flowers. In fact, the earliest plants were different from most modern plants in several important ways. They not only lacked flowers. They also lacked leaves, roots, and stems. You might not even recognize them as plants. So why are the earliest plants placed in the plant kingdom? What traits define a plant?

What Are Plants?

Plants are multicellular eukaryotes with cell walls made of cellulose. Plant cells also have chloroplasts. In addition, plants have specialized reproductive organs. These are structures that produce reproductive cells. Male reproductive organs produce sperm, and female reproductive organs produce eggs. Male and female reproductive organs may be on the same or different plants.

How Do Plants Obtain Food?

Almost all plants make food by photosynthesis. Only about 1 percent of the estimated 300,000 species of plants have lost the ability to photosynthesize. These other species are consumers, many of them predators. How do plants prey on other organisms? The Venus fly trap in **Figure** 15.1 shows one way this occurs.

What Do Plants Need?

Plants need temperatures above freezing while they are actively growing and photosynthesizing. They also need sunlight, carbon dioxide, and water for photosynthesis. Like most other organisms, plants need oxygen for cellular respiration and minerals to build proteins and other organic molecules. Most plants support themselves above the ground with stiff stems in order to get light, carbon dioxide, and oxygen. Most plants also grow roots down into the soil to absorb water and minerals.

The Importance of Plants

The importance of plants to humans and just about all other life on Earth is staggering. Life as we know it would not be possible without plants. Why are plants so important?

FIGURE 15.1
Venus fly trap plants use their flowers to trap insects. The flowers secrete enzymes that digest the insects and then they absorb the resulting nutrient molecules.

- Plants supply food to nearly all terrestrial organisms, including humans. We eat either plants or other organisms that eat plants.
- Plants maintain the atmosphere. They produce oxygen and absorb carbon dioxide during photosynthesis. Oxygen is essential for cellular respiration for all aerobic organisms. It also maintains the ozone layer that helps protect Earth's life from damaging UV radiation. Removal of carbon dioxide from the atmosphere reduces the greenhouse effect and global warming.
- Plants recycle matter in biogeochemical cycles. For example, through transpiration, plants move enormous amounts of water from the soil to the atmosphere. Plants such as peas host bacteria that fix nitrogen. This makes nitrogen available to all plants, which pass it on to consumers.
- Plants provide many products for human use, such as firewood, timber, fibers, medicines, dyes, pesticides, oils, and rubber.
- Plants create habitats for many organisms. A single tree may provide food and shelter to many species of insects, worms, small mammals, birds, and reptiles (see **Figure** 15.2).

We obviously can't live without plants, but sometimes they cause us problems. Many plants are weeds. **Weeds** are plants that grow where people don't want them, such as gardens and lawns. They take up space and use resources, hindering the growth of more desirable plants. People often introduce plants to new habitats where they lack natural predators and parasites. The introduced plants may spread rapidly and drive out native plants. Many plants produce pollen, which can cause allergies. Plants may also produce toxins that harm human health (see **Figure** 15.3).

Life Cycle of Plants

All plants have a characteristic life cycle that includes **alternation of generations**. Plants alternate between haploid and diploid generations. Alternation of generations allows for both asexual and sexual reproduction. Asexual reproduction with spores produces haploid individuals called **gametophytes**. Sexual reproduction with gametes and fertilization produces diploid individuals called **sporophytes**. A typical plant's life cycle is diagrammed in **Figure** 15.4 .

Early plants reproduced mainly with spores and spent most of their life cycle as haploid gametophytes. Spores

FIGURE 15.2
Red-eyed tree frogs like this one live in banana trees.

FIGURE 15.3
Poison ivy causes allergic skin rashes. It&#8217 s easy to recognize the plant by its arrangement of leaves in groups of three. That&#8217 s the origin of the old saying &#8220 leaves of three leave it be.&#8221

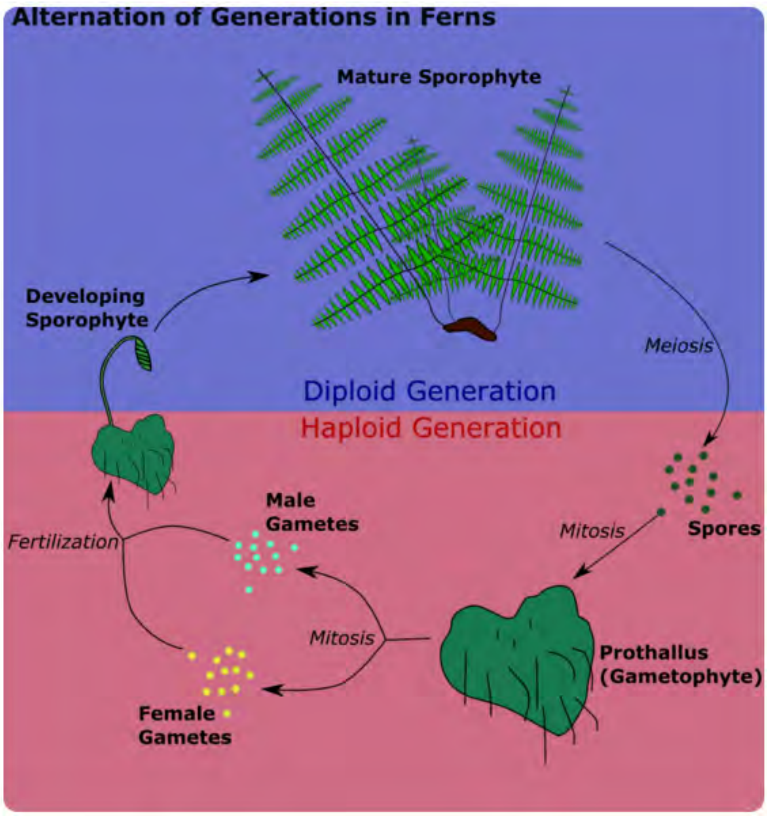

FIGURE 15.4

Life Cycle of Plants. This diagram shows the general life cycle of a plant.

require little energy and matter to produce, and they grow into new individuals without the need for fertilization. In contrast, most modern plants reproduce with gametes using pollen and seeds, and they spend most of their life cycle as diploid sporophytes. Many modern plants can also reproduce asexually using roots, stems, or leaves. This is called **vegetative reproduction**. One way this can occur is shown in **Figure** 15.5 .

FIGURE 15.5
Strawberry plants have horizontal stems called stolons that run over the ground surface. If they take root they form new plants.

Evolution of Plants

As shown in **Figure** 15.6 , plants are thought to have evolved from an aquatic green alga. Later, they evolved important adaptations for land, including vascular tissues, seeds, and flowers. Each of these major adaptations made plants better suited for dry land and much more successful.

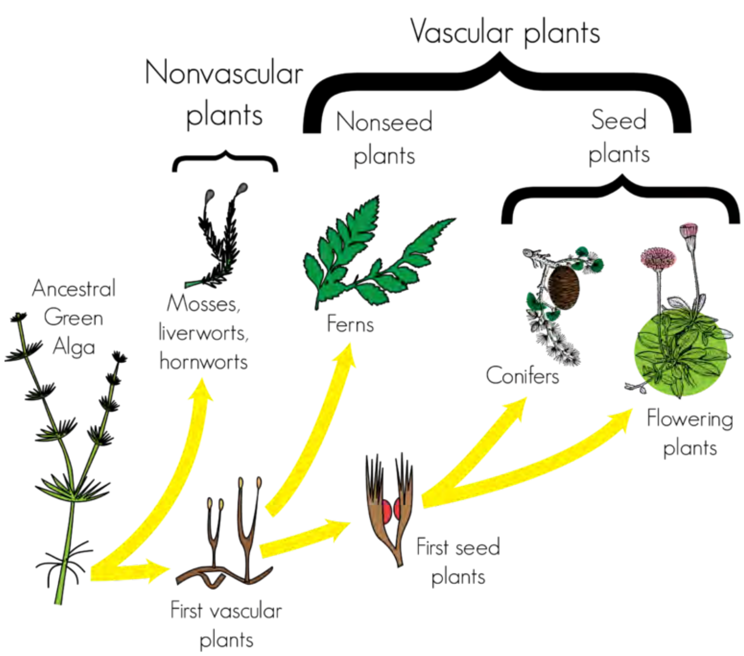

FIGURE 15.6
From a simple green alga ancestor that lived in the water plants eventually evolved several major adaptations for life on land.

The Earliest Plants

The earliest plants were probably similar to the stonewort, an aquatic algae pictured in **Figure** 15.7 . Unlike most modern plants, stoneworts have stalks rather than stiff stems, and they have hair-like structures called **rhizoids** instead of roots. On the other hand, stoneworts have distinct male and female reproductive structures, which is a plant characteristic. For fertilization to occur, sperm need at least a thin film of moisture to swim to eggs. In all these ways, the first plants may have resembled stoneworts.

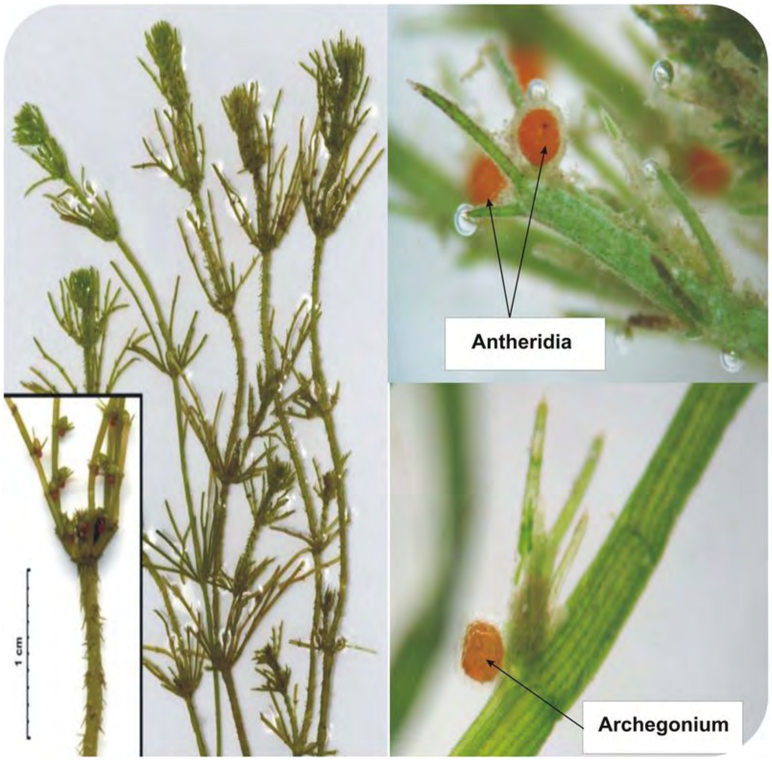

FIGURE 15.7
Modern stoneworts may be similar to the earliest plants. The male and female reproductive organs of stoneworts are shown in the pictures on the right.

Life on Land

By the time the earliest plants evolved, animals were already the dominant living things in the ocean. Plants were also constrained to the upper layer of water that received enough sunlight for photosynthesis. Therefore, plants never became dominant marine organisms. But when plants moved to land, everything was wide open. Why was the land devoid of other life? Without plants growing on land, there was nothing for other organisms to feed on. Land could not be colonized by other organisms until land plants became established.

Plants may have colonized the land as early as 700 million years ago. The oldest fossils of land plants date back about 470 million years. The first land plants probably resembled modern plants called liverworts, like the one shown in **Figure** 15.8 .

Colonization of the land was a huge step in plant evolution. Until then, virtually all life had evolved in the ocean. 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. In addition, temperatures on land were extreme and always changing. Sunlight was also strong and dangerous. It put land organisms at high risk of mutations.

Vascular Plants Evolve

Plants evolved a number of adaptations that helped them cope with these problems on dry land. One of the earliest and most important was the evolution of vascular tissues. **Vascular tissues** form a plant's "plumbing system."

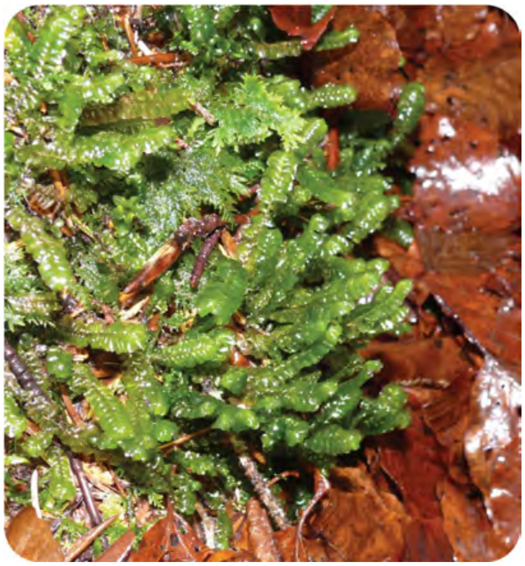

FIGURE 15.8
The first land plants may have been similar to liverworts like this one.

They carry water and minerals from soil to leaves for photosynthesis. They also carry food (sugar dissolved in water) from photosynthetic cells to other cells in the plant for growth or storage. The evolution of vascular tissues revolutionized the plant kingdom. The tissues allowed plants to grow large and endure periods of drought in harsh land environments. Early vascular plants probably resembled the fern shown in **Figure** 15.9 .

FIGURE 15.9
Early vascular plants may have looked like this modern fern.

In addition to vascular tissues, these early plants evolved other adaptations to life on land, including lignin, leaves, roots, and a change in their life cycle.

- **Lignin** is a tough carbohydrate molecule that is hydrophobic ("water fearing"). It adds support to vascular tissues in stems. It also waterproofs the tissues so they don't leak, which makes them more efficient at transporting fluids. Because most other organisms cannot break down lignin, it helps protect plants from herbivores

and parasites.
- Leaves are rich in chloroplasts that function as solar collectors and food factories. The first leaves were very small, but leaves became larger over time.
- Roots are vascular organs that can penetrate soil and even rock. They absorb water and minerals from soil and carry them to leaves. They also anchor a plant in the soil. Roots evolved from rhizoids, which nonvascular plants had used for absorption.
- Land plants evolved a dominant diploid sporophyte generation. This was adaptive because diploid individuals are less likely to suffer harmful effects of mutations. They have two copies of each gene, so if a mutation occurs in one gene, they have a backup copy. This is extremely important on land, where there's a lot of solar radiation.

With all these advantages, it's easy to see why vascular plants spread quickly and widely on land. Many nonvascular plants went extinct as vascular plants became more numerous. Vascular plants are now the dominant land plants on Earth.

Seed Plants Emerge

For reproduction, early vascular plants still needed moisture. Sperm had to swim from male to female reproductive organs for fertilization. Spores also needed some water to grow and often to disperse as well. Of course, 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. As a result, seed plants were wildly successful. They exploded into virtually all of Earth's habitats.

Why are seeds so adaptive on land? A **seed** contains an embryo and a food supply enclosed within a tough coating. An embryo is a zygote that has already started to develop and grow. Early growth and development of a plant embryo in a seed is called **germination**. The seed protects and nourishes the embryo and gives it a huge head start in the "race" of life. Many seeds can wait to germinate until conditions are favorable for growth. This increases the offspring's chance of surviving even more.

Other reproductive adaptations that evolved in seed plants include ovules, pollen, pollen tubes, and pollination by animals.

- An **ovule** is a female reproductive structure in seed plants that contains a tiny female gametophyte. The gametophyte produces an egg cell. After the egg is fertilized by sperm, the ovule develops into a seed.
- A grain of pollen is a tiny male gametophyte enclosed in a tough capsule (see **Figure** 15.10). It carries sperm to an ovule while preventing it 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.
- Wind-blown pollen might land anywhere and be wasted. Another adaptation solved this problem. Plants evolved traits that attract specific animal pollinators. Like the bee in **Figure** 15.10 , a pollinator picks up pollen on its body and carries it directly to another plant of the same species. This greatly increases the chance that fertilization will occur.
- Pollen also evolved the ability to grow a tube, called a pollen tube, through which sperm could be transferred 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 up plants from depending on moisture to reproduce.

Seed Plants Diverge

The first seed plants formed seeds in cones. **Cones** are made up of overlapping scales, which are modified leaves (see **Figure** 15.11). Male cones contain pollen, and female cones contain eggs. Seeds also develop in female cones. Modern seed plants that produce seeds in cones are called **gymnosperms**.

FIGURE 15.10

Individual grains of pollen may have prickly surfaces that help them stick to pollinators such as bees. What other animals pollinate plants

FIGURE 15.11

Gymnosperms produce seeds in cones. Each scale has a seed attached.

Later, seed plants called **angiosperms** evolved. They produce **flowers**, which consist of both male and female reproductive structures. The female reproductive structure in a flower includes an organ called an **ovary**. Eggs form in ovules inside ovaries, which also enclose and protect developing seeds after fertilization occurs. In many species of flowering plants, ovaries develop into **fruits**, which attract animals that disperse the seeds.

Classification of Plants

The scientific classification of modern land plants is under constant revision. Informally, land plants can be classified into the groups listed in **Table** 15.1 . The most basic division 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 seeds in cones and those that produce seeds in the ovaries of flowers. You can read more about each of these groups of plants in the next lesson.

Table 15.2 Major divisions and types of modern land plants are organized in this table. Why do the first five types of plants require a moist habitat?

TABLE 15.1: Classification of Living Land Plants

Major Division	Types of Plants	No. of Living Species	Description
Nonvascular Plants			
	Liverworts	7,000	
	Hornworts	150	
	Mosses	10,000	They lack leaves and roots. They have no stems, so they grow low to the ground. They reproduce with spores. They need a moist habitat.
Vascular Plants			

TABLE 15.1: (continued)

Major Division	Types of Plants	No. of Living Species	Description
	Clubmosses	1,200	They have roots and tiny leaves. They have no stems, so they grow low to the ground. They reproduce with spores. They need a moist habitat.
	Ferns	11,000	They have large leaves in fronds. They have stiff stems, so they are tall growing; some are trees. They reproduce with spores. They need a moist habitat.
	Ginkgoes	1	

TABLE 15.1: (continued)

Major Division	Types of Plants	No. of Living Species	Description
	Cycads	160	
	Conifers	700	
	Gnetae	70	Most are trees with wood trunks. They have adaptations to dryness such as needle-like leaves. They reproduce with seeds and pollen. They produce seeds in cones.
	Flowering Plants	258,650	They have tremendous diversity in size, shape, and other characteristics. They reproduce with seeds and pollen. They produce seeds in the ovaries of flowers. Ovaries may develop into fruits, which enhance seed dispersal.

KQED: Albino Redwoods, Ghosts of the Forest

Albino redwood trees? Really? Yes, these pale ghosts that hide amid their gigantic siblings, only a few dozen albino redwood trees are known to exist. They are genetic mutants that lack the chlorophyll needed for photosynthesis. But how and why they survive is a scientific mystery. See http://www.kqed.org/quest/television/science-on-the-spot-albino-redwoods-ghosts-of-the-forest and http://www.kqed.org/quest/blog/2010/11/22/ghostbusters/ to find out about these wonders of the plant kingdom, and how geneticists are trying to understand the redwood genome.

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Lesson Summary

- Plants are multicellular eukaryotes. They have organelles called chloroplasts and cell walls made of cellulose. Plants also have specialized reproductive organs. Almost all plants make food by photosynthesis. Life as we know it would not be possible without plants.
- All plants have a characteristic life cycle that includes alternation of generations. Asexual reproduction with spores produces a haploid gametophyte generation. Sexual reproduction with gametes and fertilization produces a diploid sporophyte generation.
- The earliest plants are thought to have evolved in the ocean from a green alga ancestor. Plants were among the earliest organisms to leave the water and colonize land. The evolution of vascular tissues allowed plants to grow larger and thrive on land. The evolution of seeds and pollen allowed them to reproduce on land without moisture. Flowering plants evolved flowers with ovaries that formed fruits. They have been the most successful plants of all.
- The most basic division of living plants is between nonvascular and vascular plants. Vascular plants are further divided into seedless and seed plants. Seed plants called gymnosperms produce seeds in cones. Seed plants called angiosperms produce seeds in the ovaries of flowers.

Lesson Review Questions

Recall

1. What traits do all plants share?
2. What do plants need?
3. List reasons that plants are important to life on Earth.
4. When is a plant considered a weed?
5. What are vascular tissues? What is their function?

Apply Concepts

6. Draw a diagram of a typical plant life cycle that illustrates the concept of alternation of generations.

Think Critically

7. Explain why life on land was difficult for early plants. Why did plants need to become established on land before other organisms could colonize the land?

8. Compare the different types of plants in the **Classification of Living Land Plants** (**Table** 15.1). Which type of plants would you say is most successful? Support your answer with data from the table.

9. Which major plant adaptation—vascular tissues or seeds—do you think was more important in the evolution of plants? Choose one of the two adaptations, and write a logical argument to support your choice.

10. Compare and contrast gymnosperms and angiosperms, and give an example of each.

Points to Consider

Vascular plants are now the most common plants on Earth. However, nonvascular plants should not be ignored. They were the first plants to evolve, and some still survive today.

- In what ways do you think modern nonvascular plants are different from other types of modern plants? In what ways do you think they are similar?
- How might modern nonvascular plants differ from other eukaryotes, such as fungi?

15.2 Four Types of Modern Plants

Lesson Objectives

- Describe modern nonvascular plants.
- Give an overview of living vascular plants.
- Outline the classification and evolution of seed plants.
- Summarize the adaptations and evolution of flowering plants.

Vocabulary

bryophyte type of plant that lacks vascular tissues, such as a liverwort, hornwort, or moss

endosperm stored food inside a plant seed

nectar sweet, sugary liquid produced by the flowers of many angiosperms to attract animal pollinators

petal outer parts of flowers that are usually brightly colored to attract animal pollinators

phloem type of vascular tissue in a plant that transports food from photosynthetic cells to other parts of the plant

pistil female reproductive structure of a flower that consists of a stigma, style, and ovary

seed coat tough covering of a seed that protects the embryo and keeps it from drying out until conditions are favorable for germination

sepal part of a flower that helps protect it while it is still in bud

spermatophyte type of plant that reproduces by producing seeds

stamen male reproductive structure of a flower that consists of a stalk-like filament and a pollen-producing anther

tracheophyte type of plant that has vascular tissues, such as a seed plant or flowering plant

xylem type of vascular tissue in a plant that transports water and dissolved nutrients from roots to stems and leaves

Introduction

The types of living plants today reflect the evolutionary past of the plant kingdom. From tiny nonvascular mosses to large flowering and fruiting trees, there are modern plants that represent each of the major evolutionary changes that occurred in this important eukaryotic kingdom.

Nonvascular Plants

Nonvascular plants are called **bryophytes**. Despite the dominance of vascular plants today, more than 17,000 species of bryophytes still survive. They include liverworts, hornworts, and mosses.

Characteristics of Nonvascular Plants

Most bryophytes are small. They not only lack vascular tissues; they also lack true leaves, seeds, and flowers. Instead of roots, they have hair-like rhizoids to anchor them to the ground and to absorb water and minerals (see **Figure** 15.12). Bryophytes occupy niches in moist habitats. Without the adaptations of vascular plants, they are not very efficient at absorbing water.

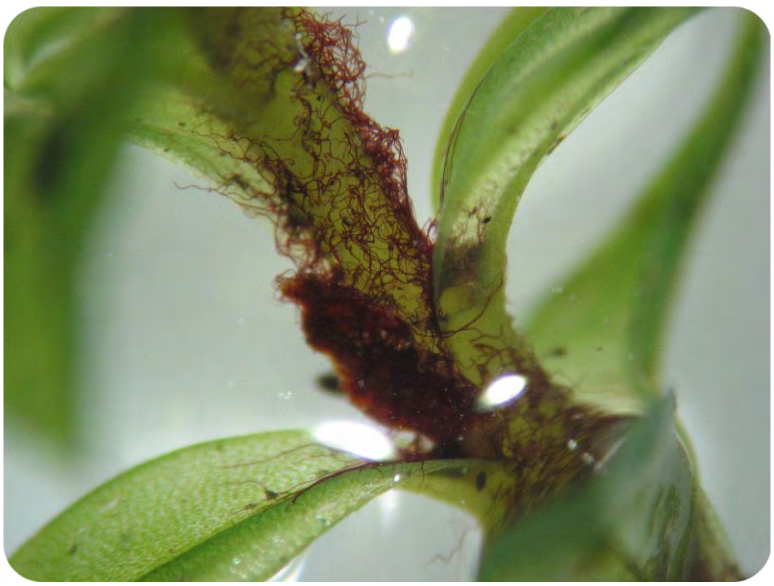


FIGURE 15.12

The rhizoids of a bryophyte *shown in purple* may be so fine that they are just one cell thick.

Bryophytes also depend on moisture to reproduce. Sperm produced by a male gametophyte must swim through a layer of rainwater or dew to reach an egg produced by a female gametophyte. The tiny, diploid sporophyte generation then undergoes meiosis to produce haploid spores. The spores may also need moisture to disperse.

Evolution of Nonvascular Plants

The first nonvascular plants to evolve were the liverworts. The hornworts evolved somewhat later, and mosses apparently evolved last. Of all the bryophytes, mosses are most similar to vascular plants. Presumably, they share the most recent common ancestor with vascular plants.

Diversity of Nonvascular Plants

The three types of modern nonvascular plants are pictured in **Figure** 15.13 .

- Liverworts are tiny nonvascular plants that have leaf-like, lobed, or ribbon-like photosynthetic tissues rather than leaves. Their rhizoids are very fine, they lack stems, and they are generally less than 10 centimeters (4 inches) tall. They often grow in colonies that carpet the ground.

- Hornworts are minute nonvascular plants, similar in size to liverworts. They also have very fine rhizoids and lack stems. Their sporophytes are long and pointed, like tiny horns. They rise several centimeters above the gametophytes of the plant.
- Mosses are larger nonvascular plants that have coarser, multicellular rhizoids that are more like roots. They also have tiny, photosynthetic structures similar to leaves that encircle a central stem-like structure. Mosses grow in dense clumps, which help them retain moisture.

FIGURE 15.13
Liverworts hornworts and mosses are modern bryophytes. Liverworts are named for the liver-shaped leaves of some species. Hornworts are named for their horn-like sporophytes.

Vascular Plants

Vascular plants are known as **tracheophytes**, which literally means "tube plants." The earliest vascular plants quickly came to dominate terrestrial ecosystems. Why were they so successful? It was mainly because of their tube-like vascular tissues.

Vascular Tissues

The vascular tissues for which these plants are named are specialized to transport fluid. They consist of long, narrow cells arranged end-to-end, forming tubes. There are two different types of vascular tissues, called xylem and phloem. Both are shown in **Figure** 15.14 .

- **Xylem** is vascular tissue that transports water and dissolved minerals from roots to stems and leaves. This type of tissue consists of dead cells that lack end walls between adjacent cells. The side walls are thick and reinforced with lignin, which makes them stiff and water proof.
- **Phloem** is vascular tissue that transports food (sugar dissolved in water) from photosynthetic cells to other parts of the plant for growth or storage. This type of tissue consists of living cells that are separated by end walls with tiny perforations, or holes.

Evolution of Vascular Plants

The first vascular plants evolved about 420 million years ago. They probably evolved from moss-like bryophyte ancestors, but they had a life cycle dominated by the diploid sporophyte generation. As they continued to evolve, early vascular plants became more plant-like in other ways as well.

- Vascular plants evolved true roots made of vascular tissues. Compared with rhizoids, roots can absorb more water and minerals from the soil. They also anchor plants securely in the ground, so plants can grow larger without toppling over.

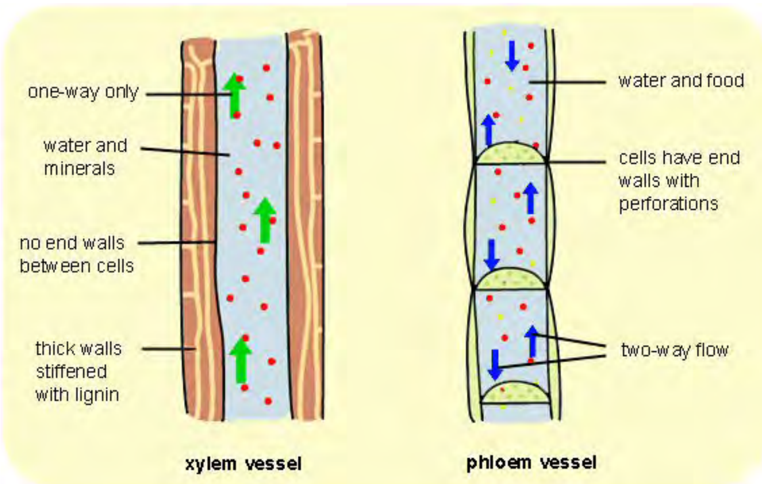


FIGURE 15.14
Xylem and phloem are the two types of vascular tissues in vascular plants.

- Vascular plants evolved stems made of vascular tissues and lignin. Because of lignin, stems are stiff, so plants can grow high above the ground where they can get more light and air. Because of their vascular tissues, stems keep even tall plants supplied with water so they don't dry out in the air.
- Vascular plants evolved leaves to collect sunlight. At first, leaves were tiny and needle-like, which helped reduce water loss. Later, leaves were much larger and broader, so plants could collect more light.

With their vascular tissues and other adaptations, early vascular plants had the edge over nonvascular plants. The could grow tall and take advantage of sunlight high up in the air. Bryophytes were the photosynthetic pioneers onto land, but early vascular plants were the photosynthetic pioneers into air.

Diversity of Seedless Vascular Plants

Surviving descendants of early vascular plants include clubmosses and ferns. There are 1,200 species of clubmoss and more than 20,000 species of fern. Both types of vascular plants are seedless and reproduce with spores. Two examples are pictured in **Figures** 15.15 and 15.16 .

- Clubmosses look like mosses and grow low to the ground. Unlike mosses, they have roots, stems, and leaves, although the leaves are very small.
- Ferns look more like "typical" plants. They have large leaves and may grow very tall. Some even develop into trees.

Seed Plants

Seed plants are called **spermatophytes**. The evolution of seeds by vascular plants was a very big deal. In fact, it was arguably as important as the evolution of vascular tissues. Seeds solved the problem of releasing offspring into a dry world. Once seeds evolved, vascular seed plants and their descendants diversified to fill terrestrial niches everywhere. Today, vascular seed plants dominate Earth.

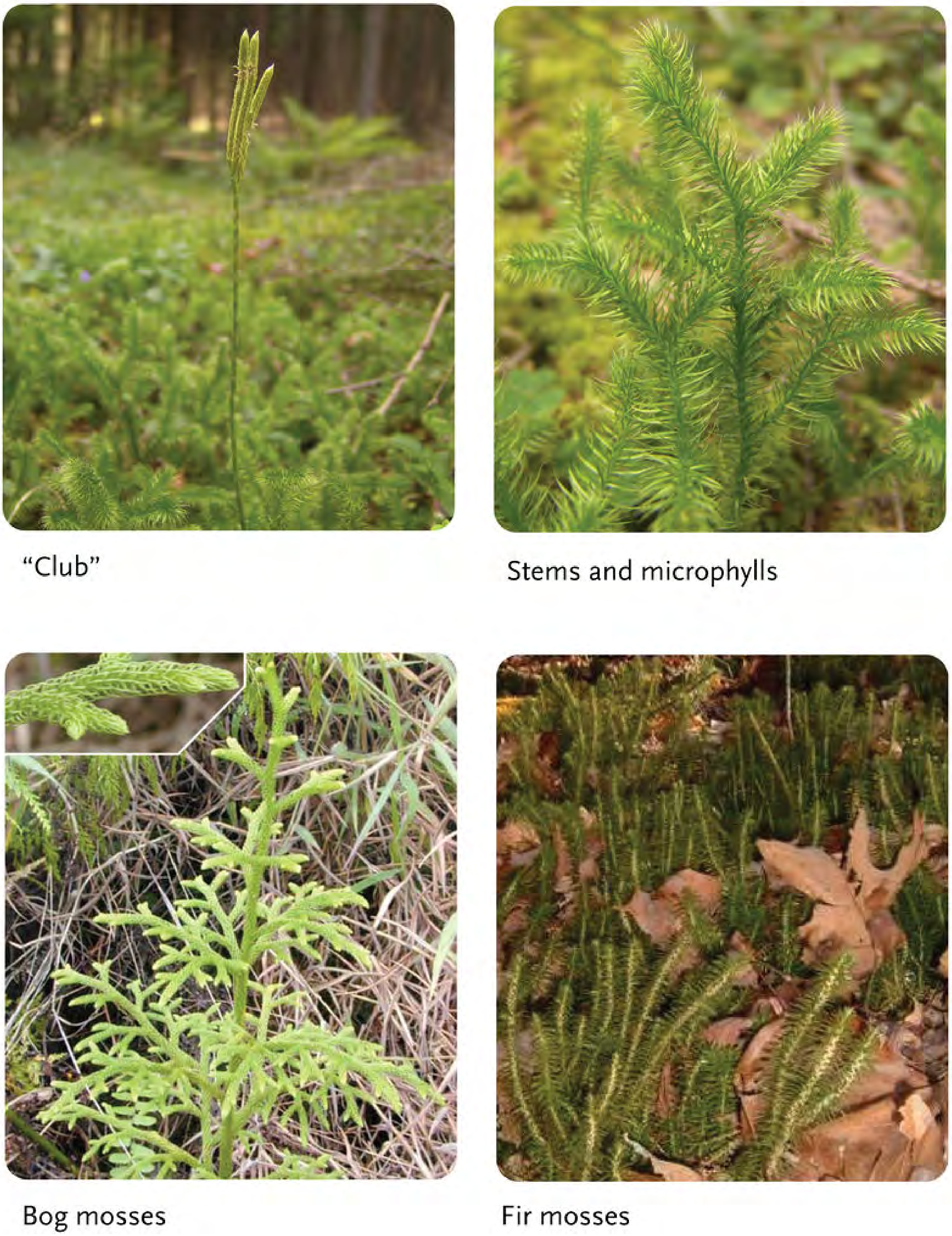


FIGURE 15.15
Clubmosses like these are often confused with mosses.

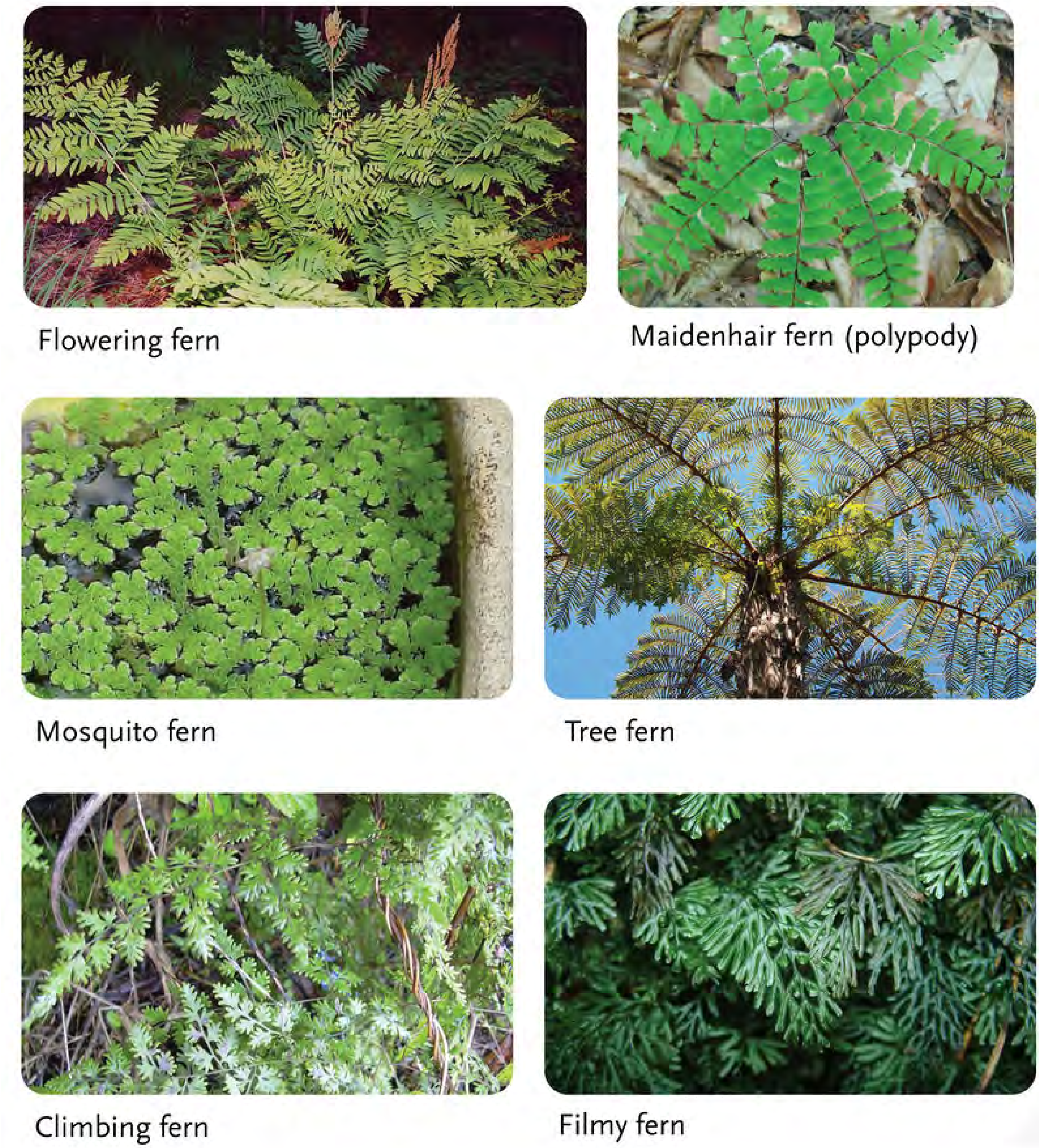


FIGURE 15.16
There&#8217 s no confusing ferns with mosses. Why do these ferns look more plant-like

Parts of a Seed

As shown in **Figure** 15.17 , a seed consists of at least three basic parts: the embryo, seed coat, and stored food.

- The embryo develops from a fertilized egg. While still inside the seed, the embryo forms its first leaf (cotyledon) and starts to develop a stem (hypocotyl) and root (radicle).
- The tough **seed coat** protects the embryo and keeps it from drying out until conditions are favorable for germination.
- The stored food in a seed is called **endosperm**. It nourishes the embryo until it can start making food on its own.

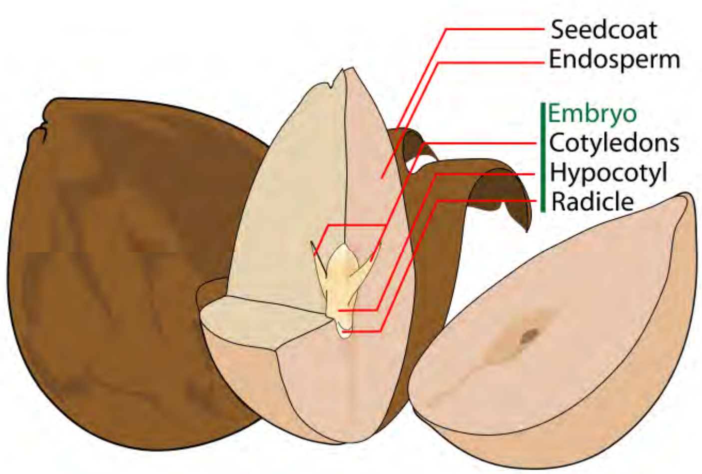


FIGURE 15.17
A typical plant seed like this avocado seed contains an embryo seed coat and endosperm. How does each part contribute to the successful development of the new plant

Many seeds have additional structures that help them disperse. Some examples are shown in **Figure** 15.18 . Structures may help them travel in the wind or stick to animals. Dispersal of seeds away from parent plants helps reduce competition with the parents and increases the chance of offspring surviving.

FIGURE 15.18
Dandelion seeds have tiny &#8220 parachutes.&#8221 Maple seeds have &#8220 wings&#8221 that act like little gliders. Burdock seeds are covered with tiny hooks that cling to animal fur.

Classification of Seed Plants

The two major divisions of seed plants are the gymnosperms (seeds in cones) and angiosperms (seeds in ovaries of flowers). **Figure** 15.19 shows how the seeds of gymnosperms and angiosperms differ. Do you see the main difference between the two seeds? The angiosperm seed is surrounded by an ovary.

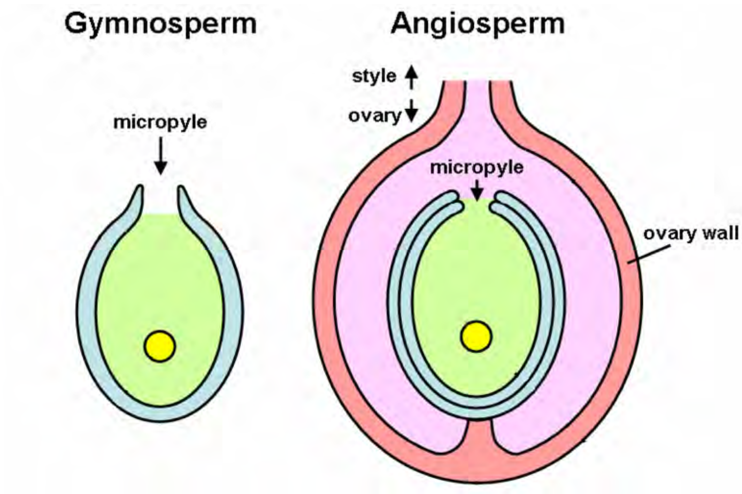


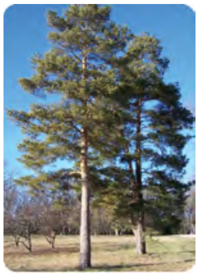
FIGURE 15.19
In gymnosperms a seed develops on the scale of a cone. Only an angiosperm seed develops inside an ovary.

There are only about 1,000 living species of gymnosperms, whereas there are hundreds of thousands of living species of angiosperms. Because angiosperms are so numerous and diverse, they are described separately below. Living gymnosperms are typically classified in the divisions described in **Table** 15.2 . Most modern gymnosperms are trees with woody trunks. The majority are conifers such as pine trees.

TABLE 15.2: Classification of Living Gymnosperms

	Division	Description
	Ginkgoes	There is only one living species (Ginkgo biloba); some living trees are more than 2000 years old; they originated in Asia but now are cultivated all over the world; they have been used for medicines for thousands of years.

TABLE 15.2: (continued)

	Division	Description
	Conifers	There are more than 700 living species; most are trees such as pines with needle-like leaves; they are often the dominant plants in their habitats; they are valuable to humans for paper and timber.
	Cycads	There are about 300 living species; they are typically trees with stout trunks and fern-like leaves; they live only in tropical and subtropical climates; they have large, brightly-colored seed cones to attract animal pollinators.
	Gnetae	There are fewer than 100 living species; most are woody vines with evergreen leaves; they live mainly in tropical climates; they are the least well known gymnosperms but the most similar to angiosperms.

Evolution of Seed Plants

The earliest seed plants probably evolved close to 300 million years ago. They were similar to modern ginkgoes and reproduced with pollen and seeds in cones. Early seed plants quickly came to dominate forests during the Mesozoic Era, or Age of the Dinosaurs, about 250 to 65 million years ago.

As seed plants continued to evolve, Earth's overall climate became drier, so early seed plants evolved adaptations to help them live with low levels of water. Some also evolved adaptations to cold. They had woody trunks and needle-like, evergreen leaves covered with a thick coating of waxy cuticle to reduce water loss. Some of the trees were huge, like today's giant sequoia, a modern conifer (see **Figure** 15.20).

Eventually, some gymnosperms started to evolve angiosperm-like traits. For example, cycad ancestors were the first plants to use insects as pollinators. They also used birds and monkeys to disperse their brightly colored seeds. Of modern gymnosperms, Gnetae probably share the most recent common ancestor with angiosperms. Among other similarities, Gnetae produce **nectar**, a sweet, sugary liquid that attracts insect pollinators. Most modern flowering

FIGURE 15.20
The people standing at the foot of this giant sequoia show just how enormous the tree is. Some early seed plants also grew very large.

plants also produce nectar.

Flowering Plants

Angiosperms, or flowering seed plants, form seeds in ovaries. As the seeds develop, the ovaries may develop into fruits. Flowers attract pollinators, and fruits encourage animals to disperse the seeds.

Parts of a Flower

A flower consists of male and female reproductive structures. The main parts of a flower are shown in **Figure** 15.21 . They include the stamen, pistil, petals, and sepals.

- The **stamen** is the male reproductive structure of a flower. It consists of a stalk-like filament that ends in an anther. The anther contains pollen sacs, in which meiosis occurs and pollen grains form. The filament raises the anther up high so its pollen will be more likely to blow in the wind or be picked up by an animal pollinator.
- The **pistil** is the female reproductive structure of a flower. It consists of a stigma, style, and ovary. The stigma is raised and sticky to help it catch pollen. The style supports the stigma and connects it to the ovary, which contains the egg. **Petals** attract pollinators to the flower. Petals are often brightly colored so pollinators will notice them.
- **Sepals** protect the developing flower while it is still a bud. Sepals are usually green, which camouflages the bud from possible consumers.

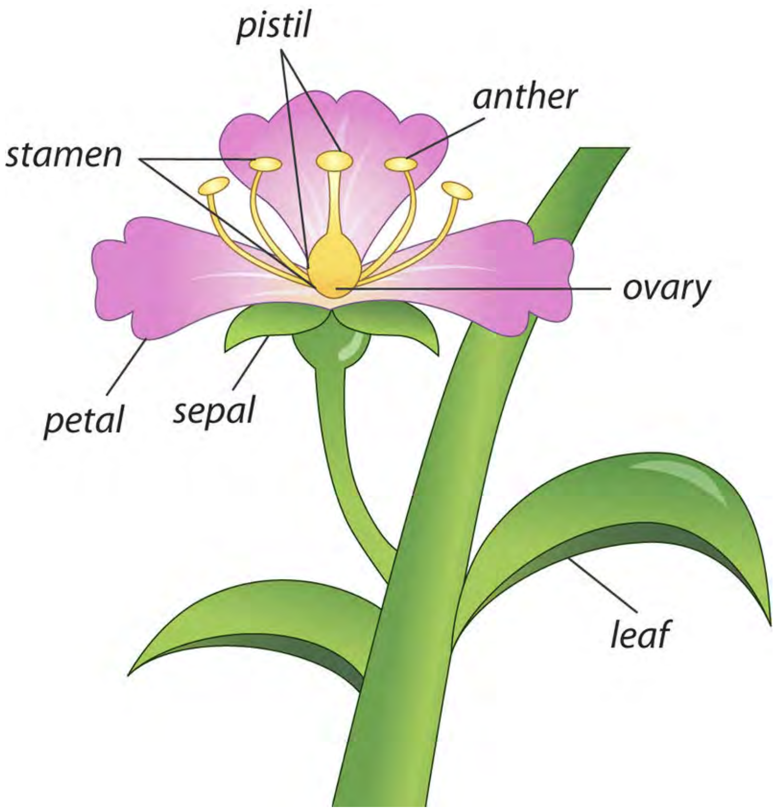


FIGURE 15.21
A flower includes both male and female reproductive structures.

Flowers and Pollinators

Many flowers have bright colors, strong scents, and sweet nectar to attract animal pollinators. They may attract insects, birds, mammals, and even reptiles. While visiting a flower, a pollinator picks up pollen from the anthers. When the pollinator visits the next flower, some of the pollen brushes off on the stigma. This allows cross-pollination, which increases genetic diversity.

Other Characteristics of Flowering Plants

Although flowers and their components are the major innovations of angiosperms, they are not the only ones. Angiosperms also have more efficient vascular tissues. In addition, in many flowering plants, the ovaries ripen into fruits. Fruits are often brightly colored, so animals are likely to see and eat them and disperse their seeds (see **Figure** 15.22).

Evolution of Flowering Plants

Flowering plants are thought to have evolved at least 200 million years ago from gymnosperms like Gnetae. The earliest known fossils of flowering plants are about 125 million years old. The fossil flowers have male and female reproductive organs but no petals or sepals.

Scientists think that the earliest flowers attracted insects and other animals, which spread pollen from flower to flower. This greatly increased the efficiency of fertilization over wind-spread pollen, which might or might not actually land on another flower. To take better advantage of this "animal labor," plants evolved traits such as brightly colored petals to attract pollinators. In exchange for pollination, flowers gave the pollinators nectar.

FIGURE 15.22

Brightly colored fruits attract animals that may disperse their seeds. It&#8217 s hard to miss the bright red apples on these trees.

Giving free nectar to any animal that happened to come along was not an efficient use of resources. Much of the pollen might be carried to flowers of different species and therefore wasted. As a result, many plants evolved ways to "hide" their nectar from all but very specific pollinators, which would be more likely to visit only flowers of the same species. For their part, animal pollinators co-evolved traits that allowed them to get to the hidden nectar. Two examples of this type of co-evolution are shown in **Figure** 15.23 .

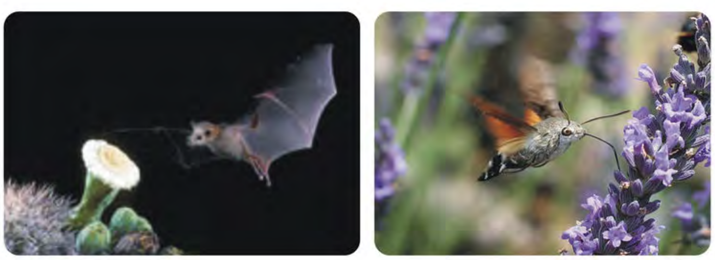


FIGURE 15.23

The hummingbird has a long narrow bill to reach nectar at the bottom of the tube-shaped flowers. The bat is active at night so bright white night-blooming flowers attract it. In each case the flowering plant and its pollinator co-evolved to become better suited for their roles in the symbiotic relationship.

Some of the most recent angiosperms to evolve are grasses. Humans started domesticating grasses such as wheat about 10,000 years ago. Why grasses? They have many large, edible seeds that contain a lot of nutritious stored food. They are also relatively easy to harvest. Since then, humans have helped shaped the evolution of grasses, as illustrated by the example in **Figure** 15.24 . Grasses supply most of the food consumed by people worldwide. What other grass seeds do you eat?

Classification of Flowering Plants

There are more than a quarter million species of flowering plants, and they show tremendous diversity. Nonetheless, almost all flowering plants fall into one of three major groups: monocots, eudicots, or magnolids. The three groups differ in several ways. For example, monocot embryos form just one cotyledon, whereas eudicot and magnolid

FIGURE 15.24
The plant on the left called teosinte is the ancestor of modern domesticated corn shown on the right. An intermediate stage is pictured in the middle. How were humans able to change the plant so dramatically

embryos form two cotyledons. The arrangement of their vascular tissues is also different. Examples of the three groups of flowering plants are given in **Table** 15.3 .

TABLE 15.3: Groups of Living Angiosperms

Group	Sample Families
Monocots	Grasses 
Orchids 	
Eudicots	Daisies 

TABLE 15.3: (continued)

Group	Sample Families
Peas 	
Magnolids	Magnolias 
Avocados 	

Lesson Summary

- Nonvascular plants are called bryophytes. They include liverworts, hornworts, and mosses. They lack roots, stems, and leaves. They are low-growing, reproduce with spores, and need a moist habitat.
- Vascular plants are known as tracheophytes. Vascular tissues include xylem and phloem. They allow plants to grow tall in the air without drying out. Vascular plants also have roots, stems, and leaves.
- Most vascular plants are seed plants, or spermatophytes. They reproduce with seeds and pollen. Some modern seed plants are gymnosperms that produce seeds in cones.
- Most modern seed plants are angiosperms that produce seeds in the ovaries of flowers. Ovaries may develop into fruits. Flowers attract pollinators, and fruits are eaten by animals, which help disperse the seeds.

Lesson Review Questions

Recall

1. Describe nonvascular plants.
2. Identify the parts of a seed and the role of each part.
3. Name and describe the division of gymnosperms.
4. Describe the male and female reproductive structures of flowers and their functions.
5. State how fruits help flowering plants reproduce.

Apply Concepts

6. Charles Darwin predicted the existence of a moth with a very long "tongue" after he discovered a species of night-blooming flowers with extremely long, tube-shaped blooms. About 50 years after Darwin died, such a moth was discovered. Apply lesson concepts to explain the basis for Darwin's prediction.

Think Critically

7. Compare and contrast xylem and phloem.

8. How did vascular tissues and lignin allow vascular plants to be "photosynthetic pioneers into air"?

9. Explain how flowering plants and their animal pollinators co-evolved.

Points to Consider

In this chapter, you read about the evolution and classification of plants. In the next chapter, you can read more about the special cells, tissues, and organs of plants that make them such important and successful organisms.

- How do you think plant cells differ from the cells of other eukaryotes, such as animals? What unique structures do plant cells contain?
- Besides vascular tissues, what other types of tissues do you think plants might have?

For **Table** 15.3 , from left to right, top to bottom,

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Chapter 16 Plant Biology

Chapter Outline

This lush green landscape is thickly carpeted with trees and a myriad of other plants. Much of Earth's land is dominated by plants. Yet compared to our active existence as animals, plants are—literally—rooted to the ground. Their sedentary lives may seem less interesting than the active lives of animals, but plants are very busy doing extremely important work. All plants are chemical factories. Each year, they transform huge amounts of carbon (from carbon dioxide) into food for themselves and virtually all other land organisms.

Plants are complex organisms that carry out complex tasks. But unlike animals, they don't have nerves, bones, or muscles to do their work. How do plants do it? Read on to find out.

16.1 Plant Tissues and Growth

Lesson Objectives

- Describe plant cell structures, and list types of plant cells.
- Compare and contrast different types of plant tissues.
- Explain how plants grow.

Vocabulary

cuticle waxy, waterproof substance produced by epidermal cells of leaves, shoots, and other above-ground parts of plants to preven damage and loss of water by evaporation

dermal tissue type of plant tissue that covers the outside of a plant in a single layer of cells called the epidermis

ground tissue type of plant tissue making up most of the interior of the roots and stems of plants that carries out basic metabolic functions and provides support and storage

meristem type of plant tissue consisting of undifferentiated cells that can continue to divide and differentiate and from which plants grow in length or width

Introduction

Like animals, plants have organs that are specialized to carry out complex functions. An organ is a structure composed of more than one type of tissue. A tissue, in turn, is a group of cells of the same kind that do the same job. In this lesson, you will read about the tissues that do the important work of plants. The cells that make up plant tissues are described first.

Plant Cells

Plant cells resemble other eukaryotic cells in many ways. For example, they are enclosed by a plasma membrane and have a nucleus and other membrane-bound organelles. A typical plant cell is represented by the diagram in **Figure** 16.1 .

Plant Cell Structures

Structures found in plant cells but not animal cells include a large central vacuole, cell wall, and plastids such as chloroplasts.

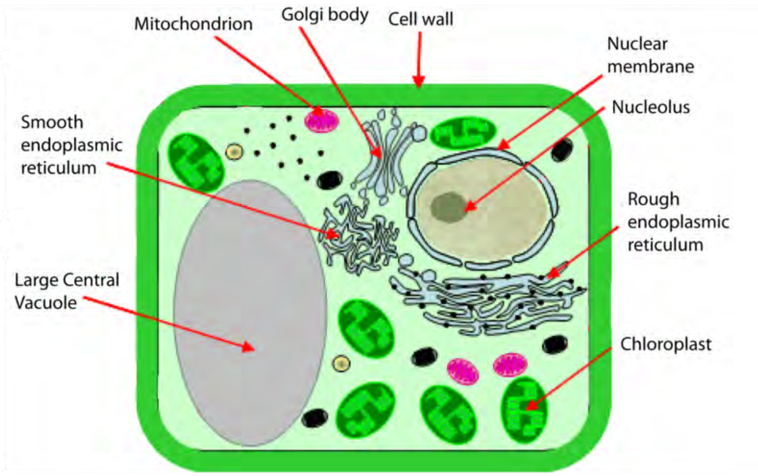


FIGURE 16.1
Plant cells have all the same structures as animal cells plus some additional structures. Can you identify the unique plant structures in the diagram

- The large central vacuole is surrounded by its own membrane and contains water and dissolved substances. Its primary role is to maintain pressure against the inside of the cell wall, giving the cell shape and helping to support the plant.
- The cell wall is located outside the cell membrane. It consists mainly of cellulose and may also contain lignin, which makes it more rigid. The cell wall shapes, supports, and protects the cell. It prevents the cell from absorbing too much water and bursting. It also keeps large, damaging molecules out of the cell.
- Plastids are membrane-bound organelles with their own DNA. Examples are chloroplasts and chromoplasts. Chloroplasts contain the green pigment chlorophyll and carry out photosynthesis. Chromoplasts make and store other pigments. They give flower petals their bright colors.

Types of Plant Cells

There are three basic types of cells in most plants. The three types are described in **Table** 16.1 . The different types of plant cells have different structures and functions.

TABLE 16.1: Types of Plant Cells

Type of Cell	Structure	Functions	Example
Parenchymal	cube-shaped loosely packed thin-walled relatively unspecialized contain chloroplasts	photosynthesis cellular respiration storage	food storage tissues of potatoes 

TABLE 16.1: (continued)

Type of Cell	Structure	Functions	Example
Collenchymal	elongated irregularly thickened walls	support wind resistance	*strings* running through a stalk of celery 
Sclerenchymal	very thick cell walls containing lignin	support strength	tough fibers in jute (used to make rope) 

Plant Tissues

All three types of plant cells are found in most plant tissues. Three major types of plant tissues are dermal, ground, and vascular tissues.

Dermal Tissue

Dermal tissue covers the outside of a plant in a single layer of cells called the epidermis. You can think of the epidermis as the plant's skin. It mediates most of the interactions between a plant and its environment. Epidermal cells secrete a waxy substance called **cuticle**, which coats, waterproofs, and protects the above-ground parts of plants. Cuticle helps prevent water loss, abrasions, infections, and damage from toxins.

Ground Tissue

Ground tissue makes up much of the interior of a plant and carries out basic metabolic functions. Ground tissue in stems provides support and may store food or water. Ground tissues in roots may also store food.

Vascular Tissue

Vascular tissue runs through the ground tissue inside a plant. It consists of xylem and phloem, which transport fluids. Xylem and phloem are packaged together in bundles, as shown in **Figure** 16.2 .

Growth of Plants

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, while cell division (mitosis) increases

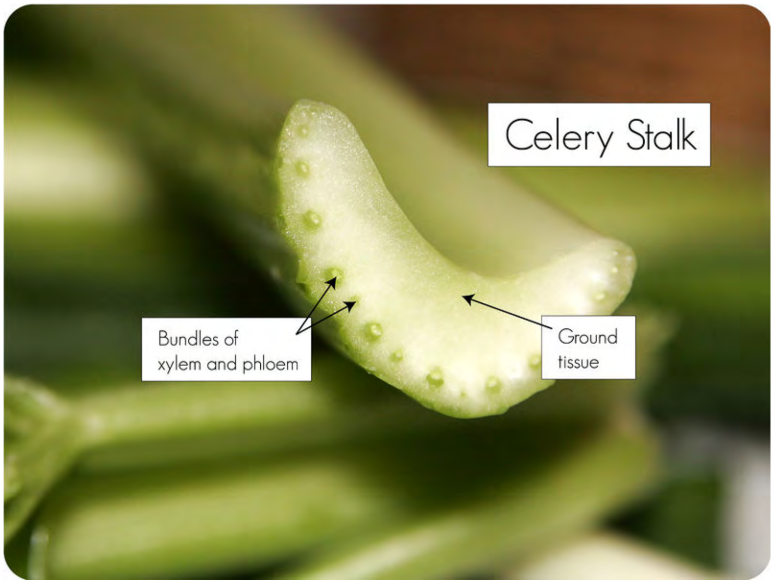


FIGURE 16.2
Bundles of xylem and phloem run through the ground tissue inside this stalk of celery. What function do these tissues serve

the number of cells. As plant cells grow, they also become specialized into different cell types through cellular differentiation. Once cells differentiate, they can no longer divide. How do plants grow or replace damaged cells after that?

The key to continued growth and repair of plant cells is **meristem**. Meristem is a type of plant tissue consisting of undifferentiated cells that can continue to divide and differentiate. Meristem at the tips of roots and stems allows them to grow in length. This is called primary growth. Meristem within and around vascular tissues allows growth in width. This is called secondary growth.

Lesson Summary

- Plants have eukaryotic cells with large central vacuoles, cell walls containing cellulose, and plastids such as chloroplasts and chromoplasts. Different types of plant cells include parenchymal, collenchymal, and sclerenchymal cells. The three types differ in structure and function.
- The three types of plant cells are found in each of the major types of plant tissues: dermal, ground, and vascular tissues. Dermal tissue covers the outside of a plant in a single layer of cells called the epidermis. It mediates most of the interactions between a plant and its environment. Ground tissue makes up most of the interior of a plant. It carries out basic metabolic functions and stores food and water. Vascular tissue runs through the ground tissue inside a plant. It consists of bundles of xylem and phloem, which transport fluids throughout the plant.
- Most plants continue to grow as long as they live. They grow through a combination of cell growth and cell division (mitosis). The key to plant growth is meristem, a type of plant tissue consisting of undifferentiated cells that can continue to divide and differentiate. Meristem allows plant stems and roots to grow longer (primary growth) and wider (secondary growth).

Lesson Review Questions

Recall

1. Identify three structures found in plant cells but not animal cells. What is the function of each structure?

2. Describe parenchymal plant cells and state their functions.

3. What is cuticle? What is its role?

4. Define meristem.

Apply Concepts

5. An important concept in biology is that form follows function. In other words, the structure of an organism, or part of an organism, depends on its function. Apply this concept to plants, and explain why plants have different types of cells and tissues.

Think Critically

6. Compare and contrast dermal, ground, and vascular tissues of plants.

7. Explain why plants need special tissues for growth.

Points to Consider

Plants are complex organisms with tissues organized into organs.

- What organs do you think plants might have?
- Think about human organs, such as the heart, stomach, lungs, and kidneys. What are their functions? Do you think plants might have organs with similar functions as these human organs?

16.2 Plant Organs: Roots, Stems, and Leaves

Lesson Objectives

- Outline the structure, function, and growth of roots.
- Give an overview of stem diversity and how stems function and grow.
- Describe leaf variation, and explain how leaves make food and change seasonally.

Vocabulary

bark tissue that provides a rough, woody external covering on the stems of trees

deciduous plant type of plant that seasonally loses its leaves to reduce water loss during the cold or dry season each year and grows new leaves later in the year

evergreen plant type of plant that keeps its leaves and stays green year-round

fibrous root threadlike root that makes up part of the fibrous root system of some plants

mesophyll specialized tissue inside plant leaves where photosynthesis takes place

root hair tiny hairlike structure that extends from an epidermal cell of a plant root and increases the surface area for absorption

root system all the roots of a plant, including primary roots and secondary roots

stomata (singular, stoma) tiny pore in the epidermis of a plant leaf that controls transpiration and gas exchange with the air

taproot single, thick primary root that characterizes the root system of some plants

Introduction

Plants have specialized organs that help them survive and reproduce in a great diversity of habitats. Major organs of most plants include roots, stems, and leaves.

Roots

Roots are important organs in all vascular plants. Most vascular plants have two types of roots: primary roots that grow downward and secondary roots that branch out to the side. Together, all the roots of a plant make up a **root system**.

Root Systems

There are two basic types of root systems in plants: taproot systems and fibrous root systems. Both are illustrated in **Figure** 16.3 .

- Taproot systems feature a single, thick primary root, called the **taproot**, with smaller secondary roots growing out from the sides. The taproot may penetrate as many as 60 meters (almost 200 feet) below the ground surface. It can plumb very deep water sources and store a lot of food to help the plant survive drought and other environmental extremes. The taproot also anchors the plant very securely in the ground.
- Fibrous root systems have many small branching roots, called fibrous roots, but no large primary root. The huge number of threadlike roots increases the surface area for absorption of water and minerals, but **fibrous roots** anchor the plant less securely.

FIGURE 16.3

Dandelions have taproot systems grasses have fibrous root systems.

Root Structures and Functions

As shown in **Figure** 16.4 , the tip of a root is called the root cap. It consists of specialized cells that help regulate primary growth of the root at the tip. Above the root cap is primary meristem, where growth in length occurs.

Above the meristem, the rest of the root is covered with a single layer of epidermal cells. These cells may have **root hairs** that increase the surface area for the absorption of water and minerals from the soil. Beneath the epidermis is ground tissue, which may be filled with stored starch. Bundles of vascular tissues form the center of the root. Waxy layers waterproof the vascular tissues so they don't leak, making them more efficient at carrying fluids. Secondary meristem is located within and around the vascular tissues. This is where growth in thickness occurs.

The structure of roots helps them perform their primary functions. What do roots do? They have three major jobs: absorbing water and minerals, anchoring and supporting the plant, and storing food.

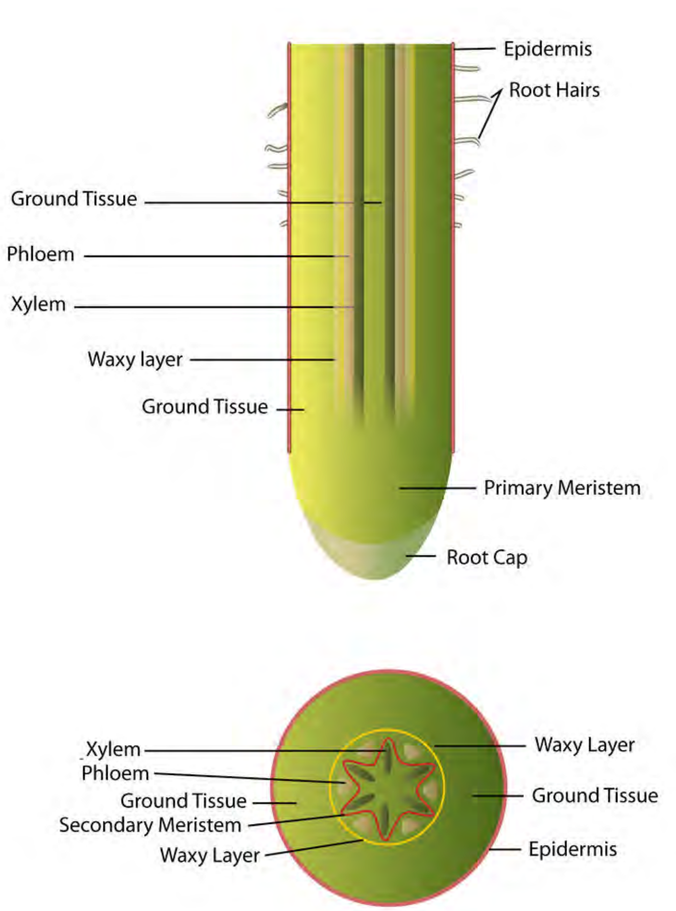


FIGURE 16.4

A root is a complex organ consisting of several types of tissue. What is the function of each tissue type

- Absorbing water and minerals: Thin-walled epidermal cells and root hairs are well suited to absorb water and dissolved minerals from the soil. The roots of many plants also have a mycorrhizal relationship with fungi for greater absorption.
- Anchoring and supporting the plant: Root systems help anchor plants to the ground, allowing plants to grow tall without toppling over. A tough covering may replace the epidermis in older roots, making them ropelike and even stronger. As shown in **Figure** 16.5 , some roots have unusual specializations for anchoring plants.
- Storing food: In many plants, ground tissues in roots store food produced by the leaves during photosynthesis. The bloodroot shown in **Figure** 16.5 stores food in its roots over the winter.

FIGURE 16.5

Mangrove roots are like stilts allowing mangrove trees to rise high above the water. The trunk and leaves are above water even at high tide. A bloodroot plant uses food stored over the winter to grow flowers in the early spring.

Root Growth

Roots have primary and secondary meristems for growth in length and width. As roots grow longer, they always grow down into the ground. Even if you turn a plant upside down, its roots will try to grow downward. How do roots "know" which way to grow? How can they tell down from up? Specialized cells in root caps are able to detect gravity. The cells direct meristem in the tips of roots to grow downward toward the center of Earth. This is generally adaptive for land plants. Can you explain why?

As roots grow thicker, they can't absorb water and minerals as well. However, they may be even better at transporting fluids, anchoring the plant, and storing food (see **Figure** 16.6).

Stems

In vascular plants, stems are the organs that hold plants upright so they can get the sunlight and air they need. Stems also bear leaves, flowers, cones, and secondary stems. These structures grow at points called nodes (shown in **Figure** 16.7). At each node, there is a bud of meristem tissue that can divide and specialize to form a particular structure.

Another vital function of stems is transporting water and minerals from roots to leaves and carrying food from leaves to the rest of the plant. Without this connection between roots and leaves, plants could not survive high above ground in the air. In many plants, stems also store food or water during cold or dry seasons.

FIGURE 16.6
Secondary growth of sweet potato roots provides more space to store food. Roots store sugar from photosynthesis as starch. What other starchy roots do people eat

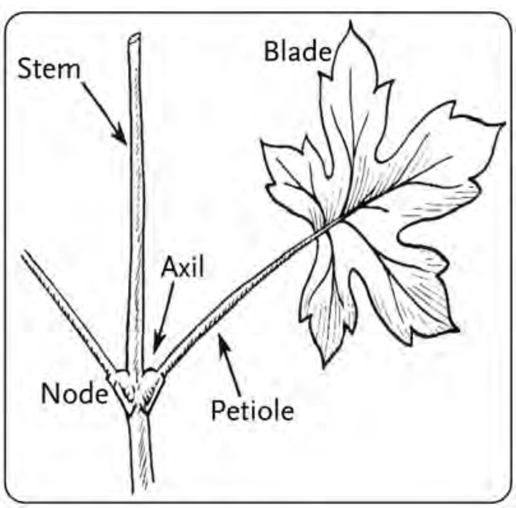


FIGURE 16.7
The stem of a vascular plant has nodes where leaves and other structures may grow.

Stem Diversity

Stems show variation because many stems are specialized. **Figure** 16.8 shows examples of stem specialization. With specialized stems, plants can exploit a diversity of niches in virtually all terrestrial ecosystems.

FIGURE 16.8

Stem specializations such as these let plants grow in many different habitats.

Stem Tissues and Functions

Like roots, the stems of vascular plants are made of dermal, vascular, and ground tissues.

- A single-celled layer of epidermis protects and waterproofs the stem and controls gas exchange.
- In trees, some of the epidermal tissue is replaced by bark. **Bark** is a combination of tissues that provides a tough, woody external covering on the stems of trees. The inner part of bark is alive and growing; the outer part is dead and provides strength, support, and protection.
- Ground tissue forms the interior of the stem. The large central vacuoles of ground tissue cells fill with water to support the plant. The cells may also store food.
- Bundles of vascular tissue run through the ground tissue of a stem and transport fluids. Plants may vary in how these bundles are arranged.

Stem Growth

The stems of all vascular plants get longer through primary growth. This occurs in primary meristem at the tips and nodes of the stems. Most stems also grow in thickness through secondary growth. This occurs in secondary meristem, which is located in and around the vascular tissues. Secondary growth forms secondary vascular tissues and bark. In many trees, the yearly growth of new vascular tissues results in an annual growth ring like the one in **Figure** 16.9 . When a tree is cut down, the rings in the trunk can be counted to estimate the tree's age.

Leaves

Leaves are the keys not only to plant life but to all terrestrial life. The primary role of leaves is to collect sunlight and make food by photosynthesis. Despite the fundamental importance of the work they do, there is great diversity

FIGURE 16.9
The number of rings in this cross-section of tree trunk show how many years the tree lived. What does each ring represent

in the leaves of plants. However, given the diversity of habitats in which plants live, it's not surprising that there is no single best way to collect solar energy for photosynthesis.

Leaf Variation

Leaves may vary in size, shape, and their arrangement on stems. Nonflowering vascular plants have three basic types of leaves: microphylls ("tiny leaves"), fronds, and needles. **Figure** 16.10 describes each type.

Flowering vascular plants also have diverse leaves. However, the leaves of all flowering plants have two basic parts in common: the blade and petiole (see **Figure** 16.7). The blade of the leaf is the relatively wide, flat part of the leaf that gathers sunlight and undergoes photosynthesis. The petiole is the part that attaches the leaf to a stem of the plant. This occurs at a node.

Flowering plant leaves vary in how the leaves are arranged on the stem and how the blade is divided. This is illustrated in **Figure** 16.11 . Generally, the form and arrangement of leaves maximizes light exposure while conserving water, reducing wind resistance, or benefiting the plant in some other way in its particular habitat.

- Leaves arranged in whorls encircle upright stems at intervals. They collect sunlight from all directions.
- Leaves arranged in basal rosettes take advantage of warm temperatures near the ground.
- Leaves arranged in alternate or opposing pairs collect light from above. They are typically found on plants with a single, upright stem.
- The blades of simple leaves are not divided. This provides the maximum surface area for collecting sunlight.
- The blades of compound leaves are divided into many smaller leaflets. This reduces wind resistance and water loss.

Factories for Photosynthesis

You can think of a single leaf as a photosynthesis factory. A factory has specialized machines to produce a product. It's also connected to a transportation system that supplies it with raw materials and carries away the finished product. In all these ways, a leaf resembles a factory. The cross section of a leaf in **Figure** 16.12 lets you look inside a leaf "factory."

FIGURE 16.10

Leaf variation in nonflowering plants reflects their evolutionary origins. Can you explain how

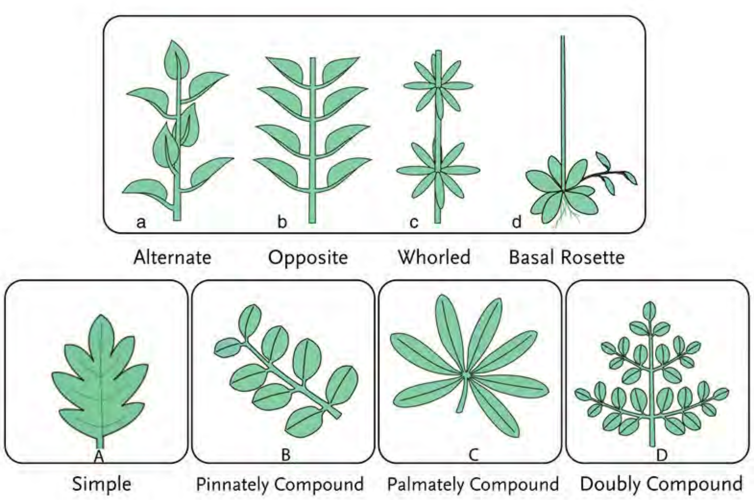


FIGURE 16.11

Leaf variation in flowering plants may include variations in the arrangement of leaves and the divisions of the blade.

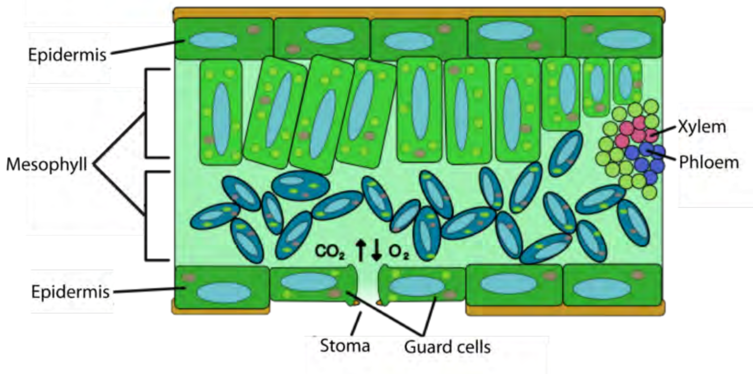


FIGURE 16.12
There&#8217 s more to a leaf than meets the eye. Can you identify the functions of each of the labeled structures in the diagram

A leaf consists of several different kinds of specialized tissues that work together to make food by photosynthesis. The major tissues are mesophyll, veins, and epidermis.

- **Mesophyll** makes up most of the leaf's interior. This is where photosynthesis occurs. Mesophyll consists mainly of parenchymal cells with chloroplasts.
- Veins are made primarily of xylem and phloem. They transport water and minerals to the cells of leaves and carry away dissolved sugar.
- The epidermis of the leaf consists of a single layer of tightly-packed dermal cells. They secrete waxy cuticle to prevent evaporation of water from the leaf. The epidermis has tiny pores called **stomata** (singular, stoma) that control transpiration and gas exchange with the air. **Figure** 16.13 explains how stomata carry out this vital function.

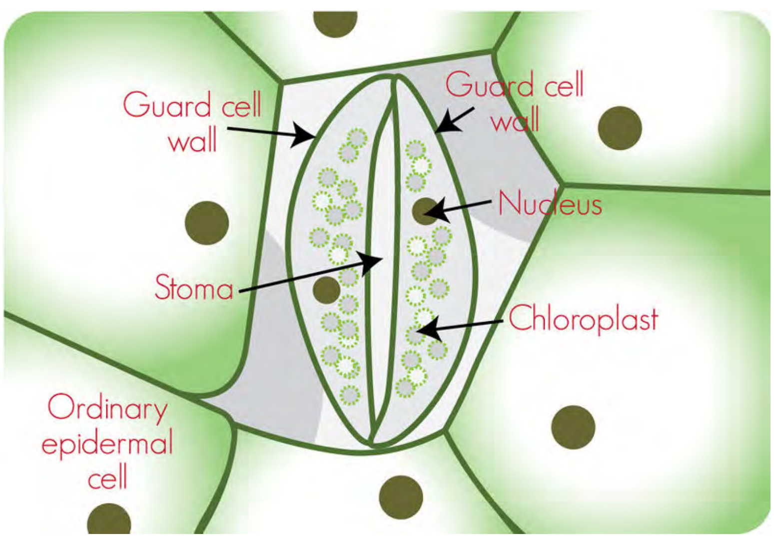


FIGURE 16.13
For photosynthesis stomata must control the transpiration of water vapor and the exchange of carbon dioxide and oxygen. Stomata are flanked by guard cells that swell or shrink by taking in or losing water through osmosis. When they do they open or close the stomata.

Seasonal Changes in Leaves

Even if you don't live in a place where leaves turn color in the fall, no doubt you've seen photos of their "fall colors" (see **Figure** 16.14). The leaves of many plants turn from green to other, glorious colors during autumn each year.

The change is triggered by shorter days and cooler temperatures. Leaves respond to these environmental stimuli by producing less chlorophyll. This allows other leaf pigments—such as oranges and yellows—to be seen.

FIGURE 16.14

A deciduous tree goes through dramatic seasonal changes each year. Can you identify the seasons in the photo

After leaves turn color in the fall, they may all fall off the plant for the winter. Plants that shed their leaves seasonally each year are called **deciduous plants**. Shedding leaves is a strategy for reducing water loss during seasons of extreme dryness. On the downside, the plant must grow new leaves in the spring, and that takes a lot of energy and matter. Some plants may "bank" energy over the winter by storing food. That way, they are ready to grow new leaves as soon as spring arrives.

Evergreen plants have a different strategy for adapting to seasonal dryness. They don't waste energy and matter growing new leaves each year. Instead, they keep their leaves and stay green year-round. However, to reduce water loss, they have needle-like leaves with very thick cuticle. On the downside, needle-like leaves reduce the surface area for collecting sunlight. This is one reason that needles may be especially rich in chlorophyll, as you can see from the dark green pine needles in **Figure** 16.15 . This is also an important adaptation for low levels of sunlight, allowing evergreens to live far from the equator.

FIGURE 16.15

Compare the color of the evergreen needles and the deciduous leaf. Why is the darker color of the needles adaptive

Lesson Summary

- Roots absorb water and minerals and transport them to stems. They also anchor and support a plant, and store food. A root system consists of primary and secondary roots. Each root is made of dermal, ground, and vascular tissues. Roots grow in length and width from primary and secondary meristem.
- Stems hold plants upright, bear leaves and other structures, and transport fluids between roots and leaves. Like roots, stems contain dermal, ground, and vascular tissues. Trees have woody stems covered with bark.
- The primary function of leaves is to collect sunlight and make food by photosynthesis. Specialized tissues in leaves work together to perform this function. In a deciduous plant, leaves seasonally turn color and fall off the plant. They are replaced with new leaves later in the year. An evergreen plant keeps its green leaves year-round. It may have needle-like leaves to reduce water loss.

Lesson Review Questions

Recall

1. What are root hairs? What is their role?
2. Identify three major functions of roots.
3. Describe two types of specialized stems. What is each type of stem specialized for?
4. What is bark? What purposes does it serve?
5. Name the two main parts of an angiosperm leaf. What is the function of each part?
6. Identify strategies used by deciduous and evergreen plants to adapt to seasonal dryness.

Apply Concepts

7. Apply lesson concepts to predict how the stem of a desert plant might be specialized for its environment.
8. Devise a model to demonstrate the concept that simple and compound leaves differ in the amount of light they absorb.

Think Critically

9. Contrast a taproot system with a fibrous root system.
10. Explain how roots "know" which way to grow.
11. Relate leaf variation to environmental variation.
12. Explain how a leaf is like a factory.

Points to Consider

In this lesson you read about the diversity of roots, stems, and leaves. The life cycles of plants are also diverse.

- What do you already know about the life cycle of plants? What type of life cycle do plants have?

- Predict how the life cycles of different plants might vary. For example, how might the life cycle of seed plants differ from the life cycle of seedless vascular plants?

16.3 Variation in Plant Life Cycles

Lesson Objectives

- Describe a general plant life cycle.
- Outline the life cycle of nonvascular plants.
- Describe the life cycle of seedless vascular plants.
- Summarize the gymnosperm life cycle.
- Describe the angiosperm life cycle.

Vocabulary

antheridia (singular, antheridium) male reproductive organs of the gametophyte generation of plants that produce motile sperm

archegonia (singular, archegonium) female reproductive organs of the gametophyte generation of plants that produce eggs

sporangium (plural, sporangia) structure on a plant of the sporophyte generation that produces spores for asexual reproduction

Introduction

The life cycle of all plants is complex because it is characterized by alternation of generations. Plants alternate between diploid sporophyte and haploid gametophyte generations, and between sexual and asexual reproduction. The ability to reproduce both sexually and asexually gives plants the flexibility to adapt to changing environments. Their complex life cycle allows for great variation.

General Plant Life Cycle

A general plant life cycle is represented by the diagram in **Figure** 16.16 . From the figure, you can see that the diploid sporophyte has a structure called a **sporangium** (plural, sporangia) that undergoes meiosis to form haploid spores. A spore develops into a haploid gametophyte. The gametophyte has male or female reproductive organs that undergo mitosis to form haploid gametes (sperm or eggs). Fertilization of gametes produces a diploid zygote. The zygote grows and develops into a mature sporophyte, and the cycle repeats.

One of the two generations of a plant's life cycle is typically dominant to the other generation. Whether it's the sporophyte or gametophyte generation, individuals in the dominant generation live longer and grow larger. They

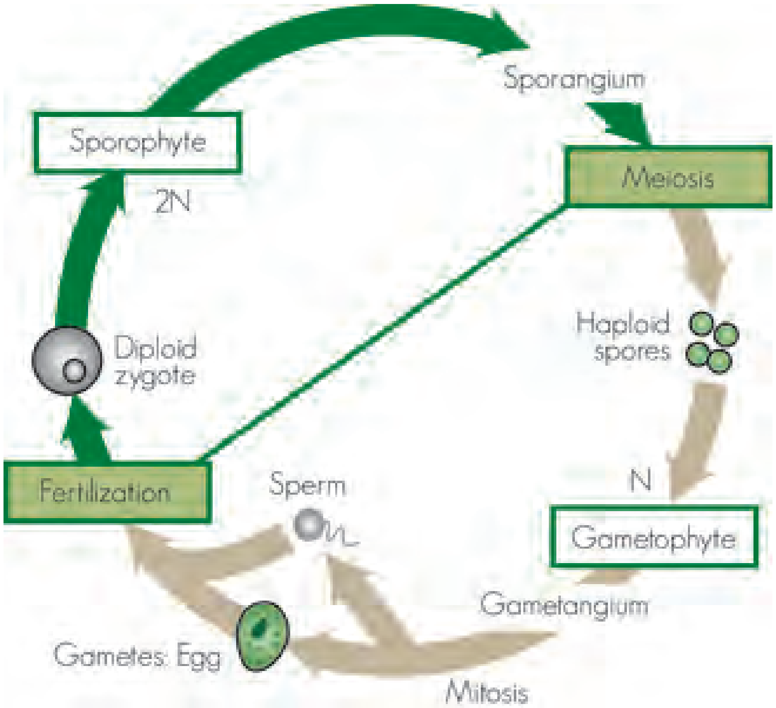


FIGURE 16.16
This diagram represents the life cycle that generally characterizes plants.

are the green, photosynthetic structures that you would recognize as a fern, tree, or other plant (see **Figure** 16.17). Individuals in the nondominant generation, in contrast, may be very small and rarely seen. They may live in or on the dominant plant.

The dominant generation in nonvascular plants is the gametophyte; in vascular plants, it's the sporophyte. Why is a dominant sporophyte generation an advantage on land?

Life Cycle of Nonvascular Plants

Nonvascular plants include mosses, liverworts, and hornworts. They are the only plants with a life cycle in which the gametophyte generation is dominant. **Figure** 16.18 shows the life cycle of moss. The familiar, green, photosynthetic moss plants are gametophytes. The sporophyte generation is very small and dependent on the gametophyte plant.

The gametophytes of nonvascular plants have distinct male or female reproductive organs (see **Figure** 16.19). Male reproductive organs, called **antheridia** (singular, antheridium), produce motile sperm with two flagella. Female reproductive organs, called archegonia (singular, **archegonium**), produce eggs.

In order for fertilization to occur, sperm must swim in a drop of water from an antheridium to an egg in an archegonium. If fertilization takes place, it results in a zygote that develops into a tiny sporophyte on the parent gametophyte plant. The sporophyte produces haploid spores, and these develop into the next generation of gametophyte plants. Then the cycle repeats.

FIGURE 16.17
All of these photos show plants of the dominant generation in their life cycle.

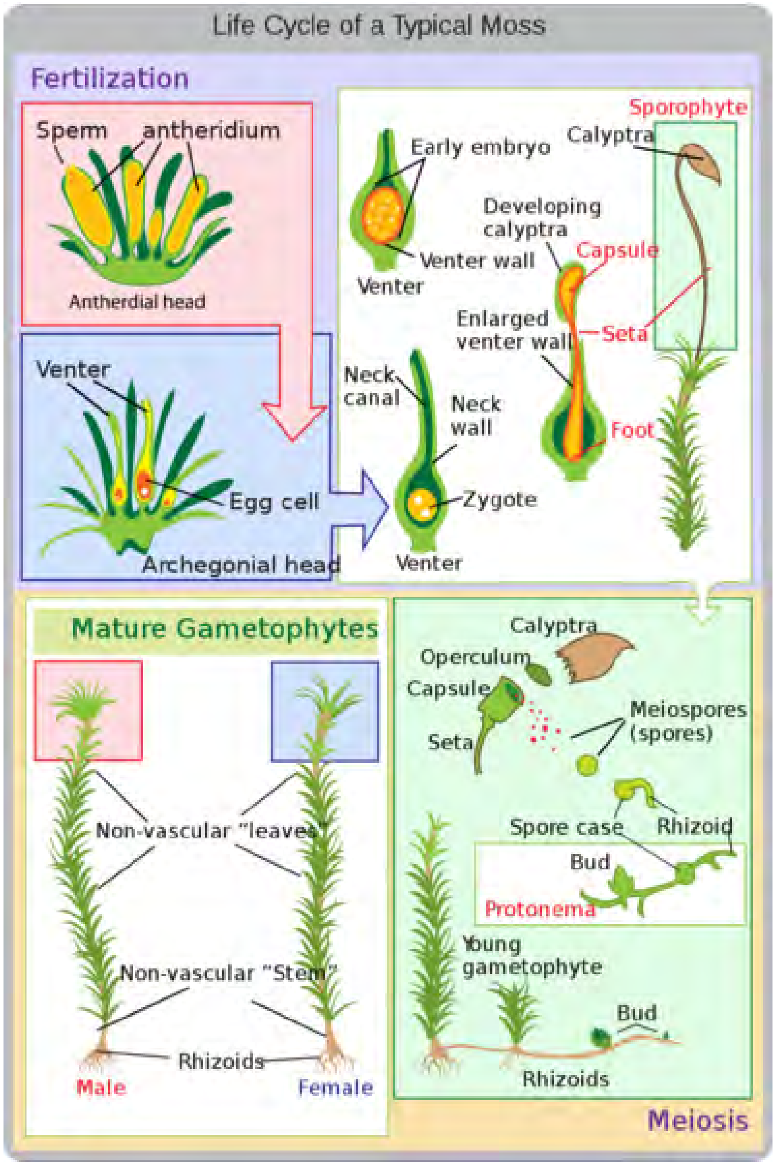


FIGURE 16.18

Like other bryophytes moss plants spend most of their life cycle as gametophytes. Find the sporophyte in the diagram. Do you see how it is growing on the gametophyte plant

FIGURE 16.19

The reproductive organs of bryophytes like this liverwort are male antheridia and female archegonia.

Life Cycle of Seedless Vascular Plants

Unlike nonvascular plants, all vascular plants—including seedless vascular plants—have a dominant sporophyte generation. Seedless vascular plants include clubmosses and ferns. **Figure** 16.20 shows a typical fern life cycle.

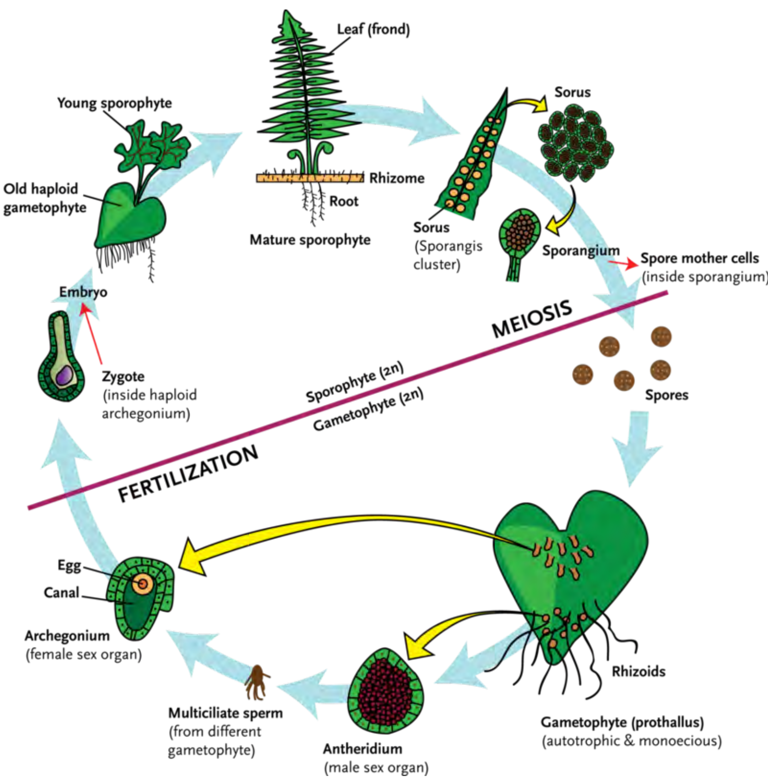


FIGURE 16.20

In the life cycle of a fern the sporophyte generation is dominant.

A mature sporophyte fern has the familiar leafy fronds. The undersides of the leaves are dotted with clusters of sporangia. Sporangia produce spores that develop into tiny, heart-shaped gametophytes. Gametophytes have antheridia and archegonia. Antheridia produce sperm with many cilia; archegonia produce eggs. Fertilization occurs when sperm swim to an egg inside an archegonium. The resulting zygote develops into an embryo that becomes a new sporophyte plant. Then the cycle repeats.

Life Cycle of Gymnosperms

Gymnosperms are vascular plants that produce seeds in cones. Examples include conifers such as pine and spruce trees. The gymnosperm life cycle has a very dominant sporophyte generation. Both gametophytes and the next generation's new sporophytes develop on the sporophyte parent plant. **Figure** 16.21 is a diagram of a gymnosperm life cycle.

Cones form on a mature sporophyte plant. Inside male cones, male spores develop into male gametophytes. Each male gametophyte consists of several cells enclosed within a grain of pollen. Inside female cones, female spores develop into female gametophytes. Each female gametophyte produces an egg inside an ovule.

Pollination occurs when pollen is transferred from a male to female cone. If sperm then travel from the pollen to

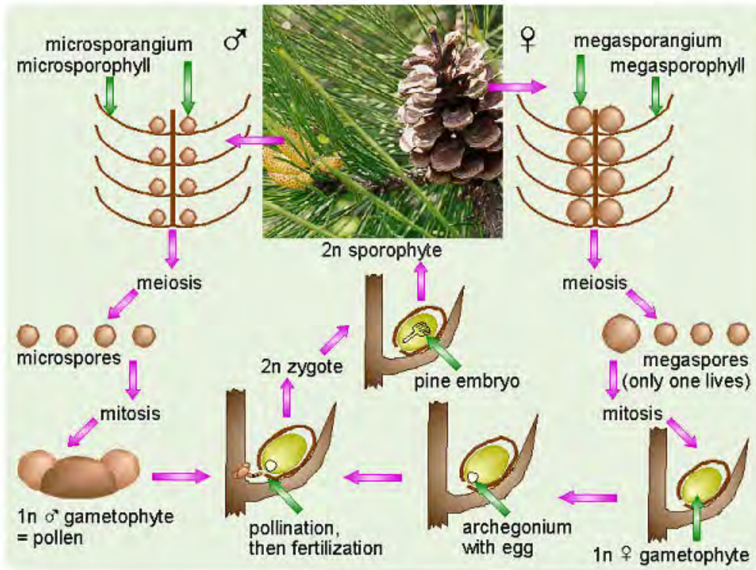


FIGURE 16.21

The gymnosperm life cycle follows the general plant life cycle but with some new adaptations. Can you identify them

an egg so fertilization can occur, a diploid zygote results. The zygote develops into an embryo within a seed, which forms from the ovule inside the female cone. If the seed germinates, it may grow into a mature sporophyte tree, which repeats the cycle.

Life Cycle of Angiosperms

Angiosperms, or flowering plants, are the most abundant and diverse plants on Earth. Angiosperms evolved several reproductive adaptations that have contributed to their success. Like all vascular plants, their life cycle is dominated by the sporophyte generation. A typical angiosperm life cycle is shown in **Figure** 16.22 .

The flower in **Figure** 16.22 is obviously an innovation in the angiosperm life cycle. Flowers form on the dominant sporophyte plant. They consist of highly specialized male and female reproductive organs. Flowers produce spores that develop into gametophytes. Male gametophytes consist of just a few cells within a pollen grain and produce sperm. Female gametophytes produce eggs inside the ovaries of flowers. Flowers also attract animal pollinators.

If pollination and fertilization occur, a diploid zygote forms within an ovule in the ovary. The zygote develops into an embryo inside a seed, which forms from the ovule and also contains food to nourish the embryo. The ovary surrounding the seed may develop into a fruit. Fruits attract animals that may disperse the seeds they contain. If a seed germinates, it may grow into a mature sporophyte plant and repeat the cycle.

Lesson Summary

- All plants have a life cycle with alternation of generations. Plants alternate between diploid sporophyte and haploid gametophyte generations, and between sexual reproduction with gametes and asexual reproduction with spores.
- In nonvascular plants, the gametophyte generation is dominant. The tiny sporophyte grows on the gametophyte plant.

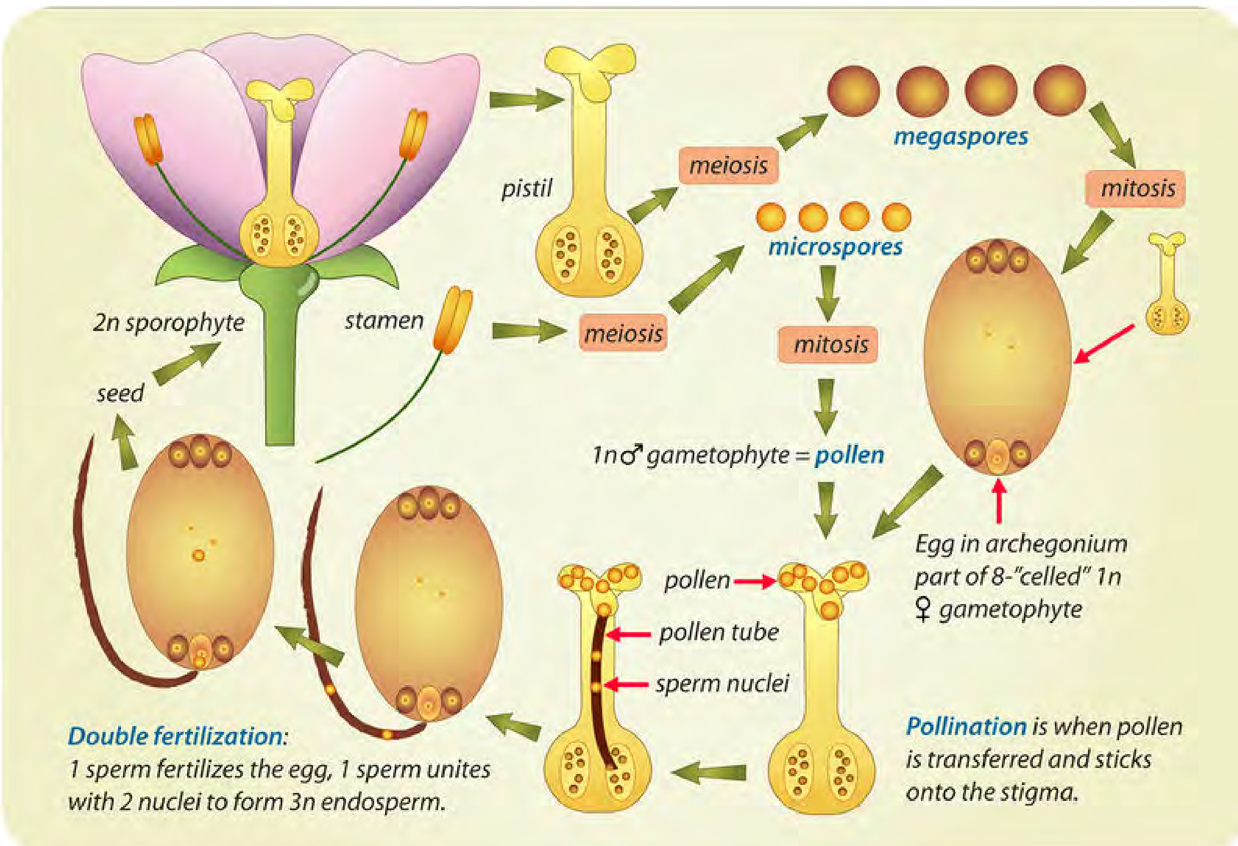


FIGURE 16.22

Life cycle of an angiosperm

- In vascular plants, the sporophyte generation is dominant. In seedless vascular plants such as ferns, the sporophyte releases spores from the undersides of leaves. The spores develop into tiny, separate gametophytes, from which the next generation of sporophyte plants grows.
- In seed plants, the gametophyte generation takes place in a cone or flower, which forms on the mature sporophyte plant. Each male gametophyte is just a few cells inside a grain of pollen. Each female gametophyte produces an egg inside an ovule. Pollination must occur for fertilization to take place. Zygotes develop into embryos inside seeds, from which the next sporophyte generation grows.

Lesson Review Questions

Recall

1. Outline the general life cycle of plants.
2. What are sporangia? What do they do?
3. Describe antheridia and archegonia and their functions.
4. What role do leaves play in the reproduction of ferns?
5. Describe how gymnosperms use cones to reproduce.
6. State the functions of flowers and fruits in angiosperm reproduction.

Apply Concepts

7. Create your own cycle diagram to represent the life cycle of a daisy.

Think Critically

8. Relate the concept of alternation of generations to the ability of plants to adapt to a diversity of habitats.
9. Compare and contrast gymnosperm and angiosperm life cycles.

Points to Consider

In this lesson, you read about many of the reproductive adaptations of plants.

- What are some other plant adaptations? For example, how have desert plants adapted to very dry conditions?
- Besides deserts, what other extreme habitats do plants occupy? What special adaptations might plants require to live in these other habitats?

16.4 Plant Adaptations and Responses

Lesson Objectives

- Explain how plants have adapted to a diversity of environments.
- Identify types of plant responses to environmental stimuli.

Vocabulary

epiphyte plant that is adapted to grow on other plants and obtain moisture from the air

tropism turning by an organism or part of an organism toward or away from an environmental stimulus

xerophyte plant that is adapted to a very dry environment

Introduction

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.

Plant Adaptations

All plants are adapted to live on land. Or are they? All living plants today have terrestrial ancestors, but some plants now live in the water. They have had to evolve new adaptations for their watery habitat.

Adaptations to Water

Aquatic plants are plants that live in water. 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 cuticles 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, so aquatic plants may have adaptations that help them keep their flowers above water. For instance, water lilies have bowl-shaped flowers and broad, flat leaves that float. This allows the lilies to collect the maximum amount of sunlight, which does not penetrate very deeply below the surface. Plants that live in moving water, such as streams and rivers, may have different adaptations. For example, cattails have narrow, strap-like leaves that reduce their resistance to the moving water (see **Figure** 16.23).

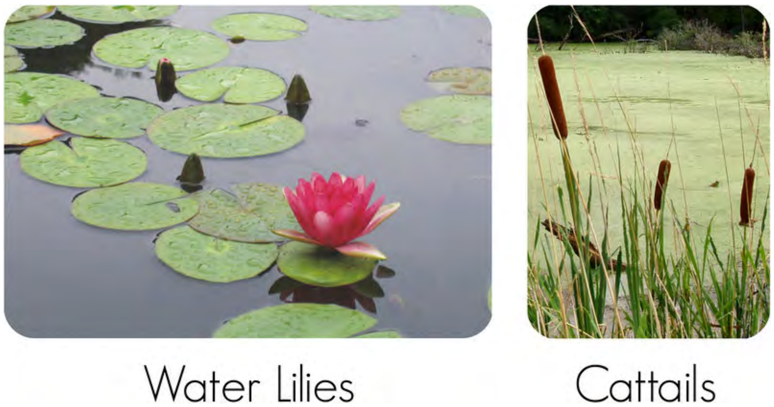


FIGURE 16.23
Water lilies and cattails have different adaptations for life in the water. Compare the leaves of the two kinds of plants. How do the leaves help the plants adapt to their watery habitats

Adaptations to Extreme Dryness

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 is available.

The saguaro cactus pictured in **Figure** 16.24 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 16.24
The saguaro cactus has many adaptations for extreme dryness. How does it store water

Adaptations to Air

Plants called **epiphytes** grow on other plants. They obtain moisture from the air and make food by photosynthesis. Most epiphytes are ferns or orchids that live in tropical or temperate rainforests (see **Figure** 16.25). Host trees provide support, allowing epiphyte plants to obtain air and sunlight high above the forest floor. Being elevated above the ground lets epiphytes get out of the shadows on the forest floor so they can get enough sunlight for photosynthesis. Being elevated may also reduce the risk of being eaten by herbivores and increase the chance of pollination by wind.

FIGURE 16.25
This elkhorn fern is growing on a rainforest tree as an epiphyte.

Epiphytes don't grow in soil, so they may not have roots. However, they still need water for photosynthesis. Rainforests are humid, so the plants may be able to absorb the water they need from the air. However, many epiphytes have evolved modified leaves or other structures for collecting rainwater, fog, or dew. The leaves of the bromeliad shown in **Figure** 16.26 are rolled into funnel shapes to collect rainwater. The base of the leaves forms a tank that can hold more than 8 liters (2 gallons) of water. Some insects and amphibians may spend their whole life cycle in the pool of water in the tank, adding minerals to the water with their wastes. The tissues at the base of the leaf are absorbent, so they can take in both water and minerals from the tank.

Plant Responses

Like all organisms, 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 to the soil. Instead, a plant's primary means of response is to change how it is growing. Plants also don't have a nervous system to control their responses. Instead, their responses are generally controlled by hormones, which are chemical messenger molecules.

FIGURE 16.26
The leaves of this bromeliad are specialized to collect store and absorb rainwater.

Plant Tropisms

As you read earlier in this chapter, plant roots always grow downward because specialized cells in root caps detect and respond to gravity. This is an example of a tropism. A **tropism** is a turning toward or away from a stimulus in the environment. Growing toward gravity is called geotropism. Plants also exhibit phototropism, or growing toward a light source. This response is controlled by a plant growth hormone called auxin. As shown in **Figure** 16.27 , auxin stimulates cells on the dark side of a plant to grow longer. This causes the plant to bend toward the light.

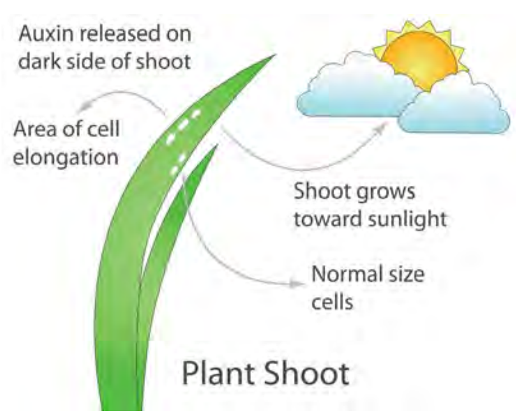


FIGURE 16.27
Phototropism is controlled by the growth hormone auxin.

Daily and Seasonal Responses

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. Environmental stimuli that indicate changing seasons trigger other responses. 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 cold and dryness of winter. Dormancy ensures that seeds will germinate and plants will grow only when conditions are favorable.

Responses to Disease

Plants don't have immune systems, 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 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 plants of threats to their health, allowing the 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.

KQED: Plant Plague: Sudden Oak Death

Devastating over one million oak trees across Northern California in the past ten years, Sudden Oak Death is a killer with no cure. But biologists now are looking to the trees' genetics for a solution. See http://www.kqed.org/quest/television/plant-plague-sudden-oak-death for more information.

Lesson Summary

- Plants live just about everywhere on Earth, so they have evolved adaptations that allow them to survive and reproduce under a diversity of conditions. Various plants have evolved adaptations to live in the water, in very dry environments, or in the air as epiphytes.
- Like all organisms, plants detect and respond to stimuli in their environment. Their main response is to change how they grow. Their responses are controlled by hormones. Some plant responses are tropisms. Plants also respond to daily and seasonal cycles and to disease.

Lesson Review Questions

Recall

1. List special challenges that aquatic plants face.
2. What are xerophytes? Give an example.
3. Identify three general ways that plants can adapt to extreme dryness.
4. Describe how epiphytes can absorb moisture without growing roots in soil.
5. What is the primary way that plants respond to environmental stimuli? What controls their responses?
6. Define tropism. Name one example in plants.
7. State ways that plants respond to disease.

Apply Concepts

8. Apply the concept of symbiosis to epiphytes and their host plants. Do you think they have a symbiotic relationship? If so, which type of symbiotic relationship do you think they have? Explain your answer.

Think Critically

9. Why are epiphytes found mainly in rainforest ecosystems?

10. Why is it adaptive for plants to detect and respond to daily and seasonal changes?

EOL Research

11. Bromeliads are some of the most common epiphytes. Research bromeliads at EOL and discuss the evolution of these species. See the *Communities and Populations* chapter for information about EOL.

Points to Consider

In this chapter you read about the cells, tissues, and organs that make up plants. You also read about plant life cycles. Like plants, animals are complex organisms with tissues and organs. Animals also have life cycles.

- How do the cells of animals differ from those of plants? What tissues and organs might be found in animals?
- What is the general animal life cycle? How does it differ from the general life cycle of plants?

CHAPTER 17 Introduction to Animals

CHAPTER OUTLINE

Do you know what these greenish, blob-like shapes are? Would it surprise you to learn that they are animals? They don't look anything like the animals you are probably familiar with—animals such as dogs and deer, fish and frogs. But the greenish blobs are animals nonetheless. They belong to a phylum called Cnidaria, but you may know them as jellyfish. They are very simple animals and not fish at all. How can an organism as simple as a jellyfish be considered an animal? How are animals defined? What traits must an organism have to be classified in the animal kingdom? In this chapter, you will learn the answers to these questions. You will find out just what it means to be an animal.

17.1 Overview of Animals

Lesson Objectives

- Identify characteristics that all animals share.
- Give an overview of animal classification.
- Outline major trends in animal evolution.

Vocabulary

amniote animal that produces eggs with internal membranes that allow gases but not water to pass through so the embryo can breathe without drying out (reptile, bird, or mammal)

animal heterotrophic, multicellular eukaryote with cells that lack cell walls; member of the animal kingdom

exoskeleton non-bony skeleton that forms on the outside of the body of some invertebrates and provides protection and support

invertebrate animal that lacks a vertebral column, or backbone

notochord stiff support rod that runs from one end of the body to the other in animals called chordates

vertebral column bony support structure that runs down the back of a vertebrate animal; also called a backbone

vertebrate animal with a vertebral column, or backbone

Introduction

There is great variation among species that make up the animal kingdom. Some of this variation is shown in **Figure** 17.1 . Despite the variation, there are a number of traits that are shared by all animals. The fact that all animals have certain traits in common shows that they share a common ancestor. How did such a diverse group of organisms evolve? What traits do all animals share? Read on to find out.

Characteristics of Animals

Animals are a kingdom of multicellular eukaryotes. They cannot make their own food. Instead, they get nutrients by eating other living things. Therefore, animals are heterotrophs.

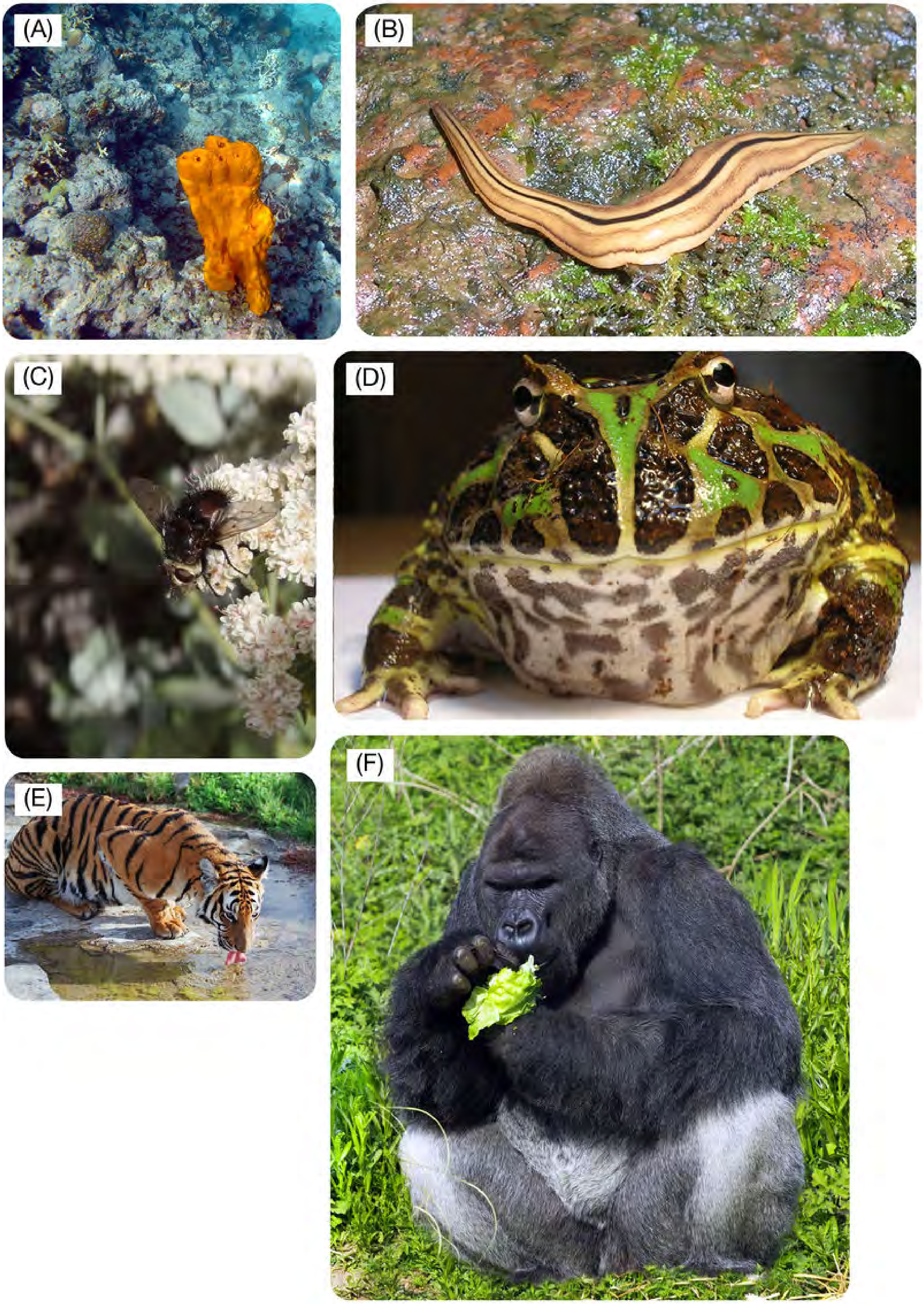


FIGURE 17.1

Diversity of Animals. These photos give just an inkling of the diversity of organisms that belong to the animal kingdom. *A* Sponge *B* Flatworm *C* Flying Insect *D* Frog *E* Tiger *F* Gorilla.

Animal Cells

Like the cells of all eukaryotes, animal cells have a nucleus and other membrane-bound organelles (see **Figure** 17.2). Unlike the cells of plants and fungi, animal cells lack a cell wall. This gives animal cells flexibility. It lets them take on different shapes so they can become specialized to do particular jobs. The human nerve cell shown in **Figure** 17.3 is a good example. Its shape suits it for its function of transmitting nerve impulses over long distances. A nerve cell would be unable to take this shape if it were surrounded by a rigid cell wall.

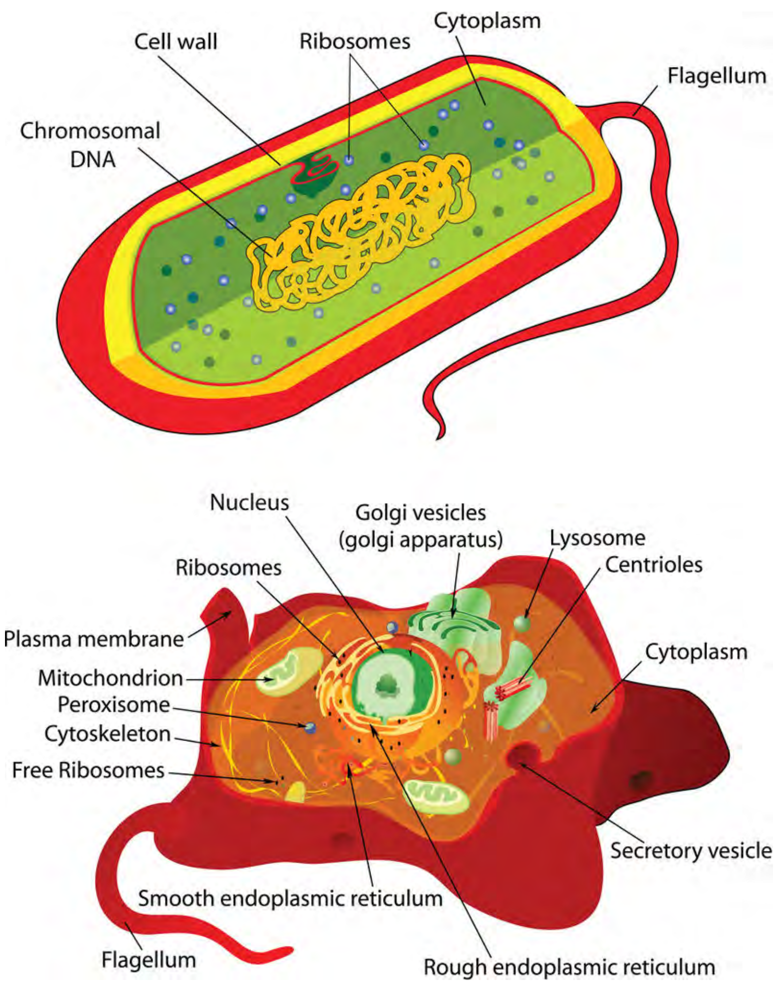


FIGURE 17.2
Animal Cell. The shape of an animal cell is not constrained by a rigid cell wall. A bacterial cell is shown above for comparison.

Animal Structure and Function

Animals not only have specialized cells. Most animals also have tissues and organs. In many animals, organs form organ systems, such as a nervous system. Higher levels of organization allow animals to perform many complex functions. What can animals do that most other living things cannot? Here are some examples. All of them are illustrated in **Figure** 17.4 .

- Animals can detect environmental stimuli, such as light, sound, and touch. Stimuli are detected by sensory nerve cells. The information is transmitted and processed by the nervous system. The nervous system, in turn, may direct the body to respond.

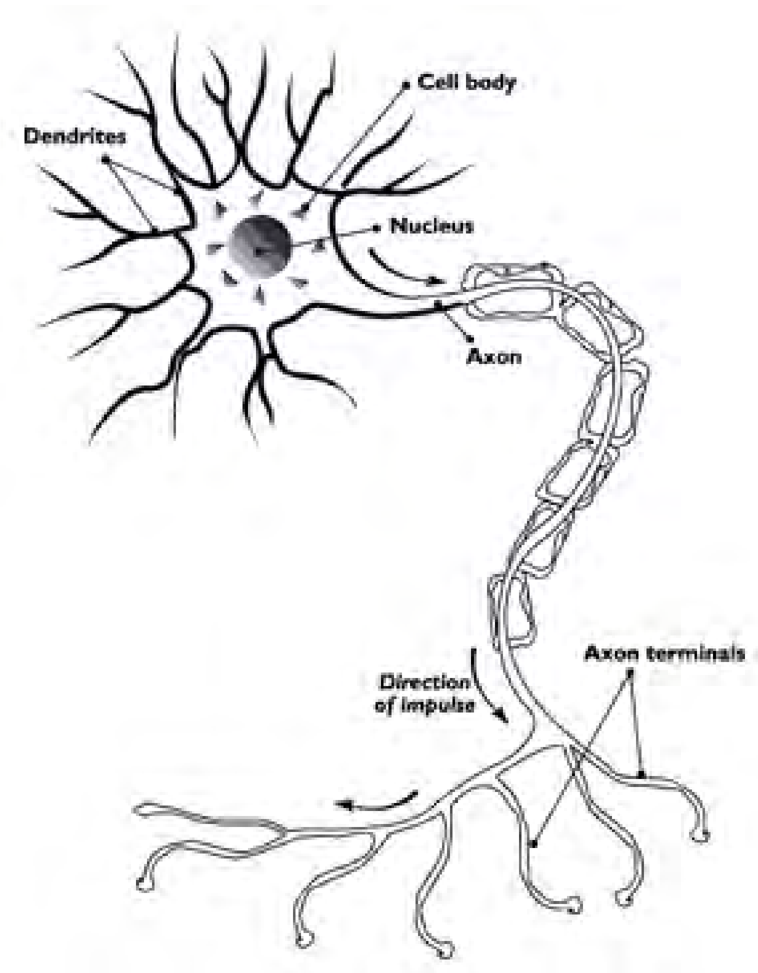


FIGURE 17.3

Human Nerve Cell. A human nerve cell is specialized to transmit nerve impulses. How do you think the cell&#8217 s shape helps it perform this function

- All animals can move, at least during some stage of their life cycle. Muscles and nerves work together to allow movement. Being able to move lets animals actively search for food and mates. It also helps them escape from predators.
- Virtually all animals have internal digestion of food. Animals consume other organisms and may use special tissues and organs to digest them. (Many other organisms absorb nutrients directly from the environment.)

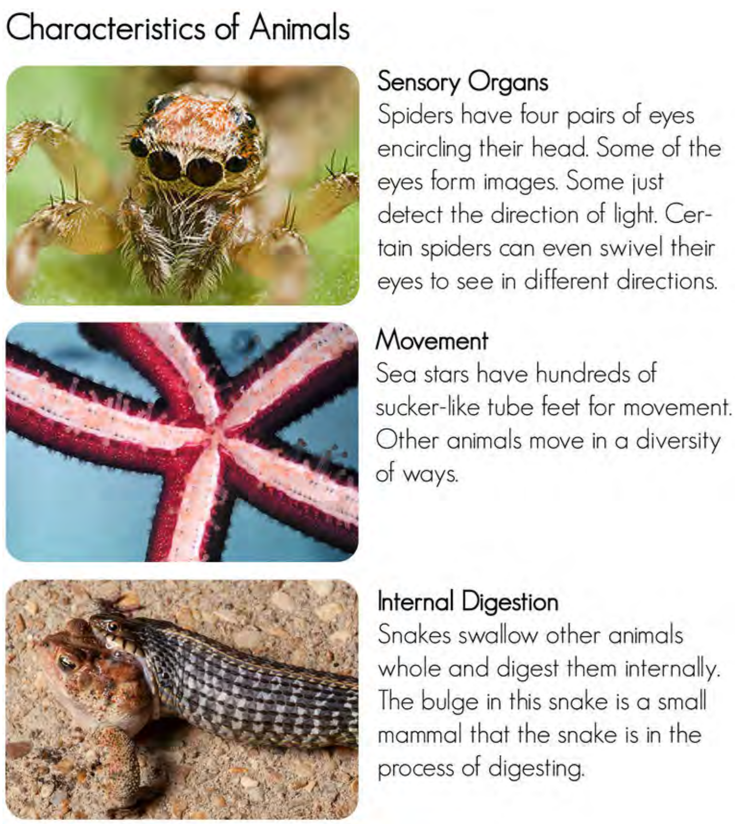


FIGURE 17.4

Characteristics of Animals. Most animals share these characteristics sensory organs movement and internal digestion.

Animal Life Cycle and Reproduction

Many animals have a relatively simple life cycle. A general animal life cycle is shown in **Figure** 17.5 . Most animals spend the majority of their life as diploid organisms. Just about all animals reproduce sexually. Diploid adults undergo meiosis to produce sperm or eggs. Fertilization occurs when a sperm and an egg fuse. The zygote that forms develops into an embryo. The embryo eventually develops into an adult.

Classification of Animals

All animals share basic traits. But animals also show a lot of diversity. They range from simple sponges to complex humans.

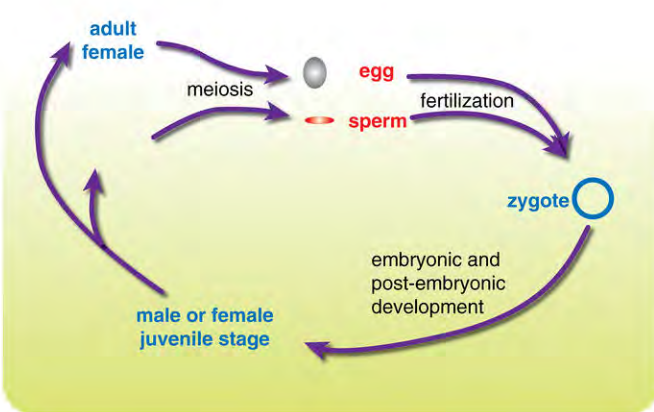


FIGURE 17.5
Animal Life Cycle. An animal life cycle that includes only sexual reproduction is shown here. Some animals also reproduce asexually. How does the animal life cycle compare with the life cycle of a plant

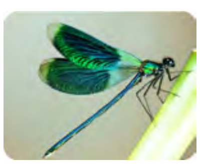
Major Animal Phyla

Members of the animal kingdom are divided into more than 30 phyla. **Table** 17.1 lists the 9 phyla with the greatest number of species. Each of the animal phyla listed in the table have at least 10,000 species.

TABLE 17.1: Major Phyla of the Animal Kingdom

	Phylum	Animals It Includes
	Porifera	sponges
	Cnidaria	jellyfish, corals

TABLE 17.1: (continued)

	Phylum	Animals It Includes
	Platyhelminthes	flatworms, tapeworms, flukes
	Nematoda	roundworms
	Mollusca	snails, clams, squids
	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

Invertebrate vs. Vertebrate

The first eight phyla listed in **Table** 17.1 include only invertebrate animals. **Invertebrates** are animals that lack a **vertebral column**, or backbone. The last phylum in the table, the Chordata, also includes many invertebrate species. Tunicates and lancelets are both invertebrates. Altogether, invertebrates make up at least 95 percent of all animal species. The remaining animals are vertebrates. **Vertebrates** are animals that have a backbone. All vertebrates belong to the phylum Chordata. They include fish, amphibians, reptiles, birds, and mammals.

Major Trends in Animal Evolution

The oldest animal fossils are about 630 million years old. By 500 million years ago, most modern phyla of animals had evolved. **Figure** 17.6 shows when some of the major events in animal evolution took place.

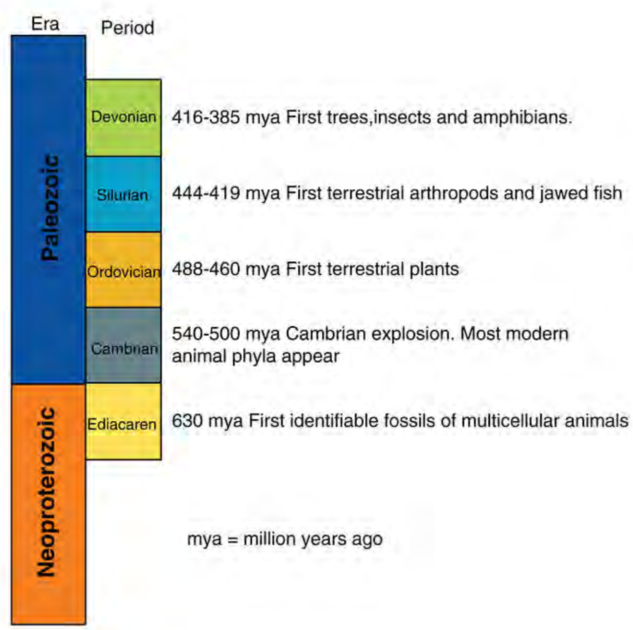


FIGURE 17.6

Partial Geologic Time Scale. This portion of the geologic time scale shows major events in animal evolution.

Animal Origins

Who were the ancestors of the earliest animals? They may have been marine protists that lived in colonies. Scientists think that cells of some protist colonies became specialized for different jobs. After a while, the specialized cells came to need each other for survival. Thus, the first multicellular animal evolved. Look at the cells in **Figure** 17.7 . One type of sponge cell, the choanocyte, looks a lot like the protist cell. How does this support the hypothesis that animals evolved from protists?

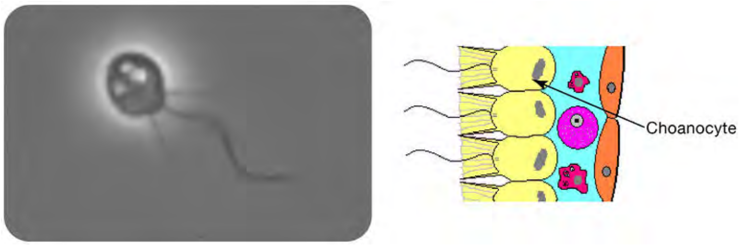


FIGURE 17.7

Choanoflagellate Protist and Choanocyte Cells in Sponges. Sponge choanocytes look a lot like choanoflagellate protists.

Evolution of Invertebrates

Many important animal adaptations evolved in invertebrates. Without these adaptations, vertebrates would not have been able to evolve. They include:

- Tissues, organs, and organ systems.
- A symmetrical body.
- A brain and sensory organs.
- A fluid-filled body cavity.
- A complete digestive system.
- A body divided into segments.

You can read about all of these adaptations in the next lesson.

Moving from Water to Land

When you think of the first animals to colonize the land, you may think of amphibians. It's true that ancestors of amphibians were the first vertebrates to move to land. However, the very first animals to go ashore were invertebrates, most likely arthropods.

The move to land 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. One way early arthropods solved these problems was by evolving an **exoskeleton.** This is a non-bony skeleton that forms on the outside of the body. It supports the body and helps retain water. The video *Walking with Monsters* is a depiction of the evolution of life from water onto land: http://www.youtube.com/watch?v=gytrNU3iwvM (4:43).

Evolution of Chordates

Another major step in animal evolution was the evolution of a notochord. A **notochord** is a rigid rod that runs the length of the body. It supports the body and gives it shape (see **Figure** 17.8). It also provides a place for muscles to anchor, and counterbalances them when they contract. Animals with a notochord are called chordates. They also have a hollow nerve cord that runs along the top of the body. Gill slits and a tail are two other chordate features. Many modern chordates have some of these structures only as embryos.

Evolution of Vertebrates

Vertebrates evolved from primitive chordates. This occurred about 550 million years ago. The earliest vertebrates may have been jawless fish, like the hagfish in **Figure** 17.9 . Vertebrates evolved a backbone to replace the notochord after the embryo stage. They also evolved a cranium, or bony skull, to enclose and protect the brain.

FIGURE 17.8

Primitive Chordate Tunicate. This tunicate is a primitive deep-sea chordate. It is using its notochord to support its head while it waits to snatch up prey in its big mouth.

FIGURE 17.9

Primitive Vertebrate Hagfish. Hagfish are very simple vertebrates.

As early vertebrates evolved, they became more complex. Around 365 million years ago, they finally made the transition from water to land. The first vertebrates to live on land were amphibians. They evolved from lobe-finned fish. You can compare a lobe-finned fish and an amphibian in **Figure** 17.10 .

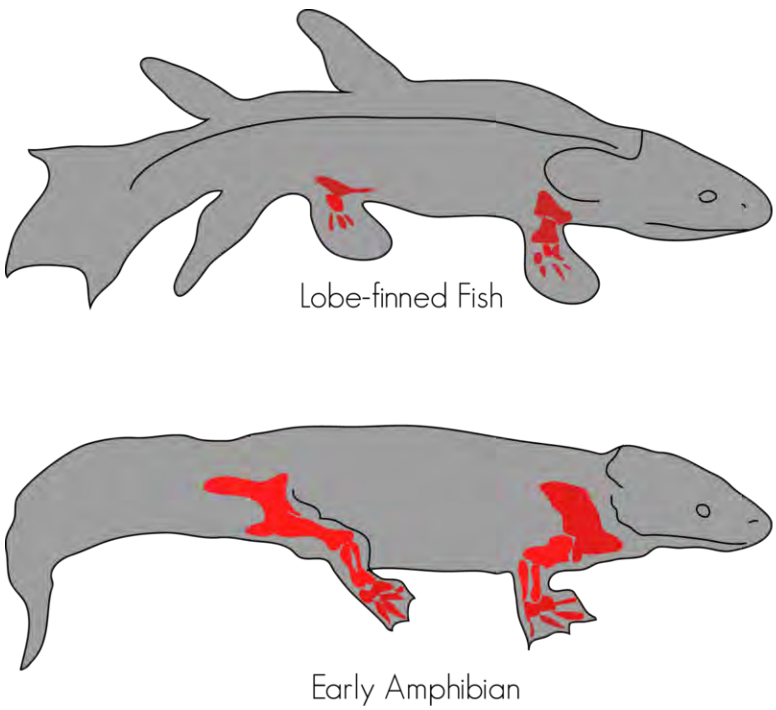


FIGURE 17.10

From Lobe-Finned Fish to Early Amphibian. Lobe-finned fish evolved into the earliest amphibians. A lobe-finned fish could breathe air for brief periods of time. It could also use its fins to walk on land for short distances. What similarities do you see between the lobe-finned fish and the amphibian

Evolution of Amniotes

Amphibians were the first animals to have true lungs and limbs for life on land. However, they still had to return to water to reproduce. That's because their eggs lacked a waterproof covering and would dry out on land. The first fully terrestrial vertebrates were amniotes. **Amniotes** are animals that produce eggs with internal membranes. The membranes let gases but not water pass through. Therefore, in an amniotic egg, an embryo can 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. They may have looked like the animal in **Figure** 17.11 . Within a few million years, two important amniote groups evolved: synapsids and sauropsids. Synapsids evolved into mammals. The sauropsids gave rise to reptiles, dinosaurs, and birds.

Lesson Summary

- Animals are multicellular eukaryotes that lack cell walls. All animals are heterotrophs. They have sensory organs, the ability to move, and internal digestion. They also have sexual reproduction.
- Vertebrates have a backbone, but invertebrates do not. Except for the chordates, all animal phyla consist only of invertebrates. Chordates include both vertebrates and invertebrates.
- The earliest animals evolved from colonial protists more than 600 million years ago. Many important animal adaptations evolved in invertebrates, including tissues and a brain. The first animals to live on land were invertebrates. Amphibians were the first vertebrates to live on land. Amniotes were the first animals that could reproduce on land.

FIGURE 17.11

Early Amniote. The earliest amniotes probably looked something like this. They were reptile-like but not actually reptiles. Reptiles evolved somewhat later.

Review Questions

Recall

1. Identify traits that characterize all animals.
2. State one way that animal cells differ from the cells of plants and fungi. What is the significance of this difference?
3. Describe a general animal life cycle.
4. State how the phylum Chordata differs from other animal phyla.
5. List three traits that evolved in invertebrate animals.

Apply Concepts

6. Assume that a new species of animal has been discovered. It is an egg-laying animal that lives and reproduces on land. Explain what you know about its eggs without ever seeing them.

Think Critically

7. Compare and contrast invertebrates and vertebrates.
8. Relate similarities between choanoflagellates and choanocytes to animal origins.

Points to Consider

Vertebrates are the animals with which we are most familiar. But there are far more invertebrates than vertebrates on the planet. The next lesson provides an overview of invertebrate animals.

- Before reading the next lesson, think about what you now know about invertebrates. Can you identify some invertebrate traits?

- Invertebrates are sometimes referred to as "lower" animals. This is because they evolved earlier and are simpler than vertebrates. Do you think invertebrates are also less adapted to their environments than vertebrates? Why or why not?

17.2 Overview of Invertebrates

Lesson Objectives

- Describe general characteristics of invertebrates.
- Outline major events in invertebrate evolution.
- Give an overview of invertebrate classification.

Vocabulary

bilateral symmetry symmetry of a body plan in which there are distinct head and tail ends, so the body can be divided into two identical right and left halves

cephalization concentration of nerve tissue in one end of an animal, forming a head region

coelom fluid-filled body cavity

complete digestive system digestive system consisting of a digestive tract and two body openings (mouth and anus)

ectoderm outer embryonic cell layer in animals

endoderm inner embryonic cell layer in animals

hydrostatic skeleton type of internal support in an animal body that results from the pressure of fluid within the body cavity known as the coelom

incomplete digestive system digestive system that consists of a digestive cavity and a single opening that serves as both mouth and anus

larva (plural, larvae) juvenile stage that occurs in the life cycle of many invertebrates, fish, and amphibians and that differs in form and function from the adult stage

mesoderm embryonic cell layer in many animals that is located between the endoderm (inner cell layer) and ectoderm (outer cell layer)

pseudocoelom partial, fluid-filled cavity inside the body of some invertebrates

radial symmetry symmetry of a body plan in which there is a distinct top and bottom but not distinct head and tail ends, so the body can be divided into two halves like a pie

segmentation division of an animal body into multiple segments

Introduction

The majority of animals today are invertebrates. They have a wide range of physical traits and ways of life. Modern invertebrates include animals as different as the sponge and tarantula shown in **Figure** 17.12 . Why are both of these animals classified as invertebrates? What traits do they have common?

FIGURE 17.12
Examples of Invertebrates. Both a sponge *left* and tarantula *right* are invertebrates. Can you identify any traits they share

Characteristics of Invertebrates

One trait the sponge and tarantula share is lack of a backbone. In fact, they don't have any bones at all. These are defining traits of all invertebrates. Some invertebrates have a skeleton, but it isn't made of bone. Many other traits of invertebrates show considerable diversity.

Digestion

Invertebrates have one of two types of digestive system. They are called incomplete and complete digestive systems. Both are shown in **Figure** 17.13 . An **incomplete digestive system** consists of a digestive cavity with one opening. The single opening serves as both mouth and anus. A **complete digestive system** consists of a digestive tract with two openings. One opening is the mouth. The other is the anus.

Movement

All invertebrates can move on their own during at least some stage of their life cycle. However, they may differ in how they move. Several ways are described below.

- Some invertebrates are simply carried along by water currents. They cannot control their movement in a particular direction. An example is a jellyfish.
- Other invertebrates can contract muscles to move independently of water currents or on solid surfaces. They can also control the direction in which they move. An example is a roundworm. It can move forward and to the left or right.
- Still other invertebrates have specialized appendages for movement. For example, they may have jointed legs for walking or climbing or wings for flying. An example is an insect such as a fly.

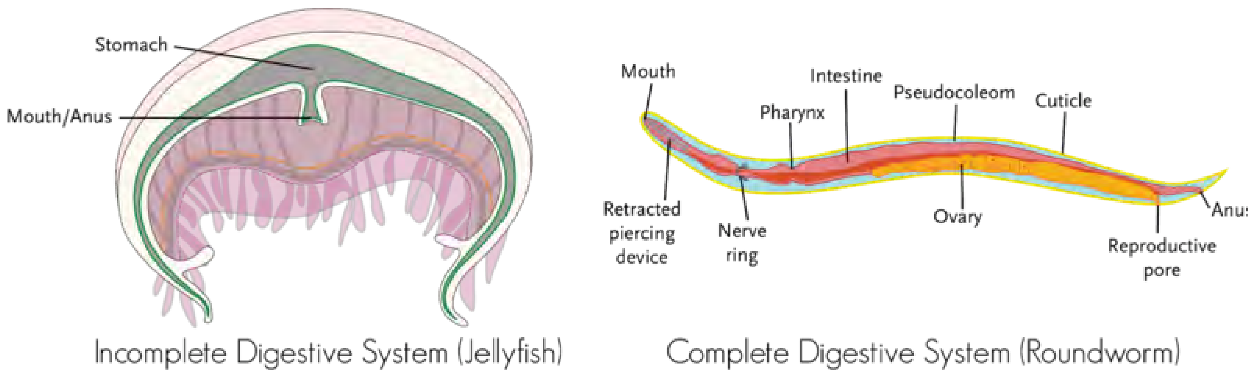


FIGURE 17.13

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. Find the parts of each digestive system in each drawing. How do the two systems differ

Nervous System

Most invertebrates have a nervous system. The nervous system allows them to sense and respond to their environment. The simplest invertebrate nervous system is just a network of nerves that can sense touch (see **Figure** 17.14). Most invertebrates have a more complex nervous system. It may include a brain and several different sense organs.

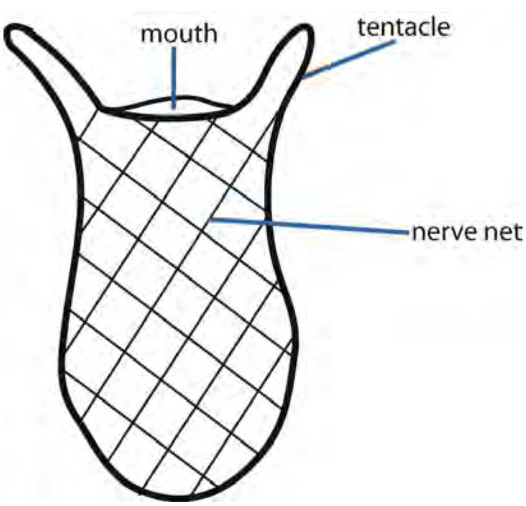


FIGURE 17.14

Nerve Net *Coral*. The body of a coral is lined with a net of nerves that can detect touch. How might this ability be adaptive

Reproduction

Most invertebrates reproduce sexually. Diploid adults produce haploid gametes (sperm and eggs). In some species, the same individuals produce both sperm and eggs. In other species, sperm and eggs are produced by separate male and female individuals. Fertilization occurs when a sperm and an egg fuse to form a diploid zygote. The zygote develops into an embryo and eventually into a new adult organism. On the way, it may pass through one or more larval stages. A **larva** (plural, larvae) is a juvenile, or immature, stage of an animal. It is generally quite different in form and function from the adult form of the species. For example, the larva may be able to swim freely, whereas the adult must remain permanently attached to a solid surface.

Some invertebrates can also reproduce asexually. This may occur by fission or budding. Fission takes place when an animal simply divides into two parts. Each part then regrows the missing part. The result is two whole organisms. Budding may take place when a parent forms a small bump, or bud. The bud remains attached to the parent while it develops into a new individual.

Invertebrate Evolution

Invertebrates evolved several important traits before vertebrates even appeared. These traits are now found in just about all animals.

Multicellularity

The first animal trait to evolve was multicellularity. This was highly adaptive. Multiple cells could do different jobs. They could evolve special adaptations that allowed them to do their job really well. However, the first invertebrates still lacked tissues. Sponges represent the first organism at this stage of invertebrate evolution.

Tissues

Living cnidarians, such as jellyfish, represent the next stage of invertebrate evolution. This 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.

Radial Symmetry

Another trait that evolved early on was symmetry. To understand symmetry, you need to see an animal that lacks symmetry. A sponge, like the one in **Figure** 17.15 , lacks symmetry. This means it cannot be divided into two identical halves. A symmetrical organism, in contrast, can be divided into two identical halves. Both the coral polyp and the beetle in **Figure** 17.15 have symmetry.

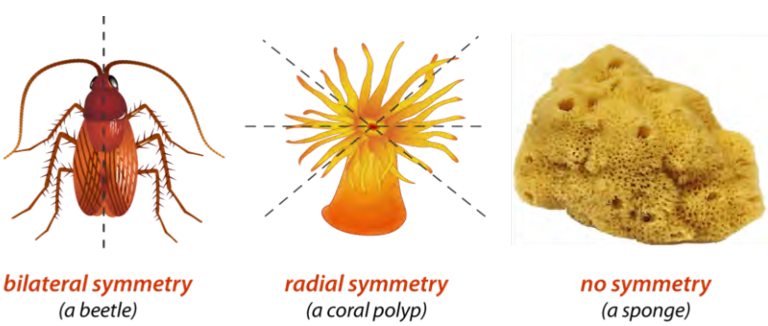


FIGURE 17.15

Symmetry in Invertebrates. Sponges lack symmetry. Radial symmetry evolved first. This was followed by bilateral symmetry. How do the two types of symmetry differ

The coral polyp in **Figure** 17.15 has **radial symmetry.** This was the first type of symmetry to evolve. The coral has a distinct top and bottom but not distinct ends. It can be divided into identical halves like a pie, but not into right and left halves. Animals with radial symmetry have no sense of directions such as forward and backward or left and right. This makes controlled movement in these directions impossible.

Cephalization

Flatworms represent the next stage of invertebrate evolution. They evolved **cephalization.** This is the concentration of nerve tissue at one end of the body, forming a head region. This is highly adaptive. It allows central control of the entire organism. Cephalization was first step in the evolution of a brain.

Bilateral Symmetry

An outcome of cephalization was **bilateral symmetry.** This is demonstrated by the beetle in **Figure** 17.15 . With concentrated nerve tissue at the head but not at the tail end, the two ends of the body are distinct from each other. The animal can be divided down the middle to form identical right and left halves. It allows the animal to tell front from back and left from right. This is needed for controlled movements in these directions.

Mesoderm

Ancestors of flatworms also evolved **mesoderm.** This is a third layer of cells between the ectoderm and the endoderm (see **Figure** 17.16). Evolution of this new cell layer allowed animals to develop new types of tissues, such as muscle.

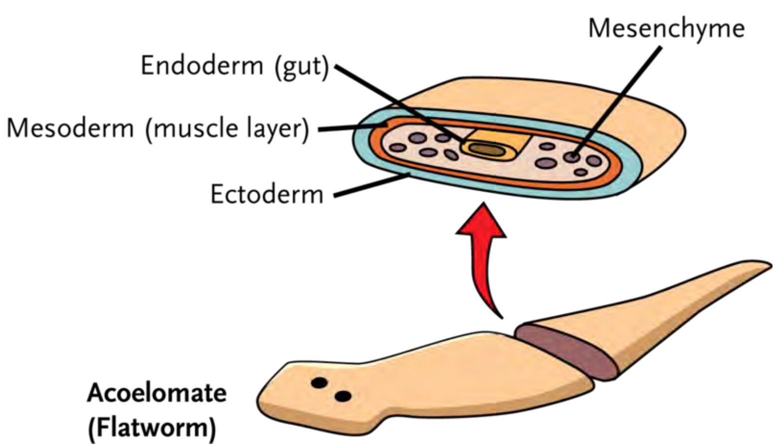


FIGURE 17.16
Three Cell Layers in a Flatworm. A flatworm has three cell layers.

Complete Digestive System

Early invertebrates had an incomplete digestive system. There was just one opening for the mouth and anus. Ancestors of modern roundworms were the first animals to evolve a complete digestive system. 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.

Pseudocoelom and Coelom

Ancestors of roundworms also evolved a **pseudocoelom.** This is a partial body cavity that is filled with fluid. It allows room for internal organs to develop. The fluid also cushions the internal organs. The pressure of the fluid within the cavity provides stiffness. It gives the body internal support, forming a **hydrostatic skeleton.** It explains why roundworms are round and flatworms are flat. Later, a true **coelom** evolved. This is a fluid-filled body cavity, completely enclosed by mesoderm. It lies between the digestive cavity and body wall (see **Figure** 17.17). Invertebrates with a true coelom include mollusks and annelids.

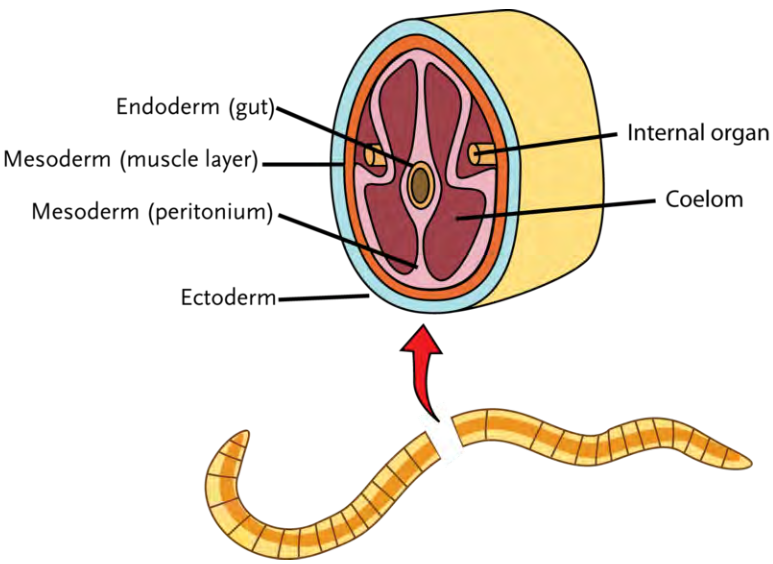


FIGURE 17.17

Cross Section of an Invertebrate with a Coelom. The coelom forms within the mesoderm.

Segmented Body

Segmentation evolved next. This is a division of the body into multiple segments. Both the earthworm and ant pictured in **Figure** 17.18 have segmented bodies. This trait increases flexibility. It permits a wider range of motion. All annelids and arthropods are segmented. Arthropods also evolved jointed appendages. For example, they evolved jointed legs for walking and “feelers” (antennae) for sensing.

FIGURE 17.18

Segmented Invertebrates. Earthworm *Annelid* and Black Ant *Arthropod*. An earthworm consists of many small segments. An ant has three larger segments. Notice the ants jointed legs and &#8220 feelers.&#8221

Notochord

Some invertebrates evolved a notochord. This is the stiff support rod in a chordate. The first chordates were probably similar to modern invertebrate chordates. The sea squirt in **Figure** 17.19 is an example. Later, some invertebrate chordates evolved into vertebrates.

FIGURE 17.19
Notochord. A sea squirt is an invertebrate with a notochord.

Classification of Invertebrates

Eight major phyla contain the majority of invertebrate species.

Major Invertebrate Phyla

Table 17.2 gives an overview of the eight invertebrate phyla with the greatest number of species. The next chapter describes each phylum in greater detail.

TABLE 17.2: **Major Invertebrate Phyla**

Phylum (includes)	Notable Characteristics	Example
Porifera (sponges)	multicellularity, specialized cells but no tissues, asymmetry, incomplete digestive system	sponges
Cnidaria (jellyfish, corals)	radial symmetry, true tissues, incomplete digestive system	jellyfish
Platyhelminthes (flatworms, tapeworms, flukes)	cephalization, bilateral symmetry, mesoderm, complete digestive system	flatworm
Nematoda (roundworms)	pseudocoelom, complete digestive system	roundworm

TABLE 17.2: (continued)

Phylum (includes)	Notable Characteristics	Example
Mollusca (snails, clams, squids)	true coelom, organ systems, some with primitive brain	snail
Annelida (earthworms, leeches, marine worms)	segmented body, primitive brain	earthworm
Arthropoda (insects, spiders, crustaceans, centipedes)	segmented body, jointed appendages, exoskeleton, brain	insect (dragonfly)
Echinodermata (sea stars, sea urchins, sand dollars, sea cucumbers)	complete digestive system, coelom, spiny internal skeleton	sea urchin

Protostomes and Deuterostomes

Most invertebrates (and higher animals) can also be placed in one of two groups based on how they develop as embryos. The two groups are called protostomes and deuterostomes. As shown in **Figure** 17.20 , organisms in the two groups have different ways of forming the coelom and mouth, among other differences.

Mollusks, annelids, and arthropods are protostomes. Echinoderms and chordates are deuterostomes. This distinction is important. Why does it matter? It shows that echinoderms are more closely related to chordates than are the other invertebrate phyla. This is not apparent based on other, more obvious traits.

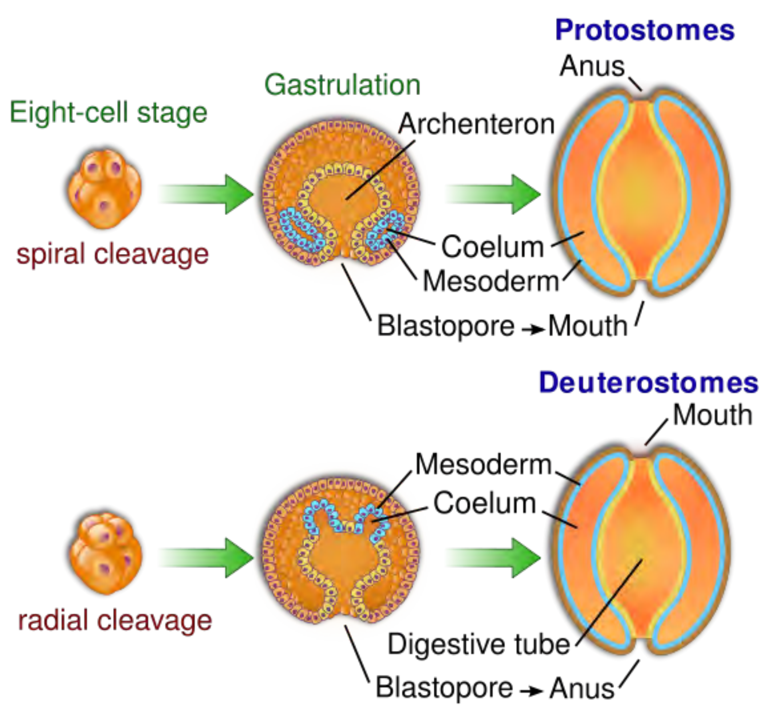


FIGURE 17.20

Protostomes vs. Deuterostomes. In protostomes such as mollusks the coelom forms within the mesoderm. In deuterostomes such as echinoderms the coelom forms from a pouch of endoderm. How does the formation of the mouth differ in these two groups of animals

Lesson Summary

- The majority of living animals are invertebrates. Invertebrates lack a backbone. They may have an incomplete or a complete digestive system. They vary in how they move and in the complexity of their nervous system. Most invertebrates reproduce sexually. After hatching, many invertebrates pass through one or more larval stages that are different from the adult stage.
- Many important traits evolved in invertebrates. They include: multicellularity, tissues and organs, radial and bilateral symmetry, cephalization, mesoderm, complete digestive system, coelom, segmented body, and notochord.
- Eight invertebrate phyla contain most invertebrate species. Invertebrates (and higher animals) can also be placed in one of two groups based on how they develop as embryos.

Lesson Review Questions

Recall

1. Describe the range of variation in the nervous systems of invertebrates.

2. Distinguish among asymmetry, radial symmetry, and bilateral symmetry.

3. Define cephalization. What is its relationship to bilateral symmetry?

4. What is mesoderm? Name an invertebrate with mesoderm.

5. Define coelom. How is the coelom related to the hydrostatic skeleton?

6. What is segmentation? Why is it adaptive?

7. Describe evidence showing that echinoderms are more closely related to chordates than are other invertebrate phyla.

Apply Concepts

8. Create a diagram to show the life cycle of an invertebrate with a larval stage. Include simple sketches of the adult and larval stages of the animal.

9. Assume you have discovered a new invertebrate. It has a segmented body, a brain, and jointed appendages. In which phylum would you place it? Why?

Think Critically

10. Compare and contrast incomplete and complete digestive systems. Why is a complete digestive system more efficient?

11. Explain how invertebrate movement is related to body symmetry.

Points to Consider

This chapter presents an overview of invertebrate phyla. The next chapter describes invertebrate phyla in greater detail.

- What questions do you have about invertebrate phyla now? For example, do you wonder where organisms in the different phyla live or what they eat?
- Invertebrates evolved hundreds of millions of years ago. Which invertebrate phylum do you think has the greatest number of species today?

Chapter 18 From Sponges to Invertebrate Chordates

Chapter Outline

This may look like a scary creature from your worst nightmare, but it wouldn't hurt a fly. In fact, it is a fly! The picture shows the charming portrait of a horsefly, up close and personal. Those big, striped, colorful orbs are its eyes. Did you ever look through a kaleidoscope? If so, then you have an idea of what the world looks like to a horsefly.

What other organs do insects like this horsefly have? Besides sensing their environment, what other functions do their organs serve? In this chapter, you will find out. You will read not only about fly eyes. You'll also read about octopus ink, spider fangs, and other fascinating features of invertebrates.

18.1 Sponges, Cnidarians, Flatworms, and Roundworms

Lesson Objectives

- Describe invertebrates in the phylum Porifera.
- Outline characteristics of cnidarians.
- Give an overview of the platyhelminths.
- Summarize traits of nematode invertebrates.

Vocabulary

Cnidaria invertebrate phylum that includes animals such as jellyfish and corals that are characterized by radial symmetry, tissues, and a stinger called a nematocyst

endoskeleton internal skeleton that provides support and protection

filter feeder animal that obtains organic matter for nutrition by filtering particles out of water

medusa (plural, medusae) basic body plan in cnidarians such as jellyfish that is bell-shaped and typically motile

Nematoda phylum of invertebrates called roundworms, which have a pseudocoelom and complete digestive system

Platyhelminthes invertebrate phylum of flatworms that are characterized by a flat body because they lack a coelom or pseudocoelom

polyp basic body plan in cnidarians such as jellyfish that is tubular in shape and typically sessile

Porifera invertebrate phylum of sponges, which have a non-bony endoskeleton and are sessile as adults

sessile of or relating to an animal that is unable to move from place to place

Introduction

Invertebrates are animals without a backbone. They are the most numerous animals on Earth. Most invertebrates are insects. However, simpler invertebrates evolved before insects. Some—like the sponges you will read about next—have existed virtually unchanged for hundreds of millions of years. Their continued existence is evidence that they are well adapted for their habitats. They also evolved some of the most important traits that are found in almost all animals today. Without the traits that evolved in sponges and other simple invertebrates, you would not exist.

Sponges

Sponges are aquatic invertebrates that make up the phylum **Porifera.** The word *porifera* means pore-bearing. The phylum is aptly named. As you can see from **Figure** 18.1 , a sponge has a porous body. There are at least 5,000 living species of sponges. Almost all of them inhabit the ocean, living mainly on coral reefs or the ocean floor.

FIGURE 18.1
Sponge on a Coral Reef. This orange sponge is covered with pores. Can you predict the function of the pores

Structure and Function of Sponges

Sponges come in a variety of shapes and sizes. For example, they may be shaped like tubes, fans, cones, or just blobs. They range in diameter from about a centimeter (0.4 inches) to over a meter (3.3 feet). Many species live in colonies that may be quite large. Adult sponges are **sessile.** This means they are unable to move from place to place. Root-like projections anchor them to solid surfaces such as rocks and reefs.

Sponges have an internal skeleton that gives them support and protection. An internal skeleton is called an **endoskeleton.** A sponge endoskeleton consists of short, sharp rods called spicules (see **Figure** 18.2). Spicules are made of silica, calcium carbonate, or spongin, a tough protein. They grow from specialized cells in the body of the sponge.

Sponges are **filter feeders.** They pump water into their body through their pores. The water flows through a large central cavity called the spongocoel (see **Figure** 18.2). As the water flows by, specialized collar cells filter out food particles such as bacteria. Collar cells have tiny hairs that trap the particles. They also have a flagellum that whips the water and keeps it moving. Once the food is trapped, the collar cells digest it (see **Figure** 18.3). Cells called amebocytes also help digest the food. They distribute the nutrients to the rest of the body as well. Finally, the water flows back out of the body through an opening called the osculum. As water flows through the sponge, oxygen diffuses from the water to the sponge's cells. The cells also expel wastes into the water for removal through

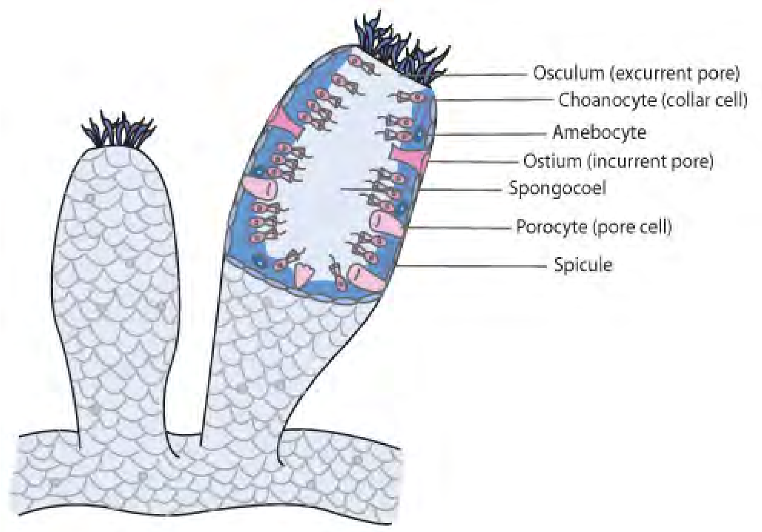


FIGURE 18.2
Sponge Anatomy. A sponge lacks tissues and organs but it has several types of specialized cells.

the osculum.

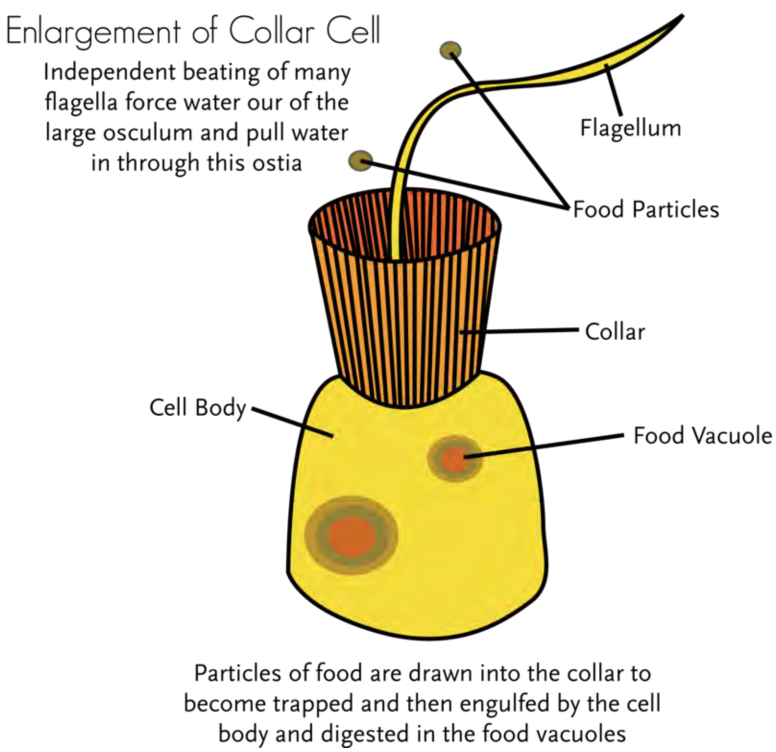


FIGURE 18.3
Collar Cell. The collar cells of sponges trap and digest food.

Sponge Reproduction

Sponges reproduce both asexually and sexually. Asexual reproduction occurs by budding. **Figure** 18.4 shows the sponge life cycle when sexual reproduction is involved. Adult sponges produce eggs and sperm. In many species, the same individuals produce both. However, they don't produce eggs and sperm at the same time. As a result, self-fertilization is unlikely to occur. What is an advantage of avoiding self-fertilization?

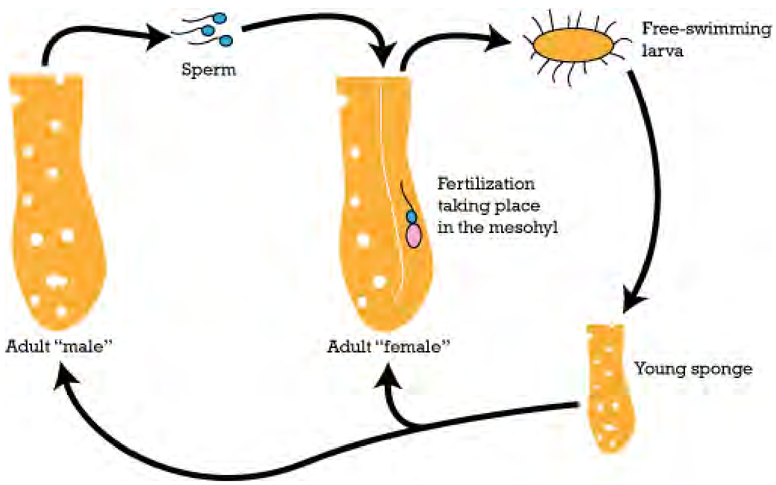


FIGURE 18.4
Sponge Life Cycle. When sponges reproduce sexually they have this life cycle.

Sperm are released into the surrounding water through the osculum. If they enter a female sponge through a pore, they may be trapped by collar cells. Trapped sperm are delivered to eggs inside the female body, where fertilization takes place. The resulting zygote develops into a larva. Unlike the adult, the larva is motile. It is covered with cilia that propel it through the water. As the larva grows, it becomes more similar to an adult sponge and loses its ability to swim.

Ecology of Sponges

Sponges that live on coral reefs have symbiotic relationships with other reef species. They 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 sessile, they cannot flee from predators. 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 the phylum **Cnidaria.** All cnidarians are aquatic. Most of them live in the ocean. Cnidarians are a little more complex than sponges. They have radial symmetry and tissues. There are more than 10,000 cnidarian species. They are very diverse, as shown in **Figure** 18.5 .

Structure and Function of Cnidarians

All cnidarians have something in common. It's a nematocyst, like the one shown in **Figure** 18.6 . A nematocyst is a long, thin, coiled stinger. It has a barb that may inject poison. These tiny poison *darts* are propelled out of special cells. They are used to attack prey or defend against predators.

There are two basic body plans in cnidarians. They are called the polyp and medusa. Both are shown in **Figure** 18.7 . The **polyp** has a tubular body and is usually sessile. The **medusa** (plural, medusae) has a bell-shaped body and is

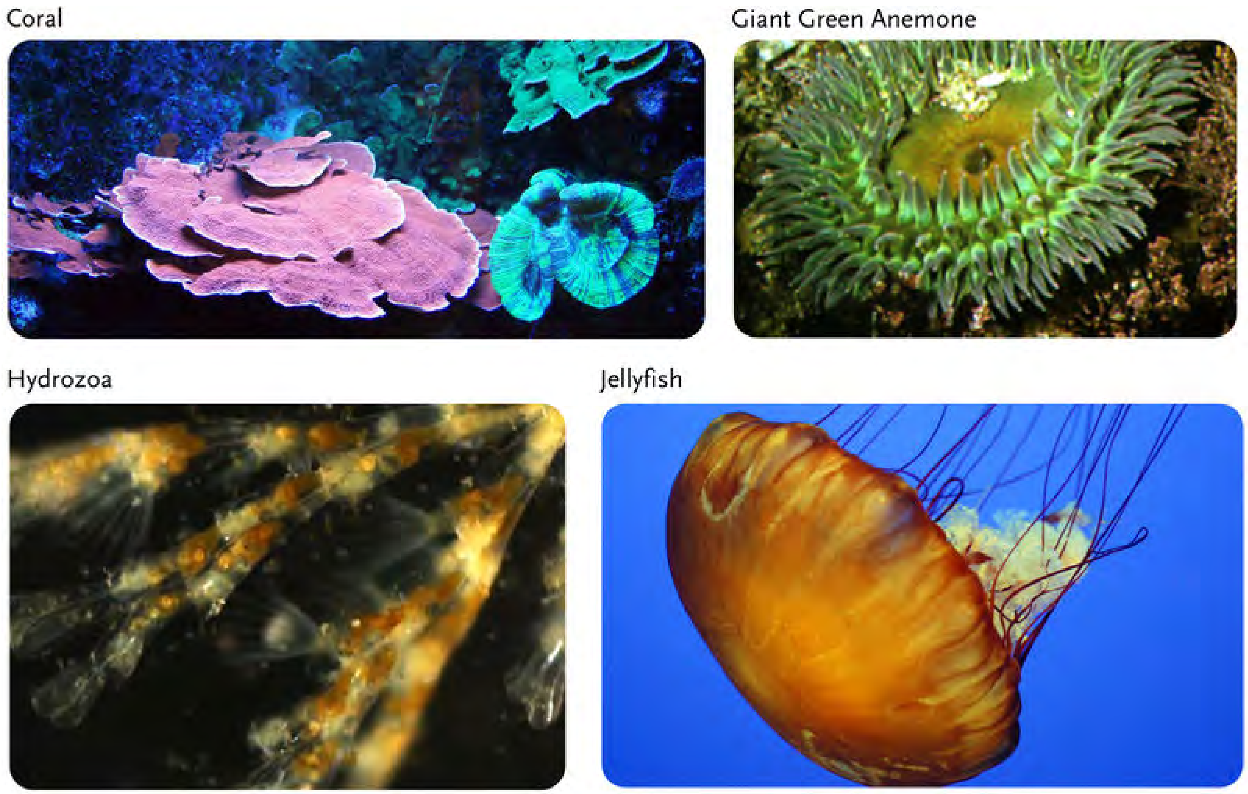


FIGURE 18.5
Cnidarian Diversity. Cnidarians show a lot of variability.

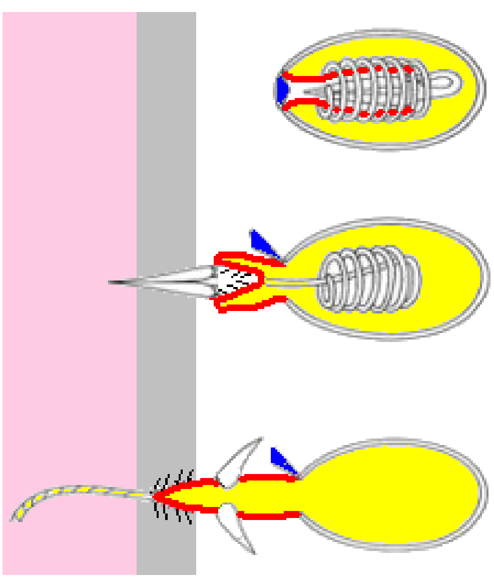


FIGURE 18.6
Cnidarian Nematocyst. A cnidarian nematocyst is like a poison dart. It is ejected from a specialized cell *shown here in yellow*.

typically motile. Some cnidarian species alternate between polyp and medusa forms. Other species exist in just one form or the other.

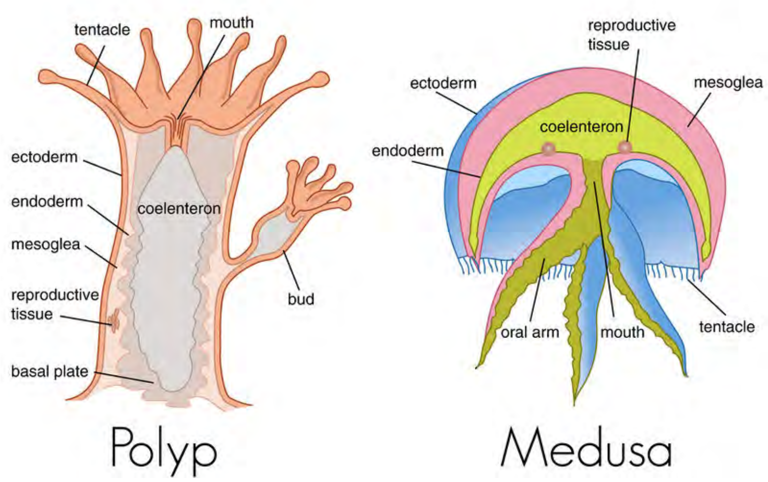


FIGURE 18.7

Cnidarian Body Plans. Cnidarians may exist in the polyp *left* or medusa *right* form.

The body of a cnidarian consists of two cell layers, ectoderm and endoderm. The cells surround a digestive cavity called the coelenteron (see **Figure** 18.8). Cnidarians have a simple digestive system. The single opening is surrounded by tentacles, which are used to capture prey. The tentacles are covered with nematocyst cells. Digestion takes place in the coelenteron. Nutrients are absorbed and gases exchanged through the cells lining this cavity. Fluid in the coelenteron creates a hydrostatic skeleton. Cnidarians have a simple nervous system consisting of a nerve net that can detect touch. They may also have other sensory structures. For example, jellyfish have light-sensing structures and gravity-sensing structures. These senses give them a sense of up versus down. It also helps them balance.

Cnidarian Reproduction

Figure 18.8 shows a general cnidarian life cycle. Polyps usually reproduce asexually. One type of asexual reproduction in polyps leads to the formation of new medusae. Medusae usually reproduce sexually. Sexual reproduction forms a zygote. The zygote develops into a larva called a planula. The planula, in turn, develops into a polyp. There are many variations on the general life cycle. Obviously, species that exist only as polyps or medusae have a life cycle without the other form.

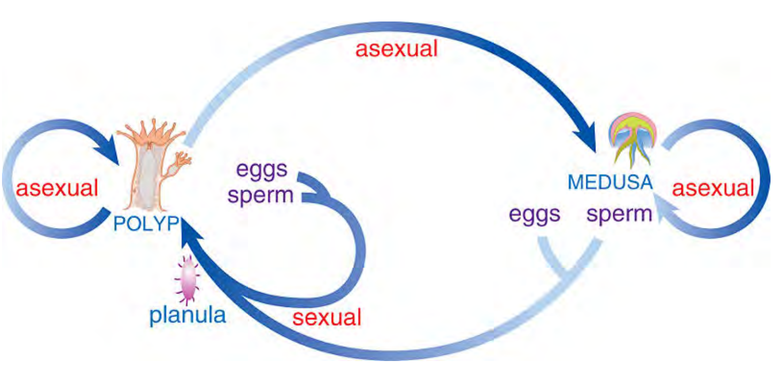


FIGURE 18.8

General Cnidarian Life Cycle. Cnidarians may reproduce both asexually and sexually.

Ecology of Cnidarians

Cnidarians can be found in almost all ocean habitats. They may live in water that is shallow or deep, warm or cold. A few species live in freshwater. Some cnidarians live alone, while others live in colonies. Corals form large colonies in shallow tropical water. They are confined to shallow water because they have a mutualistic relationship with algae that live inside them. The algae need sunlight for photosynthesis, so they must be relatively close to the surface of the water. Corals exist only as polyps. They catch plankton with their tentacles. Many secrete a calcium carbonate exoskeleton. Over time, this builds up to become a coral reef (see **Figure** 18.9). Coral reefs provide food and shelter to many ocean organisms. They also help protect shorelines from erosion by absorbing some of the energy of waves. Coral reefs are at risk of destruction today.

FIGURE 18.9
Great Barrier Reef. The Great Barrier Reef is a coral reef off the coast of Australia.

Unlike corals, jellyfish spend most of their lives as medusae. They live virtually everywhere in the ocean. They are typically carnivores. They prey on zooplankton, other invertebrates, and the eggs and larvae of fish.

KQED: Amazing Jellies

Jellyfish. They are otherworldly creatures that glow in the dark, without brains or bones, some more than 100 feet long. And there are many different types. Jellyfish are free-swimming members of the phylum Cnidaria. Jellyfish are found in every ocean, from the surface to the deep sea. To find out more about jellyfish, see http://www.kqed.org/quest/television/amazing-jellies–siphonophores2.

MEDIA
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Flatworms

Flatworms belong to the phylum **Platyhelminthes.** Examples of flatworms are shown in **Figure** 18.10 . There are more than 25,000 species in the flatworm phylum.

FIGURE 18.10
Platyhelminthes. Platyhelminths include flatworms tapeworms and flukes.

Structure and Function of Flatworms

Flatworms range in length from about 1 millimeter (0.04 inches) to more than 20 meters (66 feet). They have a flat body because they do not have a coelom or even a pseudocoelom. They also lack a respiratory system. Instead, their cells exchange gases by diffusion directly with the environment. Their digestive system is incomplete.

Flatworms reflect several major evolutionary advances in invertebrates. They have three embryonic cell layers, including mesoderm. The mesoderm layer allows them to develop organ systems. For example, they have muscular and excretory systems. The muscular system allows them to move from place to place over solid surfaces. The excretory system lets them maintain a proper balance of water and salts. Flatworms also show cephalization and bilateral symmetry.

Flatworm Reproduction

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, and the life cycle repeats.

Ecology of Flatworms

Both flukes and tapeworms are parasites with vertebrate hosts, including human hosts. Flukes live in the host's circulatory system or liver. Tapeworms live in the host's digestive system. Usually, more than one type of host is required to complete the parasite's life cycle. Look at the life cycle of the liver fluke in **Figure** 18.11 . As an adult, the fluke has a vertebrate host. As a larva, it has an invertebrate host. If you follow the life cycle, you can see how each host becomes infected so the fluke can continue its life cycle.

Tapeworms and flukes have suckers and other structures for feeding on a host. Tapeworms also have a ring of hooks on their head to attach themselves to the host (see **Figure** 18.12). Unlike other invertebrates, tapeworms lack a mouth and digestive system. Instead, they absorb nutrients directly from the host's digestive system with their suckers.

Not all flatworms are parasites. Some are free-living carnivores. They eat other small invertebrates and decaying animals. Most of the free-living species live in aquatic habitats, but some live in moist soil.

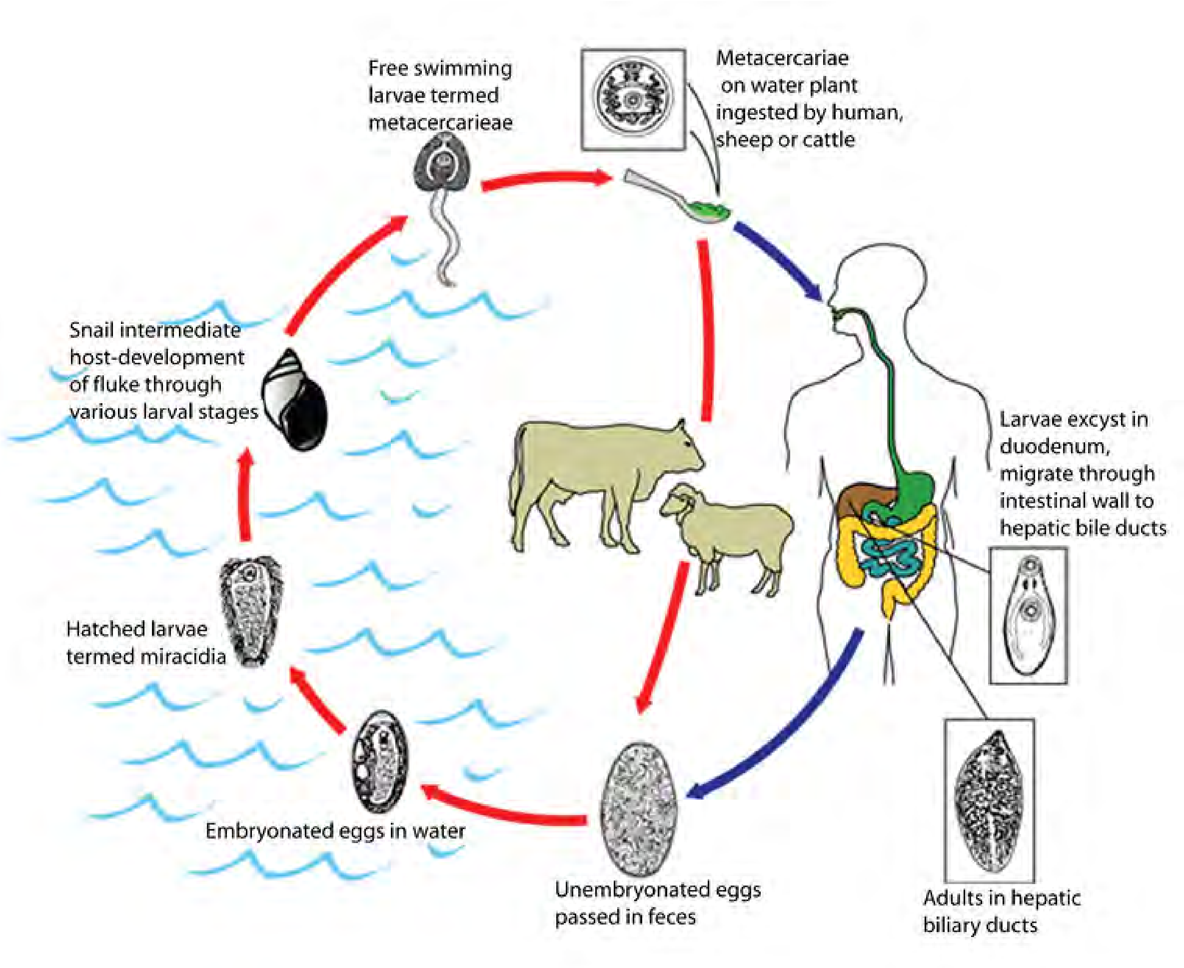

FIGURE 18.11

Life Cycle of the Sheep Liver Fluke. The sheep liver fluke has a complicated life cycle with two hosts. How could such a complicated way of life evolve

FIGURE 18.12

Tapeworm Suckers and Hooks. The head of a tapeworm has several suckers. At the very top of the head is a &#8220 crown&#8221 of hooks called a scolex.

Roundworms

Roundworms make up the phylum **Nematoda.** This is a very diverse animal phyla. It has more than 80,000 known species.

Structure and Function of Roundworms

Roundworms range in length from less than 1 millimeter to over 7 meters (23 feet) in length. As their name suggests, they have a round body. This is because they have a pseudocoelom. This is one way they differ from flatworms. Another way is their complete digestive system. It allows them to take in food, 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 the pseudocoelom. As a result, roundworms have a hydrostatic skeleton. This provides a counterforce for the contraction of muscles lining the pseudocoelom. This allows the worms to move efficiently along solid 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 cycle repeats.

Ecology of Roundworms

Roundworms may be free-living or parasitic. Free-living worms are found mainly in freshwater habitats. Some live in soil. They generally feed on bacteria, fungi, protozoans, or decaying organic matter. By breaking down organic matter, they play an important role in the carbon cycle.

Parasitic roundworms may have plant, vertebrate, or invertebrate hosts. Several species have human hosts. For example, hookworms, like the one in **Figure** 18.13 , are human parasites. They infect the human intestine. They are named for the hooks they use to grab onto the host's tissues. Hookworm larvae enter the host through the skin. They migrate to the intestine, where they mature into adults. Adults lay eggs, which pass out of the host in feces. Then the cycle repeats.

FIGURE 18.13

Hookworm Parasite. Hookworms like this one are common human parasites.

Tiny pinworms are the most common roundworm parasites of people in the U.S. In some areas, as many as one out of three children are infected. Humans become infected when they ingest the nearly microscopic pinworm eggs. The eggs hatch and develop into adults in the host's digestive tract. Adults lay eggs that pass out of the host's body to continue the cycle. Pinworms have a fairly simple life cycle with only one host.

Lesson Summary

- Sponges are aquatic invertebrates. They make up the phylum Porifera. Sponges have specialized cells and an endoskeleton. They lack tissues and body symmetry. Adult sponges are sessile filter feeders. Sponge larvae have cilia for swimming.
- Cnidarians include jellyfish and corals. They are aquatic invertebrates. They have tissues and radial symmetry. They also have tentacles with stingers. There are two cnidarian body plans: the polyp and the medusa. They differ in several ways. Many corals secrete an exoskeleton that builds up to become a coral reef.
- Platyhelminths are flatworms such as tapeworms and flukes. They have a mesoderm cell layer and simple

organ systems. They also show cephalization and bilateral symmetry. Many flatworms are parasites with vertebrate hosts. Some are free-living carnivores that live mainly in aquatic habitats.
- Roundworms make up the phylum Nematoda. They have a pseudocoelom and hydrostatic skeleton. Their body is covered with tough cuticle. Free-living roundworms are found mainly in freshwater habitats. Parasitic roundworms have a variety of hosts, including humans.

Lesson Review Questions

Recall

1. Define sessile. Name an invertebrate with a sessile adult stage.

2. Describe the skeleton of a sponge.

3. Sponges have specialized cells called collar cells. Describe how collar cells are specialized for the functions they serve.

4. What is a nematocyst? What is its function?

5. How do coral reefs form?

6. Describe specialized feeding structures of parasitic platyhelminths.

7. How do free-living nematodes contribute to the carbon cycle?

Apply Concepts

8. Create a diagram of an adult sponge body plan that shows how sponges obtain food.

9. Apply what you know about pinworms to develop one or more recommendations for preventing pinworm infections in humans.

Think Critically

10. Compare and contrast cnidarian polyps and medusae.

11. Platyhelminths and nematodes are both worms. Justify classifying them in different invertebrate phyla.

12. Some parasitic flatworms have a very complicated life cycle with more than one host. Infer why this might be adaptive.

Points to Consider

In this lesson, you read about flatworms and roundworms. In the next lesson, you'll read about worms called annelids. Mollusks such as snails are also described in the next lesson.

- How are annelids different from flatworms and roundworms?
- Why do you think annelids are placed in a lesson with mollusks instead of with flatworms and roundworms?

18.2 Mollusks and Annelids

Lesson Objectives

- Describe invertebrates in the phylum Mollusca.
- Summarize the characteristics of annelids.

Vocabulary

Annelida invertebrate phylum of segmented worms such as earthworms

deposit feeder animal that obtains organic matter for nutrition by eating soil or the sediments at the bottom of a body of water

gills organs in aquatic organisms composed of thin filaments that absorb oxygen from water

heart muscular organ in the chest that that pumps blood through blood vessels when it contracts

mantle layer of tissue that lies between the shell and body of a mollusk and forms a cavity, called the mantle cavity, that pumps water for filter feeding

Mollusca phylum of invertebrates that are generally characterized by a hard outer shell, a mantle, and a feeding organ called a radula

regeneration regrowing of tissues, organs, or limbs that have been lost or damaged

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 probably have encountered members of the phylum **Mollusca.** Mollusks include snails, scallops, and squids, as shown in **Figure** 18.14 . There are more than 100,000 known species of mollusks. About 80 percent of mollusk species are gastropods.

FIGURE 18.14
This figure shows some of the more common and familiar mollusks.

Structure and Function of Mollusks

Mollusks are a very diverse phylum. Some mollusks are nearly microscopic. The largest mollusk, a colossal squid, may be as long as a school bus and weigh over half a ton! The basic body plan of a mollusk is shown in **Figure** 18.15 . The main distinguishing feature is a hard outer shell. It 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. There is generally a muscular foot, which may be used for walking. However, the foot has evolved modifications in many species to be used for other purposes.

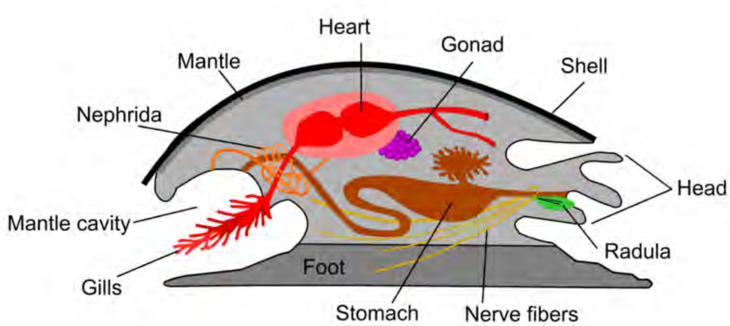

FIGURE 18.15
Basic Mollusk Body Plan. The basic body plan shown here varies among mollusk classes. For example several mollusk species no longer have shells. Do you know which ones

Two unique features of mollusks are the mantle and radula (see **Figure** 18.15). The **mantle** is a layer of tissue that lies between the shell and the body. It secretes calcium carbonate to form the shell. It forms a cavity, called the mantle cavity, between the mantle and the body. The mantle cavity pumps water for filter feeding. The radula is a feeding organ with teeth made of chitin. It is located in front of the mouth in the head region. Herbivorous mollusks use the radula to scrape food such as algae off rocks. Predatory mollusks use the radula to drill holes in the shells of their prey.

Mollusks have a coelom and a complete digestive system. Their excretory system consists of tube-shaped organs called nephridia (see **Figure** 18.15). The organs filter waste from body fluids and release the waste into the coelom. Terrestrial mollusks exchange gases with the surrounding air. This occurs across the lining of the mantle cavity. Aquatic mollusks "breathe" under water with gills. **Gills** are thin filaments that absorb gases and exchange them between the blood and surrounding water. Mollusks have a circulatory system with one or two hearts that pump blood. The **heart** is a muscular organ that pumps blood through the circulatory system when its muscles contract.

The circulatory system may be open or closed, depending on the species.

The major classes of mollusks vary in structure and function. You can read about some of their differences in **Figure** 18.16 .

FIGURE 18.16

Use this figure to compare and contrast gastropods bivalves and cephalopods

Mollusk Reproduction

Mollusks reproduce sexually. Most species have separate male and female sexes. Gametes are released into the mantle cavity. 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. Mollusks (and annelids) have a unique larval form called a trochophore. It is a tiny organism with cilia for swimming.

Ecology of Mollusks

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. Mollusks are a major food source for other organisms, including humans. You may have eaten mollusks such as clams, oysters, scallops, or mussels. The different classes of mollusks have different ways of obtaining food.

- Gastropods are may be herbivores, predators, or internal parasites. They live in both aquatic and terrestrial habitats. Marine species live mainly in shallow coastal waters. Gastropods use their foot to crawl slowly over rocks, reefs, or soil, looking for food.
- Bivalves are generally sessile filter feeders. They live in both freshwater and marine habitats. They use their foot to attach themselves to rocks or reefs or to burrow into mud. Bivalves feed on plankton and nonliving organic matter. They filter the food out of the water as it flows through their mantle cavity.
- Cephalopods are carnivores that live only in marine habitats. They may be found in the open ocean or close to shore. They are either predators or scavengers. They generally eat other invertebrates and fish.

KQED: Cool Critters: Dwarf Cuttlefish

What's the coolest critter in the ocean under 4 inches long? The Dwarf Cuttlefish! Cuttlefish are marine animals that belong to the class Cephalopoda. Despite their name, cuttlefish are not fish but molluscs. Recent studies indicate that cuttlefish are among the most intelligent invertebrates, with one of the largest brain-to-body size ratios of all invertebrates. Cuttlefish have an internal shell called the cuttlebone and eight arms and two tentacles furnished with denticulated suckers, with which they secure their prey. For more information on the cuttlefish, see http://www.kqed.org/quest/television/cool-critters-dwarf-cuttlefish.

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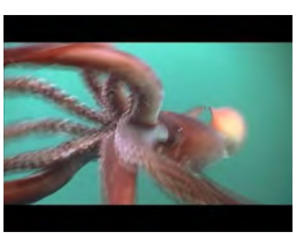
KQED: The Fierce Humboldt Squid

The Humboldt squid is a large, predatory invertebrate found in the waters of the Pacific Ocean. A mysterious sea creature up to 7 feet long, with 10 arms, a sharp beak and a ravenous appetite, packs of fierce Humboldt Squid attack nearly everything they see, from fish to scuba divers. Traveling in groups of 1,000 or more and swimming at speeds of more than 15 miles an hour, these animals hunt and feed together, and use jet propulsion to shoot out of the water to escape predators. Humboldt squid live at depths of between 600 and about 2,000 feet, coming to the surface at night to feed. They live for approximately two years and spend much of their short life in the ocean's oxygen-minimum zone, where very little other life exists. Because they live at such depths, little is known about these mysterious sea creatures. The Humboldt squid usually lives in the waters of the Humboldt Current, ranging from the southern tip of South America north to California, but in recent years, this squid has been found as far north as Alaska. Marine biologists are working to discover why they have headed north from their traditional homes off South America. See http://www.kqed.org/quest/television/the-fierce-humboldt-squid for additional information.



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Where's the Octopus?

When marine biologist Roger Hanlon captured the first scene in this video he started screaming. Hanlon, senior scientist at the Marine Biological Laboratory in Woods Hole, studies camouflage in cephalopods–squid, cuttlefish and octopus. They are masters of optical illusion. The video at http://www.sciencefriday.com/videos/watch/10397 shows some of Hanlon's top video picks of sea creatures going in and out of hiding.

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Annelids

The phylum **Annelida** is made up of segmented worms such as earthworms. Segmented worms are divided into many repeating segments. There are roughly 15,000 species of annelids. Most belong to one of three classes. A species in each class is pictured in **Figure** 18.17 .

FIGURE 18.17

Classes of Annelids. The majority of annelids are polychaetes. They live on the ocean floor so you may not be familiar with them.

Structure and Function of Annelids

Annelids range in length from less than 1 millimeter to over 3 meters. They never attain the large size of some mollusks. Like mollusks, however, they have a coelom. In fact, the annelid coelom is even larger, allowing greater development of internal organs. Annelids have other similarities with mollusks, including:

- A closed circulatory system (like cephalopods).

- An excretory system consisting of tubular nephridia.
- A complete digestive system.
- A brain.
- Sensory organs for detecting light and other stimuli.
- Gills for gas exchange (but many exchange gas through their skin).

The segmentation of annelids is highly adaptive. For one thing, it allows more efficient movement. Each segment generally has its own nerve and muscle tissues. Thus, localized muscle contractions can move just those segments needed for a particular motion. Segmentation also allows an animal to have specialized segments to carry out particular functions. This allows the whole animal to be more efficient. Annelids have the amazing capacity to regrow segments that break off. This is called **regeneration.**

Annelids have a variety of structures on the surface of their body for movement and other functions. These vary, depending on the species. Several of the structures are described in **Figure** 18.18 .

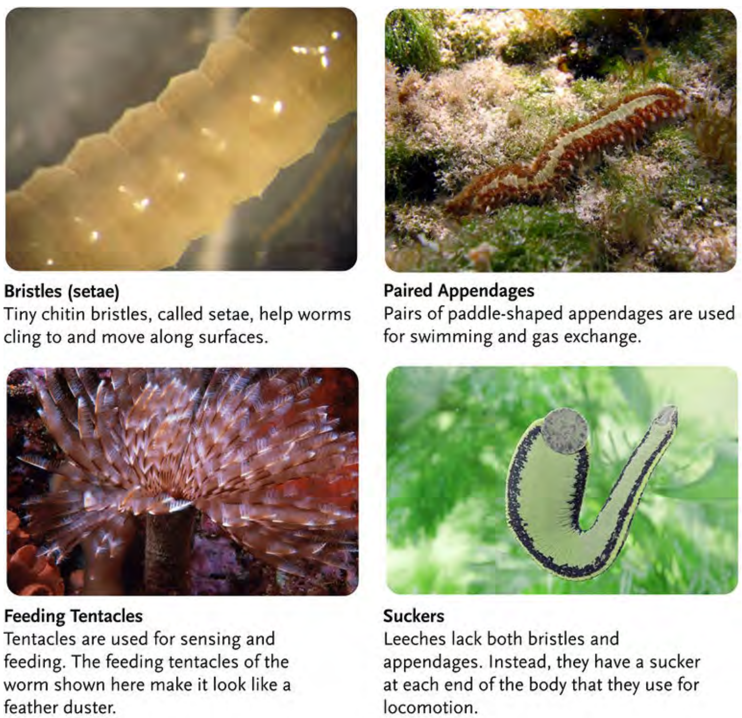

FIGURE 18.18

Annelid External Structures. Many annelids have bristles and other types of external structures. Each structure is not present in all species.

Annelid Reproduction

Most species of annelids can reproduce both asexually and sexually. However, leeches can reproduce only sexually. Asexual reproduction may occur by budding or fission. Sexual reproduction varies by species.

- In some species, the same individual produces both sperm and eggs. But worms mate to exchange sperm, rather than self-fertilizing their own eggs. Fertilized eggs are deposited in a mucous cocoon. Offspring emerge from the cocoon looking like small adults. They grow to adult size without going through a larval stage.
- In polychaete species, there are separate sexes. Adult worms go through a major transformation to develop reproductive organs. This occurs in many adults at once. Then they all swim to the surface and release their gametes in the water, where fertilization takes place. Offspring go through a larval stage before developing into adults.

Ecology of Annelids

Annelids live in a diversity of freshwater, marine, and terrestrial habitats. They vary in what they feed on and how they obtain their food.

- Earthworms are **deposit feeders.** They burrow through the ground, eating soil and extracting organic matter from it. Earthworm feces, called worm casts, are very rich in plant nutrients. Earthworm burrows help aerate soil, which is also good for plants.
- Polychaete worms live on the ocean floor. They may be sedentary filter feeders or active predators or scavengers. Active species crawl along the ocean floor in search of food.
- Leeches are either predators or parasites. As predators, they capture and eat other invertebrates. As parasites, they feed off the blood of vertebrate hosts. They have a tubular organ, called a proboscis, for feeding.

Lesson Summary

- Mollusks are invertebrates such as snails, scallops, and squids. They have a hard outer shell. There is a layer of tissue called the mantle between the shell and the body. Most mollusks have tentacles for feeding and sensing, and many have a muscular foot. Mollusks also have a coelom, a complete digestive system, and specialized organs for excretion. The majority of mollusks live in the ocean. Different classes of mollusks have different ways of obtaining food.
- Annelids are segmented worms such as earthworms and leeches. Annelids have a coelom, closed circulatory system, excretory system, and complete digestive system. They also have a brain. Earthworms are important deposit feeders that help form and enrich soil. Leeches are either predators or parasites. Parasitic leeches feed off the blood of vertebrate hosts.

Lesson Review Questions

Recall

1. Describe the basic body plan of a mollusk.

2. What are gills? What is their function?

3. What is the difference between an open and a closed circulatory system?

4. What is a radula? What is it used for?

5. Define regeneration.

Apply Concepts

6. Create a Venn diagram to show important similarities and differences among the three major classes of mollusks.

Think Critically

7. Explain the advantages of a segmented body.

8. Polychaete worms have an interesting reproductive strategy. Describe this strategy and infer its adaptive significance.

Points to Consider

Most invertebrates you have read about so far live in aquatic habitats. Many of those that are not aquatic live inside other organisms as parasites. In the next lesson you will read about invertebrates that live mainly on land. They are the arthropods, such as insects.

- Compared with aquatic invertebrates, what challenges do you think terrestrial invertebrates might face?
- How might terrestrial invertebrates meet these challenges? What special tissues, organs, or appendages might they have evolved to adapt to life on land?

18.3 Arthropods and Insects

Lesson Objectives

- Give an overview of the phylum Arthropoda.
- Outline the characteristics and importance of insects.

Vocabulary

arthropod invertebrate in the phylum Arthropoda, characterized by a segmented body, hard exoskeleton, and jointed appendages

metamorphosis process in which a larva undergoes a major transformation to change into the adult form, which occurs in amphibians, arthropods, and other invertebrates

molting process in which an animal sheds and replaces the outer covering of the body, such as the exoskeleton in arthropods

pupa life cycle stage of many insects that occurs between the larval and adult stages and during which the insect is immobile, may be encased within a cocoon, and changes into the adult form

trilobite oldest known arthropod, which is now extinct and known only from numerous fossils

Introduction

Arthropods are not only the largest phylum of invertebrates. They are by far the largest phylum of the animal kingdom. Some 80 percent of all species living on Earth today are arthropods. Obviously, arthropods have been extremely successful. What accounts for their success? In this lesson, you will find out.

Arthropods

There are more than a million known species of arthropods. There may actually be ten times that many. Arthropods include insects, spiders, lobsters, and centipedes. The arthropods pictured in **Figure** 18.19 give just a hint of the phylum's diversity.

FIGURE 18.19

Arthropod Diversity. Dust mites are among the smallest of arthropods. Japanese spider crabs are the largest. Besides size what other differences among arthropods do you see in these photos

Structure and Function of Arthropods

Arthropods range in length from about 1 millimeter to 4 meters (about 13 feet). They have a segmented body with a hard exoskeleton. They also have jointed appendages. The body segments are the head, thorax, and abdomen (see **Figure** 18.20). In some arthropods, the head and thorax are joined together as a cephalothorax.

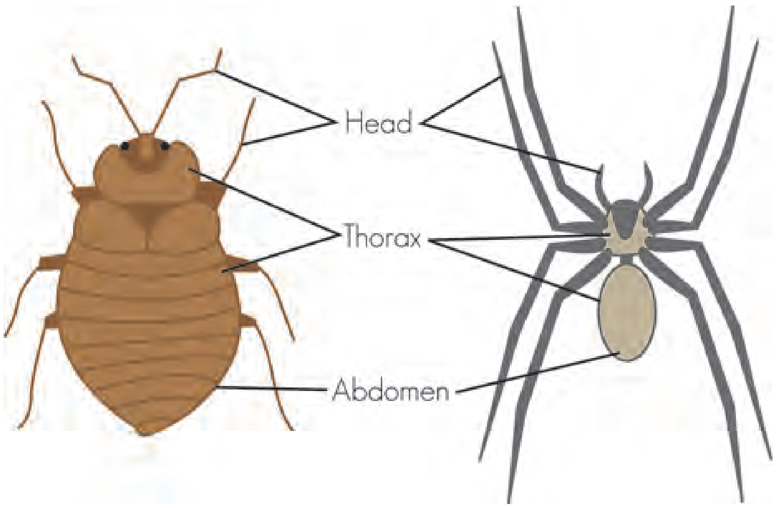

FIGURE 18.20
Arthropod Body Plan. The honeybee shows the general body plan of an arthropod.

The arthropod exoskeleton consists of several layers of cuticle. The exoskeleton prevents water loss and gives support and protection. It also acts as a counterforce for the contraction of muscles. The exoskeleton doesn't grow as the animal grows. Therefore, it must be shed and replaced with a new one periodically through life. This is called **molting**. The jointed appendages of arthropods may be used as legs for walking. Being jointed makes them more flexible. Try walking or climbing stairs without bending your knees, and you'll see why joints are helpful. In most arthropods, the appendages on the head have been modified for other functions. **Figure** 18.21 shows some of head appendages found in arthropods. Sensory organs such as eyes are also found on the head.

Some arthropods have special excretory structures. They are called coxal glands and Malphigian tubules. Coxal glands collect and concentrate liquid waste from blood. They excrete the waste from the body through a pore. Malphigian tubules carry waste from the digestive tract to the anus. The waste is excreted through the anus.

Like mollusks and annelids, aquatic arthropods may have gills to exchange gases with the water (discussed below). Terrestrial arthropods, on the other hand, have special respiratory structures to exchange gases with the air. These are described in **Figure** 18.22 .

Underwater Spiders

In the ponds of northern Europe lives a tiny brown spider that spends its entire life underwater. But just like land spiders, it needs oxygen to breathe. So, how does this spider breath? Does it use book lungs? No. In fact, aquatic spiders, known as *diving bell spiders*, have gills, and every so often, the spider leaves its underwater web to visit the surface and bring back a bubble of air that sticks to its hairy abdomen. It deposits the bubble into a little silk air tank. This *diving bell,* is a gill that sucks oxygen from the water, allowing the spider to stay underwater for up to 24 hours. See http://news.sciencemag.org/sciencenow/2011/06/spiders.html?ref=hp for additional information and additional pictures. http://www.youtube.com/watch?v=GidrcvjoeKE shows these spiders in action.

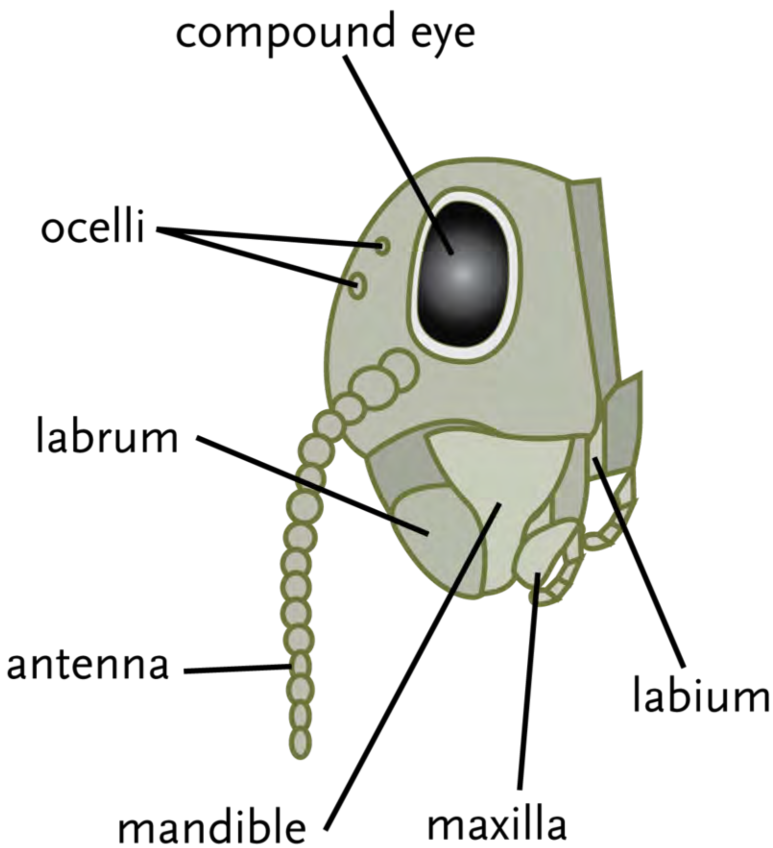

FIGURE 18.21

Arthropod Head. Arthropods have evolved a variety of specialized appendages and other structures on their head.

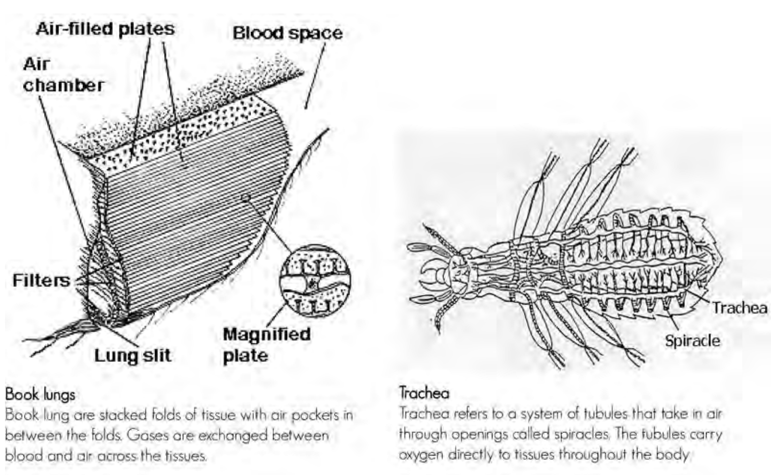

FIGURE 18.22

How Terrestrial Arthropods Breathe Air. Terrestrial arthropods have respiratory structures that let them breathe air.

FIGURE 18.23
A pair of diving bell *water* spiders.

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Arthropod Reproduction

Arthropods have a life cycle with sexual reproduction. Most species go through larval stages after hatching. The larvae are very different from the adults. They change into the adult form in a process called **metamorphosis**. This may take place within a cocoon. A familiar example of metamorphosis is the transformation of a caterpillar (larva) into a butterfly (adult). Other arthropod species, in contrast, hatch young that look like small adults. These species lack both larval stages and metamorphosis.

Evolution of Arthropods

The oldest known arthropods are **trilobites**. A fossil trilobite is shown in **Figure** 18.24 . Trilobites were marine arthropods. They had many segments with paired appendages for walking. As arthropods continued to evolve, segments fused. Eventually, arthropods with three major segments evolved. Appendages were also lost or modified during the course of arthropod evolution.

Arthropods were the first animals to live on land. The earliest terrestrial arthropods were probably millipedes. They moved to land about 430 million years ago. Early land arthropods evolved adaptations such as book lungs or trachea to breathe air. The exoskeleton was another important adaptation. It prevents an animal from drying out. It also provides support in the absence of buoyant water.

FIGURE 18.24

Trilobite Fossil. This trilobite fossil represents the earliest arthropods. Trilobites first appeared more than 500 million years ago. They lived for at least 200 million years before going extinct. They left behind large numbers of fossils.

Classification of Arthropods

Living arthropods are divided into four subphyla. They are described in **Table** 18.1 . The Hexapoda subphylum includes mainly insects. There are so many insects and they are so important that they are described in greater detail below.

TABLE 18.1: Classification of Living Arthropods

Subphylum (includes)	Description	Example
Myriapoda (centipedes, millipedes)	terrestrial; herbivores or predators; 10–400 walking legs; poison claws for hunting	centipede 
Chelicerata (spiders, scorpions, mites, ticks, horseshoe crabs, sea spiders)	mainly terrestrial; predators or parasites; 8 walking legs; appendages called chelicerae for grasping prey; poison fangs for killing prey; no mandibles, maxillae, antennae; two body segments	spider 
Crustacea (lobsters, crabs, shrimp, barnacles, krill)	mainly aquatic, predators, scavengers, or filter feeders; two pairs of antennae and claws for hunting; unique larval stage (called "nauplius") with head appendages for swimming	lobster 

TABLE 18.1: (continued)

Subphylum (includes)	Description	Example
Hexapoda (ants, flies, grasshoppers, beetles, butterflies, moths, bees, springtails)	mainly terrestrial or aerial; herbivores, predators, parasites, scavengers, or decomposers; 6 walking legs; many modified appendages, such as wings for flying	beetle 

Insects

Most members of the subphylum Hexapoda 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, most of them yet to be identified. It's clear that insects, and not humans, dominate life on Earth.

Structure and Function of Insects

Insects range in length from less than a millimeter to about the length of your arm. They can be found in most habitats, but they are mainly terrestrial. Many can fly, so they are also aerial. Like other arthropods, insects have a head, thorax, and abdomen. They have a wide variety of appendages, including six legs attached to the thorax. Insects have a pair of antennae for "smelling" and "tasting" chemicals. Some insects can also use their antennae to detect sound. Other sensory organs on the head include several simple eyes and a pair of compound eyes. The compound eyes let insects see images. Butterflies and bees can even see in color. For feeding, the head contains one pair of mandibles and two pairs of maxillae. Insects consume a wide range of foods, and their mouthparts have become specialized. Several variations are shown in **Figure** 18.25 .

An insect's abdomen contains most of the internal organs. Like other arthropods, insects have a complete digestive system. They also have an open circulatory system and central nervous system. Like other terrestrial arthropods, they have trachea for breathing air and Malphigian tubules for excretion.

Insect Flight

The main reason that insects have been so successful is their ability to fly. Insects are the only invertebrates that can fly and the first animals to evolve flight. Flight has important advantages. It's a guaranteed means of escape from nonflying predators. It also aids in the search for food and mates. Insects generally have two pairs of wings for flight. Wings are part of the exoskeleton and attached to the thorax. Insect wings show a lot of variation. As you can see in **Figure** 18.26 , butterfly wings are paper-thin, whereas beetle wings are like armor. Not all insect wings work the same way, either. They differ in how the muscles are attached and whether the two pairs of wings work independently or together. Besides flight, wings serve other functions. They may protect the body (beetles), communicate visually with other insects (butterflies), or produce sounds to attract mates (katydids).

Insect Reproduction

Nearly all insects reproduce sexually. Some can also reproduce asexually. An example of an insect life cycle is shown in **Figure** 18.27 .

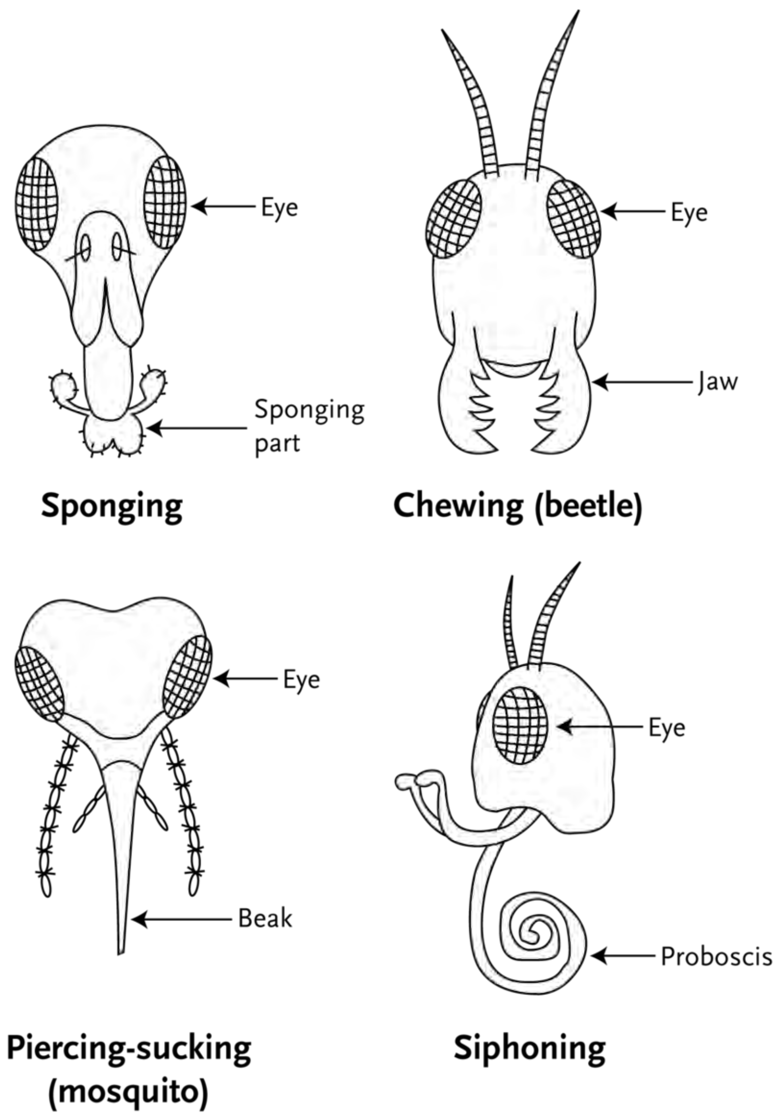


FIGURE 18.25

Mouthpart Specialization in Insects. The mouthparts of insects are adapted for different food sources. How do you think the different mouthparts evolved

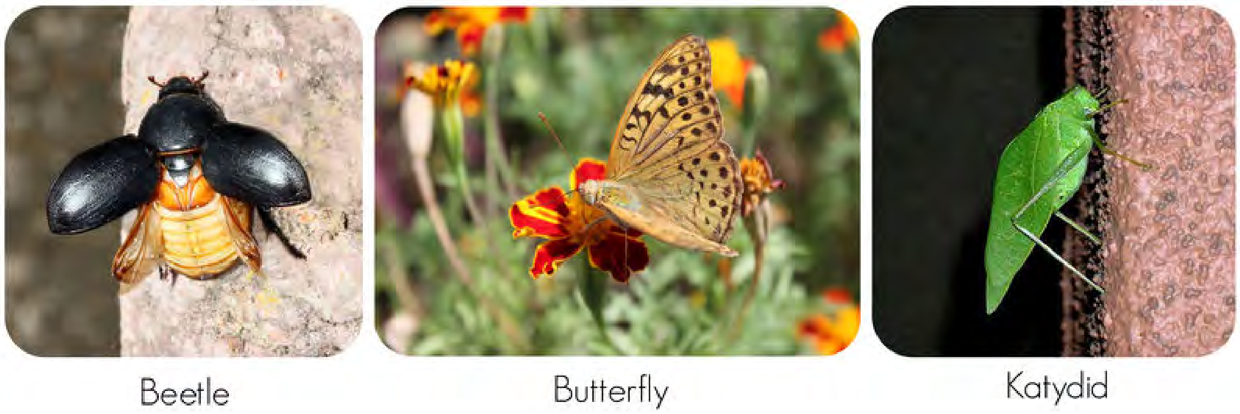


FIGURE 18.26
Form and Function in Insect Wings. Beetles butterflies and katydids all have two pairs of wings that they use for flight. However the wings are very different because they have other functions as well.

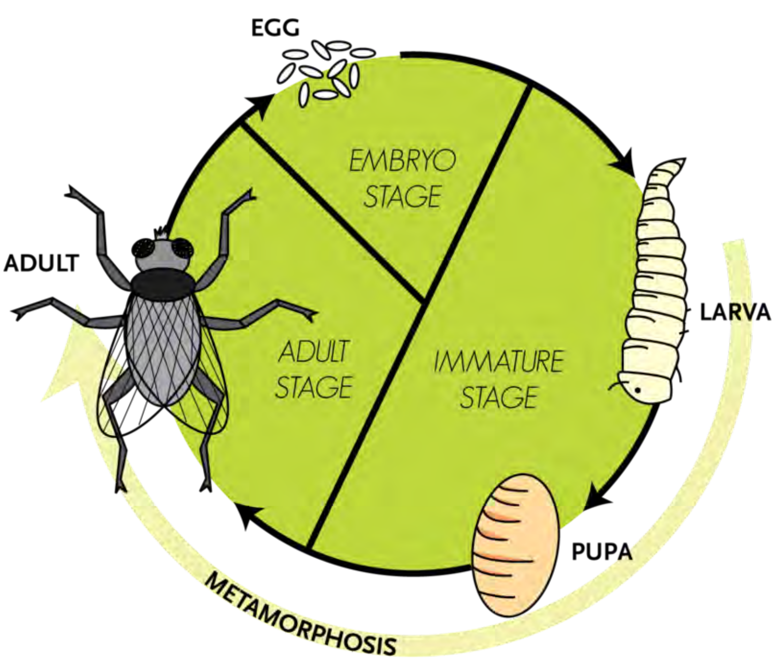


FIGURE 18.27
Insect Life Cycle. This diagram represents the life cycle of a fly. Most insects have a similar life cycle.

When an insect egg hatches, a larva emerges. The larva eats and grows and then enters the pupa stage. The **pupa** is immobile and may be encased in a cocoon. During the pupa stage, the insect goes through metamorphosis. Tissues and appendages of the larva break down and reorganize into the adult form. How did such an incredible transformation evolve? Metamorphosis is actually very advantageous. It allows functions to be divided between life stages. Each stage can evolve adaptations to suit it for its specific functions without affecting the adaptations of the other stage.

Insect Behavior

Insects are capable of a surprising range of behaviors. Most of their behaviors, such as flying and mating, are instinctive. These are behaviors that don't need to be learned. They are largely controlled by genes. However, some insect behaviors are learned. For example, ants and bees can learn where food is located and keep going back for more.

Many species of insects have evolved complex social behaviors. They live together in large, organized colonies (see **Figure** 18.28). This is true of ants, termites, bees, and wasps. Colonies may include millions of individual insects. Colony members divide up the labor of the colony. Different insects are specialized for different jobs. Some reproduce, while others care for the young. Still others get food or defend the nest.

FIGURE 18.28

Termite Nest. This cathedral-like structure is the nest of a huge colony of termites in Australia. In fact it is the world&#8217 s largest known termite nest. It towers 7.5 meters 25 $feet$ above the ground and houses millions of termites.

Living in a large colony requires good communication. Ants communicate with chemicals called pheromones. For example, an ant deposits pheromones on the ground as it returns to the nest from a food source. It is marking the path so other ants can find the food. Honeybees communicate by doing a "waggle dance."

KQED: Ants: The Invisible Majority

Most of us think ants are just pests. But not Brian Fisher. Known as "The Ant Guy," he's on a mission to show the world just how important and amazing these little creatures are and in the process, catalog all of the world's 30,000 ant species before they become casualties of habitat loss. See http://www.kqed.org/quest/television/ants-the-invisible-majority2 for more information.

MEDIA

Click image to the left for more content.

KQED: Landbugs: A Population of Millions

Ladybugs, also known as ladybird beetles, have a life cycle of four to six weeks. In one year as many as six generations of ladybird beetles may hatch. In the spring, each adult female lays up to 300 eggs in small clusters on plants where aphids are present. After a week the wingless larvae hatch. Both the ladybird beetle larvae and adults are active predators, eating only aphids, scales, mites and other plant-eating insects. The ladybugs live on the vegetation where their prey is found, which includes roses, oleander, milkweed and broccoli. Adult ladybugs don't taste very good. A bird careless enough to try to eat one will not swallow it.

By late May to early June, when the larvae have depleted the food supply, the adults migrate to the mountains. There, they eat mainly pollen. The ladybugs gain fat from eating the pollen and this tides them over their nine-month hibernation. Thousands of adults hibernate overwinter in tight clusters, called aggregates, under fallen leaves and ground litter near streams. In the clear, warmer days of early spring, the ladybugs break up the aggregates and begin several days of mating. Learn about ladybugs at http://www.kqed.org/quest/television/ladybug-pajama-party.

Insects and Humans

Most humans interact with insects every day. Many of these interactions are harmless and often go unnoticed. However, insects cause humans a lot of harm. They spread human diseases. For example, the deadly bubonic plague of the middle ages was spread by fleas. Today, millions of people die each year from malaria, which is spread by mosquitoes. Insects also eat our crops. Sometimes they travel in huge swarms that completely strip the land of all plant material (see **Figure** 18.29). On the other hand, we depend on insects for the very food we eat. Without insects to pollinate them, flowering plants—including many food crops—could not reproduce.

FIGURE 18.29

Locust Swarm. A swarm of locusts in the African country of Mauritania darkens the mid-day sky. The hungry insects will eat virtually all the plants in their path.

KQED: Better Bees: Super Bee and Wild Bee

Honeybees are one of the most well-known insects on the planet. Bees are naturalized on every continent except Antarctica. Honeybees have a highly developed social structure and depend on their community, or colony, for survival, with a colony containing up to 20,000 bees. When bees search plants for nectar, pollen sticks to the fuzzy hairs that cover their hind legs. At the next flower, some of the pollen rubs off and fertilizes that flower. In this way, bees help improve fruit production. Bees pollinate an estimated 130 different varieties of fruit, flowers, nuts and vegetables in the United States alone. Farmers obviously depend on bees to pollinate crops, such as fruit and nuts, but in recent years thousands of bee colonies have disappeared. This could be a devastating issue for farmers. Can anything be done? Meet two Northern California researchers looking for ways to make sure we always have bees to pollinate our crops at http://www.kqed.org/quest/television/better-bees-super-bee-and-wild-bee.

MEDIA

Click image to the left for more content.

Lesson Summary

- Arthropods are the largest phylum in the animal kingdom. Most arthropods are insects. The phylum also includes spiders, centipedes, and crustaceans. The arthropod body consists of three segments with a hard exoskeleton and jointed appendages. Terrestrial arthropods have adaptations for life on land, such as trachea or book lungs for breathing air. The earliest arthropods were trilobites. The earliest land arthropods were millipedes.
- Insects are arthropods in the class Hexapoda. They are the most numerous organisms in the world. Most are terrestrial, and many are aerial. Insects have six legs and a pair of antennae for sensing chemicals. They also have several eyes and specialized mouthparts for feeding. Insects are the only invertebrates than can fly. Flight is the main reason for their success. Insects may live in large colonies and have complex social behaviors. Insects spread disease and destroy crops. However, they are essential for pollinating flowering plants.

Lesson Review Questions

Recall

1. Identify distinguishing traits of most arthropods.
2. What is molting? Why does it occur?
3. Name three arthropod head appendages and state their functions.
4. Describe two structures that allow arthropods to breathe air.
5. List several traits that characterize insects.
6. State two important advantages of flight in insects.
7. Give examples of insect behavior.

Apply Concepts

8. Assume you see a "bug" crawling over the ground. It has two body segments and lacks antennae. Which arthropod subphylum does the "bug" belong to? Explain your answer.

9. Create a timeline of arthropod evolution.

Think Critically

10. Present facts and a logical argument to support the following statement: Insects dominate life on Earth.

11. Relate form to function in the mouthparts of insects.

12. Explain why distinctive life stages and metamorphosis are adaptive.

Points to Consider

The invertebrates described so far in this chapter are protostomes. They differ from the other major grouping of animals, the deuterostomes, in how their embryos develop. The next lesson describes invertebrates that are deuterostomes. These invertebrates are more closely related to vertebrates such as humans. Some of these invertebrates are even placed in the chordate phylum.

- What traits do you think might characterize deuterostome invertebrates?
- How might chordate invertebrates differ from nonchordate invertebrates?

18.4 Echinoderms and Invertebrate Chordates

Lesson Objectives

- Summarize traits of echinoderm invertebrates.
- Outline the characteristics and classification of chordates.
- Describe the two subphyla of invertebrate chordates.

Vocabulary

chordates consists of all animals with a notochord, dorsal hollow nerve cord, post-anal tail, and pharyngeal slits during at least some stage of their life

echinoderms invertebrates such as sea stars and sand dollars that are characterized by a spiny endoskeleton, radial symmetry as adults, and a water vascular system

lancelets members of the subphylum Cephalochordata

tunicates members of the subphylum Urochordata are tunicates (also called sea squirts)

Introduction

The invertebrate phyla described in the first three lessons of this chapter are all nonchordates. They don't have a notochord, and they are not closely related to chordates. In this lesson, you will read about invertebrates that are closely related to chordates—including you.

Echinoderms

Echinoderms are marine organisms that make up the phylum Echinodermata. They can be found in the ocean from the equator to the poles. There are roughly 6000 living species of echinoderms. They are among the most distinctive organisms within the animal kingdom. Members of the phylum include sea stars (starfish), sand dollars, and feather stars, all shown in **Figure** 18.30 .

Structure and Function of Echinoderms

Echinoderms are named for their "spiny skin." However, the spines aren't on their skin. They are part of the endoskeleton. The endoskeleton consists of calcium carbonate plates and spines, covered by a thin layer of skin. Adult

FIGURE 18.30

Examples of Echinoderms. You may have seen sea stars and sand dollars at the beach because they live in shallow water near the shore. Other echinoderms such as feather stars are less commonly seen because they live in the deep ocean.

echinoderms have radial symmetry. This is easy to see in the sea star and sand dollar in **Figure** 18.30 . However, echinoderms evolved from an ancestor with bilateral symmetry. Evidence for this is the bilateral symmetry of their larvae.

A unique feature of echinoderms is their water vascular system. This is a network of canals that extend along each body part. In most echinoderms, the canals have external projections called tube feet (see **Figure** 18.31). The feet have suckers on the ends. Muscle contractions force water into the feet, causing them to extend outward. As the feet extend, they attach their suckers to new locations, farther away from their previous points of attachment. This results in a slow but powerful form of movement. The suckers are very strong. They can even be used to pry open the shells of prey.

FIGURE 18.31

Tube Feet of a Sea Star. The tube feet of a sea star *in white* are part of its water vascular system. There is a sucker on the end of each foot that allows the animal to &#8220 walk&#8221 slowly over a surface. The suckers are strong enough to pry open shells.

Echinoderms lack respiratory and excretory systems. Instead, the thin walls of their tube feet allow oxygen to diffuse in and wastes to diffuse out. Echinoderms also lack a centralized nervous system. They have an open circulatory system and lack a heart. On the other hand, echinoderms have a well-developed coelom and a complete digestive system. Echinoderms use pheromones to communicate with each other. They detect the chemicals with sensory cells on their body surface. Some echinoderms also have simple eyes (ocelli) that can sense light. Like annelids, echinoderms have the ability to regenerate a missing body part.

Echinoderm Reproduction

Some echinoderms can reproduce asexually by fission, but most echinoderms reproduce sexually. They generally have separate sexes and external fertilization. Eggs hatch into free-swimming larvae. The larvae undergo metamorphosis to change into the adult form. During metamorphosis, their bilateral symmetry changes to radial symmetry.

Echinoderm Classification

Living echinoderms are placed in five classes. These five classes show many similarities. Organisms in each class are described in **Table** 18.2 .

TABLE 18.2: Classes of Living Echinoderms

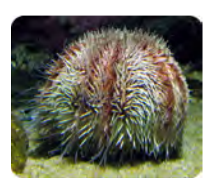
Class (includes)	Description	Example
Crinoidea • feathers stars • sea lilies	fewer than 100 species; many have more than five arms; earliest and most primitive echinoderms; live on the ocean floor, mainly in deep water; filter feeders	feather star 
Asteroidea • sea stars	almost 2000 species; most have five arms; many are brightly colored; live on the ocean floor, mainly in shallow water; predators or scavengers	sea star 
Ophiuroidea • brittle stars	about 2000 species; central disk distinct from arms; move by flapping their arms, which lack suckers; live on the ocean floor in shallow or deep water; predators, scavengers, deposit feeders, or filter feeders	brittle star 
Echinoidea • sea urchins • sand dollars • sea biscuits • heart urchins	about 100 species; do not have arms but do have tube feet; have a specialized mouth part with teeth to scrape food from rocks; live on the ocean floor in shallow or deep water; predators, herbivores, or filter feeders	sea urchin 

TABLE 18.2: (continued)

Class (includes)	Description	Example
Holothuroidea • sea cucumbers	about 1000 species; long body without arms; unlike other echinoderms, have a respiratory system; live on the ocean floor in shallow or deep water; deposit feeders, or filter feeders	sea cucumber 

Introduction to Chordates

The phylum Chordata consists of both invertebrates and vertebrates **chordates**. It is a large and diverse phylum. It includes some 60,000 species. Chordates range in length from about a centimeter to over 30 meters (100 feet). They live in marine, freshwater, terrestrial, and aerial habitats. They can be found from the equator to the poles. Several examples of chordates are pictured in **Figure** 18.32 .

Characteristics of Chordates

Chordates have three embryonic cell layers. They also have a segmented body with a coelom and bilateral symmetry. Chordates have a complete digestive system and a closed circulatory system. Their nervous system is centralized. There are four additional traits that are unique to chordates. These four traits, shown in **Figure** 18.33 , define the chordate phylum.

- Post-anal tail: The tail is opposite the head and extends past the anus.
- Dorsal hollow nerve cord: The nerve cord runs along the top, or dorsal, side of the animal. (In nonchordate animals, the nerve cord is solid and runs along the bottom).
- Notochord: The notochord lies between the dorsal nerve cord and the digestive tract. It provides stiffness to counterbalance the pull of muscles.
- Pharyngeal slits: Pharyngeal slits are located in the pharynx. This is the tube that joins the mouth to the digestive and respiratory tracts.

In some chordates, all four traits persist throughout life and serve important functions. However, in many chordates, including humans, all four traits are present only during the embryonic stage. After that, some of the traits disappear or develop into other organs. For example, in humans, pharyngeal slits are present in embryos and later develop into the middle ear.

Classification of Chordates

Living species of chordates are classified into three major subphyla: Vertebrata, Urochordata, and Cephalochordata. Vertebrates are all chordates that have a backbone. The other two subphyla are invertebrate chordates that lack a backbone.

Invertebrate Chordates

Members of the subphylum Urochordata are **tunicates** (also called sea squirts). Members of the subphylum Cephalochordata are **lancelets**. Both tunicates and lancelets are small and primitive. They are probably similar to the earliest

FIGURE 18.32
Diversity of Chordates. These six species illustrate the diversity of the phylum Chordata.

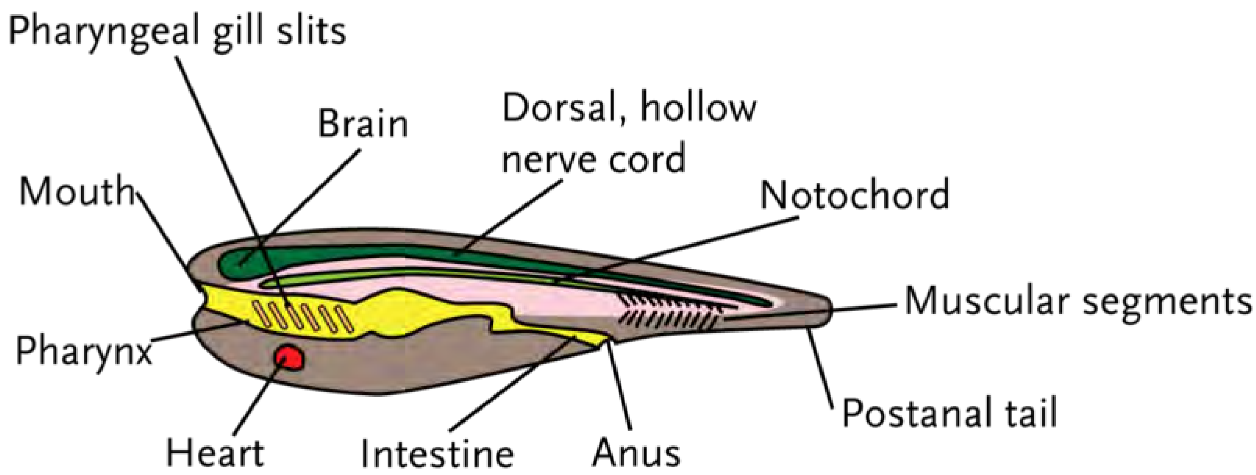


FIGURE 18.33

Body Plan of a Typical Chordate. The body plan of a chordate includes a post-anal tail notochord dorsal hollow nerve cord and pharyngeal slits.

chordates that evolved more than 500 million years ago.

Tunicates

There are about 3,000 living species of tunicates (see **Figure** 18.34). They inhabit shallow marine waters. Larval tunicates are free-swimming. They have all four defining chordate traits. Adult tunicates are sessile. They no longer have a notochord or post-anal tail.

FIGURE 18.34

Tunicates *Urochordata*. Tunicates are one of two subphyla of invertebrate chordates.

Adult tunicates are barrel-shaped. They have two openings that siphon water into and out of the body. The flow of water provides food for filter feeding. Tunicates reproduce sexually. Each individual produces both male and female gametes. However, they avoid self-fertilization. Tunicates can also reproduce asexually by budding.

Lancelets

There are only about 25 living species of lancelets. They inhabit the ocean floor where the water is shallow. Lancelet larvae are free-swimming. The adults can swim but spend most of their time buried in the sand. Like tunicates, lancelets are filter feeders. They take in water through their mouth and expel it through an opening called the atriopore (see **Figure** 18.35). Lancelets reproduce sexually and have separates sexes.

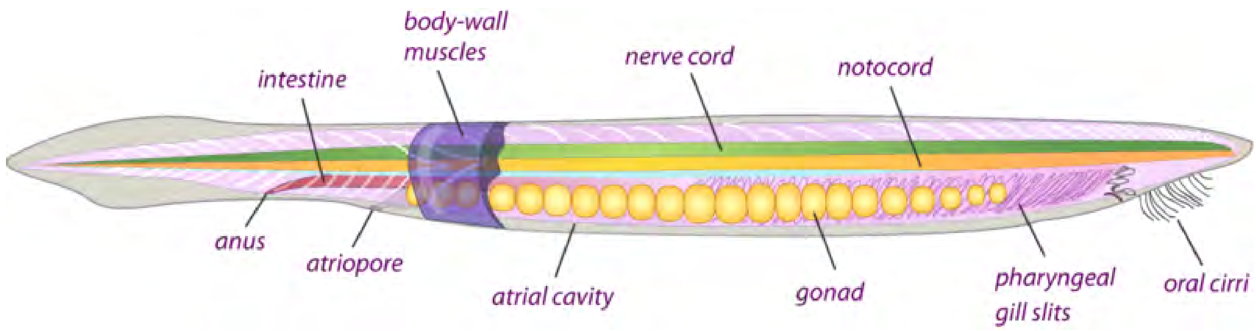


FIGURE 18.35

Lancelet *Cephalochordata*. Unlike tunicates lancelets retain all four defining chordate traits in the adult stage. Can you find them

Lesson Summary

- Echinoderms are marine invertebrates. They include sea stars, sand dollars, and feather stars. They have a spiny endoskeleton. They have radial symmetry as adults but bilateral symmetry as larvae. Echinoderms have a unique water vascular system with tube feet. This allows slow but powerful movement.
- Chordates include vertebrates and invertebrates that have a notochord. Chordates also have a post-anal tail, dorsal hollow nerve cord, and pharyngeal slits. Vertebrate chordates have a backbone. Invertebrate chordates do not. Invertebrate chordates include tunicates and lancelets. Both are primitive marine organisms.

Lesson Review Questions

Recall

1. Describe the echinoderm endoskeleton.
2. Give an example of an organism in each class of living echinoderms.
3. Identify the four defining traits of chordates.
4. Name and describe the two subphyla of invertebrate chordates.

Apply Concepts

5. Create a labeled drawing that explains how the tube feet of echinoderms allow them to "walk."

Think Critically

6. Adult sea stars and other echinoderms have obvious radial symmetry. What evidence supports the claim that echinoderms evolved from an ancestor with bilateral symmetry?

7. Adult humans lack the defining traits of chordates. Why are humans still classified in the chordate phylum?

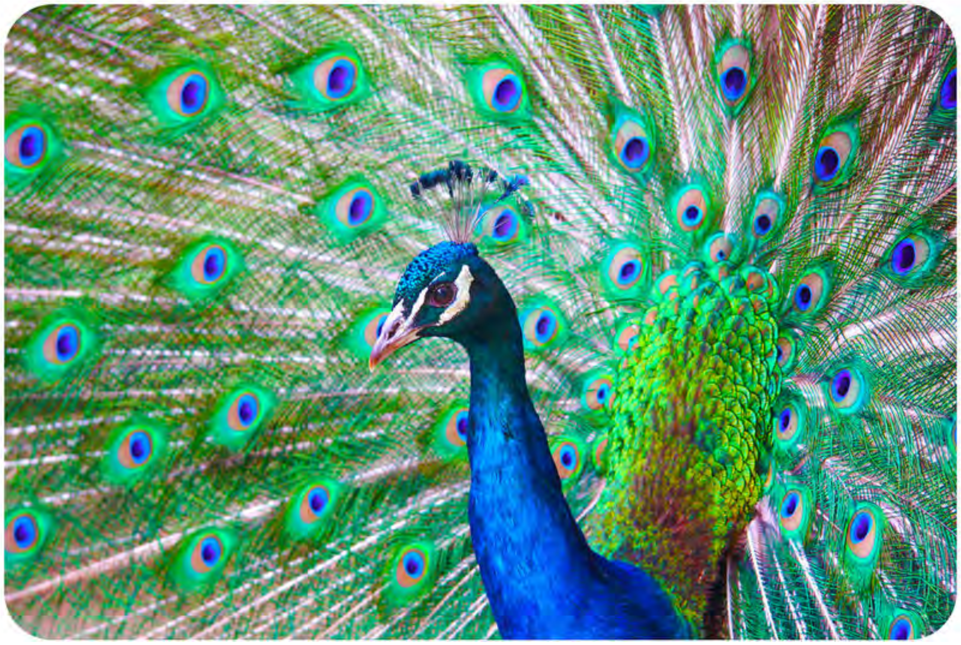
Points to Consider

This chapter and the chapter before it describe the amazing diversity of invertebrates. The remaining chapters are devoted to vertebrates.

- How do vertebrates differ from invertebrates? What is the main distinguishing feature of vertebrates?
- Many traits that evolved in invertebrates characterize all vertebrate animals as well. Which invertebrate traits do you think are also found in vertebrates such as humans?

CHAPTER 19 From Fish to Birds

Chapter Outline



This stunning bird is a peacock. Do you know why he is spreading out his big, colorful tail feathers like a fan? He is trying to attract a female for mating. Both the feathers and the behavior evolved because they increase the chances that males of the species will reproduce and pass their genes to the next generation. Many other vertebrates have similar behaviors for attracting mates. Even fish display some remarkably sophisticated mating behaviors.

Fish and birds are both vertebrates. Vertebrates are a diverse and fascinating group of animals. In many ways, they are very different from the invertebrates described in previous chapters. Elaborate mating behaviors are just one way they differ. This chapter describes many other differences between vertebrates and invertebrates. It also describes in detail the classes of vertebrates from fish to birds.

19.1 Overview of Vertebrates

Lesson Objectives

- List the characteristics of vertebrates.
- Explain how vertebrates reproduce.
- Identify the nine classes of vertebrates.
- Give an overview of vertebrate evolution.

Vocabulary

bone hard tissue in most vertebrates that consists of a collagen matrix, or framework, filled in with minerals such a calcium

cartilage dense connective tissue that provides a smooth surface for the movement of bones at joints

cranium part of a vertebrate endoskeleton that encloses and protects the brain; also called the skull

ectothermy regulation of body temperature from the outside through behavioral changes such as basking in the sun

endothermy regulation of body temperature from the inside through metabolic or other physical changes

immune system body system that consists of skin, mucous, membranes, and other tissues and organs that defends the body from pathogens and cancer

kidney main organ of the excretory system that filters blood and forms urine

ovipary type of reproduction in which an embryo develops within an egg outside the mother's body

ovovivipary type of reproduction in which an embryo develops inside an egg within the mother's body but in which the mother provides no nourishment to the developing embryo in the egg

vertebrae (singular, vertebra) repeating bony units that make up the vertebral column of vertebrates

vivipary type of reproduction in which an embryo develops within, and is nourished by, the mother's body

Introduction

Vertebrates are a subphylum of the phylum Chordata. Like all chordates, vertebrates have a notochord, a dorsal hollow nerve cord, pharyngeal slits, and a post-anal tail. What other characteristics do vertebrates have? What traits set them apart from invertebrate chordates?

Characteristics of Vertebrates

The main distinguishing feature of vertebrates is their vertebral column, or backbone (see **Figure** 19.1). The backbone runs from the head to the tail along the dorsal (top) side of the body. The vertebral column is the core of the endoskeleton. It allows a vertebrate to hold its shape. It also houses and protects the spinal (nerve) cord that passes through it. The vertebral column is made up of repeating units called **vertebrae** (singular, vertebra). In many species, there are shock-absorbing discs between the vertebrae to cushion them during movement.

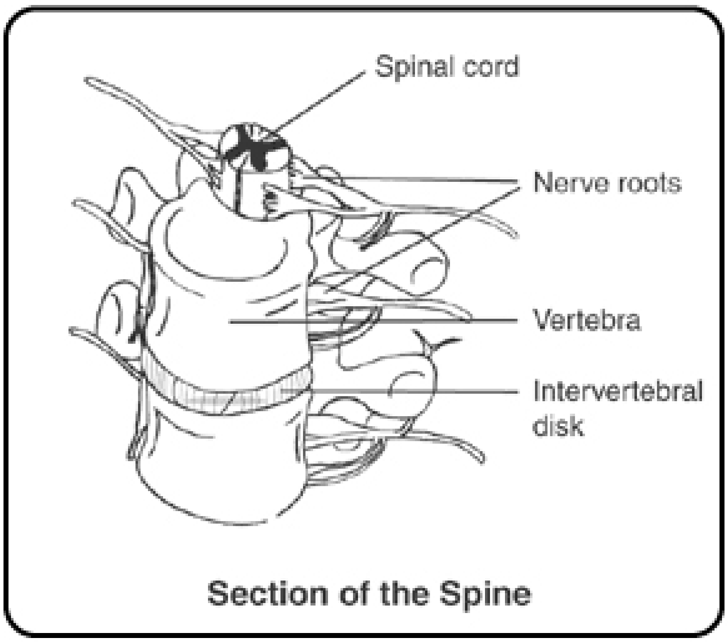


FIGURE 19.1

Human Vertebral Column and Vertebrae. The human vertebral column consists of 33 vertebrae. Two vertebrae are shown here enlarged.

Vertebrate Endoskeleton

Another distinguishing feature of vertebrates is an endoskeleton made of bone or cartilage. **Cartilage** is a tough tissue that contains a protein called collagen. **Bone** is a hard tissue that consists of a collagen matrix, or framework, filled in with minerals such as calcium. Bone is less flexible than cartilage but stronger. An endoskeleton made of bone rather than cartilage allows animals to grow larger and heavier. Bone also provides more protection for soft tissues and internal organs. As shown in **Figure** 19.2 , the vertebrate endoskeleton includes a **cranium,** or skull, to enclose and protect the brain. It also generally includes two pairs of limbs. Limb girdles (such as the human hips and shoulders) connect the limbs to the rest of the endoskeleton.

Other Vertebrate Traits

There are several additional traits found in virtually all vertebrates.

- Vertebrates have a system of muscles attached to the endoskeleton to enable movement. Muscles control

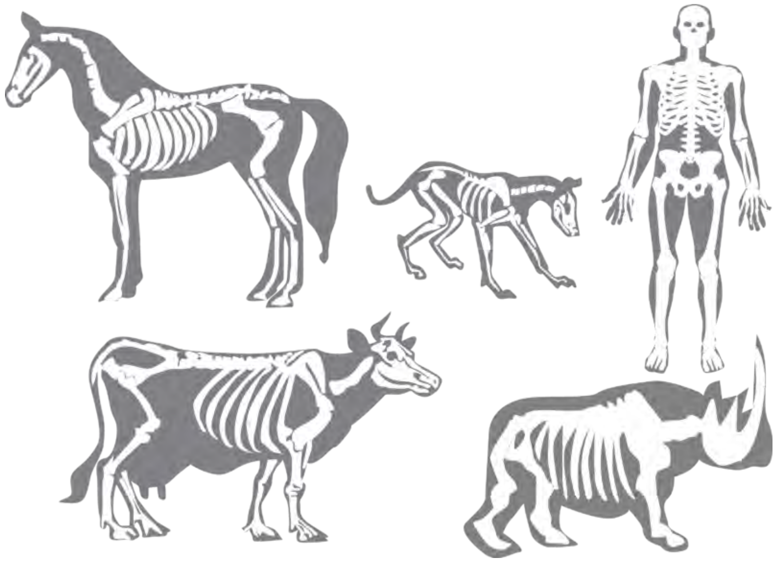


FIGURE 19.2
Vertebrate Endoskeletons. The vertebrate endoskeleton includes a vertebral column cranium limbs and limb girdles. Can you find these parts in each endoskeleton shown here

movement by alternately contracting (shortening) and relaxing (lengthening). Generally, muscles work together in opposing pairs.

- Vertebrates have a closed circulatory system with a heart. Blood is completely contained within blood vessels that carry the blood throughout the body. The heart is divided into chambers that work together to pump blood. There are between two and four chambers in the vertebrate heart. With more chambers, there is more oxygen in the blood and more vigorous pumping action.
- Most vertebrates have skin covered with scales, feathers, fur, or hair. These features serve a variety of functions, such as waterproofing and insulating the body.
- Vertebrates have an excretory system that includes a pair of kidneys. **Kidneys** are organs that filter wastes from blood so they can be excreted from the body.
- Vertebrates have an endocrine system of glands that secrete hormones. Hormones are chemical messengers that control many body functions.
- Vertebrates have an adaptive immune system. The **immune system** is the organ system that defends the body from pathogens and other causes of disease. Being adaptive means that the immune system can *learn* to recognize specific pathogens. Then it can produce tailor-made chemicals called antibodies to *attack* them. This allows the immune system to launch a rapid attack whenever the pathogens invade the body again.
- Vertebrates have a centralized nervous system. As shown in **Figure** 19.3 , the nervous system consists of a brain in the head region. It also includes a long spinal cord that runs from the brain to the tail end of the backbone. Long nerve fibers extend from the spinal cord to muscles and organs throughout the body.

Vertebrate Reproduction

Vertebrates reproduce sexually, and almost all of them have separate male and female sexes. Generally, aquatic species have external fertilization, whereas terrestrial species have internal fertilization. Can you think of a reason why aquatic and terrestrial vertebrates differ in this way? Vertebrates have one of the following 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 amphibians and reptiles and in all birds.

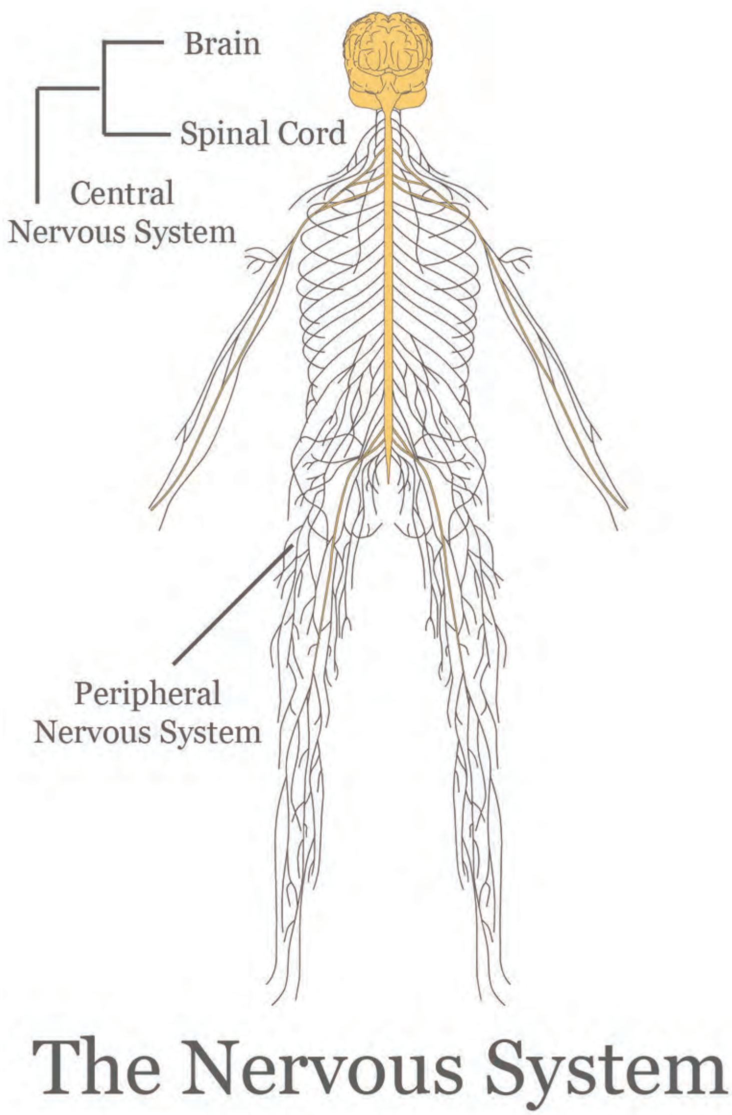


FIGURE 19.3

Nervous System *Human*. The vertebrate nervous system includes a brain and spinal cord. It also includes a body-wide network of nerves called peripheral nerves. They connect the spinal cord with the rest of the body.

- **Ovovivipary** refers to the development of an embryo inside an egg within the mother's body until it hatches. 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. Birth may be followed by a period of parental care of the offspring. This reproductive strategy occurs in almost all mammals.

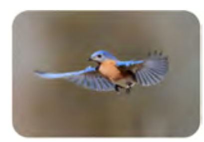
Vertebrate Classification

There are about 50,000 vertebrate species, and they are placed in nine different classes. Five of the classes are fish. The other classes are amphibians, reptiles, birds, and mammals. **Table** 19.1 lists some of the distinguishing traits of each class.

TABLE 19.1: 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 
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 

TABLE 19.1: (continued)

Class	Distinguishing Traits	Example
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 
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, similar to living hagfish. They lived between 500 and 600 million years ago. They had a cranium but no vertebral column. The phylogenetic tree in **Figure** 19.4 gives an overview of vertebrate evolution. As more data become available, new ideas about vertebrate evolution emerge.

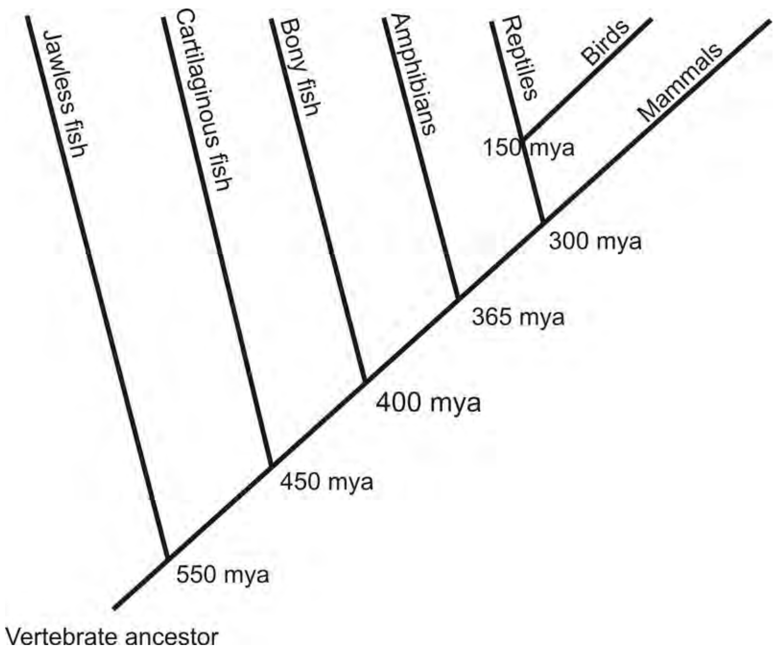


FIGURE 19.4

Phylogenetic Tree of Vertebrate Evolution. The earliest vertebrates evolved almost 550 million years ago. Which class of vertebrates evolved last

Evolution of Fish

Not too long after hagfish first appeared, fish similar to lampreys evolved a partial vertebral column. The first fish with a complete vertebral column evolved about 450 million years ago. These fish also had jaws and may have been similar to living sharks. Up to this point, all early vertebrates had an endoskeleton made of cartilage rather than bone. About 400 million years ago, the first bony fish appeared. A bony skeletal could support a larger body. Early bony fish evolved into modern ray-finned and lobe-finned fish.

Evolution of Other Vertebrate Classes

Amphibians, reptiles, mammals, and birds evolved after fish.

- The first amphibians evolved from a lobe-finned fish ancestor about 365 million years ago. They were the first vertebrates to live on land, but they had to return to water to reproduce. This meant they had to live near bodies of water.
- The first reptiles evolved from an amphibian ancestor at least 300 million years ago. They laid amniotic eggs and had internal fertilization. They were the first vertebrates that no longer had to return to water to reproduce. They could live just about anywhere.
- Mammals and birds both evolved from reptile-like ancestors. The first mammals appeared about 200 million years ago and the earliest birds about 150 million years ago.

Evolution of Endothermy

Until mammals and birds evolved, all vertebrates were ectothermic. **Ectothermy** means regulating body temperature from the outside through behavioral changes. For example, an ectotherm might stay under a rock in the shade in order to keep cool on a hot, sunny day. Almost all living fish, amphibians, and reptiles are ectothermic. Their metabolic rate and level of activity depend mainly on the outside temperature. They can raise or lower their own temperature only slightly through behavior alone.

Both mammals and birds evolved endothermy. **Endothermy** means regulating body temperature from the inside through metabolic or other physical changes. On a cold day, for example, an endotherm may produce more heat by raising its metabolic rate. On a hot day, it may give off more heat by increasing blood flow to the surface of the body. Keeping body temperature stable allows cells to function at peak efficiency at all times. The metabolic rate and activity level can also remain high regardless of the outside temperature. On the other hand, maintaining a stable body temperature requires more energy—and more food.

Lesson Summary

- Vertebrates are a subphylum of chordates that have a vertebral column and an endoskeleton made of cartilage or bone. Vertebrates also have complex organ systems, including a closed circulatory system with a heart, an excretory system with a pair of kidneys, and an adaptive immune system.
- Vertebrates reproduce sexually, and almost all have separate male and female sexes. Aquatic species generally have external fertilization, whereas terrestrial species usually have internal fertilization. Vertebrates have one of three reproductive strategies, known as ovipary, ovovivipary, or vivipary.
- The 50,000 species of living vertebrates are placed in nine classes: hagfish, lampreys, cartilaginous fish, ray-finned fish, lobe-finned fish, amphibians, reptiles, birds, and mammals.
- The earliest vertebrates resembled hagfish and lived more than 500 million years ago. As other classes of fish appeared, they evolved traits such as a complete vertebral column, jaws, and a bony endoskeleton. Amphibians were the first tetrapod vertebrates as well as the first vertebrates to live on land. Reptiles were the first amniotic vertebrates. Mammals and birds, which both descended from reptile-like ancestors, evolved endothermy, or the ability to regulate body temperature from the inside.

Lesson Review Questions

Recall

1. Describe the vertebrate vertebral column, and list its functions.

2. Contrast cartilage and bone, and state the advantages of a bony endoskeleton relative to a cartilaginous endoskeleton.

3. Identify the components of the vertebrate nervous system.

4. What is an adaptive immune system?

5. Define ovipary, ovovivipary, and vivipary. Which vertebrates use each type of reproductive strategy?

Apply Concepts

6. Create a time line of vertebrate evolution that shows how and when important vertebrate traits evolved.

Think Critically

7. Explain the significance of changes in the number of heart chambers during the course of vertebrate evolution.

8. Compare and contrast ectothermy and endothermy, including their pros and cons.

Points to Consider

The earliest and simplest vertebrates are fish. Fish also have the greatest number of vertebrate classes. Think about some of the fish you are familiar with, such as fish you eat or fish you may have seen in aquariums.

- Using the **Classes of Vertebrates Table** 19.1 , which fish class or classes should these fish be placed in?
- How are all of the fish the same? In what ways do they differ?

19.2 Fish

Lesson Objectives

- Describe structure and function in fish.
- Explain how fish reproduce and develop.
- Give an overview of the five living classes of fish.
- Summarize the evolution of fish.
- Outline the ecology of the different fish classes.

Vocabulary

fish ectothermic, aquatic vertebrate with a streamlined body and gills for absorbing oxygen from water

spawning depositing large numbers of gametes in the same place and at the same time by fish or amphibians

swim bladder balloon-like internal organ in most fish that can be used to move up or down through the water column by changing the amount of gas it contains

Introduction

Fish are aquatic vertebrates. They make up more than half of all vertebrate species. They are especially important in the study of vertebrate evolution because several important vertebrate traits evolved in fish.

Structure and Function in Fish

Fish show great diversity in body size. They range in length from about 8 millimeters (0.3 inches) to 16 meters (about 53 feet). Most are ectothermic and covered with scales. Scales protect fish from predators and parasites and reduce friction with the water. Multiple, overlapping scales provide a flexible covering that allows fish to move easily while swimming.

Adaptations for Water

Many structures in fish are adaptations for their aquatic lifestyle. Several are described below and shown in **Figure** 19.5 .

- Fish have gills that allow them to "breathe" oxygen in water. Water enters the mouth, passes over the gills, and exits the body through a special opening. Gills absorb oxygen from the water as it passes over them.

- Fish have a stream-lined body. They are typically long and narrow, which reduces water resistance when they swim.
- Most fish have several fins for swimming. They use some of their fins to propel themselves through the water and others to steer the body as they swim.
- Fish have a system of muscles for movement. Muscle contractions ripple through the body in waves from head to tail. The contractions whip the tail fin against the water to propel the fish through the water.
- Most fish have a **swim bladder.** This is a balloon-like internal organ that contains gas. By changing the amount of gas in the bladder, a fish can move up or down through the water column.

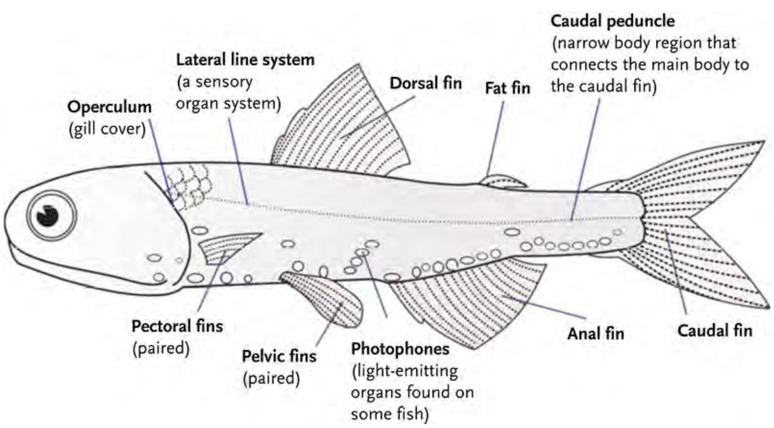


FIGURE 19.5

General Fish Body Plan. A fish has a stream-lined body with gills and fins. 1 operculum *gill cover* 2 lateral line system *a sensory organ system* 3 dorsal fin 4 fat fin 5 caudal peduncle *narrow body region that connects the main body to the* 6 caudal fin 7 anal fin 8 photophores *light emitting organs found on some fish* 9 pelvic fins *paired* 10 pectoral fins *paired*.

Fish Organ Systems

Fish have a circulatory system with a two-chambered heart. Their digestive system is complete and includes several organs and glands. Jawed fish use their jaws and teeth to grind up food before passing it to the rest of the digestive tract. This allows them to consume larger prey.

Fish also have a centralized nervous system with a brain. Fish brains are small compared with the brains of other vertebrates, but they are large and complex compared with the brains of invertebrates. Fish also have highly developed sense organs that allow them to see, hear, feel, smell, and taste. Sharks and some other fish can even sense the very low levels of electricity emitted by other animals. This helps them locate prey.

Fish Reproduction and Development

Nearly all fish reproduce sexually, and most species have separate sexes. Those without separate sexes avoid self-fertilization by producing sperm and eggs at different times. Each fish typically produces a large number of gametes. In most fish species, fertilization takes place externally. These fish are oviparous. Eggs are laid and embryos develop outside the mother's body. In a minority of fish, including sharks, eggs develop inside the mother's body but without nourishment from the mother. These fish are ovoviviparous.

Spawning

In many species of fish, a large group of adults come together to release their gametes into the water at the same time. This is called **spawning.** It increases the chances that fertilization will take place. It also means that many embryos will form at once, which helps ensure that at least some of them will be able to escape predators. With spawning, there is no way for fish parents to know which embryos are their own. Therefore, fish generally don't provide any care to their eggs or offspring. There are some exceptions, however, including the fish described in **Figure** 19.6 .

FIGURE 19.6
Mouth Brooding. Some species of fish carry their fertilized eggs in their mouth until they hatch. This is called mouth brooding. If you look closely you can see the eggs inside the mouth of the African tilapia fish pictured here.

Fish Larvae

Fish eggs hatch into larvae that are different from the adult form of the species (see **Figure** 19.7). A larva swims attached to a large yolk sac, which provides the larva with food. The larva eventually goes through metamorphosis and changes into the adult form. However, it still needs to mature before it can reproduce.

Classification of Fish

There are about 28,000 existing species of fish, and they are placed in five different classes. The classes are commonly referred to as hagfish, lampreys, cartilaginous fish, ray-finned fish, and lobe-finned fish (see **Table** 19.1 in the previous lesson).

Hagfish

Hagfish are very primitive fish. They retain their notochord throughout life rather than developing a backbone, and they lack scales and fins. They are classified as vertebrates mainly because they have a cranium. Hagfish are noted for secreting large amounts of thick, slimy mucus. The mucus makes them slippery, so they can slip out of the jaws of predators.

FIGURE 19.7
Salmon Larva. This newly hatched salmon larva doesn&#8217 t look very fish-like. The structure hanging from the larva is the yolk sac.

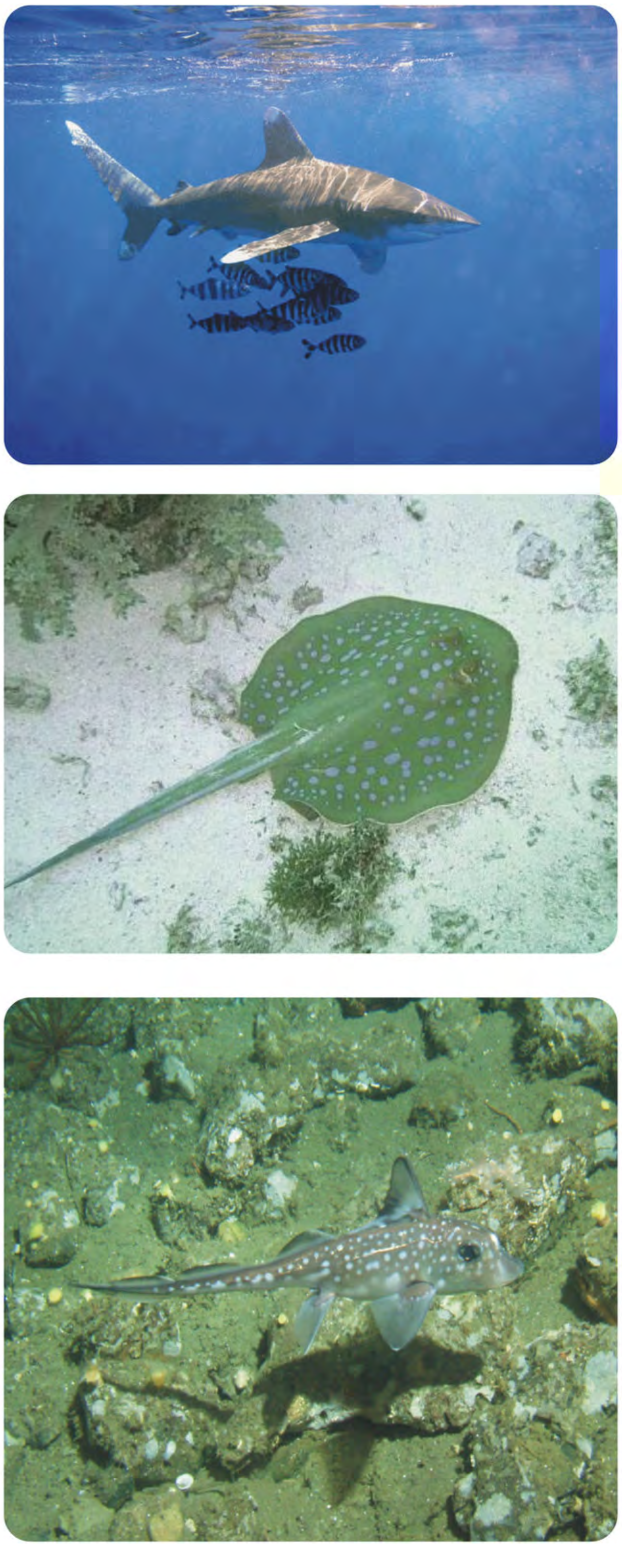
Lampreys

Like hagfish, lampreys also lack scales, but they have fins and a partial backbone. The most striking feature of lampreys is a large round sucker, lined with teeth, that surrounds the mouth (see **Figure** 19.8). Lampreys use their sucker to feed on the blood of other fish species.

FIGURE 19.8
Sucker Mouth of a Lamprey. The mouth of a lamprey is surrounded by a tooth-lined sucker.

Cartilaginous Fish

Cartilaginous fish include sharks, rays, and ratfish (see **Figure** 19.9). In addition to an endoskeleton composed of cartilage, these fish have a complete backbone. They also have a relatively large brain. They can solve problems and interact with other members of their species. They are generally predators with keen senses. Cartilaginous fish lack a swim bladder. Instead, they stay afloat by using a pair of muscular fins to push down against the water and create lift.



(a) (b) (c)

FIGURE 19.9

Cartilaginous Fish. All of these fish belong to the class of cartilaginous fish with jaws. *a* Oceanic whitetip shark *b* Ray *c* Ratfish

One of the most important traits of cartilaginous fish is their jaws. Jaws allow them to bite food and break it into smaller pieces. This is a big adaptive advantage because it greatly expands the range of food sources they can consume. Jaws also make cartilaginous fish excellent predators. It you've ever seen the film *Jaws,* then you know that jaws make sharks very fierce predators (see also **Figure** 19.10).

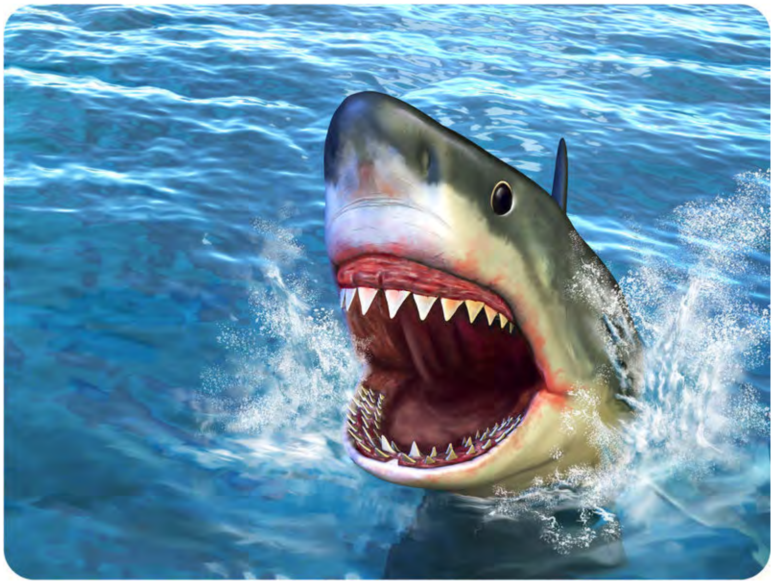


FIGURE 19.10
Jaws of a Shark. Sharks have powerful jaws with multiple rows of sharp saw-like teeth. Most other fish are no match for these powerful predators.

Ray-Finned Fish

Ray-fined fish include the majority of living fish species. including goldfish, tuna, salmon, perch, and cod. They have a bony endoskeleton and a swim bladder. Their thin fins consist of webs of skin over flexible bony rays, or spines. The fins lack muscle, so their movements are controlled by muscles in the body wall. You can compare their ray fins with the fleshy fins of lobe-finned fish in **Figure** 19.11 .

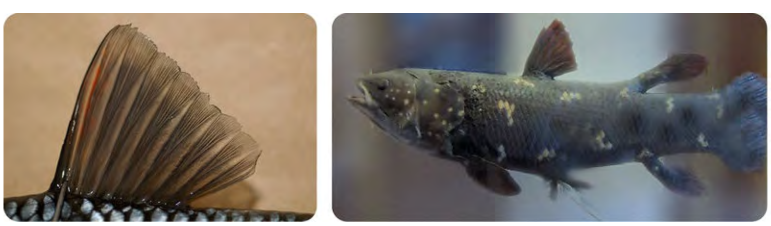


FIGURE 19.11
Fins of Bony Fish. The fins of ray-finned and lobe-finned fish are quite different. How is the form of the fins related to their different functions in the two classes of fish Ray Fin $left$ Lobe Fin *right*

Lobe-Finned Fish

Lobe-fined fish are currently far fewer in number than ray-finned fish. Their fins, like the one shown in **Figure** 19.11 , contain a stump-like appendage of bone and muscle. There are two groups of lobe-finned fish still alive today:

coelacanths and lungfish.

a. Coelacanths are ancient fish with just two living species. They are at risk of extinction because of their very small numbers.
b. Lungfish have a lung-like organ for breathing air. The organ is an adaptation of the swim bladder. It allows them to survive for long periods out of water.

Evolution of Fish

Invertebrate chordates use their gills to filter food out of water, not to absorb oxygen. In the early evolution of fish, there was a switch to using gills to absorb oxygen instead of to filter food. Gills consist of many thin, folded tissues that provide a large surface area for oxygen uptake. With more oxygen absorbed by the gills, fish could become much larger and more active.

Timing of Fish Evolution

Ancestors of hagfish are thought to have been the earliest vertebrates. Their fossils date back to about 550 million years ago. Fossils of cartilaginous fish with jaws, resembling living sharks, first appeared in the fossil record about 450 million years ago. They were followed about 50 million years later by the bony fish.

The Bony Fish

At first, the lobe-finned bony fish were much more common than the ray-finned bony fish that dominate today. Lobe-finned fish were also ancestral to amphibians. Their stump-like appendages and lung-like organs evolved into amphibian legs and lungs. Ray-finned bony fish may have been the first fish to evolve in freshwater. They eventually became the most diverse and dominant class of fish.

Ecology of Fish

The habitats and diets of fish are varied. They live throughout the ocean and also in freshwater lakes, ponds, rivers, and streams.

Fish Food

Most fish are predators, but the nature of their prey and how they consume it differs from one class to another and even within classes.

- 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 ocean water or freshwater. They either consume small invertebrates or suck blood from larger fish with their sucker mouth.
- Cartilaginous fish such as sharks may live on the bottom of the ocean. However, most live in the water column. They prey on other fish and aquatic mammals or else consume plankton.
- Bony fish may live in salt water or freshwater. They consume a wide range of foods. For example, they may eat algae, smaller fish, detritus, or dead organisms, depending on the species of fish.

Fish at Risk

Today, more than 1,000 species of fish are at risk of extinction. This is mainly because of human actions. Specific causes include over-fishing and habitat destruction caused by water pollution, dam building, and the introduction of non-native species.

Lesson Summary

- Fish are aquatic, ectothermic vertebrates. Many structures in fish are adaptations for their aquatic lifestyle. For example, fish have a stream-lined body that reduces water resistance while swimming. They also have gills for "breathing" oxygen in water and fins for propelling and steering their body through water.
- Nearly all fish reproduce sexually and have separate sexes. Fertilization is generally external, and most fish are oviparous. Many adults of the same species may come together in a group and release gametes into the water at the same time, which is called spawning. Fish hatch into larvae that are different from the adult form of the species.
- There are about 28,000 existing species of fish, and they are placed in five classes: hagfish, lampreys, cartilaginous fish, ray-finned bony fish, and lobe-finned bony fish.
- The evolution of fish included a shift from using the gills for filtering food to using them to absorb oxygen from water. The earliest fish, resembling living hagfish, evolved about 550 million years ago. Adaptations that eventually evolved in fish include a complete vertebral column, jaws, and an endoskeleton made of bones instead of cartilage.
- Fish live throughout the ocean and in freshwater lakes and streams. Most fish are predators, but the nature of their prey and how they consume it may vary. Many species of fish are threatened by human actions, such as water pollution and over-fishing.

Lesson Review Questions

Recall

1. What are gills? What purpose do they serve in fish?
2. Describe fish scales, and state their functions.
3. Describe how fish use their muscles to swim.
4. What is a swim bladder? How is it used?
5. List two ways that fish can sense prey animals.

Apply Concepts

6. Assume that a new species of fish has been discovered deep in the ocean. It has a complete vertebral column made of cartilage. Which class should the new species be placed in? Name one other trait you would expect to find in the new species of fish. Explain your answers.

Think Critically

7. Explain why the practice of spawning is adaptive.

8. Fish with jaws may be very large. Infer how their jaws may be related to their large body size.

Points to Consider

Lobe-finned fish were the ancestors of amphibians, which were the first vertebrates to live on land.

- What are some examples of amphibians?
- How do you think amphibians might differ from lobe-finned fish? What adaptations do you think amphibians needed to evolve in order to live on land?

19.3 Amphibians

Lesson Objectives

- Describe structure and function in amphibians.
- Outline the reproduction and development of amphibians.
- Identify the three living amphibian orders.
- Describe how amphibians evolved.
- State where amphibians live and how they obtain food.

Vocabulary

amphibian ectothermic, tetrapod vertebrate that may live on land but must return to water in order to reproduce

cloaca body cavity with a single opening in amphibians, reptiles, and monotreme mammals that collects and excretes wastes from the digestive and excretory systems and gametes from the reproductive system

keratin tough, fibrous protein in skin, nails, and hair

tetrapod vertebrate with four legs (amphibian, reptile, bird, or mammal)

Introduction

Amphibians are vertebrates that exist in two worlds. They divide their time between freshwater and terrestrial habitats. They share a number of features with air-breathing lungfish, but they also differ from lungfish in many ways. One way they differ is their appendages. Amphibians are the first true **tetrapods,** or vertebrates with four limbs. Modern amphibians include frogs, salamanders, and caecilians, as shown **Figure** 19.12 .

Structure and Function in Amphibians

Amphibians have less variation in size than fish, ranging in length from 1 centimeter (2.5 inches) to 1.5 meters (about 5 feet). They generally have moist skin without scales. Their skin contains **keratin,** a tough, fibrous protein found in the skin, scales, feathers, hair, and nails of tetrapod vertebrates, from amphibians to humans. Some forms of keratin are tougher than others. The form in amphibian skin is not very tough, and it allows gases and water to pass through their skin.

FIGURE 19.12
Examples of Living Amphibians. In what ways do these three amphibians appear to be similar In what ways do they appear to be different

Amphibian Ectothermy

Amphibians are ectothermic, so their internal body temperature is generally about the same as the temperature of their environment. When it's cold outside, their body temperature drops, and they become very sluggish. When the outside temperature rises, so does their body temperature, and they are much more active. What do you think might be some of the pros and cons of ectothermy in amphibians?

Amphibian Organ Systems

All amphibians have digestive, excretory, and reproductive systems. All three systems share a body cavity called the **cloaca.** Wastes enter the cloaca from the digestive and excretory systems, and gametes enter the cloaca from the reproductive system. An opening in the cloaca allows the wastes and gametes to leave the body.

Amphibians have a relatively complex circulatory system with a three-chambered heart. Their nervous system is also rather complex, allowing them to interact with each other and their environment. Amphibians have sense organs to smell and taste chemicals. Other sense organs include eyes and ears. Of all amphibians, frogs generally have the best vision and hearing. Frogs also have a larynx, or voice box, to make sounds.

Most amphibians breathe with gills as larvae and with lungs as adults. Additional oxygen is absorbed through the skin in most species. The skin is kept moist by mucus, which is secreted by mucous glands. In some species, mucous glands also produce toxins, which help protect the amphibians from predators. The golden frog shown in **Figure** 19.13 is an example of a toxic amphibian.

FIGURE 19.13

Toxic Frog. This golden frog is only about 5 centimeters 2 *inches* long but it&#8217 s the most poisonous vertebrate on Earth. One dose of its toxin can kill up to 20 humans

Amphibian Reproduction and Development

Amphibians reproduce sexually with either external or internal fertilization. They attract mates in a variety of ways. For example, the loud croaking of frogs is their mating call. Each frog species has its own distinctive call that other members of the species recognize as their own. Most salamanders use their sense of smell to find a mate. The males produce a chemical odor that attracts females of the species.

Amphibian Eggs

Unlike other tetrapod vertebrates (reptiles, birds, and mammals), amphibians do not produce amniotic eggs. Therefore, they must lay their eggs in water so they won't dry out. Their eggs are usually covered in a jelly-like substance, like the frog eggs shown in **Figure** 19.14 . The *jelly* helps keep the eggs moist and offers some protection from predators.

Amphibians generally lay large number of eggs. Often, many adults lay eggs in the same place at the same time. This helps to ensure that eggs will be fertilized and at least some of the embryos will survive. Once eggs have been laid, most amphibians are done with their parenting.

Amphibian Larvae

The majority of amphibian species go through a larval stage that is very different from the adult form, as you can see from the frog in **Figure** 19.15 . The early larval, or tadpole, stage resembles a fish. It lacks legs and has a long tail, which it uses to swim. The tadpole also has gills to absorb oxygen from water. As the larva undergoes metamorphosis, it grows legs, loses its tail, and develops lungs. These changes prepare it for life on land as an adult frog.

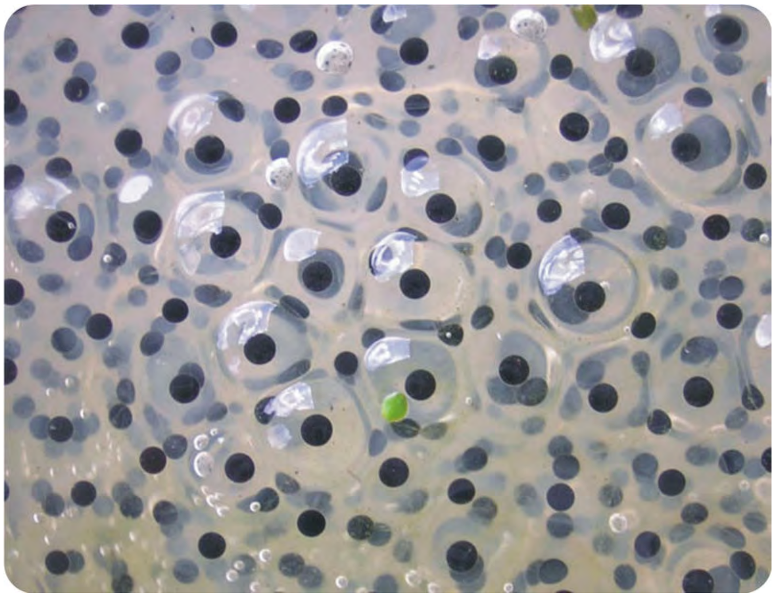


FIGURE 19.14

Frog Eggs. Frog eggs are surrounded by &#8220 jelly.&#8221 What is its function

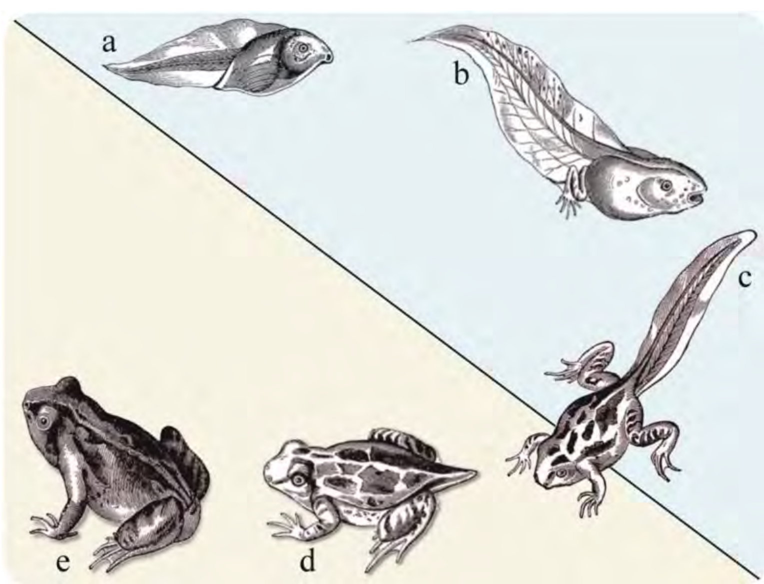


FIGURE 19.15

Frog Development From Tadpole to Adult. A frog larva $tadpole$ goes through many changes by adulthood. How do these changes prepare it for life as an adult frog

Classification of Amphibians

There are about 6,200 known species of living amphibians. They are placed in three different orders:

a. Frogs and toads
b. Salamanders and newts
c. Caecilians

Frogs and Toads

One feature that distinguishes frogs and toads from other amphibians is lack of a tail in adulthood. Frogs and toads also have much longer back legs than other amphibians. Their back legs are modified for jumping. Frogs can jump up to 20 times their own body length. That's the same as you jumping at least 100 feet, or more than the length of a basketball court. Think how fast you could move if you could travel that far on one jump!

Frogs and toads are closely related, but they differ in several ways. Generally, frogs spend more time in water, and toads spend more time on land. As you can see from **Figure** 19.16 , frogs also have smoother, moister skin than toads, as well as longer hind legs.

Salamanders and Newts

Unlike frogs and toads, salamanders and newts keep their tails as adults (see **Figure** 19.17). They also have a long body with short legs, and all their legs are about the same length. This is because they are adapted for walking and swimming rather than jumping. An unusual characteristic of salamanders is their ability to regenerate, or regrow, legs that have been lost to predators.

Caecilians

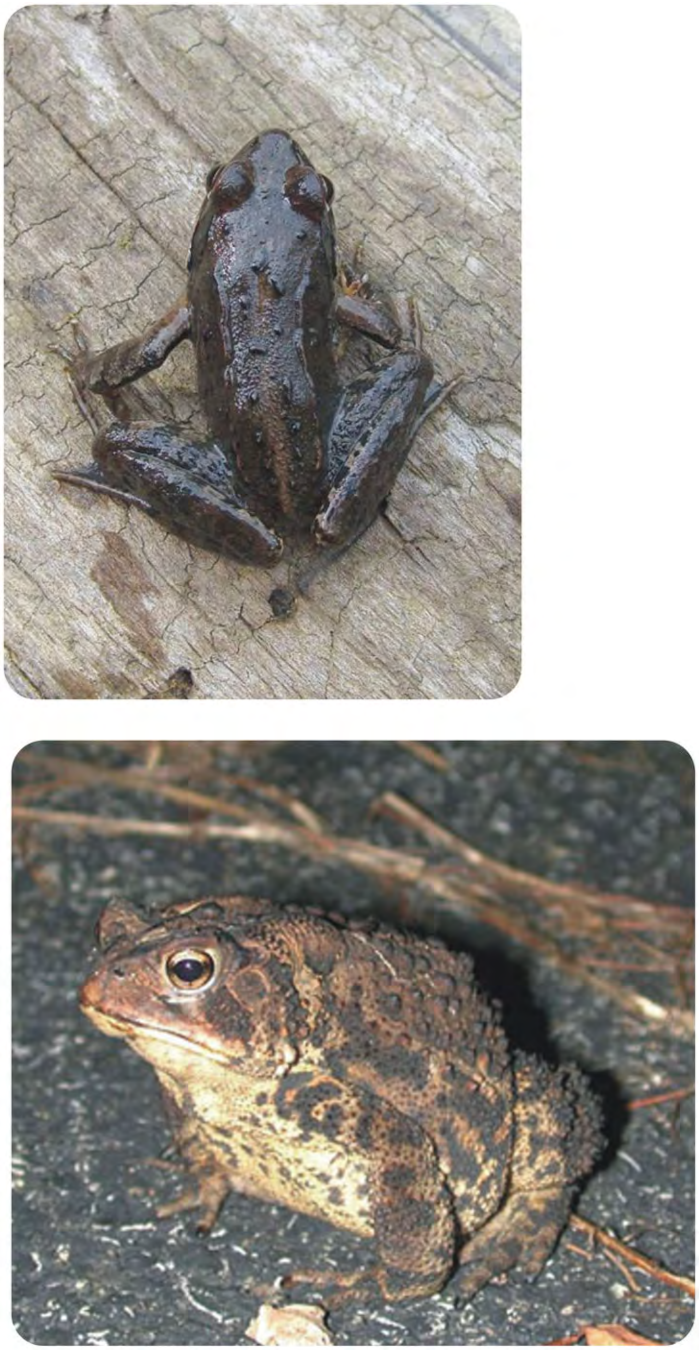
Caecilians are most closely related to salamanders. As you can see from **Figure** 19.18 , they have a long, worm-like body without legs. Caecilians evolved from a tetrapod ancestor, but they lost their legs during the course of their evolution.

Evolution of Amphibians

Fossil evidence shows that amphibians evolved about 365 million years ago from a lobe-finned lungfish ancestor. As the earliest land vertebrates, they were highly successful. Some of them were much larger than today's amphibians. For more than 100 million years, amphibians remained the dominant land vertebrates. Then some of them evolved into reptiles. Once reptiles appeared, with their amniotic eggs, they replaced amphibians as the dominant land vertebrates.

Ecology of Amphibians

Amphibians can be found in freshwater and moist terrestrial habitats throughout the world. The only continent without amphibians is Antarctica. Amphibians are especially numerous in temperate lakes and ponds and in tropical rainforests.



(a)

(b)

FIGURE 19.16

Frog and Toad. Frogs a and toads b are placed in the same amphibian order. What traits do they share

FIGURE 19.17
Salamander and Newt. Salamanders and newts can walk or swim. Salamander on a leaf *left* newt swimming in the water *right*.

FIGURE 19.18
Swimming Caecilian. Caecilians are the only amphibians without legs.

Amphibians as Prey and Predators

Amphibians are an important food source for animals such as birds, snakes, raccoons, and fish. Amphibians are also important predators. As larvae, they feed mainly on small aquatic animals such as water insects. They may also feed on algae. As adults, amphibians are completely carnivorous. They may catch and eat worms, snails, and insects, as the frog in **Figure** 19.19 is doing. Unlike other amphibians, caecilians are burrowers. They use their head to dig in the soil, and they feed on earthworms and other annelids. Caecilians can be found in moist soil near rivers and streams in tropical regions.

FIGURE 19.19

Frog Predator. A frog eating its insect prey.

The Threat of Amphibian Extinction

Currently, almost one third of all amphibian species face the threat of extinction. The reasons include habitat loss, pollution, climate change, and the introduction of non-native species. Most of these problems are the result of human actions.

Amphibians have permeable skin that easily absorbs substances from the environment. This may explain why they seem to be especially sensitive to pollution. Monitoring the health and survival of amphibians may help people detect pollution early, before other organisms are affected.

Lesson Summary

- Amphibians are ectothermic vertebrates that divide their time between freshwater and terrestrial habitats. They are the first true tetrapods, or vertebrates with four limbs. Amphibians breathe with gills as larvae and with lungs as adults. They have a three-chambered heart and relatively complex nervous system.
- Amphibians reproduce sexually with either external or internal fertilization. They may attract mates with calls or scents. They do not produce amniotic eggs, so they must reproduce in water. Their larvae go through metamorphosis to change into the adult form.
- There are about 6,200 known species of living amphibians that are placed in three orders: frogs and toads, salamanders and newts, and caecilians. Frogs and toads are adapted for jumping. Salamanders and newts may walk or swim. Caecilians live in the water or soil and are the only amphibians without legs.

- Amphibians evolved about 365 million years ago from a lobe-finned fish ancestor. As the earliest land vertebrates, amphibians were highly successful for more than 100 million years until reptiles took over as the dominant land vertebrates.
- Amphibians are found throughout the world except in Antarctica and Greenland. They are important prey for animals such as birds, snakes, and raccoons. They are important predators of insects, worms, and other invertebrates. Up to one third of all amphibian species are at risk of extinction because of human actions, such as habitat destruction, climate change, and pollution.

Lesson Review Questions

Recall

1. What is a tetrapod?
2. How does the temperature of the environment affect the level of activity of an amphibian?
3. What is the cloaca? What functions does it serve in amphibians?
4. Describe three different ways that amphibians may absorb oxygen.
5. Outline the life cycle of frogs.

Apply Concepts

6. Assume that a certain species of toad appears to be dying out in a given ecosystem, perhaps because of pollution. Many people think that the toad problem is unimportant because "it's just a toad." Write a letter to a hypothetical newspaper editor in which you explain why the health and survival of amphibians such as this toad species are important to all living things in an ecosystem.

Think Critically

7. Compare and contrast the three orders of living amphibians.
8. Explain why amphibians were able to become the dominant land vertebrates for millions of years.

Points to Consider

Amphibians gave rise to reptiles, which replaced them as the dominant land vertebrates.

- Besides amniotic eggs, can you think of other ways that reptiles differ from amphibians?
- What other adaptations might reptiles have evolved that contributed to their success on land?

19.4 Reptiles

Lesson Objectives

- Give an overview of form and function in reptiles.
- Describe the amniotic egg and reptile reproduction.
- Identify the four living orders of reptiles
- Summarize how reptiles evolved.
- Describe where reptiles live and what they eat.

Vocabulary

diaphragm large, sheet-like muscle below the lungs that allows breathing to occur when it contracts and relaxes

reptile ectothermic, tetrapod vertebrate that lays amniotic eggs; includes crocodiles, lizards, snakes, and turtles

sauropsid type of early amniote that evolved during the Carboniferous Period and eventually gave rise to dinosaurs, reptiles, and birds

synapsid type of early amniote that evolved during the Carboniferous Period and eventually gave rise to mammals

Introduction

Reptiles are a class of tetrapod vertebrates that produce amniotic eggs. They include crocodiles, alligators, lizards, snakes, and turtles. The reptile class is one of the largest classes of vertebrates. It consists of all amniotes except birds and mammals.

Structure and Function in Reptiles

Reptiles have several adaptations for living on dry land that amphibians lack. For example, as shown in **Figure** 19.20 , the skin of most reptiles is covered with scales. The scales are made of very tough keratin, and they protect reptiles from injury, and also prevent them from losing water.

Reptile Respiration

The scales of reptiles prevent them from absorbing oxygen through their skin, as amphibians can. Instead, reptiles breathe air only through their lungs. However, their lungs are more efficient than the lungs of amphibians, with more surface area for gas exchange. This is another important reptile adaptation for life on land.

FIGURE 19.20

Crocodile Scales. These crocodiles are covered with tough waterproof scales.

Reptiles have various ways of moving air into and out of their lungs. Lizards and snakes use muscles of the chest wall for this purpose. These are the same muscles used for running, so lizards have to hold their breath when they run. Crocodiles and alligators have a large sheet of muscle below the lungs, called a **diaphragm,** that controls their breathing. This is a structure that is also found in mammals.

Ectothermy in Reptiles

Like amphibians, reptiles are ectotherms with a slow metabolic rate. Their metabolism doesn't generate enough energy to keep their body temperature stable. Instead, reptiles regulate their body temperature through their behavior. For example, the crocodile in **Figure** 19.21 is soaking up heat from the environment by basking in the sun. Because of their ectothermy, reptiles can get by with as little as one tenth the food needed by endotherms such as mammals. Some species of reptiles can go several weeks between meals.

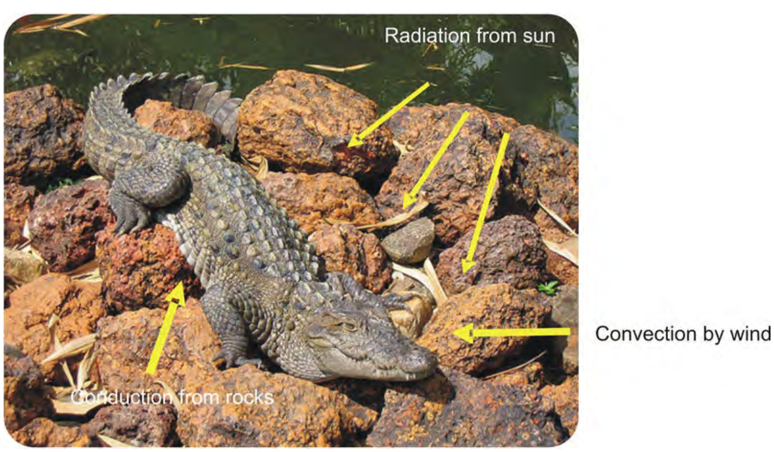


FIGURE 19.21

Heat Transfer to an Ectothermic Reptile. This crocodile is being warmed by the environment in three ways. Heat is radiating directly from the sun to the animal&#8217 s back. Heat is also being conducted to the animal from the rocks it rests on. In addition convection currents are carrying warm air from surrounding rocks to the animal&#8217 s body.

Other Reptile Structures

Like amphibians, most reptiles have a heart with three chambers, although crocodiles and alligators have a four-chambered heart like birds and mammals. The reptile brain is also similar in size to the amphibian brain, taking into account overall body size. However, the parts of the reptile brain that control the senses and learned behavior are larger than in amphibians.

Most reptiles have good eyesight and a keen sense of smell. Snakes smell scents in the air using their forked tongue (see **Figure** 19.22). This helps them locate prey. Some snakes have heat-sensing organs on their head that help them find endothermic prey, such as small mammals and birds.

FIGURE 19.22

Snake &#8220 Smelling&#8221 the Air. A snake flicks its tongue in and out to capture scent molecules in the air.

Reptile Reproduction

Most reptiles reproduce sexually and have internal fertilization. Males have one or two penises that pass sperm from their cloaca to the cloaca of a female. Fertilization occurs within the cloaca, and fertilized eggs leave the female's body through the opening in the cloaca. In a minority of species, the eggs are retained inside the female's body until they hatch. Then the offspring leave the mother's body through the cloaca opening.

Amniotic Eggs

Unlike amphibians, reptiles produce amniotic eggs (see **Figure** 19.23). The shell, membranes, and other structures of an amniotic egg protect and nourish the embryo. They keep the embryo moist and safe while it grows and develops. They also provide it with a rich, fatty food source (the yolk).

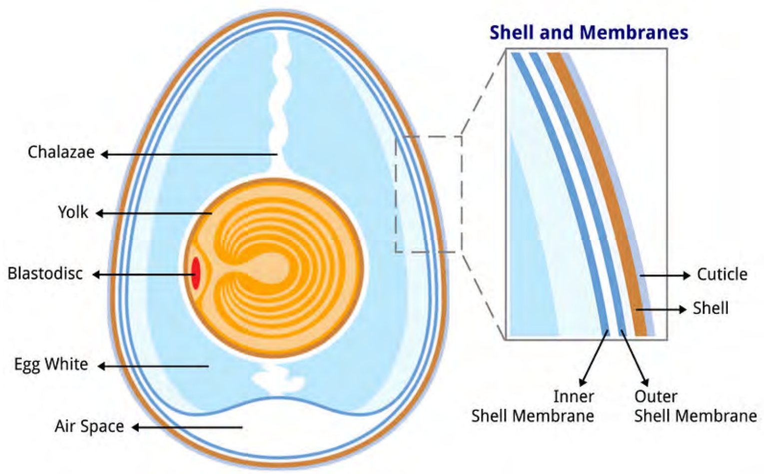


FIGURE 19.23

Amniotic Egg. The amniotic egg is an important adaptation in fully terrestrial vertebrates. It first evolved in reptiles. The shells of reptile eggs are either hard or leathery.

Reptile Young

Unlike amphibians, reptiles do not have a larval stage. Instead, newly hatched reptiles look like smaller versions of the adults. They are able to move about on their own, but they are vulnerable to predators. Even so, most reptile parents provide no care to their hatchlings. In fact, most reptiles don't even take care of their eggs. For example, female sea turtles lay their eggs on a sandy beach and then return to the ocean. The only exceptions are female crocodiles and alligators. They may defend their nest from predators and help the hatchings reach the water. If the young remain in the area, the mother may continue to protect them for up to a year.

Classification of Reptiles

There are more than 8,200 living species of reptiles, with the majority being snakes or lizards. They are commonly placed in four different orders. The four orders are described in **Table** 19.2 .

TABLE 19.2: Orders of Living Reptiles

Order	Characteristics	Example
Crocodilia: crocodiles, alligators, caimans, gharials	They have four sprawling legs that can be used to gallop; they replace their teeth throughout life; they have strong jaws and a powerful bite; they have a more advanced brain and greater intelligence than other reptiles; they have a four-chambered heart.	caiman 
Sphenodontia: tuataras	They are the least specialized of all living reptiles; their brain is very similar to the amphibian brain; they have a three-chambered heart, but it is more primitive than the heart of other reptiles.	tuatara 

TABLE 19.2: (continued)

Order	Characteristics	Example
Squamata: lizards, snakes	Lizards: most have four legs for running or climbing, and they can also swim; many change color when threatened; they have a three-chambered heart. Snakes: they do not have legs, although they evolved from a tetrapod ancestor; they have a very flexible jaw for swallowing large prey whole; some inject poison into their prey through fangs; they have a three-chambered heart.	lizard 
Testudines: turtles, tortoises, terrapins	They have four legs for walking; they have a hard shell covering most of their body; they have a three-chambered heart.	terrapin 

Evolution of Reptiles

The earliest amniotes evolved about 350 million years ago. They resembled small lizards, but they were not yet reptiles. Their amniotic eggs allowed them to move away from bodies of water and become larger. They soon became the most important land vertebrates.

Synapsids and Sauropsids

By about 320 million years ago, early amniotes had diverged into two groups, called synapsids and sauropsids. **Synapsids** were amniotes that eventually gave rise to mammals. **Sauropsids** were amniotes that evolved into reptiles, dinosaurs, and birds. The two groups of amniotes differed in their skulls. The earliest known reptile, pictured in **Figure** 19.24 dates back about 315 million years.

At first, synapsids were more successful than sauropsids. They became the most common vertebrates on land. However, during the Permian mass extinction 245 million years ago, most synapsids went extinct. Their niches were taken over by sauropsids, which had been relatively unimportant until then. This is called the "Triassic takeover."

Rise and Fall of the Dinosaurs

By the middle of the Triassic about 225 million years ago, sauropsids had evolved into dinosaurs. Dinosaurs became increasingly important throughout the rest of the Mesozoic Era, as they radiated to fill most terrestrial niches. This is why the Mesozoic Era is called the "Age of the Dinosaurs." During the next mass extinction, which occurred at the end of the Mesozoic Era, all of the dinosaurs went extinct. Many other reptiles survived, however, and they eventually gave rise to modern reptiles.

FIGURE 19.24
Earliest Reptile Hylonomus. The earliest known reptile is given the genus name Hylonomus. It was about 20 to 30 centimeters 8 *to* 12 *inches* long lived in swamps and ate insects and other small invertebrates.

Evolution of Modern Reptile Orders

Figure 19.25 shows a traditional phylogenetic tree of living reptiles. Based on this tree, some of the earliest reptiles to diverge were ancestors of turtles. The first turtle-like reptiles are thought to have evolved about 250 million years ago. Ancestral crocodilians evolved at least 220 million years ago. Tuataras may have diverged from squamates (snakes and lizards) not long after that. Finally, lizards and snakes went their separate ways about 150 million years ago.

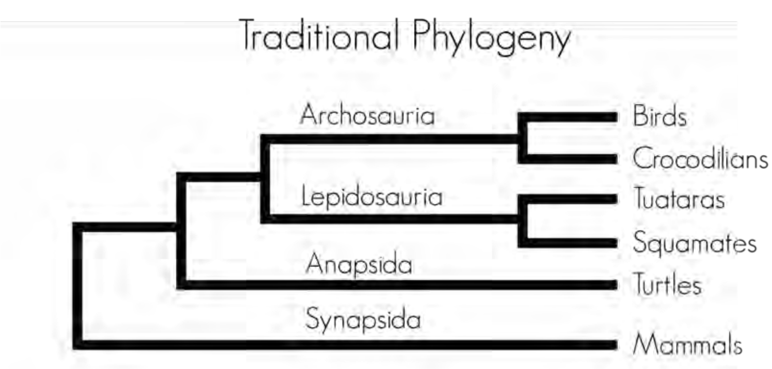


FIGURE 19.25
Traditional Reptile Phylogenetic Tree. This phylogenetic tree is based on physical traits of living and fossil reptiles. Trees based on DNA comparisons may differ from the traditional tree and from each other depending on the DNA sequences used. Reptile evolution is currently an area of intense research and constant revision.

Ecology of Reptiles

Today, reptiles live in a wide range of habitats. They can be found on every continent except Antarctica. Many turtles live in the ocean, while others live in freshwater or on land. Lizards are all terrestrial, but their habitats may range from deserts to rainforests, and from underground burrows to the tops of trees. Most snakes are terrestrial and live in a wide range of habitats, but some snakes are aquatic. Crocodilians live in and around swamps or bodies of freshwater or salt water.

Reptile Diets

What reptiles eat is also very diverse, but the majority of reptiles are carnivores. Large reptiles such as crocodilians are the top predators in their ecosystems, preying on birds, fish, deer, turtles, and sometimes domestic livestock. Their powerful jaws can crush bones and even turtle shells. Smaller reptiles—including tuataras, snakes, and many lizards—are also important predators, preying on insects, frogs, birds, and small mammals such as mice.

Most terrestrial turtles are herbivores. They graze on grasses, leaves, flowers, and fruits. Marine turtles and some species of lizards are omnivores, feeding on plants as well as insects, worms, amphibians, and small fish.

Reptiles at Risk

Many species of reptiles, especially marine reptiles, are at risk of extinction. Some are threatened by habitat loss. For example, many beaches where turtles lay their eggs have been taken over and developed by people. Other marine reptiles have been over-hunted by humans. Marine turtles and their eggs are still eaten in some countries despite being protected species.

Some reptiles are preyed upon by non-native species introduced by humans. For example, marine iguanas on the Galápagos Islands are threatened by dogs and cats that people have brought to the islands. The iguanas are slow and tame and have no adaptations to these new predators.

Lesson Summary

- Reptiles are a class of ectothermic, tetrapod vertebrates. They have several adaptations for living on dry land, such as tough keratin scales and efficient lungs for breathing air. They also have a three-chambered heart and relatively well-developed brain.
- Most reptiles reproduce sexually and have internal fertilization. Their eggs are amniotic, so they can be laid on land instead of in water. Reptiles do not have a larval stage, and their hatchlings are relatively mature. Reptile parents provide little if any care to their young.
- There are more than 8,200 living species of reptiles, and they are placed in four orders: Crocodilia, which includes crocodiles and alligators; Sphenodontia, or tuataras; Squamata, which includes lizards and snakes; and Testudines, such as turtles and tortoises.
- The earliest amniotes appeared about 350 million years ago, and the earliest reptiles evolved from a sauropsid ancestor by about 315 million years ago. Dinosaurs evolved around 225 million years ago and dominated animal life on land until 65 million years ago, when they all went extinct. Other reptiles survived and evolved into the classes of reptiles that exist today.
- Reptiles can be found on every continent except Antarctica. They may live in terrestrial, freshwater, or marine habitats. Most reptiles are carnivores, and large reptiles are the top predators in their ecosystems. Many species of reptiles, especially marine reptiles, are at risk of extinction.

Lesson Review Questions

Recall

1. Describe reptile scales and the functions they serve.

2. What is a diaphragm? What does it do?

3. Describe two senses that reptiles may use to locate prey.

4. Outline the structure and function of an amniotic egg.
5. Identify amniotes called synapsids and sauropsids.
6. Give a brief overview of reptile evolution.

Apply Concepts

7. Pretend you are a reptile such as a lizard. Explain how you might stay warm on a cold day.

Think Critically

8. Compare and contrast crocodilians with other orders of reptiles.
9. Explain why reptiles were able to replace amphibians as the dominant land vertebrates.

Points to Consider

Birds evolved from a reptile ancestor but they are very different from reptiles today. Birds are also the most numerous tetrapod vertebrates.

- What are some traits that differ in birds and modern reptiles?
- What traits might explain why birds have been so successful?

19.5 Birds

Lesson Objectives

- Outline structure and function in birds.
- Describe how birds reproduce and care for their young.
- Identify several common orders of modern birds.
- Give an overview of the evolution of birds.
- Summarize the diversity of bird habitats and food sources.

Vocabulary

bird bipedal, endothermic, tetrapod vertebrate that lays amniotic eggs and has wings and feathers

courtship animal behavior that is intended to attract a mate

crop sac-like structure in the digestive system of birds that stores and moistens food before it is digested

generalist organism that can consume many different types of food

gizzard food-grinding organ in the digestive system of birds and some other animals that may contain swallowed stones

incubation period of bird reproduction when one or both parents sit on, or brood, the eggs in order to keep them warm until they hatch

Introduction

Birds are endothermic tetrapod vertebrates. They are bipedal, which means they walk on two legs. Birds also lay amniotic eggs, and the eggs have hard, calcium carbonate shells. Although birds are the most recent class of vertebrates to evolve, they are now the most numerous vertebrates on Earth. Why have birds been so successful? What traits allowed them to increase and diversify so rapidly?

Structure and Function in Birds

Birds can vary considerably in size, as you can see from the world's smallest and largest birds, pictured in **Figure** 19.26 . The tiny bee hummingbird is just 5 centimeter (2 inches) long, whereas the ostrich towers over people at a height of 2.7 meters (9 feet). All modern birds have wings, feathers, and beaks. They have a number of other unique traits as well, most of which are adaptations for flight. Flight is used by birds as a means of locomotion in order to find food and mates and to avoid predators. Although not all modern birds can fly, they all evolved from ancestors that could.

FIGURE 19.26
Range of Body Size in Birds. The bee hummingbird is the smallest bird. The ostrich is the largest.

Wings and Feathers

Wings are an obvious adaptation for flight. They are actually modified front legs. Birds move their wings using muscles in the chest. These muscles are quite large, making up as much as 35 percent of a bird's body weight.

Feathers help birds fly and also provide insulation and serve other purposes. Birds actually have two basic types of feathers: flight feathers and down feathers. Both are shown in **Figure** 19.27 . Flight feathers are long, stiff, and waterproof. They provide lift and air resistance without adding weight. Down feathers are short and fluffy. They trap air next to a bird's skin for insulation.

FIGURE 19.27
Types of Bird Feathers. These two types of bird feathers have different uses. How is each feather&#8217 s structure related to its function

Organ Systems Adapted for Flight

Birds need a light-weight body in order to stay aloft. Even so, flying is hard work, and flight muscles need a constant supply of oxygen- and nutrient-rich blood. The organ systems of birds are adapted to meet these needs.

- Birds have light-weight bones that are filled with air. They also lack a jaw, which in many vertebrates is a dense, heavy bone with many teeth. Instead, birds have a light-weight keratin beak without teeth.
- Birds have air sacs that store inhaled air and push it into the lungs like bellows. This keeps the lungs constantly filled with oxygenated air. The lungs also contain millions of tiny passages that create a very large surface area for gas exchange with the blood (see **Figure** 19.28).
- Birds have a relatively large, four-chambered heart. The heart beats rapidly to keep oxygenated blood flowing to muscles and other tissues. Hummingbirds have the fastest heart rate at up to 1,200 times per minute. That's almost 20 times faster than the human resting heart rate!
- Birds have a sac-like structure called a **crop** to store and moisten food that is waiting to be digested. They also have an organ called a **gizzard** that contains swallowed stones. The stones make up for the lack of teeth by grinding food, which can then be digested more quickly. Both structures make it easier for the digestive system to produce a steady supply of nutrients from food.

Nervous System and Sense Organs

Birds have a large brain relative to the size of their body. Not surprisingly, the part of the brain that controls flight is the most developed part. The large brain size of birds is also reflected by their high level of intelligence and complex behavior. In fact, birds such as crows and ravens may be more intelligent than many mammals. They are smart enough to use objects such as twigs for tools. They also demonstrate planning and cooperation. Most birds have a poor sense of smell, but they make up for it with their excellent sense of sight. Predatory birds have especially good eyesight. Hawks, for example, have vision that is eight times sharper than human vision.

Bird Reproduction

Reproduction in birds may be quite complicated and lengthy. Birds reproduce sexually and have separate sexes and internal fertilization, so males and females must mate for fertilization to occur. Mating is generally preceded by courtship. In most species, parents also take care of their eggs and hatchlings.

Courtship and Mating

Courtship is behavior that is intended to attract a mate. It may involve singing specific courtship songs or putting on some type of visual display. For example, a bird may spread out and display its tail feathers or do a ritualized mating "dance." Typically, males perform the courtship behavior, and females choose a mate from among competing males.

During mating, a male bird presses his cloaca against his mate's cloaca and passes sperm from his cloaca to hers. After fertilization, eggs pass out of the female's body, exiting through the opening in the cloaca.

Nesting and Incubation

Eggs are usually laid in a nest. The nest may be little more than a small depression in the ground, or it may be very elaborate, like the weaver bird nest in **Figure** 19.29 . Eggs that are laid on the ground may be camouflaged to look like their surroundings (also shown in **Figure** 19.29). Otherwise, eggs are usually white or pastel colors such as pale blue or pink.

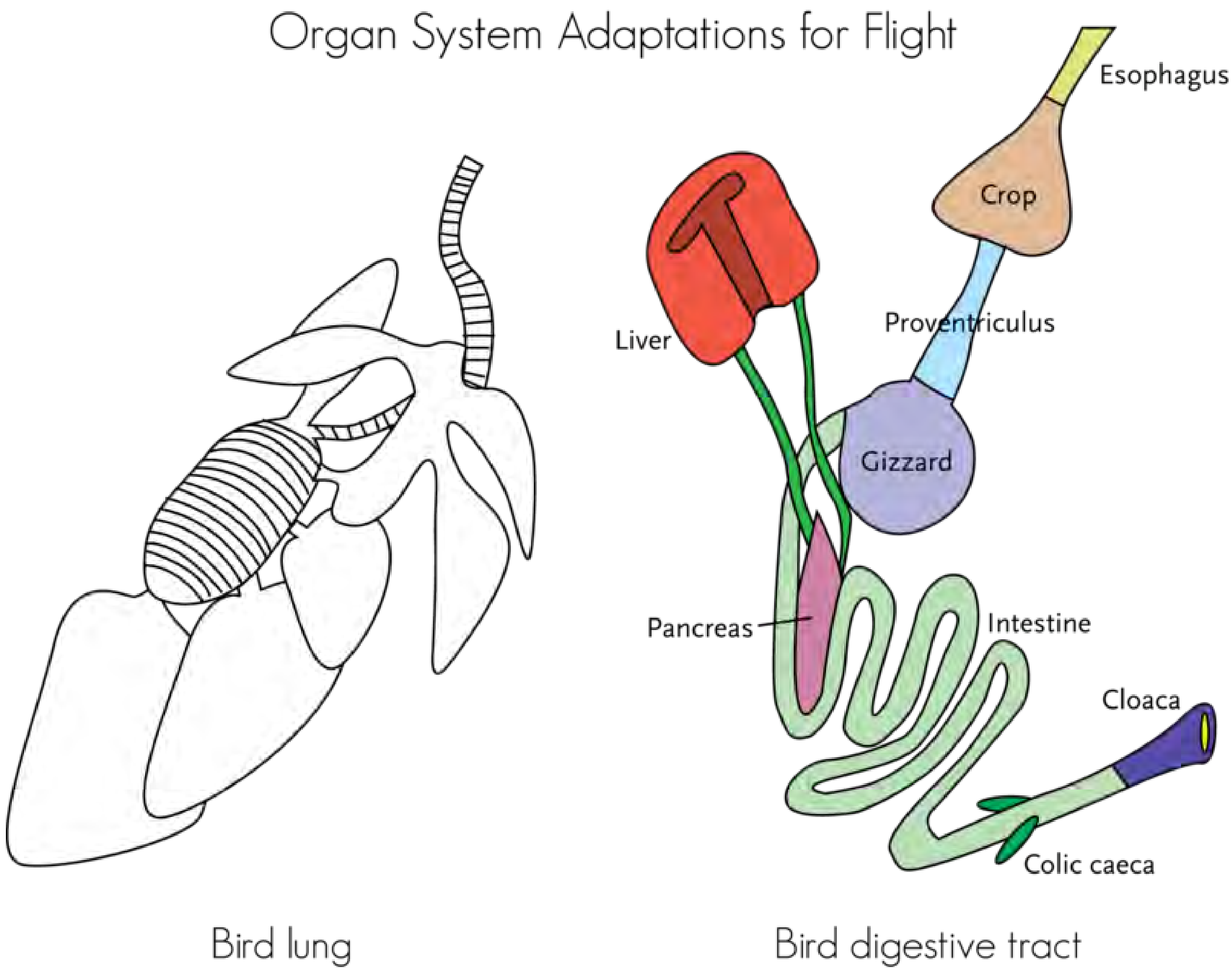


FIGURE 19.28

Organ System Adaptations for Flight. The intricate passageways in a bird&#8217 s lung are adapted for efficient gas exchange. Find the crop and gizzard in the digestive tract diagram. What are their functions Bird Lung *left* Bird Digestive Tract *right*

FIGURE 19.29

Variation in Bird Nests. A weaver bird uses grasses to weave an elaborate nest *left*. The eggs of a ground-nesting gull are camouflaged to blend in with the nesting materials *right*.

After birds lay their eggs, they generally keep the eggs warm with their body heat while the embryos inside continue to develop. This is called **incubation,** or brooding. In most species, parents stay together for at least the length of the breeding season. In some species, they stay together for life. By staying together, the males as well as females can incubate the eggs and later care for the hatchlings. Birds are the only nonhuman vertebrates with this level of male parental involvement.

Hatchlings

Ground-nesting birds, such as ducks and chickens, have hatchlings that are able to run around and feed themselves almost as soon as they break through the eggshell. Being on the ground makes them vulnerable to predators, so they need to be relatively mature when they hatch in order to escape. In contrast, birds that nest off the ground—in trees, bushes, or buildings—have hatchlings that are naked and helpless. The parents must protect and feed the immature offspring for weeks or even months. However, this gives the offspring more time to learn from the parents before they leave the nest and go out on their own.

Classification of Birds

There are about 10,000 living species of birds. Almost all of them can fly, but there are several exceptions.

Flightless Birds

Some birds have lost the ability to fly during the course of their evolution. Several flightless birds are shown in **Figure** 19.30 . They include the ostrich, kiwi, rhea, cassowary, and moa. All of these birds have long legs and are adapted for running. The penguins shown in the figure are also flightless birds, but they have a very different body shape. That's because they are adapted for swimming rather than running.

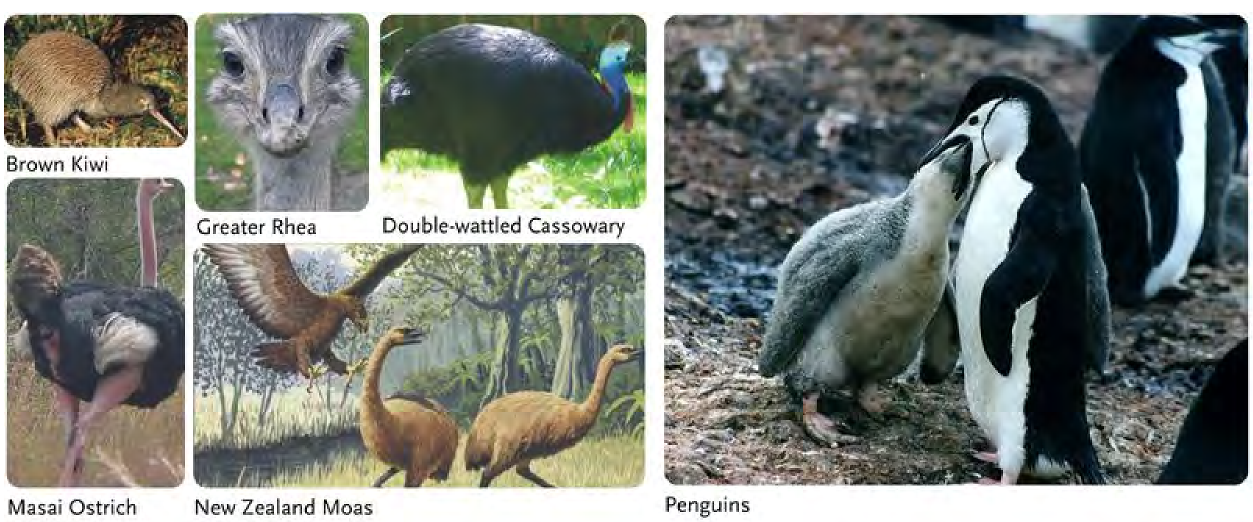


FIGURE 19.30

Flightless Birds. Flightless birds that are adapted for running include the ostrich kiwi rhea cassowary and moa. Penguins are flightless birds adapted for swimming.

Flying Birds

Birds that are able to fly are divided into 29 orders that differ in their physical traits and behaviors. **Table** 19.3 describes seven of the most common orders. As shown in the table, the majority of flying birds are perching birds, like the honeyeater described in the last row of the table. The order of perching birds has more species than all the other bird orders combined. In fact, this order of birds is the largest single order of land vertebrates.

TABLE 19.3: 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 19.3: (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 

Evolution of Birds

Birds are thought to have evolved from a group of bipedal dinosaurs called theropods. The ancestor of birds was probably similar to the theropod called *Deinonychus,* which is represented by the sketch in **Figure** 19.31 . Fossils of *Deinonychus* were first identified in the 1960s. This was an extremely important discovery. It finally convinced most scientists that birds had descended from dinosaurs, which had been debated for almost a century.

FIGURE 19.31
Extinct Bird Relative Deinonychus. Deinonychus shared many traits with birds. What similarities with birds to you see

What was

Deinonychus is the genus name of an extinct dinosaur that is considered to be one of the closest non-bird relatives of modern birds. It lived about 110 million years ago in what is now North America. *Deinonychus* was a predatory carnivore with many bird-like features. For example, it had feathers and wings. It also had strong legs with clawed feet, similar to modern raptors. Its respiratory, circulatory, and digestive systems were similar to those of birds as well. The location of fossilized eggs near *Deinonychus* fossils suggests that it may have brooded its eggs. This would mean that it was endothermic. (Can you explain why?) On the other hand, *Deinonychus* retained a number of reptile-like traits, such as jaws with teeth and hands with claws at the tips of its wings.

Evolution of Flight

Scientists have long speculated about the evolution of flight in birds. They wonder how and why birds evolved wings from a pair of front limbs. Several hypotheses have been suggested. Here are just two:

a. Wings evolved in a bird ancestor that leapt into the air to avoid predators or to capture prey. Therefore, wings are modified arms that helped the animal leap higher.
b. Wings evolved in a bird ancestor that lived in trees. Thus, wings are modified arms that helped the animal glide from branch to branch.

Scientists still don't know how or why wings and flight evolved, but they continue to search for answers. In addition to fossils, they are studying living vertebrates such as bats that also evolved adaptations for flight.

Ecology of Birds

Birds live and breed in most terrestrial habitats on all seven continents, from the Arctic to Antarctica. Because they are endothermic, birds can live in a wider range of climates than reptiles or amphibians, although the greatest diversity of birds occurs in tropical regions. Birds are important members of every ecosystem in which they live, occupying a wide range of ecological positions.

Bird Diets

Some birds are generalists. A **generalist** is an organism that can eat many different types of food. Other birds are highly specialized in their food needs and can eat just one type of food. Raptors such as hawks and owls are carnivores. They hunt and eat mammals and other birds. Vultures are scavengers. They eat the remains of dead animals, such as roadkill. Aquatic birds generally eat fish or water plants. Perching birds may eat insects, fruit, honey, or nectar. Many fruit-eating birds play a key role in seed dispersal, and some nectar-feeding birds are important pollinators. Bird beaks are generally adapted for the food they eat. For example, the sharp, hooked beak of a raptor is well suited for killing and tearing apart prey. The long beak of the hummingbird in **Figure** 19.32 co-evolved with the tube-shaped flowers from which it sips nectar.

Birds at Risk

Hundreds of species of birds have gone extinct as a result of human actions. A well-known example is the passenger pigeon. It was once the most common bird in North America, but over-hunting and habitat destruction led to its extinction in the 1800s. Habitat destruction and use of the pesticide DDT explain the recent extinction of the dusky seaside sparrow. This native Florida bird was declared extinct in 1990.

Today, some 1,200 species of birds are threatened with extinction by human actions. Humans need to take steps to protect this precious and important natural resource. What can you do to help?

FIGURE 19.32

Hummingbird Sipping Nectar. A hummingbird gets nectar from flowers and pollinates the flowers in return. What type of relationship exists between the bird and the flowering plant

KQED: The Golden Eagle

Although not as famous as its bald cousin, Golden Eagles are much easier to find in Northern California - one of the largest breeding populations for Golden Eagles. The largest of the raptors, Golden Eagles weigh typically between 8 and 12 pounds, and their wing span is around 6 to 7 feet. These eagles dive towards earth to catch prey, and can reach speeds of up to 200 mph! Meet one of the largest birds of prey at http://www.kqed.org/quest/television/cool-critters-the-golden-eagle.

MEDIA

Click image to the left for more content.

KQED: The Great Horned Owl

Owls are amazing creatures. They have many adaptations that allow them to thrive in their environments. Their claws are enormous and powerful, they have excellent hearing, and fantastic vision in low light. And the Great Horned Owl can fly almost silently due to "fringes" on their feathers that help to break up the sound of air passing over their wings. Learn more of the Great Horned Owl at http://www.kqed.org/quest/television/cool-critters-great-horned-owls-.

MEDIA

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KQED: The Turkey Vulture

Ever wonder why a vulture's head is bald? Turkey Vultures are very interesting birds. The Turkey Vulture has no vocal organs – they can only grunt or hiss, although they usually stay silent. They do not build nests – they lay their eggs directly on the ground in caves, crevices, burrows, hollow logs, under fallen trees, or even in abandoned buildings. While these vultures have few natural predators, their main form of defense is vomiting. The foul smelling substance deters most creatures, and will also sting if the offending animal is close enough to get vomit on them. Learn more about Turkey Vultures at http://www.kqed.org/quest/television/cool-critters-turkey-vultures. Also see http://www.wildlife-museum.org/ for the Lindsay Wildlife Museum.

MEDIA

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Lesson Summary

- Birds are endothermic tetrapod vertebrates. They are bipedal and have wings and feathers. Their organ systems are adapted for flight. For example, they have light-weight air-filled bones and a large four-chambered heart. Birds also have relatively large brains and a high level of intelligence.
- Birds reproduce sexually and have internal fertilization. Mating is generally preceded by courtship. Their amniotic eggs have hard shells and are laid in a nest. The eggs are usually incubated until they hatch. Most species have a relatively long period of parental care.
- There are about 10,000 living species of birds, almost all of which can fly. Flying birds are divided into 29 orders. The most common orders include landfowl, waterfowl, shorebirds, diurnal and nocturnal raptors, parrots, and perching birds.
- Birds are thought to have evolved from theropod dinosaurs around 150 million years ago. Their ancestor may have been similar to the extinct theropod *Deinonychus,* whose fossils convinced most scientists that birds evolved from dinosaurs. Scientist still don't know how or why wings and flight evolved, but they continue to search for answers.
- Birds live and breed in most terrestrial habitats on all seven continents. They occupy a wide range of ecological positions. Raptors are carnivores; aquatic birds eat fish or water plants; and perching birds may eat insects, fruit, honey, or nectar. Some birds are pollinators that co-evolved with plants. Human actions have caused the extinction of hundreds of species of birds, and some 1,200 species are threatened with extinction today.

Lesson Review Questions

Recall

1. List two functions of feathers in birds.

2. Describe the bird crop and gizzard. What are their functions?

3. How do birds keep their lungs filled with oxygenated air?

4. Give an example of bird behavior that shows their relatively great intelligence.

5. What is courtship? What is its purpose?

Apply Concepts

6. Draw a sketch of a hypothetical bird that preys on small mammals. The bird must exhibit traits that suit it for its predatory role.

Think Critically

7. Relate two unique traits of birds to flight.

8. Contrast hatchling maturity in birds that are ground-nesting and those that nest off the ground. What is the adaptive significance of the differences?

9. Why did the hummingbird pictured in the **Hummingbird Sipping Nectar Figure** 19.32 evolve such a long, pointed beak?

Points to Consider

Birds share a number of important traits with mammals, including a four-chambered heart and endothermy. The next chapter describes mammals in detail.

- What are some examples of mammals?
- What other traits do you think mammals might have? What traits do you think set mammals apart from all other vertebrates, including birds?

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CHAPTER 20 Mammals and Animal Behavior

CHAPTER OUTLINE

You might think that these young tigers are fighting, but they're really playing. Like most other young mammals, tigers like to play. Why do mammals play? Is playing just for fun, or does it serve some other purpose as well?

Playing is actually an important way of learning. By playing, these tigers are learning moves that will help them become successful predators as adults. Playing is just one of many ways that mammals and other animals learn how to behave. In this chapter, you will learn more about mammals such as tigers. You will also learn more about animal behavior and other ways that animals learn.

20.1 Mammalian Traits

Lesson Objectives

- List characteristics of mammals.
- Describe structure and function in mammals.

Vocabulary

alveoli (singular, alveolus) tiny sacs at the ends of bronchioles in the lungs where pulmonary gas exchange takes place

arboreal of or pertaining to trees, as in arboreal, or tree-living, mammal

cerebrum largest part of the brain that controls conscious functions such as reasoning and sight

lactation production of milk for an offspring by mammary glands, which occurs in all female mammals after giving birth or laying eggs

mammal endothermic, tetrapod vertebrate that lays amniotic eggs and has mammary glands (in females) and hair or fur

mammary gland gland in female mammals that produces milk for offspring

neocortex layer of nerve cells covering the cerebrum of the mammalian brain that plays an important role in many complex brain functions

Introduction

Mammals are a class of endothermic vertebrates. They have four limbs and produce amniotic eggs. Examples of mammals include bats, whales, mice, and humans. Clearly, mammals are a very diverse group. Nonetheless, they share many traits that set them apart from other vertebrates.

Characteristics of Mammals

Two characteristics are used to define the mammal class. They are mammary glands and body hair (or fur).

a. Female mammals have **mammary glands**. The glands produce milk after the birth of offspring. Milk is a nutritious fluid. It contains disease-fighting molecules as well as all the nutrients a baby mammal needs. Producing milk for an offspring is called **lactation**.
b. Mammals have hair or fur. It insulates the body to help conserve body heat. It can also be used for sensing and communicating. For example, cats use their whiskers to sense their surroundings. They also raise their fur to look larger and more threatening (see **Figure** 20.1).

FIGURE 20.1
Cat Communicating a Warning. By raising its fur this cat is &#8220 saying&#8221 that it&#8217 s big and dangerous. This might discourage a predator from attacking.

Most mammals share several other traits. The traits in the following list are typical of, but not necessarily unique to, mammals.

- The skin of many mammals is covered with sweat glands. The glands produce sweat, the salty fluid that helps cool the body.
- Mammalian lungs have millions of tiny air sacs called **alveoli**. They provide a very large surface area for gas exchange.
- The heart of a mammal consists of four chambers. This makes it more efficient and powerful for delivering oxygenated blood to tissues.
- The brain of a mammal is relatively large and has a covering called the **neocortex**. This structure plays an important role in many complex brain functions.
- The mammalian middle ear has three tiny bones that carry sound vibrations from the outer to inner ear. The bones give mammals exceptionally good hearing. In other vertebrates, the three bones are part of the jaw and not involved in hearing.
- Mammals have four different types of teeth. The teeth of other vertebrates, in contrast, are all alike.

Structure and Function in Mammals

Many structures and functions in mammals are related to endothermy. Mammals can generate and conserve heat when it's cold outside. They can also lose heat when they become over-heated. How do mammals control their body temperature in these ways?

How Mammals Stay Warm

Mammals generate heat mainly by keeping their metabolic rate high. The cells of mammals have many more mitochondria than the cells of other animals. The extra mitochondria generate enough energy to keep the rate of metabolism high. Mammals can also generate little bursts of heat by shivering. Shivering occurs when many muscles contract a little bit all at once. Each muscle that contracts produces a small amount of heat.

Conserving heat is also important, especially in small mammals. A small body has a relatively large surface area compared to its overall size. Because heat is lost from the surface of the body, small mammals lose a greater proportion of their body heat than large mammals. Mammals conserve body heat with their hair or fur. It traps a layer of warm air next to the skin. Most mammals can make their hair stand up from the skin, so it becomes an even better insulator (see **Figure** 20.2). Mammals also have a layer of fat under the skin to help insulate the body. This fatty layer is not found in other vertebrates.

FIGURE 20.2
Goosebumps. Mammals raise their hair with tiny muscles in the skin. Even humans automatically contract these muscles when they are cold. They cause &#8220 goosebumps &#8221 as shown here.

How Mammals Stay Cool

One way mammals lose excess heat is by increasing blood flow to the skin. This warms the skin so heat can be given off to the environment. That's why you may get flushed, or red in the face, when you exercise on a hot day. You are likely to sweat as well. Sweating also reduces body heat. Sweat wets the skin, and when it evaporates, it cools the body. Evaporation uses energy, and the energy comes from body heat. Animals with fur, such as dogs, use panting instead of sweating to lose body heat (see **Figure** 20.3). Evaporation of water from the tongue and other moist surfaces of the mouth and throat uses heat and helps cool the body.

Eating and Digesting Food

Maintaining a high metabolic rate takes a lot of energy. The energy must come from food. Therefore, mammals need a nutritious and plentiful diet. The diets of mammals are diverse. Except for leaf litter and wood, almost any kind of organic matter may be eaten by mammals. Some mammals are strictly herbivores or strictly carnivores. However, most mammals will eat other foods if necessary. Some mammals are omnivores. They routinely eat a variety of both plant and animal foods. Most mammals also feed on a variety of other species. The few exceptions include koalas,

FIGURE 20.3
Panting Dog. This dog is overheated. It is losing excess body heat by panting.

which feed only on eucalyptus plants, and giant pandas, which feed only on bamboo. Types of mammalian diets and examples of mammals that eat them are given in **Table** 20.1 . How would you classify your own diet?

TABLE 20.1: Mammalian Diets

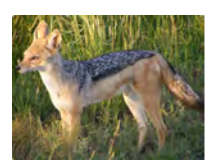
Type of Diet	Foods Eaten	Examples of Mammals with this Type of Diet
herbivorous diet: plants	leaves, grasses, shoots, stems, roots, tubers, seeds, nuts, fruits, bark, conifer needles, flowers	rabbit, mouse, sea cow, horse, goat, elephant, zebra, giraffe, deer, elk, hippopotamus, kangaroo, monkey 
carnivorous diet: animals	other mammals, birds, reptiles, amphibians, fish, mollusks, worms, insects	aardvark, anteater, whale, hyena, dog, jackal, dolphin, wolf, weasel, seal, walrus, cat, otter, mole 

TABLE 20.1: (continued)

Type of Diet	Foods Eaten	Examples of Mammals with this Type of Diet
omnivorous diet: plants and animals	any of the foods eaten in herbivorous and carnivorous diets	bear, badger, mongoose, fox, raccoon, human, rat, chimpanzee, pig 

Different diets require different types of digestive systems. Mammals that eat a carnivorous diet generally have a relatively simple digestive system. Their food consists mainly of proteins and fats that are easily and quickly digested. Herbivorous mammals, on the other hand, tend to have a more complicated digestive system. Complex plant carbohydrates such as cellulose are more difficult to digest. Some herbivores have more than one stomach. The stomachs store and slowly digest plant foods.

Mammalian teeth are also important for digestion. The four types of teeth are specialized for different feeding functions, as shown in **Figure** 20.4 . Together, the four types of teeth can cut, tear, and grind food. This makes food easier and quicker to digest.

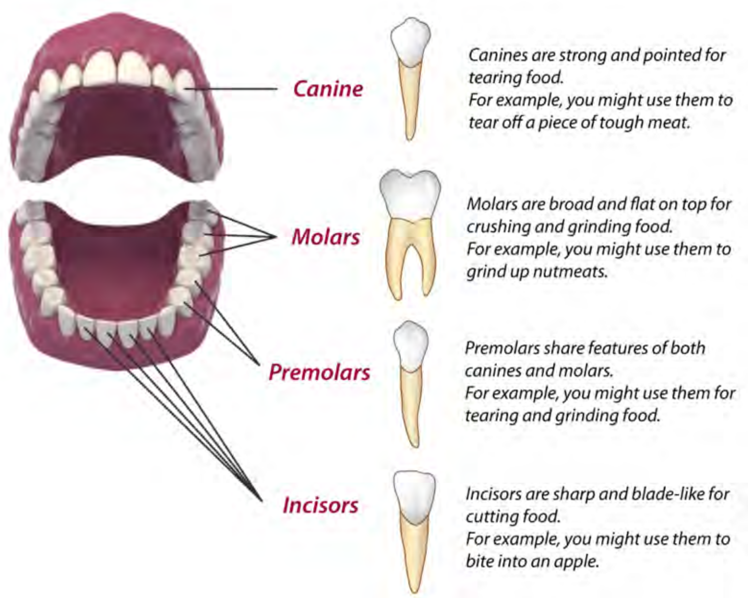


FIGURE 20.4
Mammalian Teeth *Human*. With their different types of teeth mammals can eat a wide range of foods.

Lungs and Heart of Mammals

Keeping the rate of metabolism high takes a constant and plentiful supply of oxygen. That's because cellular respiration, which produces energy, requires oxygen. The lungs and heart of mammals are adapted to meet their oxygen needs.

The lungs of mammals are unique in having alveoli. These are tiny, sac-like structures. Each alveolus is surrounded by a network of very small blood vessels (see **Figure** 20.5). Because there are millions of alveoli in each lung, they greatly increase the surface area for gas exchange between the lungs and bloodstream. Human lungs, for example, contain about 300 million alveoli. They give the lungs a total surface area for gas exchange of up to 90 square meters (968 square feet). That's about as much surface area as one side of a volleyball court!

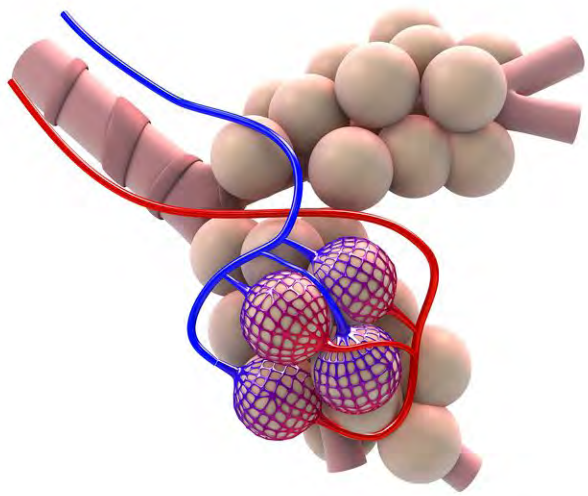


FIGURE 20.5

Alveoli of Mammalian Lungs. Clusters of alveoli resemble tiny bunches of grapes. They are surrounded by many blood vessels for gas exchange.

Mammals breathe with the help of a diaphragm. This is the large muscle that extends across the bottom of the chest below the lungs. When the diaphragm contracts, it increases the volume of the chest. This decreases pressure on the lungs and allows air to flow in. When the diaphragm relaxes, it decreases the volume of the chest. This increases pressure on the lungs and forces air out.

The four-chambered mammalian heart can pump blood in two different directions. The right side of the heart pumps blood to the lungs to pick up oxygen. The left side of the heart pumps blood containing oxygen to the rest of the body. Because of the dual pumping action of the heart, all of the blood going to body cells is rich in oxygen.

The Mammalian Brain

Of all vertebrates, mammals have the biggest and most complex brain for their body size (see **Figure** 20.6). The front part of the brain, called the **cerebrum**, is especially large in mammals. This part of the brain controls functions such as memory and learning.

The brains of all mammals have a unique layer of nerve cells covering the cerebrum. This layer is called the neocortex (the pink region of the brains in **Figure** 20.6). The neocortex plays an important role in many complex brain functions. In some mammals, such as rats, the neocortex is relatively smooth. In other mammals, especially humans, the neocortex has many folds. The folds increase the surface area of the neocortex. The larger this area is, the greater the mental abilities of an animal.

Intelligence of Mammals

Mammals are very intelligent. Of all vertebrates, they are the animals that are most capable of learning. Mammalian offspring are fed and taken care of by their parents for a relatively long time. This gives them plenty of time to learn from their parents. By learning, they can benefit from the experiences of their elders. The ability to learn is the main

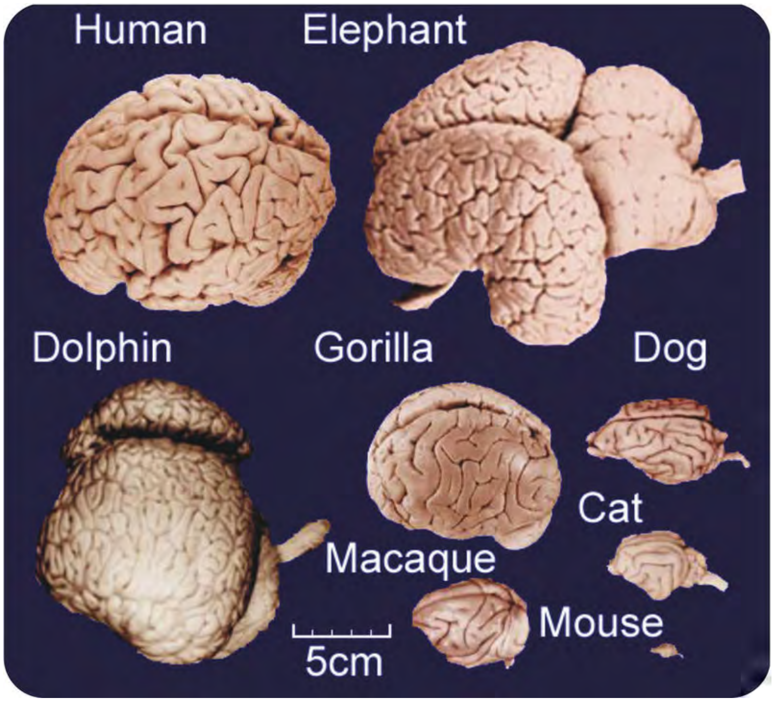


FIGURE 20.6
Vertebrate Brains. Vertebrate brains come in a range of sizes. Even the brains of mammals show a lot of variation in size. The area of the neocortex is greatest in humans.

reason that the large mammalian brain evolved. It's also the primary reason for the success of mammals.

Social Living in Mammals

Many mammals live in social groups. Social living evolved because it is adaptive. Consider these two examples:

a. Herbivores such as zebras and elephants live in herds. Adults in the herd surround and protect the young, who are most vulnerable to predators.
b. Lions live in social groups called prides. Adult females in the pride hunt cooperatively, which is more efficient than hunting alone. Then they share the food with the rest of the pride. For their part, adult males defend the pride's territory from other predators.

Locomotion in Mammals

Mammals are noted for the many ways they can move about. Generally, their limbs are very mobile. Often, they can be rotated. Many mammals are also known for their speed. The fastest land animal is a predatory mammal. Can you guess what it is? Racing at speeds of up to 112 kilometers (70 miles) per hour, the cheetah wins hands down. In addition, the limbs of mammals let them hold their body up above the ground. That's because the limbs are attached beneath the body, rather than at the sides as in reptiles (see **Figure** 20.7).

Mammals may have limbs that are specialized for a particular way of moving. They may be specialized for running, jumping, climbing, flying, or swimming. Mammals with these different modes of locomotion are pictured in **Figure** 20.8 .

The deer in the **Figure** 20.8 is specialized for running. Why? It has long legs and hard hooves. Can you see why the other animals in the figure are specialized for their particular habitats? Notice how **arboreal**, or tree-living animals, have a variety of different specializations for moving in trees. For example, they may have:

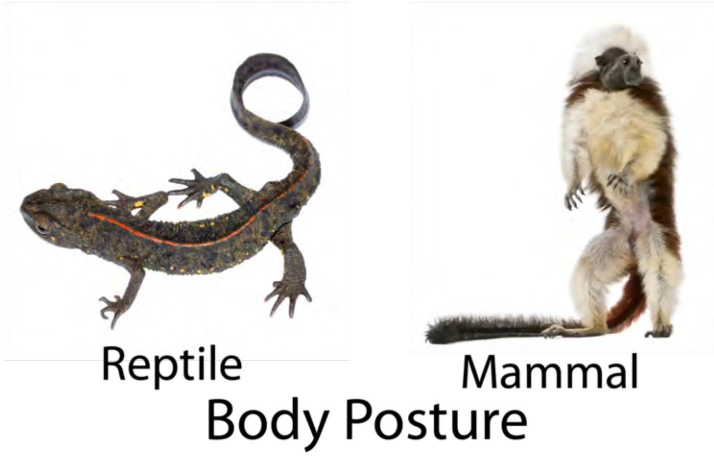


FIGURE 20.7
Limb Positions in Reptiles and Mammals. The sprawling limbs of a reptile keep it low to the ground. A mammal has a more upright stance.

- A prehensile, or grasping, tail. This is used for climbing and hanging from branches.
- Very long arms for swinging from branch to branch. This way of moving is called brachiation.
- Sticky pads on their fingers. The pads help them cling to tree trunks and branches.

Lesson Summary

- Mammals are a class of endothermic vertebrates. They have four limbs and produce amniotic eggs. The mammal class is defined by the presence of mammary glands and hair (or fur). Other traits of mammals include sweat glands in their skin, alveoli in their lungs, a four-chambered heart, and a brain covering called the neocortex.
- Mammals have several ways of generating and conserving heat, such as a high metabolic rate and hair to trap heat. They also have several ways to stay cool, including sweating or panting. Mammals may be herbivores, carnivores, or omnivores. They have four types of teeth, so they can eat a wide range of foods. Traits of the heart and lungs keep the cells of mammals well supplied with oxygen and nutrients.
- Mammals have a relatively large brain and a high level of intelligence. They also have many ways of moving about and may move very quickly.

Lesson Review Questions

Recall

1. List five traits that are shared by all mammals, including the two traits that are used to define the mammal class.

2. Describe how mammals stay warm.

3. What is the function of sweating?

4. Identify mammals that are herbivores, carnivores, and omnivores.

5. What are alveoli? What is their function?

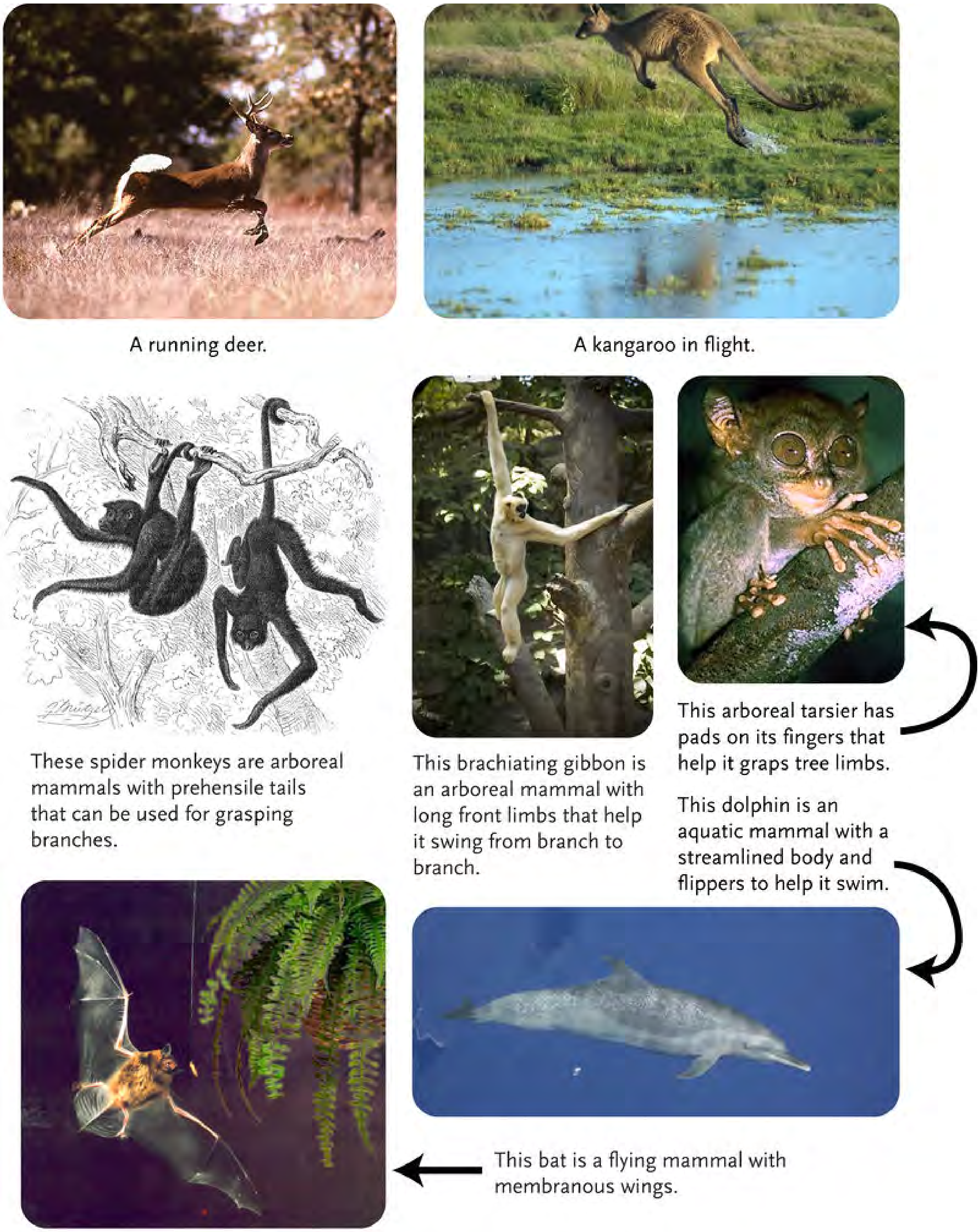


FIGURE 20.8
Mammalian Locomotion. Mammals have many different modes of locomotion.

Apply Concepts

6. A certain mammal has very long forelimbs. What does that suggest about where the animal lives and how it moves?

Think Critically

7. Explain how mammalian teeth differ from the teeth of other vertebrates. How are mammalian teeth related to endothermy?

8. Compare and contrast the mammalian brain with the brains of other vertebrates. How is the brain of mammals related to their ability to learn?

Points to Consider

Most mammals are born as live young, as opposed to hatching from eggs. Giving birth to live young has certain advantages over egg laying.

- What do you think the advantages of live births might be? How might this form of reproduction help ensure that the offspring survive?
- Do you think that giving birth to live young, as opposed to laying eggs, might have disadvantages? What might the disadvantages be?

20.2 Reproduction in Mammals

Lesson Objectives

- Describe female reproductive structures of therian mammals.
- Outline reproduction in placental mammals.
- Explain how marsupials reproduce.
- Describe monotreme reproduction.

Vocabulary

marsupial therian mammal in which the embryo is born at an early, immature stage and completes its development outside the mother's body in a pouch on her belly

monotreme type of mammal that reproduces by laying eggs

placenta temporary organ that consists of a large mass of maternal and fetal blood vessels through the mother's and fetus's blood exchange substances

placental mammal therian mammal in which a placenta develops during pregnancy to sustain the fetus while it develops inside the mother's uterus

therian mammal viviparous mammal that may be either a marsupial or placental mammal

uterus (plural, uteri) female reproductive organ in therian mammals where an embryo or fetus grows and develops until birth

vagina female reproductive organ that receives sperm during sexual intercourse and provides a passageway for a baby to leave the mother's body during birth

Introduction

Most mammals are viviparous. Their young are born live. They are born either as relatively large, well-developed fetuses or as tiny, immature embryos. Mammals that are viviparous are called **therian mammals**. Only a few mammals lay eggs instead of giving birth to an infant or embryo.

Therian Mammals

Like other female vertebrates, all female mammals have ovaries. These are the organs that produce eggs (see **Figure** 20.9). Therian mammals also have two additional female reproductive structures that are not found in other vertebrates. They are the uterus and vagina.

- The **uterus** (plural, uteri) is a pouch-like, muscular organ. The embryo or fetus develops inside the uterus. Muscular contractions of the uterus push the offspring out during birth.
- The **vagina** is a tubular passageway through which the embryo or fetus leaves the mother's body during birth. The vagina is also where the male deposits sperm during mating.

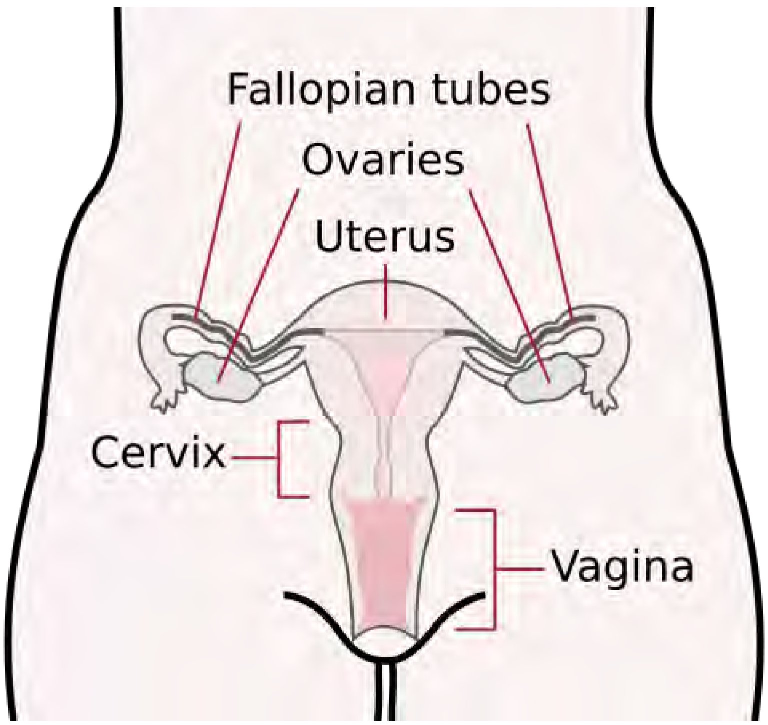


FIGURE 20.9

Female Reproductive System of a Therian Mammal *Human*. The female reproductive system of all therian mammals is similar to that of humans.

Therian mammals are divided into two groups: placental mammals and marsupial mammals. Each group has a somewhat different reproductive strategy.

Placental Mammals

Placental mammals are therian mammals in which a placenta develops during pregnancy. The placenta sustains the fetus while it grows inside the mother's uterus. Placental mammals give birth to relatively large and mature infants. Most mammals are placental mammals.

The Placenta

The **placenta** is a spongy structure. It consists of membranes and blood vessels from both mother and embryo (see **Figure** 20.10). The placenta passes oxygen, nutrients, and other useful substances from the mother to the fetus. It also passes carbon dioxide and other wastes from the fetus to the mother. The placenta lets blood from the fetus and mother exchange substances without actually mixing. Thus, it protects the fetus from being attacked by the mother's immune system as a "foreign parasite."

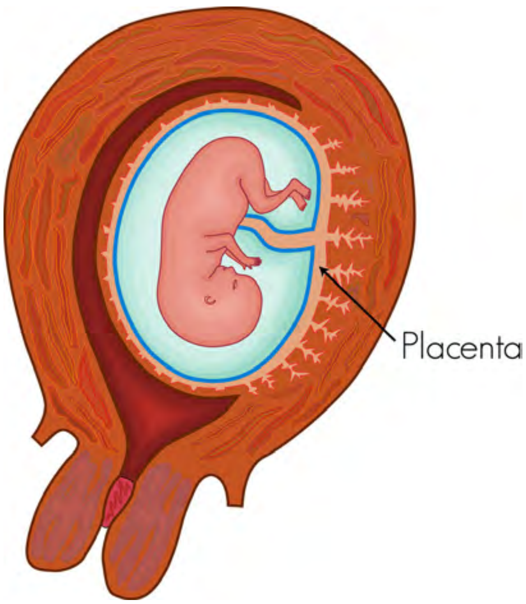


FIGURE 20.10

Placenta of a Placental Mammal *Human*. The placenta allows the exchange of gases nutrients and other substances between the fetus and mother.

Pros and Cons of Placental Reproduction

The placenta permits a long period of fetal growth in the uterus. As a result, the fetus can become large and mature before birth. This increases its chances of surviving.

On the other hand, supporting a growing fetus is very draining and risky for the mother. The mother has to eat more food to nourish the fetus. She also becomes heavier and less mobile as the fetus gets larger. As a result, she may be less able to escape from predators. Because the fetus is inside her, she can't abandon it to save her own life if she is pursued or if food is scarce. Giving birth to a large infant is also risky. It may even result in the mother's death.

Marsupials

Marsupials have a different way of reproducing that reduces the mother's risks. A **marsupial** is a therian mammal in which the embryo is born at an early, immature stage. The embryo completes its development outside the mother's body in a pouch on her belly. Only a minority of therian mammals are marsupials. They live mainly in Australia. Examples of marsupials are pictured in **Figure** 20.11 .

The Marsupial Embryo

The marsupial embryo is nourished inside the uterus with food from a yolk sac instead of through a placenta. The yolk sac stores enough food for the short period of time the embryo remains in the uterus. After the embryo is born, it moves into the mother's pouch, where it clings to a nipple (see **Figure** 20.12). It remains inside the pouch for several months while it continues to grow and develop. Even after the offspring is big enough to leave the pouch,

FIGURE 20.11
Marsupials. Marsupials include the kangaroo koala and opossum.

it may often return to the pouch for warmth and nourishment. Eventually, the offspring is mature enough to remain outside the pouch on its own.

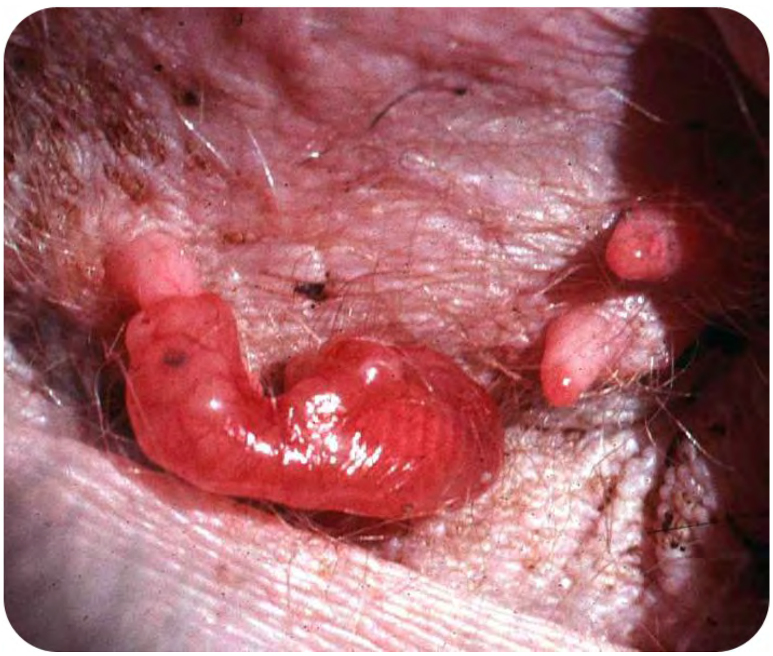


FIGURE 20.12
Marsupial Embryo in the Pouch. A kangaroo embryo suckles a nipple inside its mother&#8217 s pouch.

Pros and Cons of Marsupial Reproduction

In marsupials, the short period of development within the mother's uterus reduces the risk of her immune system attacking the embryo. In addition, the marsupial mother doesn't have to eat extra food or carry a large fetus inside her. The risks of giving birth to a large fetus are also avoided. Another pro is that the mother can expel the embryo from her pouch if she is pursued by a predator or if food is scarce. On the other hand, a newborn marsupial is tiny and fragile. Therefore, it may be less likely to survive than a newborn placental mammal.

KQED: The North American Marsupial: The Opossum

Most people think of Opossums as scary creatures. Is this because they look kind of funny, walk kind of funny, have beady eyes and sharp teeth, and can emit a very foul odor? Maybe. But what is so different about opossums is that they are the only marsupial in North America.

But opossums can be beneficial to humans. They use their sharp teeth to crush bone – which means that they are good getting rid of unwanted rodents in your neighborhood. They have excellent immune systems and they emit that terrible oder for protection. Learn more about opossums at http://www.kqed.org/quest/television/cool-critters-possums and http://www.kqed.org/quest/blog/2009/03/31/producers-notes-for-cool-critters-opossums/.

MEDIA

Click image to the left for more content.

Monotremes

Only five living species of mammals are not therian mammals. They are called monotremes. **Monotremes** are mammals that reproduce by laying eggs. The only living monotreme species are the platypus and echidnas (see **Figure** 20.13 and **Figure** 20.14). They are found solely in Australia and New Guinea (an island not far from Australia).

FIGURE 20.13

Platypus. The platypus is a monotreme a mammal that reproduces by laying eggs.

Eggs and Lactation in Monotremes

Female monotremes lack a uterus and vagina. Instead, they have a cloaca with one opening, like the cloacas of reptiles and birds. The opening is used to excrete wastes as well as lay eggs.

Monotreme eggs have a leathery shell, like the eggs of reptiles. The eggs are retained inside the mother's body for at least a couple of weeks. During that time, the mother provides the eggs with nutrients. Platypus females lay their eggs in a burrow. Echidna females have a pouch in which they store their eggs. Female monotremes have mammary glands but lack nipples. Instead, they "sweat" milk from a patch on their belly.

FIGURE 20.14
Echidna. Like the platypus the echidna is a monotreme. The only living monotreme species inhabit Australia and New Guinea.

Pros and Cons of Monotreme Reproduction

The mother's risks are less in monotremes than in therian mammals. The mother doesn't need to eat more or put herself at risk by carrying and delivering a fetus or an embryo. On the other hand, externally laid eggs are more difficult to protect than an embryo in a pouch or a fetus in a uterus. Therefore, monotreme offspring may be less likely to survive than the offspring of therian mammals.

Lesson Summary

- Therian mammals are viviparous. They give birth to an embryo or infant rather than laying eggs. The female reproductive system of a therian mammal includes a uterus and a vagina. There are two groups of therian mammals: placental mammals and marsupials.
- Placental mammals give birth to a relatively large and mature fetus. This is possible because they have a placenta to nourish the fetus and protect it from the mother's immune system. This allows for a long period of growth and development before birth. Because the offspring is relatively large and mature at birth, it has a good chance of surviving. However, carrying and giving birth to a large fetus is risky for the mother. It also requires her to eat more food.
- Marsupials give birth to a tiny, immature embryo. The embryo then continues to grow and develop in a pouch on the mother's belly. This is less risky for the mother. However, the embryo is fragile, so it may be less likely to survive than the fetus of a placental mammal.
- Monotremes reproduce by laying eggs. They have a cloaca instead of a uterus and vagina. The eggs pass through the opening of the cloaca. This form of reproduction is the least risky for the mother. However, eggs are harder to protect than is an embryo or a fetus in a pouch or uterus. Therefore, monotreme offspring may have a lower chance of surviving than the offspring of therian mammals.

Lesson Review Questions

Recall

1. What are the functions of the uterus and vagina in therian mammals?

2. What is the placenta? What is its role?

3. Where does a marsupial embryo develop? How is it nourished?

4. Describe eggs and egg laying in monotremes.

5. How does lactation differ in monotremes and therian mammals?

Apply Concepts

6. Create a chart that you could use to explain to a younger student the different ways that mammals reproduce.

Think Critically

7. Compare and contrast the advantages and disadvantages of the three forms of reproduction in mammals.

8. Placental mammals greatly outnumber the other two groups of mammals. Infer why placental mammals have been so successful.

Points to Consider

Monotremes are less similar to therian mammals than the two groups of therian mammals are to each other.

- How might the different groups of mammals have evolved?
- Which group of mammals do you think evolved first?

20.3 Evolution and Classification of Mammals

Lesson Objectives

- Describe the therapsid ancestors of mammals.
- Outline the evolution of monotreme, marsupial, and placental mammals.
- Summarize the evolution of modern mammals.
- Contrast traditional and phylogenetic classifications of mammals.

Vocabulary

therapsid type of extinct organism that lived during the Permian Period and gave rise to mammals

Introduction

Which mammalian trait evolved first? What was the first mammal like? When did the earliest mammal live? Detailed answers to these questions are still in dispute. However, scientists generally agree on the major events in the evolution of mammals. These are summarized in **Table** 20.2 . Refer back to the table as you read about the events in this lesson. *mya = millions of years ago

TABLE 20.2: Major Events in Mammalian Evolution

Era	Period	Epoch	Major Events	Start (mya)*
Cenozoic	Neogene	Holocene	Rise of human civilization; spread and dominance of modern humans	0.01
-	-	Pleistocene	Spread and then extinction of many large mammals; appearance of modern humans	1.8
-	-	Pliocene	Appearance of many existing genera of mammals, including the genus *Homo*	5.3

TABLE 20.2: (continued)

Era	Period	Epoch	Major Events	Start (mya)*
-	-	Miocene	Appearance of remaining modern mammal families; diversification of horses and mastodons; first apes	23.0
-	Paleogene	Oligocene	Rapid evolution and diversification of placental mammals	33.9
-	-	Eocene	Appearance of several modern mammal families; diversification of primitive whales	55.8
-	-	Paleocene	Appearance of the first large mammals	65.5
Mesozoic	Cretaceous	-	Emergence of monotreme, marsupial, and placental mammals; possible first appearance of four clades (superorders) of placental mammals (Afrotheria, Xenarthra, Laurasiatheria, Supraprimates)	145.5
-	Jurassic	-	Spread of mammals, which remain small in size	199.6
-	Triassic	-	Evolution of cynodonts to become smaller and more mammal-like; appearance of the first mammals	251.0
Paleozoic	Permian	-	Evolution and spread of synapsids (pelycosaurs and therapsids)	299.0
-	Carboniferous	-	Appearance of amniotes, the first fully terrestrial vertebrates	359.0

Mammalian Ancestors

Ancestors of mammals evolved close to 300 million years ago. They were amniotes called synapsids. **Figure** 20.15 shows how modern mammals evolved from synapsids. The stages of evolution from synapsids to mammals are described below.

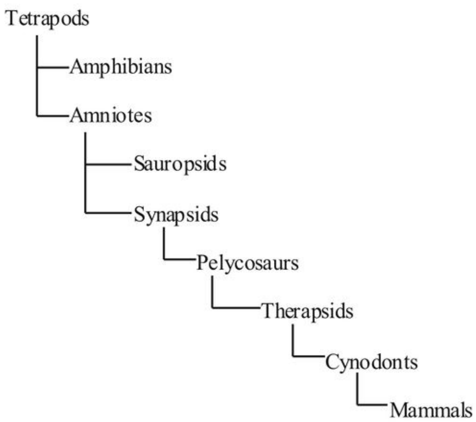


FIGURE 20.15
Phylogeny of Mammalian Evolution. This diagram represents the evolution of mammals.

Pelycosaurs

Synapsids called pelycosaurs became the most common land vertebrates during the first half of the Permian Period. A pelycosaur genus called *Dimetrodon* is shown in **Figure** 20.16 . *Dimetrodon* had sprawling legs and walked like a lizard. It also had a fairly small brain. However, it had started to develop some of the traits of mammals. For example, it had teeth of different types.

Therapsids

Some pelycosaurs gave rise to a group of animals called **therapsids**. The earliest therapsids lived about 260 million years ago. At first, the therapsids looked a lot like *Dimetrodon*. But after a while, they could easily be mistaken for mammals. They evolved a number of mammalian traits, such as legs positioned under the body instead of along the sides. Therapsids became the most common and diverse land vertebrates during the second half of the Permian Period.

The Permian Period ended about 250 million years ago with a mass extinction. Most therapsids went extinct. Their niches were taken over by sauropsids. These were the amniotes that evolved into dinosaurs, reptiles, and birds. Not all therapsids went extinct, however. The few that remained no longer had to compete with many other therapsids. Some of them eventually evolved into mammals.

Cynodonts

The surviving therapsids were small animals. Some of the most successful were the cynodonts (see **Figure** 20.17). They flourished worldwide during the first half of the Triassic Period. Some of them ate insects and were nocturnal,

FIGURE 20.16

Pelycosaur Synapsid Dimetrodon. Dimetrodon was a pelycosaur. It lived about 275 million years ago.

or active at night. Being nocturnal may have helped save them from extinction. Why? A nocturnal niche was one of the few niches that dinosaurs did not take over in the Triassic Period.

Cynodonts became more mammal-like as they continued to evolve. Some of their mammalian traits may have been adaptations to their nocturnal niche. For example:

- The ability to regulate body temperature might have been selected for because it would allow nocturnal animals to remain active in the cool of the night.
- A good sense of hearing might have been selected for because it would be more useful than good vision when hunting in the dark.

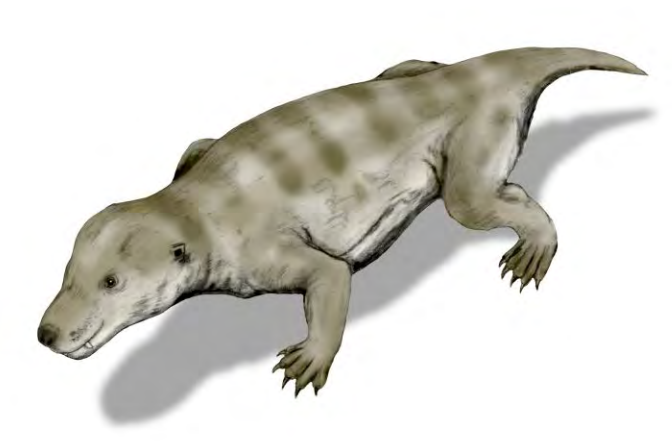


FIGURE 20.17
Probable Mammalian Ancestor Cynodont. Cynodonts were mammal-like therapsids. They may have been ancestral to mammals. They were about the size of a rat.

By the end of the Triassic Period, cynodonts had become even smaller in size. They also had evolved many mammalian traits. For example, they had

- Four different types of teeth.
- A relatively large brain.
- Three tiny bones in the middle ear.
- A diaphragm for breathing.
- Endothermy.
- Lactation.
- Hair.

Cynodonts probably gave rise to mammals about 200 million years ago. However, they are not considered to be mammals themselves. In fact, competition with early mammals may have led to their extinction. They went extinct sometime during the Jurassic or Cretaceous Period.

Evolution of Early Mammals

The earliest mammals evolved from cynodonts. But the evolution of mammals didn't end there. Mammals continued to evolve. Monotreme mammals probably split off from other mammals first. They were followed by marsupials. Placental mammals probably evolved last.

Evolution of Monotremes

The first monotremes may have evolved about 150 million years ago. Early monotreme fossils have been found in Australia. An example is a genus called *Steropodon*, shown in **Figure** 20.18 . It may have been the ancestor of the platypus. Early monotremes retained some of the traits of their therapsid ancestors. For example, they laid eggs and had a cloaca. These traits are still found in modern monotremes.

FIGURE 20.18
Probable Monotreme Ancestor Steropodon. Like the platypus Steropodon probably had a bill.

Evolution of Marsupials

The first marsupials may have evolved about 130 million years ago. One of the earliest was the extinct genus *Sinodelphys*. A fossil of this mammal is shown in **Figure** 20.19 . It is a remarkable fossil find. It represents a nearly complete animal. Even tufts of hair and imprints of soft tissues were preserved.

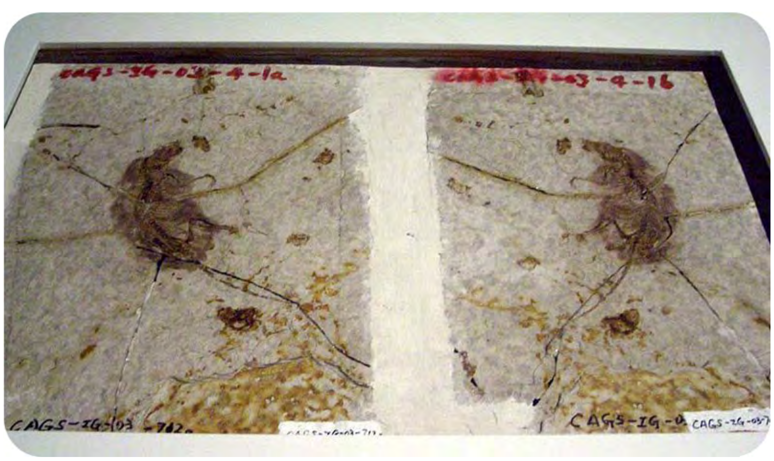


FIGURE 20.19
Early Marsupial Sinodelphys. The dark shapes on these two rock slabs are two halves of the fossil named Sinodelphys. The head is at the top of the image. The legs point toward the center.

Sinodelphys was about 15 centimeters (6 inches) long. Its limb structure suggests that it was a climbing animal. It could escape from predators by climbing into trees. It probably lived on a diet of insects and worms.

Evolution of Placental Mammals

The earliest placental mammals may have evolved about 110 million years ago. The ancestor of placental mammals may be the extinct genus *Eomaia*. Fossils of *Eomaia* have been found in what is now China. It was only about 10 centimeters (4 inches) long. It was a tree climber and probably ate insects and worms. *Eomaia* had several traits of placental mammals. **Figure** 20.20 shows how *Eomaia* may have looked.

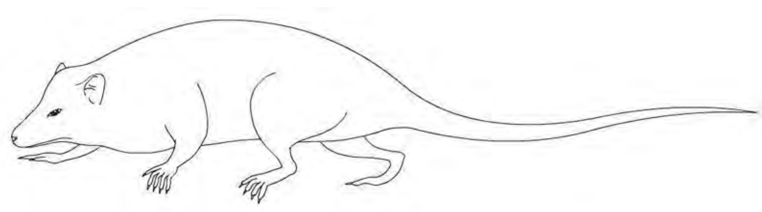


FIGURE 20.20

Probable Ancestor of Placental Mammals Eomaia. Eomaia lived a little over 100 million years ago.

The placental mammal descendants of *Eomaia* were generally more successful than marsupials and monotremes. On most continents, placental mammals became the dominant mammals, while marsupials and monotremes died out. Marsupials remained the most common and diverse mammals in Australia. The reason for their success there is not yet resolved.

Evolution of Modern Mammals

The Cretaceous Period ended with another mass extinction. This occurred about 65 million years ago. All of the dinosaurs went extinct at that time. Did the extinction of the dinosaurs allow mammals to take over?

Traditional View

Scientists have long assumed that the extinction of the dinosaurs opened up many niches for mammals to exploit. Presumably, this led to an explosion of new species of mammals early in Cenozoic Era. Few mammalian fossils from the early Cenozoic have been found to support this theory. Even so, it was still widely accepted until recently.

View from the Mammalian Supertree

In 2007, an international team of scientists compared the DNA of almost all known species of living mammals. They used the data to create a supertree of mammalian evolution. The supertree shows that placental mammals started to diversify as early as 95 million years ago.

What explains the diversification of mammals long before the dinosaurs went extinct? What else was happening at that time? One change was a drop in Earth's temperature. This may have favored endothermic mammals over ectothermic dinosaurs. Flowering plants were also spreading at that time. They may have provided new and plentiful foods for small mammals or their insect prey.

The supertree also shows that another major diversification of mammals occurred about 50 million years ago. Again, worldwide climate change may have been one reason. This time Earth's temperature rose. The warmer temperature led to a greater diversity of plants. This would have meant more food for mammals or their prey.

Classification of Placental Mammals

Traditional classifications of mammals are based on similarities in structure and function. Increasingly, mammals are being classified on the basis of molecular similarities.

Traditional Classification

The most widely accepted traditional classification of mammals divides living placental mammals into 17 orders. These orders are shown in **Table** 20.3 . This classification of mammals was widely accepted for more than 50 years. Placental mammals are still commonly placed in these orders. However, this classification is not very useful for studies of mammalian evolution. That's because it groups together some mammals that do not seem to be closely related by descent from a recent common ancestor.

TABLE 20.3: Orders of Placental Mammals (Traditional Classification)

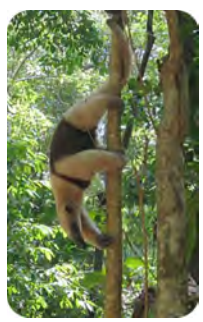
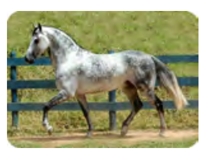
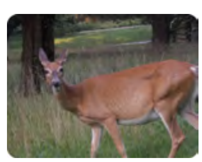
Order	Example	Sample Trait
Insectivora	mole 	small sharp teeth
Edentata	anteater 	few or no teeth
Pholidota	pangolin 	large plate-like scales

TABLE 20.3: (continued)

Order	Example	Sample Trait
Chiroptera	bat 	digits support membranous wings
Carnivora	coyote 	long pointed canine teeth
Rodentia	mouse 	incisor teeth grow continuously
Lagomorpha	rabbit 	chisel-like incisor teeth
Perissodactyla	horse 	odd-toed hooves
Artiodactyla	deer 	even-toed hooves
Cetacea	whale 	paddlelike forelimbs

TABL

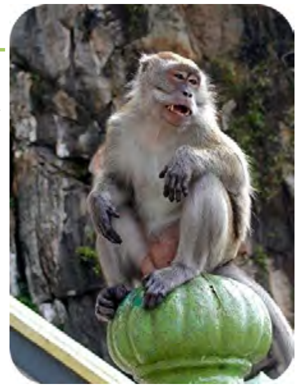
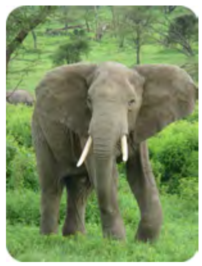
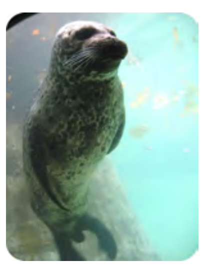
Order	Example	Sample Trait
Primates	monkey 	five digits on hands and feet
Proboscidea	elephant 	tusks
Hyracoidea	hyrax 	rubbery pads on feet
Dermoptera	colugo 	membrane of skin between legs for gliding
Pinnipedia	seal 	feet with fins
Sirenia	manatee 	paddle-like tail

TABLE 20.3: (continued)

Order	Example	Sample Trait
Tubulidentata	aardvark	teeth without enamel

Phylogenetic Classification

The mammalian supertree classifies placental mammals phylogenetically. It groups together mammals that are closely related because they share a recent common ancestor. These groups are not necessarily the same as the traditional groups based on structure and function. The supertree classification places placental mammals in four superorders. The four superorders and some of the mammals in them are:

- Afrotheria—aardvarks, elephants, manatees.
- Xenarthra—anteaters, sloths, armadillos.
- Laurasiatheria—bats, whales, hoofed mammals, carnivores.
- Supraprimates—primates, rabbits, rodents.

All four superorders appear to have become distinct from one another between 85 and 105 million years ago. The exact relationships among the superorders are still not clear. Revisions in this classification of mammals may occur as new data become available.

Lesson Summary

- Amniotes called synapsids were the ancestors of mammals. Synapsids named pelycosaurs had some of the traits of mammals by 275 million years ago. Some of them evolved into therapsids, which became widespread during the Permian Period. The few therapsids that survived the Triassic takeover were small, arboreal insect eaters. They were also nocturnal. Being active at night may explain why they survived and evolved still more mammalian traits.
- Monotremes evolved about 150 million years ago. Like modern monotremes, they had a cloaca and laid eggs. Marsupials evolved about 130 million years ago. They were very small and ate insects and worms. Placental mammals evolved about 110 million years ago. They were also small and climbed trees. Placental mammals became the dominant land mammals. Most marsupials and monotremes died out except in Australia.
- Mammals used to be classified on the basis of similarities in structure and function into 17 different orders. Recently, DNA analyses have shown that the traditional orders include mammals that are not closely related. Phylogenetic classification, based on DNA data, groups placental mammals in four superorders. The superorders appear to have become distinct from each other 85–105 million years ago.

Lesson Review Questions

Recall

1. What were the synapsids? When were they most widespread?

2. Identify the therapsids. How were they related to mammals?

3. Describe cynodonts. What is their place in the evolution of mammals?

4. Outline the evolution of monotreme, marsupial, and placental mammals.

5. What is the mammalian supertree?

Apply Concepts

6. Assume that a new species of placental mammal has been discovered. Scientists have examined it closely and studied its DNA. It has wings similar to a bat that it uses for gliding. Its DNA is most similar to the DNA of rodents such as mice. How would you classify the new mammal? Explain your answer.

Think Critically

7. Explain why the extinction of most therapsids at the end of the Permian Period may have allowed mammals to evolve.

8. Relate the extinction of dinosaurs to the diversification of modern mammals.

9. Compare and contrast traditional and phylogenetic classifications of placental mammals. Explain which type of classification is more useful for understanding how mammals evolved.

Points to Consider

Some mammalian traits, such as different types of teeth, evolved in ancestors of mammals. Other traits, such as placental reproduction, evolved after the first mammals appeared. Mammals also evolved many behavioral traits.

- How do mammals behave? What behaviors do you think characterize mammals?
- How do you think these behaviors evolved?

20.4 Overview of Animal Behavior

Lesson Objectives

- Describe how and why ethologists study animal behavior.
- Explain how animal behaviors evolve.
- Define innate behavior.
- State ways that animals learn.
- Identify types of animal behavior.

Vocabulary

aggression behavior that is intended to cause harm or pain

animal behavior any way that animals interact with each other or the environment

circadian rhythm regular change in biology or behavior that occurs in a 24-hour cycle

cooperation type of animal behavior in which social animals live and work together for the good of the group

ethology branch of biology that studies animal behavior

innate behavior behavior closely controlled by genes that occurs naturally, without learning or practice, in all members of a species whenever they are exposed to a certain stimulus; also called instinctive behavior

instinct ability of an animal to perform a behavior the first time it is exposed to the proper stimulus

learning change in behavior that occurs as a result of experience

nature-nurture debate debate over the extent to which genes (nature) or experiences in a given environment (nurture) control traits such as animal behaviors

reflex rapid motor response to a sensory stimulus in which nerve impulses travel in an arc that includes the spinal cord but not the brain

social animal animal that lives in a society

society close-knit group of animals of the same species that live and work together

stimulus something that triggers a behavior

Introduction

Did you ever see a dog sit on command? Have you ever watched a cat trying to catch a mouse? These are just two examples of the many behaviors of animals. **Animal behavior** includes all the ways that animals interact with each other and the environment. Examples of common animal behaviors are pictured in **Figure** 20.21 .

FIGURE 20.21
Examples of Animal Behavior. Can you think of other examples of animal behavior besides the three shown here

Studying Animal Behavior

The branch of biology that studies animal behavior is called **ethology**. Ethologists usually study how animals behave in their natural environment, rather than in a lab. They generally try to answer four basic questions about the behaviors they observe:

a. What causes the behavior? What is the **stimulus**, or trigger, for the behavior? What structures and functions of the animal are involved in the behavior?
b. How does the behavior develop? Is it present early in life? Or does it appear only as the animal matures? Are certain experiences needed for the behavior to develop?
c. Why did the behavior evolve? How does the behavior affect the fitness of the animal performing it? How does it affect the survival of the species?
d. How did the behavior evolve? How does it compare with similar behaviors in related species? In what ancestor did the behavior first appear?

As you read about animal behavior in the rest of this lesson, think about these four questions. Try to answer the questions for different types of animal behavior.

Evolution of Animal Behavior

To the extent that behaviors are controlled by genes, they may evolve through natural selection. If behaviors increase fitness, they are likely to become more common over time. If they decrease fitness, they are likely to become less common.

Nature vs. Nurture

Some behaviors seem to be controlled solely by genes. Others appear to be due to experiences in a given environment. Whether behaviors are controlled mainly by genes or by the environment is often a matter of debate. This is called the **nature-nurture debate**. Nature refers to the genes an animal inherits. Nurture refers to the environment that the animal experiences. In reality, most animal behaviors are not controlled by nature or nurture. Instead, they are influenced by both nature and nurture. In dogs, for example, the tendency to behave toward other dogs in a certain way is probably controlled by genes. However, the normal behaviors can't develop in an environment that lacks other dogs. A puppy raised in isolation from other dogs may never develop the normal behaviors. It may always fear other dogs or act aggressively toward them.

How Behaviors Evolve

It's easy to see how many common types of behavior evolve. That's because they obviously increase the fitness of the animal performing them. For example, when wolves hunt together in a pack, they are more likely to catch prey (see **Figure** 20.22). Therefore, hunting with others increases a wolf's fitness. The wolf is more likely to survive and pass its genes to the next generation by behaving this way.

FIGURE 20.22

Wolves Hunting Cooperatively. Wolves hunt together in packs. This is adaptive because it increases their chances of killing prey and obtaining food.

The evolution of certain other types of behavior is not as easy to explain. An example is a squirrel chattering loudly to warn other squirrels that a predator is near. This is likely to help the other squirrels avoid the predator. Therefore, it could increase their fitness. But what about the squirrel raises the alarm? This squirrel is more likely to be noticed by the predator. Therefore, the behavior may actually lower this squirrel's fitness. How could such a behavior evolve through natural selection?

One possible answer is that helping others often means helping close relatives. Close relatives share many of the same genes that they inherited from their common ancestor. As a result, helping a close relative may actually increase the chances that copies of one's own genes will be passed to the next generation. In this way, a behavior that puts oneself at risk could actually increase through natural selection. This form of natural selection is called kin selection.

Innate Behavior

Behaviors that are closely controlled by genes with little or no environmental influence are called **innate behaviors**. These are behaviors that occur naturally in all members of a species whenever they are exposed to a certain stimulus. Innate behaviors do not have to be learned or practiced. They are also called instinctive behaviors. An **instinct** is the ability of an animal to perform a behavior the first time it is exposed to the proper stimulus. For example, a dog will drool the first time—and every time—it is exposed to food.

Significance of Innate Behavior

Innate behaviors are rigid and predictable. All members of the species perform the behaviors in the same way. Innate behaviors usually involve basic life functions, such as finding food or caring for offspring. Several examples are shown in **Figure** 20.23 . If an animal were to perform such important behaviors incorrectly, it would be less likely to survive or reproduce.

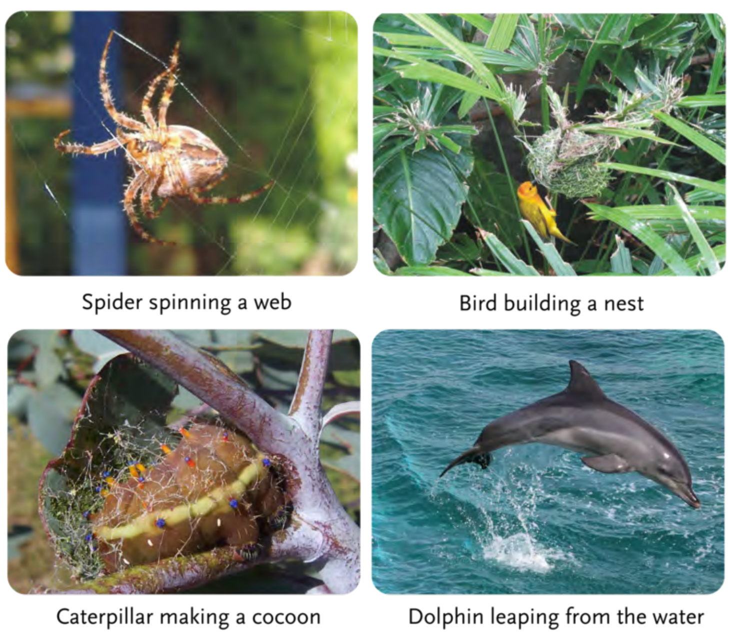


FIGURE 20.23
Examples of Innate Behavior. These innate behaviors are necessary for survival or reproduction. Can you explain why each behavior is important

Intelligence and Innate Behavior

Innate behaviors occur in all animals. However, they are less common in species with higher levels of intelligence. Humans are the most intelligent species, and they have very few innate behaviors. The only innate behaviors in humans are reflexes. A **reflex** is a response that always occurs when a certain stimulus is present. For example, a human infant will grasp an object, such as a finger, that is placed in its palm. The infant has no control over this reaction because it is innate. Other than reflexes such as this, human behaviors are learned–or at least influenced by experience—rather than being innate.

Learned Behavior

Learning is a change in behavior that occurs as a result of experience. Compared with innate behaviors, learned behaviors are more flexible. They can be modified to suit changing conditions. This may make them more adaptive than innate behaviors. For example, drivers may have to modify how they drive (a learned behavior) when roads are wet or icy. Otherwise, they may lose control of their vehicle.

Animals may learn behaviors in a variety of ways. Some ways are quite simple. Others are more complex. Several types of learning are described in **Figure** 20.24 .

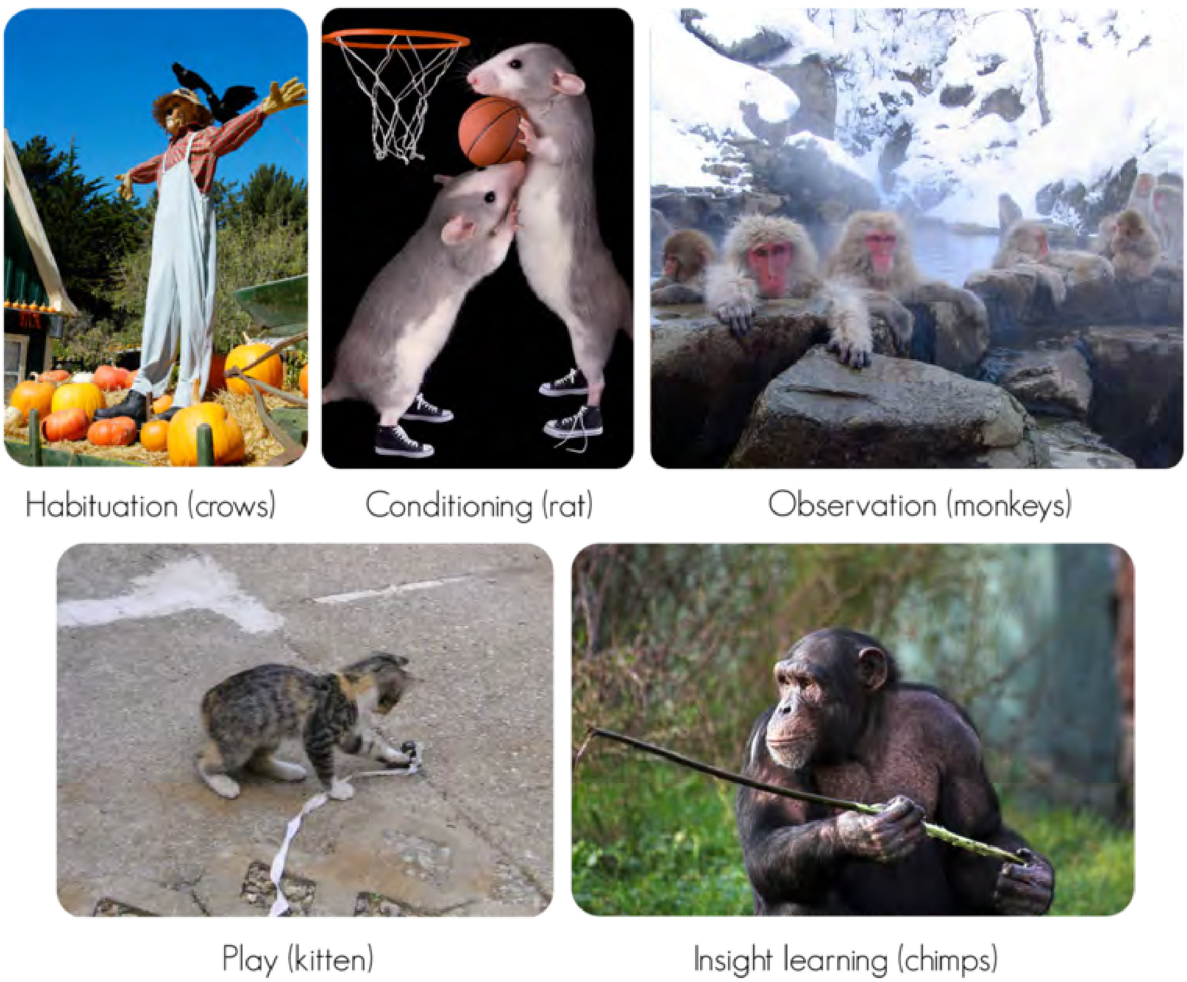


FIGURE 20.24

Types of Learning. Five different ways that animals may learn behaviors are shown here. What have you learned in each of these ways

Insight learning, which is based on past experience and reasoning, is a hallmark of the human animal. Humans have used insight learning to solve problems ranging from starting a fire to traveling to the moon.

Types of Animal Behavior

Different types of behavior evolved in animals because the behaviors helped them survive or reproduce. Several different types of animal behavior are described below.

Social Behavior and Cooperation

In many species, animals live together in a close-knit group with other members of their species. Such a group is referred to as a **society**. Animals that live in a society are known as **social animals**. They live and work together for the good of the group. This called cooperation. Generally, each member of the group has a specific role that it plays in the society. **Cooperation** allows the group to do many things that a lone animal could never do. Look at the ants in **Figure** 20.25 . By working together, they are able to carry a large insect back to the nest to feed other members of their society.

FIGURE 20.25
Cooperation in a Social Insect. These ants are cooperating in a task that a single ant would be too small to do alone.

Communication

For individuals to cooperate, they need to communicate. Animals can communicate with sounds, chemicals, or visual cues. For example, to communicate with sounds, birds sing and frogs croak. Both may be communicating that they are good mates. Ants communicate with chemicals called pheromones. For example, they use the chemicals to mark trails to food sources so other ants can find them. Male dogs use pheromones in urine to mark their territory. They are "telling" other dogs to stay out of their yard. You can see several examples of visual communication in **Figure** 20.26 .

Cyclic Behaviors

Many animal behaviors occur in a regular cycle. Two types of cyclic behaviors are circadian rhythms and migration.

- **Circadian rhythms** are regular changes in biology or behavior that occur in a 24-hour cycle. In humans, for example, blood pressure and body temperature change in a regular way throughout each 24-hour day.

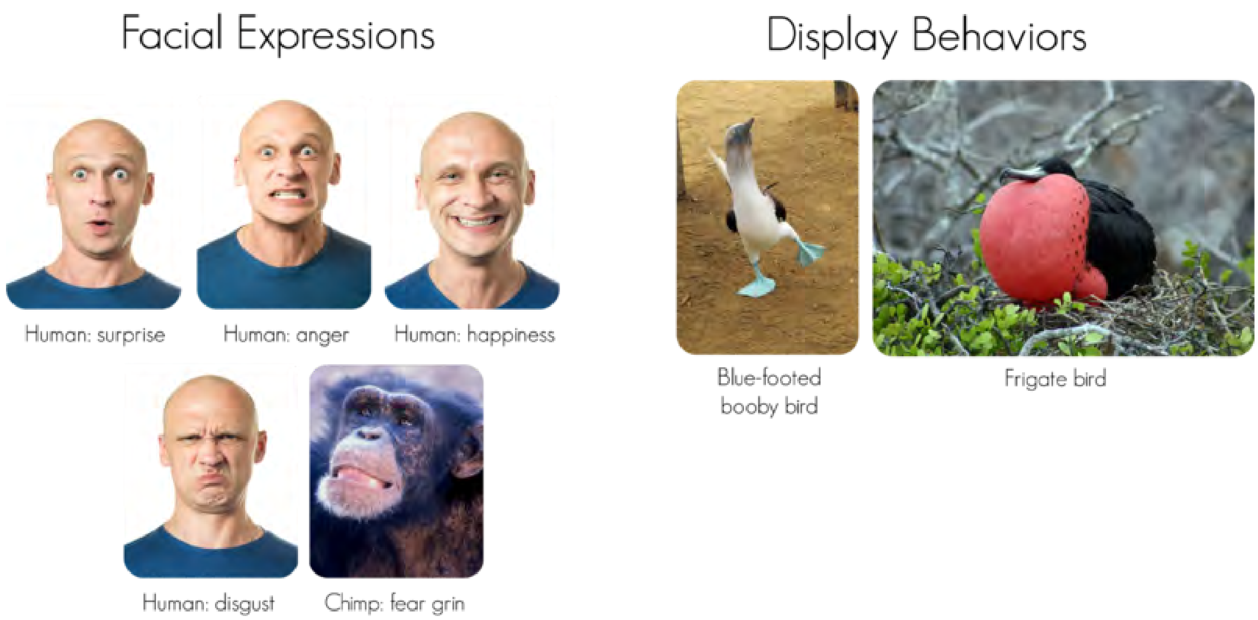


FIGURE 20.26
Visual Communication in Animals. Many animals use visual cues to communicate.

- Migration refers to seasonal movements of animals from one area to another. Migrants typically travel long distances. Usually, the migrants move to another area in order to find food or mates. Many birds, fish, and insects migrate. Mammals such as whales and caribou migrate as well. **Figure** 20.27 shows the migration route of a bird called a godwit.

KQED: Flyways: The Migratory Routes of Birds

For thousands of years and countless generations, migratory birds have flown the same long-distance paths between their breeding and feeding grounds. Understanding the routes these birds take, called *flyways,* helps conservation efforts and gives scientists better knowledge of global changes, both natural and man-made. See http://www.kqed.org/quest/television/the-great-migration for additional information.

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Click image to the left for more content.

Aggression

Aggression is behavior that is intended to cause harm or pain. It may involve physical violence against other individuals. For example, two male gorillas may fight and use their canine teeth to inflict deep wounds. Expressing aggression this way may lead to serious injury and even death. In many species, display behaviors—rather than actual physical attacks—are used to show aggression. This helps prevent injury and death. Male gorillas, for example, are

FIGURE 20.27

Godwit Migration Route. Godwits make this incredibly long journey twice a year. In the fall they migrate from the Arctic to Antarctica. They make the return flight in the spring.

more likely to put on a display of aggression than to attack another male. In fact, gorillas have a whole series of display behaviors that they use to show aggression. They beat on their chest, dash back and forth, and pound the ground with their hands.

Competition

Aggressive behavior often occurs when individuals compete for the same resources. Animals may compete for territory, water, food, or mates. There are two basic types of competition: intraspecific and interspecific.

- Intraspecific competition occurs between members of the same species. For example, two male deer may compete for mates by clashing their antlers together.
- Interspecific competition occurs between members of different species. For example, one species of ant may attack and take over the colony of another ant species.

Mating and Courtship

Mating refers to the union of a male and female of the same species for reproduction. The relationship between mates varies by species. Adults may have many mates, or they may mate with just one individual. Mates may stay together only while mating. Or they may stay together for an entire breeding season or even for life. Females are likely to be more selective than males in choosing mates. In many species, males put on courtship displays to encourage females to choose them as mates. For example, to attract a mate, a male bowerbird builds an elaborate nest decorated with hundreds of small blue objects (see **Figure** 20.28). Other examples were described above and in previous lessons.

FIGURE 20.28
Bowerbird Decorating His Nest. A male bowerbird spends many hours collecting bits of blue glass and other small blue objects to decorate his nest. A female bowerbird inspects the nests of many males before choosing as a mate the male with the best nest.

Parental Care

In most species of fish, amphibians, and reptiles, parents provide no care to their offspring. In birds and mammals, on the other hand, parental care is common. Most often, the mother provides the care. However, in some species, both parents or just the father may be involved.

Parental care is generally longest and most involved in mammals. Besides feeding and protecting their offspring, parents may teach their offspring skills they will need to survive on their own. For example, meerkat adults teach their pups how to eat scorpions. They show the pups how to safely handle the poisonous insects and how to remove the stingers.

Lesson Summary

- The branch of biology that studies animal behavior is called ethology. Ethologists usually study how animals behave in their natural environment. They try to determine the cause of behaviors, how behaviors develop, and how and why behaviors evolve.
- Most animal behaviors are controlled by both genes and experiences in a given environment. To the extent that behaviors are controlled by genes, they may evolve. Behaviors that improve fitness increase through natural selection.
- Innate behaviors are instinctive. They are controlled by genes and always occur in the same way. They do not have to be learned or practiced. Innate behaviors generally involve basic life functions, so it's important that they be performed correctly.
- Learning is a change in behavior that occurs as a result of experience. Learned behaviors are adaptive because they are flexible. They can change if the environment changes. Behaviors can be learned in several different ways, including through play.
- Types of animal behavior include social behaviors such as cooperation, communication such as facial expressions, and cyclic behaviors such as migration. Competition may lead to aggressive behaviors or displays of aggression. Behaviors relating to reproduction include mating, courtship, and parenting behaviors.

Lesson Review Questions

Recall

1. Define animal behavior.

2. What is the nature-nurture debate?

3. What are innate behaviors? Give an example.

4. What is the relationship between intelligence and learning?

5. Name three types of learning in animals.

6. Describe an example of courtship behavior in animals.

Apply Concepts

7. Assume you are an ethologist. Apply lesson concepts to develop a hypothesis about a particular animal behavior. As an ethologist, how would you study the behavior in order to test your hypothesis?

8. Create a bulletin board or brief video to demonstrate the role of facial expressions in human communication.

Think Critically

9. Infer how and why cooperative hunting in female lions evolved.

10. Compare and contrast instinct and learning.

11. Explain why communication is needed for social living.

Points to Consider

In this lesson , you learned some of the ways that humans differ from other mammals. For example, humans have a larger and more complex brain than other mammals. That's why they are also the most intelligent mammals. The next chapter introduces the biology of the human animal.

- Besides their big brain and intelligence, how else might humans differ from other mammals?
- What organs and organ systems do you think make up the human body?

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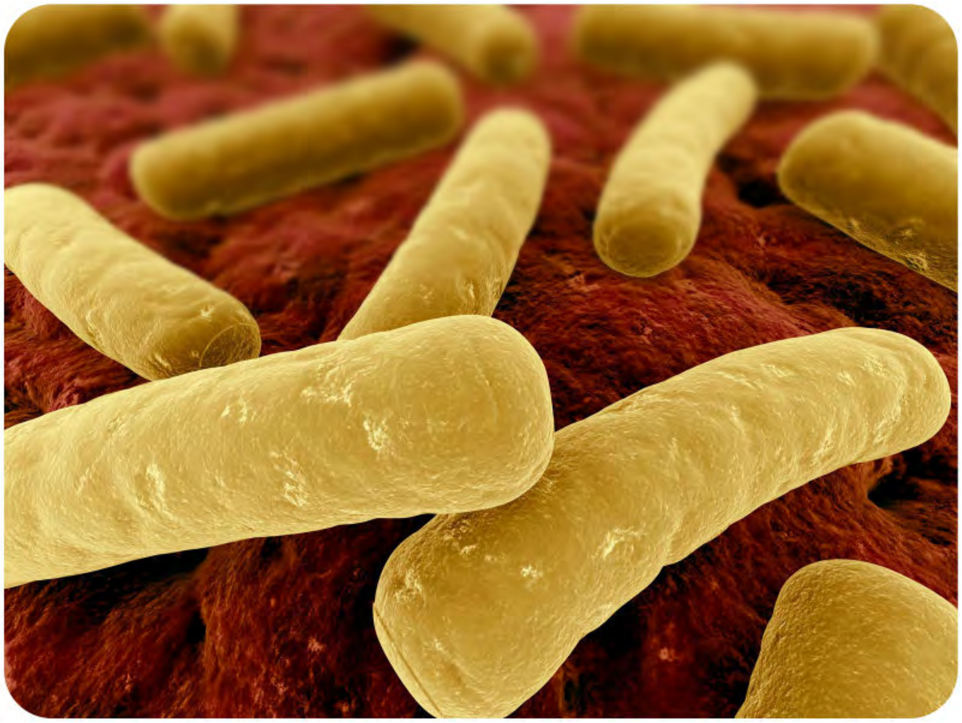
CHAPTER 21 Introduction to the Human Body: Bones, Muscles, and Skin

CHAPTER OUTLINE



This image was made by an electron microscope. What do you think it shows? To give you an idea of the scale of the image, the cylindrical yellow objects are bacterial cells. Here's another hint: the image shows a tiny part of the largest organ of the human body. Now can you guess what it is? Is it the stomach? The heart? The answer may surprise you. It's the human skin.

The word *organ* may bring to mind internal organs such as the stomach or heart, but the skin is an organ too. The skin is thin, averaging only 2 mm in thickness, but it covers a large area—about 2 m^2 in adults, making it the largest organ of the human body. You will learn more about the skin and how these organs come together to form the human body when you read this chapter.

21.1 Organization of the Human Body

Lesson Objectives

- Outline the levels of organization of the human body.
- Explain how organ systems maintain homeostasis of the body.

Vocabulary

connective tissue tissue made up of cells that form the body's structure, such as bone and cartilage

epithelial tissue tissue made up of cells that line inner and outer body surfaces, such as skin

muscle tissue tissue made up of cells that can contract; includes smooth, skeletal, and cardiac muscle tissue

nervous tissue tissue made up of neurons, or nerve cells, that carry electrical messages

Introduction

Many people have compared the human body to a machine. Think about some common machines, such as drills and washing machines. Each machine consists of many parts, and each part does a specific job, yet all the parts work together to perform an overall function. The human body is like a machine in all these ways. In fact, it may be the most fantastic machine on Earth, as you will discover when you learn more about it in this and the remaining chapters of this FlexBook.

As a preview of the human machine, the Emmy award-winning video at this link is highly recommended: http://www.youtube.com/watch?v=chqwSh4ii84#38;feature=related.

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Click image to the left for more content.

Levels of Organization

The human machine is organized at different levels, starting with the cell and ending with the entire organism (see **Figure** 21.1). At each higher level of organization, there is a greater degree of complexity.

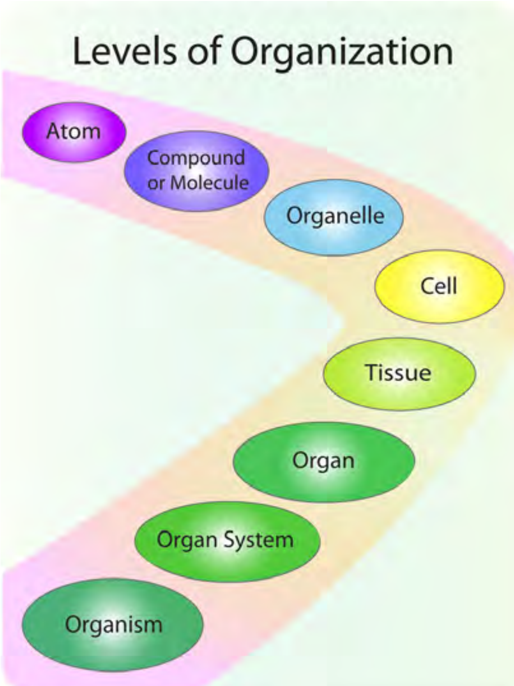


FIGURE 21.1
The human organism has several levels of organization.

Cells

The most basic parts of the human machine are cells—an amazing 100 trillion of them by the time the average person reaches adulthood! Cells are the basic units of structure and function in the human body, as they are in all living things. Each cell carries out basic life processes that allow the body to survive. Many human cells are specialized in form and function, as shown in **Figure** 21.2 . Each type of cell in the figure plays a specific role. For example, nerve cells have long projections that help them carry electrical messages to other cells. Muscle cells have many mitochondria that provide the energy they need to move the body.

You can watch a video about some of the specialized cells of the human body and how they function at this link: http://www.youtube.com/watch?v=I8uXewS9dJU#38;feature=related.

Tissues

After the cell, the tissue is the next level of organization in the human body. A tissue is a group of connected cells that have a similar function. There are four basic types of human tissues: epithelial, muscle, nervous, and connective tissues. These four tissue types, which are shown in **Figure** 21.3 , make up all the organs of the human body.

- **Connective tissue** is made up of cells that form the body's structure. Examples include bone and cartilage.
- **Epithelial tissue** is made up of cells that line inner and outer body surfaces, such as the skin and the lining of the digestive tract. Epithelial tissue protects the body and its internal organs, secretes substances such as hormones, and absorbs substances such as nutrients.
- **Muscle tissue** is made up of cells that have the unique ability to contract, or become shorter. Muscles attached to bones enable the body to move.
- **Nervous tissue** is made up of neurons, or nerve cells, that carry electrical messages. Nervous tissue makes up the brain and the nerves that connect the brain to all parts of the body.

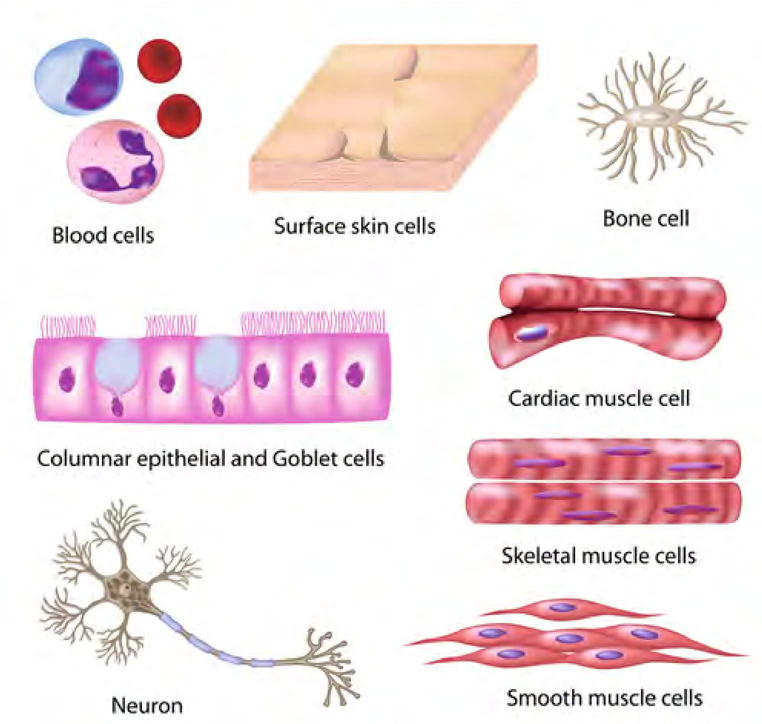


FIGURE 21.2
Different types of cells in the human body are specialized for specific jobs. Do you know the functions of any of the cell types shown here

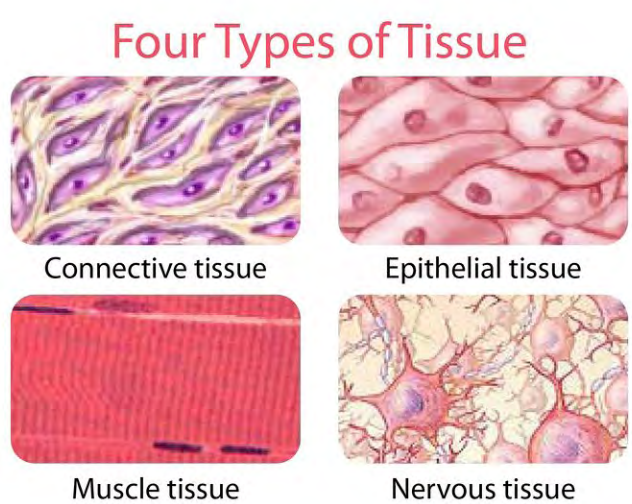


FIGURE 21.3
The human body consists of these four tissue types.

Organs and Organ Systems

After tissues, organs are the next level of organization of the human body. An organ is a structure that consists of two or more types of tissues that work together to do the same job. Examples of human organs include the brain, heart, lungs, skin, and kidneys. Human organs are organized into organ systems, many of which are shown in **Figure** 21.4 . An organ system is a group of organs that work together to carry out a complex overall function. Each organ of the system does part of the larger job.

You can watch overviews of the human organ systems and their functions at the links below.

- http://www.youtube.com/watch?v=po8D290YF9o#38;feature=related
- http://www.youtube.com/watch?v=SSqwRkDLyH4#38;feature=related
- http://www.youtube.com/watch?v=KidJ-2H0nyY#38;feature=player_embedded#!

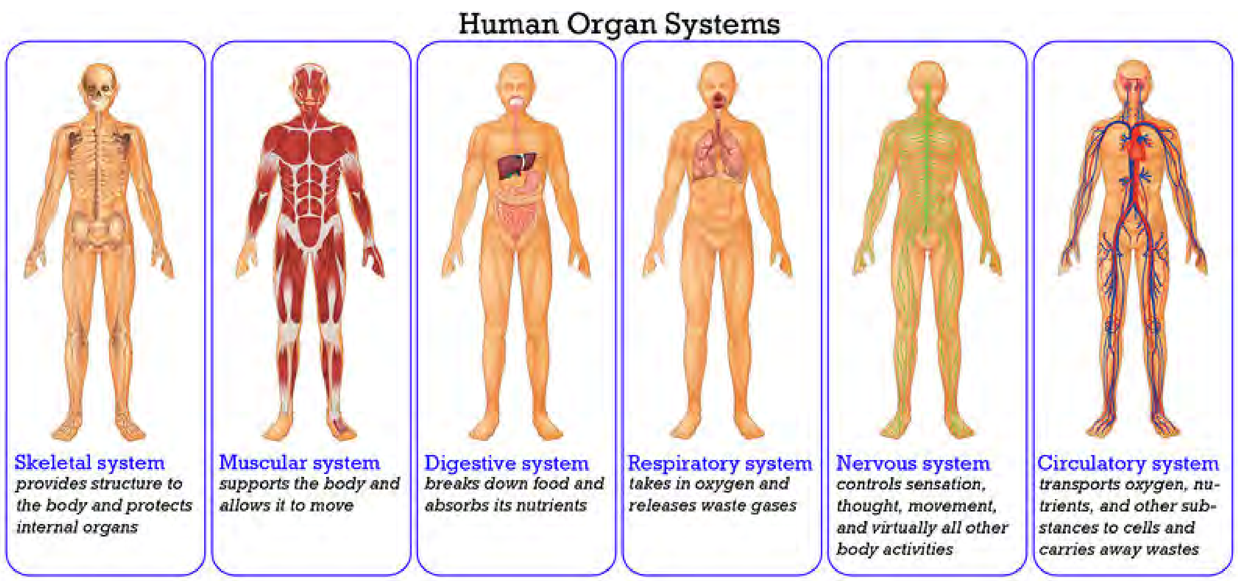


FIGURE 21.4

Many of the organ systems that make up the human body are represented here. What is the overall function of each organ system

A Well-Oiled Machine

All of the organs and organ systems of the human body work together like a well-oiled machine. This is because they are closely regulated by the nervous and endocrine systems. The nervous system controls virtually all body activities, and the endocrine system secretes hormones that regulate these activities. Functioning together, the organ systems supply body cells with all the substances they need and eliminate their wastes. They also keep temperature, pH, and other conditions at just the right levels to support life processes.

Maintaining Homeostasis

The process in which organ systems work to maintain a stable internal environment is called homeostasis. Keeping a stable internal environment requires constant adjustments. Here are just three of the many ways that human organ systems help the body maintain homeostasis:

- Respiratory system: A high concentration of carbon dioxide in the blood triggers faster breathing. The lungs exhale more frequently, which removes carbon dioxide from the body more quickly.
- Excretory system: A low level of water in the blood triggers retention of water by the kidneys. The kidneys produce more concentrated urine, so less water is lost from the body.
- Endocrine system: A high concentration of sugar in the blood triggers secretion of insulin by an endocrine gland called the pancreas. Insulin is a hormone that helps cells absorb sugar from the blood.

Failure of Homeostasis

Many homeostatic mechanisms such as these work continuously to maintain stable conditions in the human body. Sometimes, however, the mechanisms fail. When they do, cells may not get everything they need, or toxic wastes may accumulate in the body. If homeostasis is not restored, the imbalance may lead to disease or even death.

Lesson Summary

- The human body is organized at different levels, starting with the cell. Cells are organized into tissues, and tissues form organs. Organs are organized into organ systems such as the skeletal and muscular systems.
- All of the organ systems of the body work together to maintain homeostasis of the organism. If homeostasis fails, death or disease may result.

Lesson Review Questions

Recall

1. What are the levels of organization of the human body?
2. Which type of tissue covers the surface of the body?
3. What are the functions of the skeletal system?
4. Which organ system supports the body and allows it to move?
5. What is homeostasis?
6. Describe how one of the human organ systems helps maintain homeostasis.

Apply Concepts

7. A house has several systems, such as the electrical system, plumbing system, and heating and cooling system. In what ways are the systems of a house similar to human body systems?

Think Critically

8. Explain how form and function are related in human cells. Include examples.
9. Compare and contrast epithelial and muscle tissues.

Points to Consider

In this lesson, you learned that an organ system is a group of organs that work together to do a common job. You also learned that organ systems help maintain homeostasis of the body.

- The skeletal system is one of the human organ systems. Can you name the organs of the skeletal system?
- How do you think the skeletal system helps the body maintain homeostasis?

21.2 The Skeletal System

Lesson Objectives

- Give an overview of the human skeleton and its functions.
- Describe the cells and tissues that make up bones.
- Explain how bones grow and develop.
- Distinguish different types of joints and how they move.
- List common problems that may affect bones and joints.

Vocabulary

bone marrow soft connective tissue in spongy bone that produces blood cells

bone matrix rigid framework of bone that consists of tough protein fibers and mineral crystals

compact bone dense outer layer of bone that is very hard and strong

joint place where two or more bones of the skeleton meet

ligament band of fibrous connective tissue that holds bones together

ossification process in which mineral deposits replace cartilage and change it into bone

osteoblast type of bone cell that makes new bone cells and secretes collagen

osteoclast type of bone cell that dissolves minerals in bone and releases them back into the blood

osteocyte type of bone cell that regulates mineral homeostasis by directing the uptake of minerals from the blood and the release of minerals back into the blood as needed

periosteum tough, fibrous membrane that covers the outer surface of bone

skeletal system human body system that consists of all the bones of the body as well as cartilage and ligaments

spongy bone light, porous inner layer of bone that contains bone marrow

Introduction

The **skeletal system** consists of all the bones of the body. How important are your bones? Try to imagine what you would look like without them. You would be a soft, wobbly pile of skin, muscles, and internal organs, so you might look something like a very large slug. Not that you would be able to see yourself—folds of skin would droop down over your eyes and block your vision because of your lack of skull bones. You could push the skin out of the way, if you could only move your arms, but you need bones for that as well!

The Skeleton

The human skeleton is an internal framework that, in adults, consists of 206 bones, most of which are shown in **Figure** 21.5 . Bones are described in detail in the following sections of this lesson, as well as in the animation "Bones Narrated" at the link below. In addition to bones, the skeleton also consists of cartilage and ligaments. http://www.medtropolis.com/vbody.asp

- Cartilage is a type of dense connective tissue, made of tough protein fibers, that provides a smooth surface for the movement of bones at joints.
- A **ligament** is a band of fibrous connective tissue that holds bones together and keeps them in place.

The skeleton supports the body and gives it shape. It has several other functions as well, including:

a. protecting internal organs
b. providing attachment surfaces for muscles
c. producing blood cells
d. storing minerals
e. maintaining mineral homeostasis.

Maintaining mineral homeostasis is a very important function of the skeleton, because just the right levels of calcium and other minerals are needed in the blood for normal functioning of the body. When mineral levels in the blood are too high, bones absorb some of the minerals and store them as mineral salts, which is why bones are so hard. When blood levels of minerals are too low, bones release some of the minerals back into the blood, thus restoring homeostasis.

Structure of Bones

Many people think of bones as being dead, dry, and brittle. These adjectives correctly describe the bones of a preserved skeleton, but the bones in a living human being are very much alive. As shown in **Figure** 21.6 , the basic structure of bones is **bone matrix**, which forms the underlying rigid framework of bones, formed of both compact and spongy bone. The bone matrix consists of tough protein fibers—mainly collagen—that become hard and rigid due to mineralization with calcium crystals. Bone matrix is crisscrossed by blood vessels and nerves and also contains specialized bone cells that are actively involved in metabolic processes.

You can watch an animated video of bone matrix and other structures of bone at this link: http://www.youtube.com/watch?v=4qTiw8lyYbs.

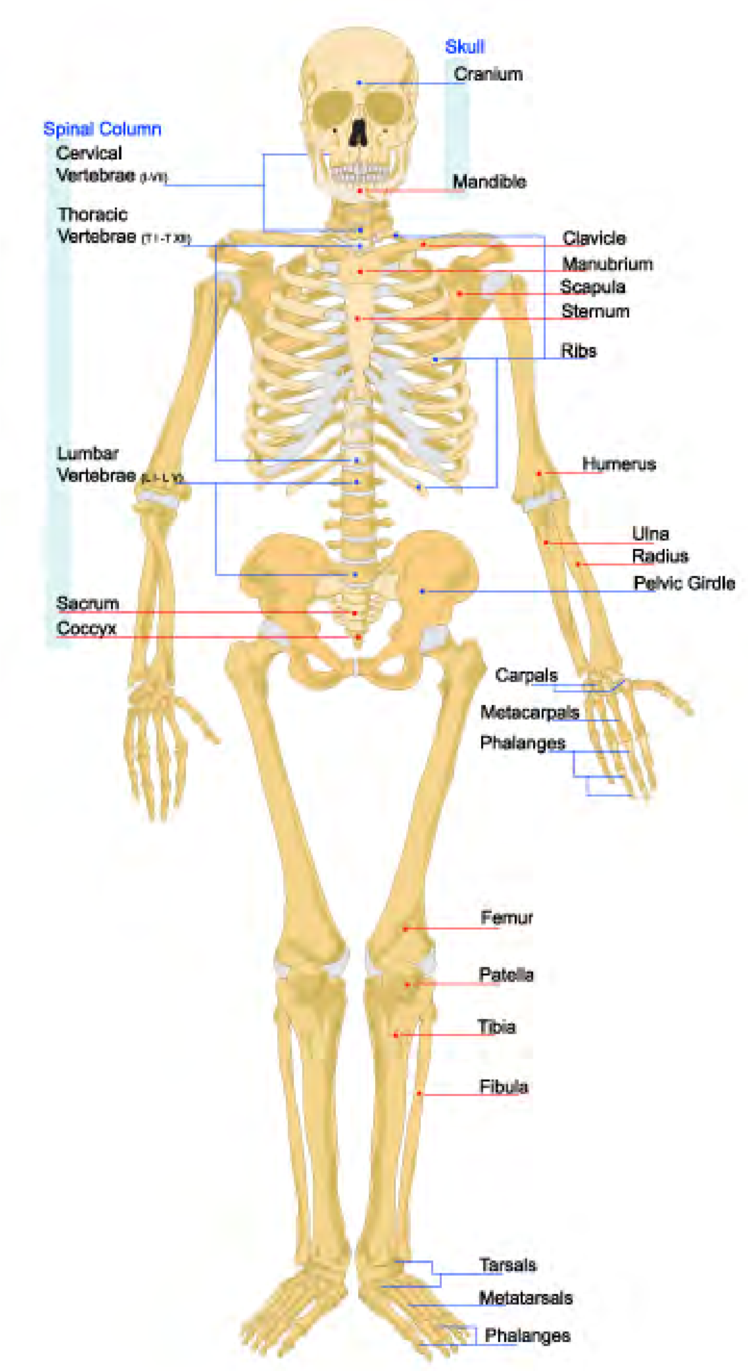


FIGURE 21.5

The human skeleton consists of bones cartilage and ligaments.

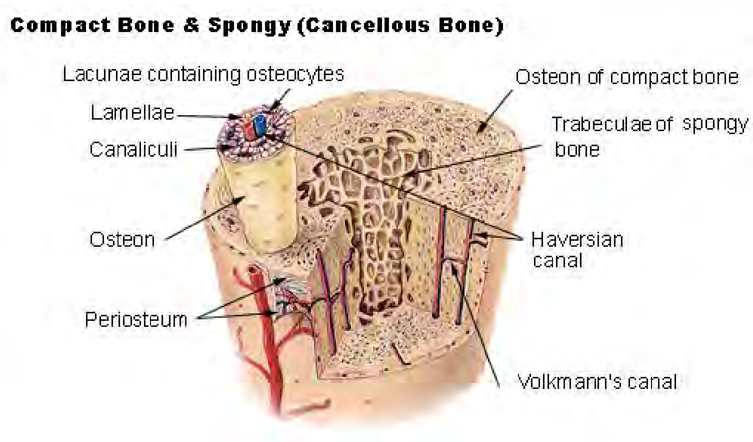


FIGURE 21.6
Bone matrix provides bones with their basic structure. Notice the spongy bone in the middle and the compact bone towards the outer region. The osteon is the functional unit of compact bone.

Bone Cells

There are three types of specialized cells in human bones: osteoblasts, osteocytes, and osteoclasts. These cells are responsible for bone growth and mineral homeostasis.

- **Osteoblasts** make new bone cells and secrete collagen that mineralizes to become bone matrix. They are responsible for bone growth and the uptake of minerals from the blood.
- **Osteocytes** regulate mineral homeostasis. They direct the uptake of minerals from the blood and the release of minerals back into the blood as needed.
- **Osteoclasts** dissolve minerals in bone matrix and release them back into the blood.

Bones are far from static, or unchanging. Instead, they are dynamic, living tissues that are constantly being reshaped. Under the direction of osteocytes, osteoblasts continuously build up bone, while osteoclasts continuously break it down. You can watch an animated video of these processes in bone at http://www.youtube.com/watch?v=yENNqRJ2mu0#38;feature=related.

Bone Tissues

Bones consist of different types of tissue, including compact bone, spongy bone, bone marrow, and periosteum. All of these tissue types are shown in **Figure** 21.7 .

- **Compact bone** makes up the dense outer layer of bone. It is very hard and strong.
- **Spongy bone** is found inside bones and is lighter and less dense than compact bone. This is because spongy bone is porous.
- **Bone marrow** is a soft connective tissue that produces blood cells. It is found inside the pores of spongy bone.
- **Periosteum** is a tough, fibrous membrane that covers and protects the outer surfaces of bone.

Growth and Development of Bones

Early in the development of a human fetus, the skeleton is made entirely of cartilage. The relatively soft cartilage gradually turns into hard bone through **ossification**. This is a process in which mineral deposits replace cartilage. As

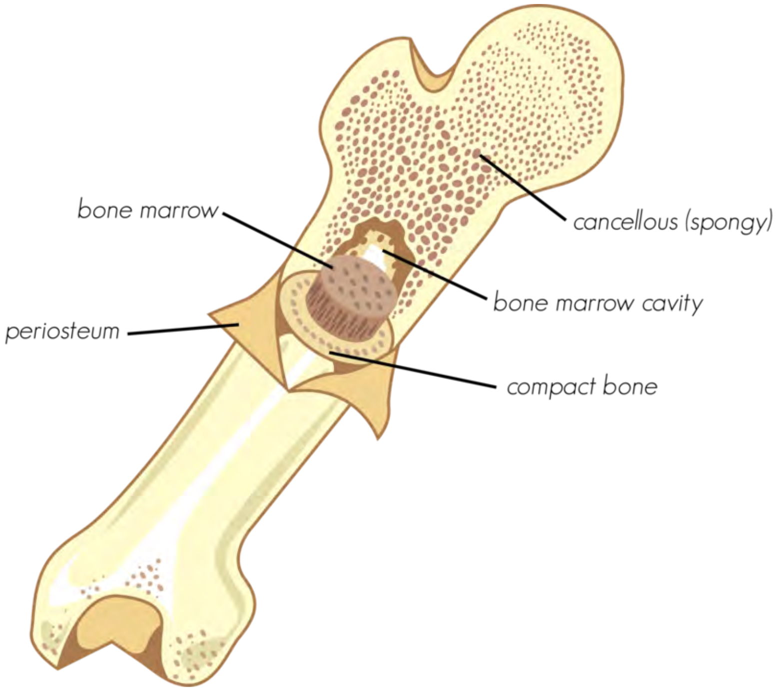


FIGURE 21.7
This bone contains different types of bone tissue. How does each type of tissue contribute to the functions of bone

shown in **Figure** 21.8 , ossification of long bones, which are found in the arms and legs, begins at the center of the bones and continues toward the ends. By birth, several areas of cartilage remain in the skeleton, including the ends of the long bones. This cartilage grows as the long bones grow, so the bones can keep increasing in length during childhood.

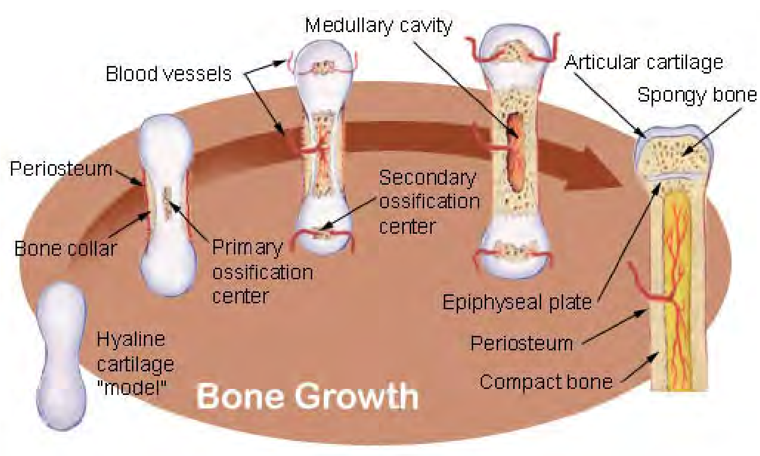


FIGURE 21.8
Long bones ossify and get longer as they grow and develop.

In the late teens or early twenties, a person reaches skeletal maturity. By then, all of the cartilage has been replaced by bone, so no further growth in bone length is possible. However, bones can still increase in thickness. This may occur in response to increased muscle activity, such as weight training.

Joints

A **joint** is a place where two or more bones of the skeleton meet. With the help of muscles, joints work like mechanical levers, allowing the body to move with relatively little force. The surfaces of bones at joints are covered with a smooth layer of cartilage that reduces friction at the points of contact between the bones.

Types of Joints

There are three main types of joints: immovable, partly movable, and movable. For a video about these types of joints, go to the following link: http://www.youtube.com/watch?v=SOMFX_83sqk.

- Immovable joints allow no movement because the bones at these joints are held securely together by dense collagen. The bones of the skull are connected by immovable joints.
- Partly movable joints allow only very limited movement. Bones at these joints are held in place by cartilage. The ribs and sternum are connected by partly movable joints.
- Movable joints allow the most movement. Bones at these joints are connected by ligaments. Movable joints are the most common type of joints in the body, so they are described in more detail next.

Movable Joints

Movable joints are also known as synovial joints. This is because the space between the bones is filled with a thick fluid, called synovial fluid, that cushions the joint (see **Figure** 21.9).

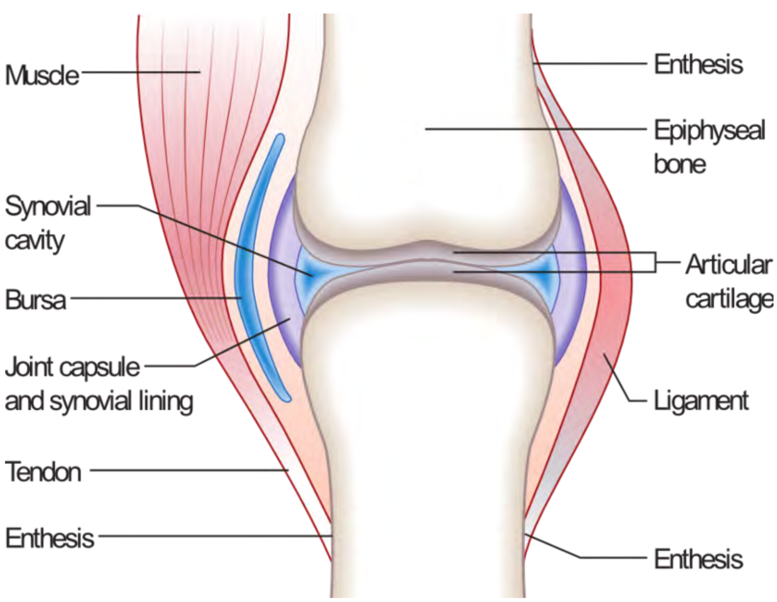


FIGURE 21.9
A movable or synovial joint is protected and cushioned by cartilage and synovial fluid.

There are a variety of types of movable joints, which are illustrated in **Figure** 21.10 . The joints are classified by how they move. For example, a ball-and-socket joint, such as the shoulder, has the greatest range of motion, allowing movement in several directions. Other movable joints, including hinge joints such as the knee, allow less movement.

You can watch an animation of movable joints and how they function at this link: http://www.youtube.com/watch?v=zWo9-3GJpr8#38;feature=related.

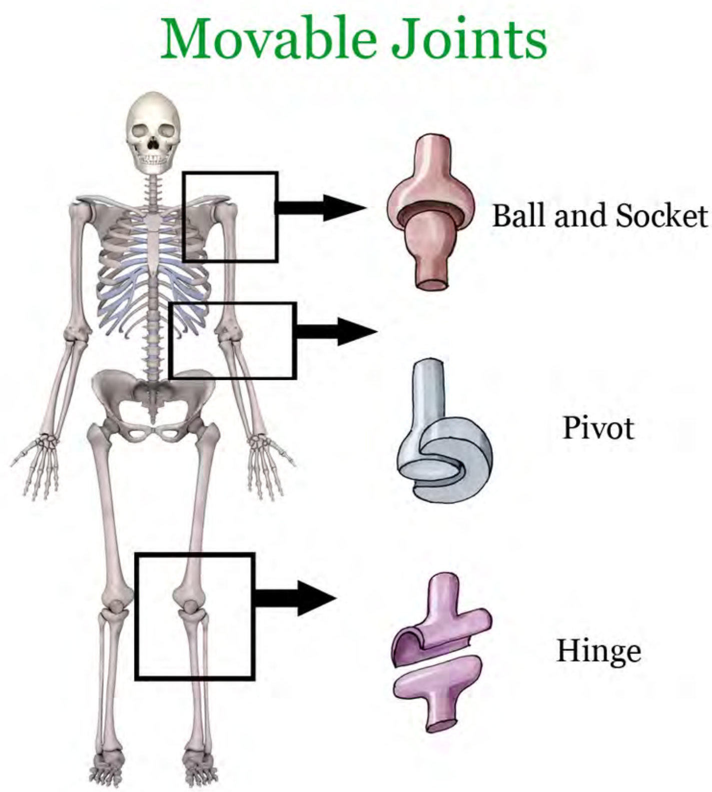


FIGURE 21.10

Types of Movable Joints in the Human Skeleton. Movable joints can move in a variety of ways. Try moving each of the joints indicated in the diagram. Can you tell how their movements differ Other joints in the human skeleton that are not depicted here include saddle elipsoid and plane joints.

Skeletal System Problems

Despite their hardness and strength, bones can suffer from injury and disease. Bone problems include fractures, osteoarthritis, and rickets.

- Fractures are breaks in bone, usually caused by excessive stress on bone. Fractures heal when osteoclasts form new bone. The animation at this link shows how this happens: http://www.youtube.com/watch?v=qVougiCEgH8#38;feature=PlayList#38;p=33EEC8ACDC4F4B45#38;playnext_from=PL#38;playnext=1#38;index=2.
- Osteoarthritis is a condition in which cartilage breaks down in joints due to wear and tear, causing joint stiffness and pain. For a brief animation about osteoarthritis, go to this link: http://www.youtube.com/watch?v=0dUSmaev5b0.
- Rickets is softening of the bones in children that occurs because bones do not have enough calcium. Rickets can lead to fractures and bowing of the leg bones, which is shown in the X-ray in **Figure** 21.11 .

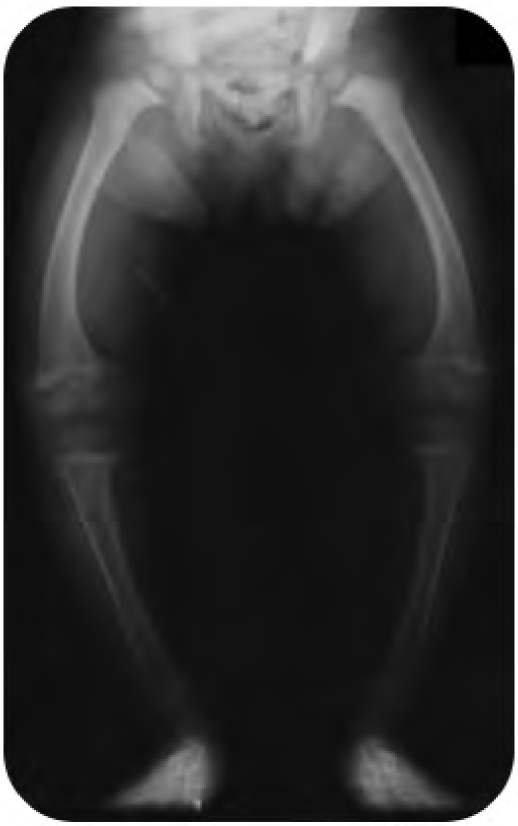


FIGURE 21.11
The bones of a child with rickets are so soft that the weight of the body causes them to bend.

Lesson Summary

- The adult human skeleton includes 206 bones and other tissues. It supports the body, protects internal organs, produces blood cells, and maintains mineral homeostasis.
- Under the direction of osteocytes, osteoblasts continuously build up bone, while osteoclasts continuously break down bone to maintain mineral homeostasis. Bone tissues include compact bone, spongy bone, bone marrow, and periosteum.

- Bones become increasingly ossified and grow larger during fetal development, childhood, and adolescence. When skeletal maturity is reached at about age 20, no additional growth in bone length can occur.
- Joints are places where two or more bones of the skeleton meet. With the help of muscles, joints allow the body to move with relatively little force. Some joints can move more than others.
- Skeletal system problems include fractures, osteoarthritis, and rickets.

Lesson Review Questions

Recall

1. What is cartilage? What is its role in the skeletal system?

2. List three functions of the human skeleton.

3. Identify the three types of specialized bone cells and what they do.

4. Define immovable joint, and give an example of bones that are connected by this type of joint.

5. Describe the movement of a pivot joint, such as the elbow.

Apply Concepts

6. A newborn baby has a soft spot on the top of its head. Over the next few months, the soft spot gradually hardens. What explains this?

7. Jana is 17 years old and 172 cm tall. She plays basketball and hopes to grow at least 4 cm more before she turns 18 and goes to college. Jana recently injured her leg, and her doctor took an X-ray of it. Based on the X-ray, the doctor determined that Jana had reached skeletal maturity. How much taller is Jana likely to grow? Explain your answer.

Think Critically

8. Explain how bones maintain mineral homeostasis in the body.

9. Compare and contrast the structure and function of compact bone and spongy bone.

10. Osteoporosis is a disease in which osteoclasts are more active than osteoblasts. How is this likely to affect the bones? Why would a person with osteoporosis have a greater-than-normal risk of bone fractures?

Points to Consider

Human organ systems work together to carry out many of their functions. The skeletal and muscular systems are no exception.

- Do you know how the skeletal and muscular systems work together?
- How do you think muscles are able to move bones?

21.3 The Muscular System

Lesson Objectives

- Identify and describe the three types of human muscle tissue.
- Describe the structure of skeletal muscles, and explain how they move bones.
- Explain how muscles contract according to the sliding filament theory.

Vocabulary

cardiac muscle involuntary, striated muscle found only in the walls of the heart

muscle fiber long, thin muscle cell that has the ability to contract, or shorten

muscular system human body system that includes all the muscles of the body

skeletal muscle voluntary, striated muscle that is attached to bones of the skeleton and helps the body move

sliding filament theory theory that explains muscle contraction by the sliding of myosin filaments over actin filaments within muscle fibers

smooth muscle involuntary, nonstriated muscle that is found in the walls of internal organs such as the stomach

tendon tough connective tissue that attaches skeletal muscle to bones of the skeleton

Introduction

The **muscular system** consists of all the muscles of the body. Does the word *muscle* make you think of the bulging biceps of a weightlifter, like the man in **Figure** 21.12 ? Muscles such as biceps that move the body are easy to feel and see, but they aren't the only muscles in the human body. Many muscles are deep within the body. They form the walls of internal organs such as the heart and stomach. You can flex your biceps like a body builder but you cannot control the muscles inside you. It's a good thing that they work on their own without any conscious effort your part, because movement of these muscles is essential for survival.

What Are Muscles?

Muscles are organs composed mainly of muscle cells, which are also called **muscle fibers**. Each muscle fiber is a very long, thin cell that can do something no other cell can do. It can contract, or shorten. Muscle contractions are

FIGURE 21.12
This weightlifter works hard to build big muscles in his upper arms.

responsible for virtually all the movements of the body, both inside and out. There are three types of muscle tissues in the human body: cardiac, smooth, and skeletal muscle tissues. They are shown in **Figure** 21.13 and described below. You can also watch an overview of the three types at this link: http://www.youtube.com/watch?v=TermIXEkavY.

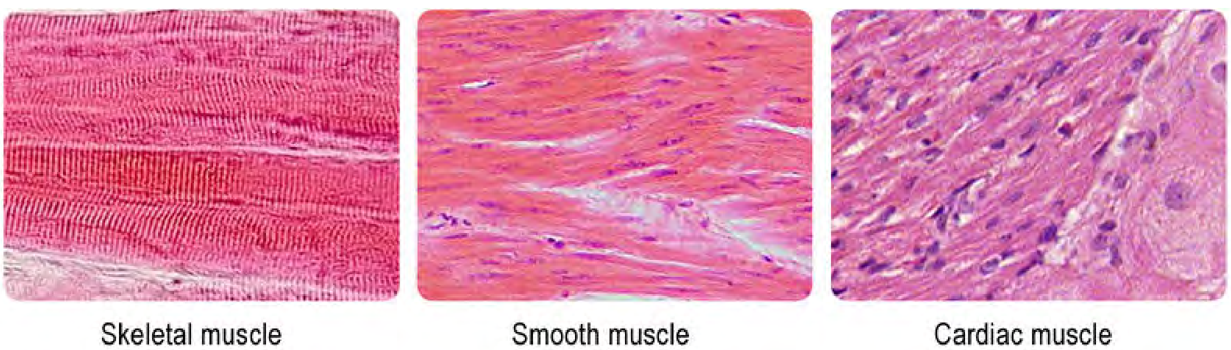


FIGURE 21.13
Types of Muscle Tissue. Both skeletal and cardiac muscles appear striated or striped because their cells are arranged in bundles. Smooth muscles are not striated because their cells are arranged in sheets instead of bundles.

Smooth Muscle

Muscle tissue in the walls of internal organs such as the stomach and intestines is **smooth muscle**. When smooth muscle contracts, it helps the organs carry out their functions. For example, when smooth muscle in the stomach contracts, it squeezes the food inside the stomach, which helps break the food into smaller pieces. Contractions of smooth muscle are involuntary. This means they are not under conscious control.

Skeletal Muscle

Muscle tissue that is attached to bone is **skeletal muscle**. Whether you are blinking your eyes or running a marathon, you are using skeletal muscle. Contractions of skeletal muscle are voluntary, or under conscious control. Skeletal muscle is the most common type of muscle in the human body, so it is described in more detail below.

Cardiac Muscle

Cardiac muscle is found only in the walls of the heart. When cardiac muscle contracts, the heart beats and pumps blood. Cardiac muscle contains a great many mitochondria, which produce ATP for energy. This helps the heart resist fatigue. Contractions of cardiac muscle are involuntary like those of smooth muscle.

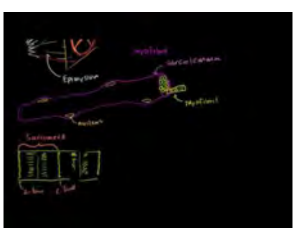
Skeletal Muscles

There are well over 600 skeletal muscles in the human body, some of which are identified in **Figure** 21.14 . Skeletal muscles vary considerably in size, from tiny muscles inside the middle ear to very large muscles in the upper leg.

Structure of Skeletal Muscles

Each skeletal muscle consists of hundreds or even thousands of skeletal muscle fibers. The fibers are bundled together and wrapped in connective tissue as shown **Figure** 21.15 . The connective tissue supports and protects the delicate muscle cells and allows them to withstand the forces of contraction. It also provides pathways for nerves and blood vessels to reach the muscles. Skeletal muscles work hard to move body parts. They need a rich blood supply to provide them with nutrients and oxygen and to carry away their wastes. You can watch a video about skeletal muscle structure and how skeletal muscles work at this link: http://www.youtube.com/watch?v=XoP1diaXVCI.

The Anatomy of a Muscle Cell is available at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/48/uY2ZOsCnXIA (16:32).



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Skeletal Muscles and Bones

Skeletal muscles are attached to the skeleton by tough connective tissues called **tendons** (see **Figure** 21.15). Many skeletal muscles are attached to the ends of bones that 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. You can watch a video showing how muscles and bones move together at this link: http://www.youtube.com/watch?v=7Rzi7zYlWno#38;feature=related. Muscles can only contract. They cannot actively extend, or lengthen. Therefore, to move bones in opposite directions, pairs of muscles must work in opposition. For example, the biceps and triceps muscles of the upper arm work in opposition to bend and extend the arm at the elbow (see **Figure** 21.16). You can watch an animation of these two muscles working in opposition at the link below. What other body movements do you think require opposing muscle pairs? http://www.youtube.com/watch?v=T-ozRNVhGVg#38;feature=related

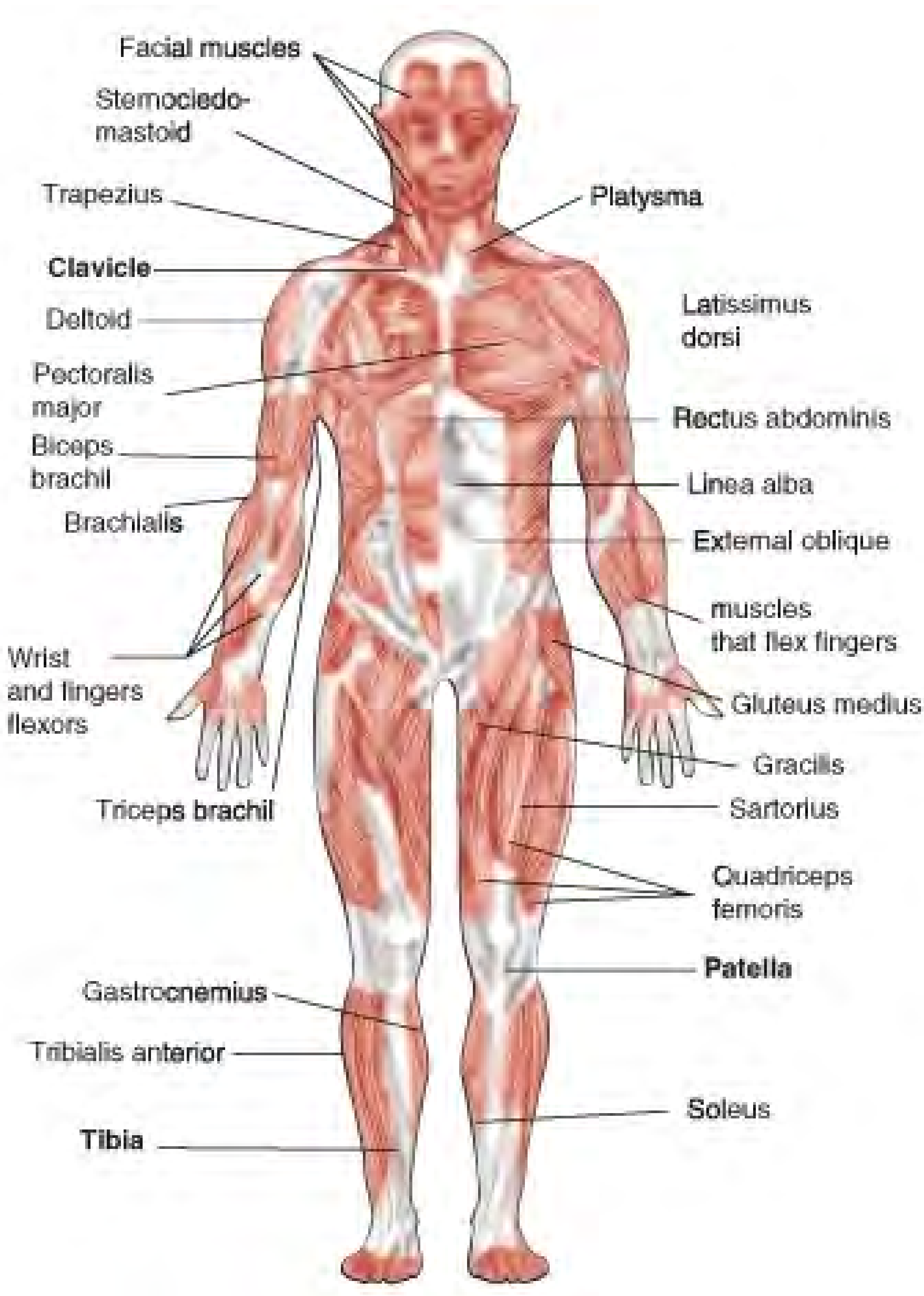

FIGURE 21.14

Skeletal Muscles. Skeletal muscles enable the body to move.

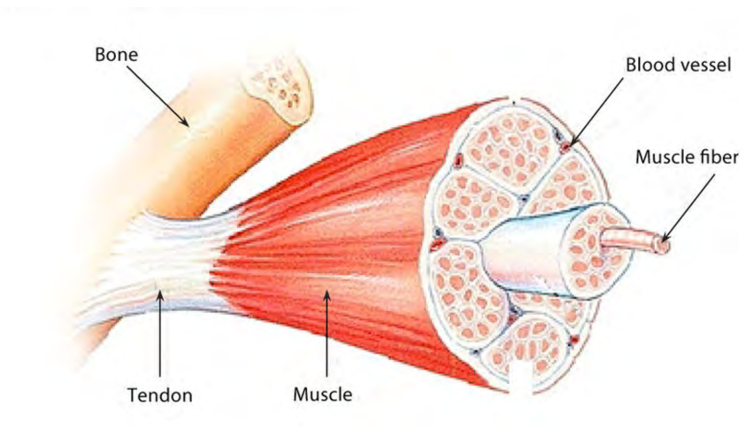

FIGURE 21.15
Skeletal Muscle Structure. A skeletal muscle contains bundles of muscle fibers inside a &#8220 coat&#8221 of connective tissue.

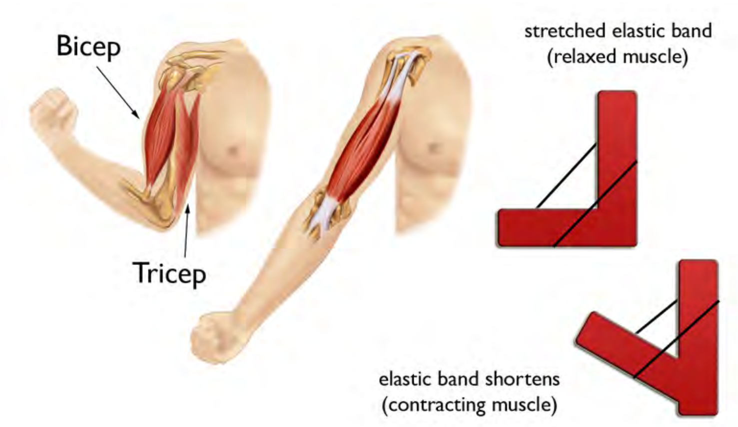

FIGURE 21.16
Triceps and biceps muscles in the upper arm are opposing muscles.

Use It or Lose It

In exercises such as weight lifting, skeletal muscle contracts against a resisting force (see **Figure** 21.17). Using skeletal muscle in this way increases its size and strength. In exercises such as running, the cardiac muscle contracts faster and the heart pumps more blood. Using cardiac muscle in this way increases its strength and efficiency. Continued exercise is necessary to maintain bigger, stronger muscles. If you don't use a muscle, it will get smaller and weaker—so use it or lose it.

FIGURE 21.17
This exercise pits human muscles against a force. What force is it

Muscle Contraction

Muscle contraction occurs when muscle fibers get shorter. Literally, the muscle fibers get smaller in size. To understand how this happens, you need to know more about the structure of muscle fibers.

Structure of Muscle Fibers

Each muscle fiber contains hundreds of organelles called myofibrils. Each myofibril is made up of two types of protein filaments: actin filaments, which are thinner, and myosin filaments, which are thicker. Actin filaments are anchored to structures called Z lines (see **Figure** 21.18). The region between two Z lines is called a sarcomere. Within a sarcomere, myosin filaments overlap the actin filaments. The myosin filaments have tiny structures called cross bridges that can attach to actin filaments.

Sliding Filament Theory

The most widely accepted theory explaining how muscle fibers contract is called the **sliding filament theory**. According to this theory, myosin filaments use energy from ATP to "walk" along the actin filaments with their cross bridges. This pulls the actin filaments closer together. The movement of the actin filaments also pulls the Z lines closer together, thus shortening the sarcomere. You can watch this occurring in a video animation at http://www.youtube.com/watch?v=7V-zFVnFkWg#38;feature=related. When all of the sarcomeres in a muscle fiber shorten, the

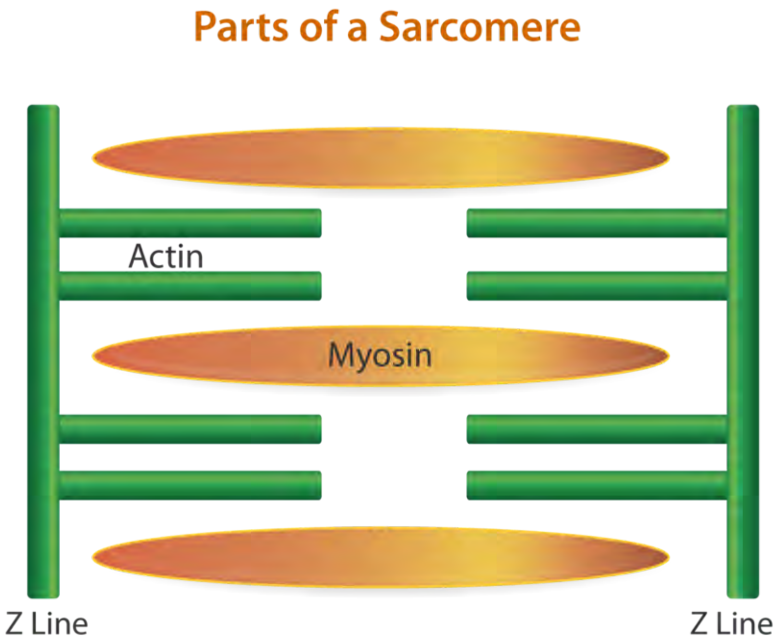

FIGURE 21.18
Sarcomere. A sarcomere contains actin and myosin filaments between two Z lines.

fiber contracts. A muscle fiber either contracts fully or it doesn't contract at all. The number of fibers that contract determines the strength of the muscular force. When more fibers contract at the same time, the force is greater.

Actin, myosin and muscle contraction are discussed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/45/zopoN2i7ALQ (9:38).

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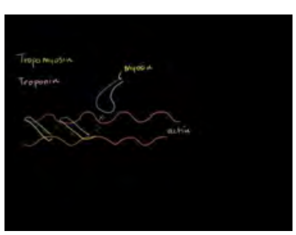
Additional information about muscle contraction is available at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/46/LiOfeSsjrB8 (9:22) and http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/47/SauhB2fYQkM (14:42).



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Muscles and Nerves

Muscles cannot contract on their own. They need a stimulus from a nerve cell to "tell" them to contract. Let's say you decide to raise your hand in class. Your brain sends electrical messages to nerve cells, called motor neurons, in your arm and shoulder. The motor neurons, in turn, stimulate muscle fibers in your arm and shoulder to contract, causing your arm to rise. Involuntary contractions of cardiac and smooth muscles are also controlled by nerves.

Lesson Summary

- There are three types of human muscle tissue: smooth muscle (in internal organs), skeletal muscle, and cardiac muscle (only in the heart).
- Skeletal muscles are attached to the skeleton and cause bones to move when they contract.
- According to the sliding filament theory, a muscle fiber contracts when myosin filaments pull actin filaments closer together and thus shorten sarcomeres within a fiber. When all the sarcomeres in a muscle fiber shorten, the fiber contracts.

Lesson Review Questions

Recall

1. What can muscle cells do that other cells cannot?
2. Why are skeletal and cardiac muscles striated?
3. Where is smooth muscle tissue found?
4. What is the function of skeletal muscle?
5. How are skeletal muscles attached to bones?

Apply Concepts

6. A serious neck injury may leave a person paralyzed from the neck down. Explain why.

Think Critically

7. Compare and contrast the three types of muscle tissue.
8. Explain why many skeletal muscles must work in opposing pairs.
9. Explain how muscles contract according to the sliding filament theory.

Points to Consider

Bones and muscles are organs. They are contained within the skin, which is also an organ.

- Do you know which organ system the skin belongs to?
- What other organs might belong to the same organ system as the skin?

21.4 The Integumentary System

Lesson Objectives

- Describe the skin and its functions, and identify common skin problems.
- Outline the structure and functions of the hair and nails.

Vocabulary

dermis lower layer of the skin that is made of tough connective tissue and contains blood vessels, nerve endings, hair follicles, and glands

epidermis outer layer of skin that consists mainly of epithelial cells and lacks nerve endings and blood vessels

hair follicle structure in the dermis of skin where a hair originates

integumentary system human body system that includes the skin, nails, and hair

melanin brown pigment produced by melanocytes in the skin that gives skin most of its color and prevents UV light from penetrating the skin

sebaceous gland gland in the dermis of skin that produces sebum, an oily substance that waterproofs the skin and hair

sweat gland gland in the dermis of skin that produces the salty fluid called sweat, which excretes wastes and helps cool the body

Introduction

The skin is the major organ of the **integumentary system**, which also includes the nails and hair. Because these organs are external to the body, you may think of them as little more than "accessories," like clothing or jewelry, but the organs of the integumentary system serve important biological functions. They provide a protective covering for the body and help the body maintain homeostasis. For an overview of the integumentary system, you can watch the animation at this link: http://www.youtube.com/watch?v=IAAt_MfIJ-Y.

The Skin

The skin is the body's largest organ and a remarkable one at that. Consider these skin facts. The average square inch (6.5 cm^2) of skin has 20 blood vessels, 650 sweat glands, and more than a thousand nerve endings. It also has an incredible 60,000 pigment-producing cells. All of these structures are packed into a stack of cells that is just 2 mm thick, or about as thick as the cover of a book.

You can watch an excellent video introduction to the skin and its marvels at the following link: http://www.youtube.com/watch?v=uH_uzjY2bEE#38;feature=fvw.

Although the skin is thin, it consists of two distinct layers, called the epidermis and the dermis. These layers are shown in **Figure** 21.19 . You can watch animations of the two layers of skin and how they function at these links: http://www.youtube.com/watch?v=d-IJhAWrsm0#38;feature=related and http://www.youtube.com/watch?v=c_IGuPYLsFI#38;feature=related.

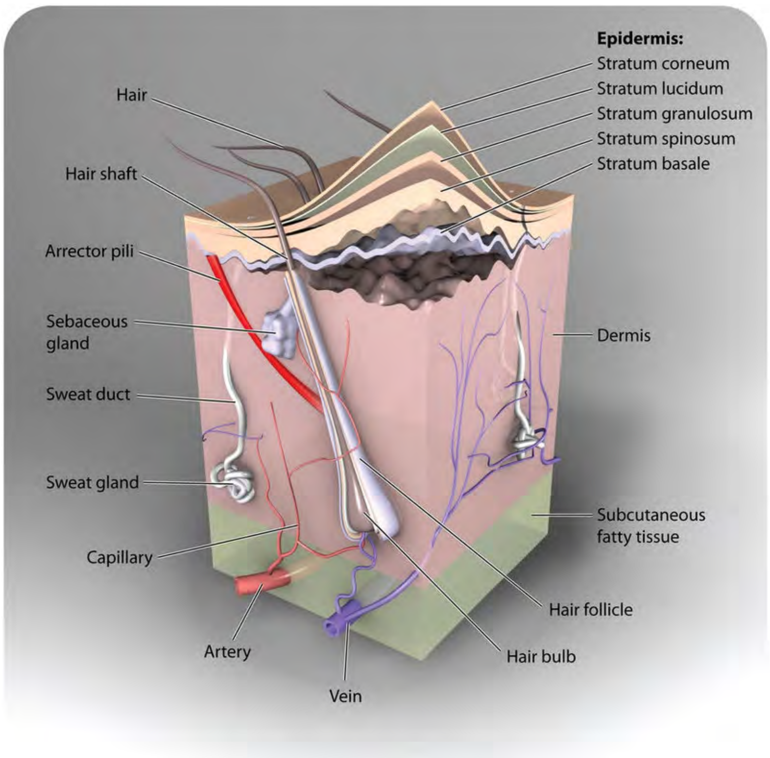


FIGURE 21.19

Layers of Human Skin. The outer layer of the skin is the epidermis and the inner layer is the dermis. Most skin structures originate in the dermis.

Epidermis

The **epidermis** is the outer layer of skin, consisting of epithelial cells and little else (see **Figure** 21.20). For example, there are no nerve endings or blood vessels in the epidermis. The innermost cells of the epidermis are continuously dividing through mitosis to form new cells. The newly formed cells move up through the epidermis toward the skin surface, while producing a tough, fibrous protein called keratin. The cells become filled with keratin and die by the time they reach the surface, where they form a protective, waterproof layer called the stratum corneum. The dead cells are gradually shed from the surface of the skin and replaced by other cells.

The epidermis also contains melanocytes, which are cells that produce melanin. **Melanin** is the brownish pigment that gives skin much of its color. Everyone has about the same number of melanocytes, but the melanocytes of people with darker skin produce more melanin. The amount of melanin produced is determined by heredity and exposure to UV light, which increases melanin output. Exposure to UV light also stimulates the skin to produce vitamin D. Because melanin blocks UV light from penetrating the skin, people with darker skin may be at greater risk of vitamin D deficiency.

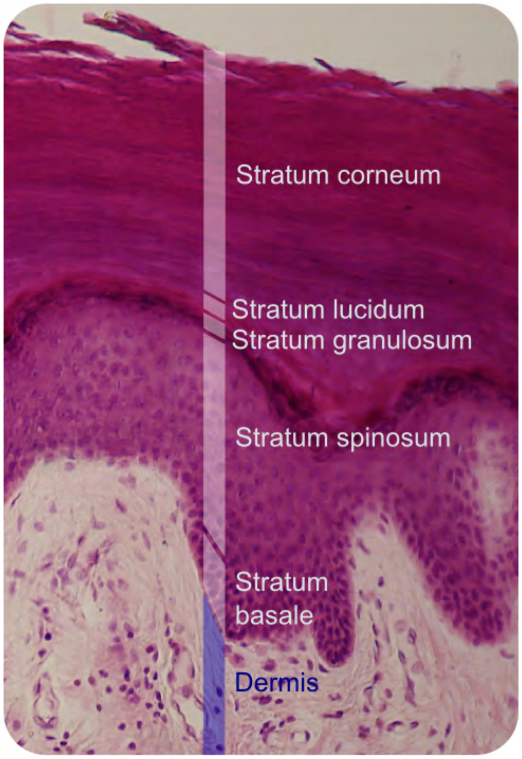


FIGURE 21.20
Cell Layers of the Epidermis. The epidermis consists mainly of epithelial cells.

Dermis

The **dermis** is the lower layer of the skin, located directly beneath the epidermis (see **Figure** 21.21). It is made of tough connective tissue and attached to the epidermis by collagen fibers. The dermis contains blood vessels and nerve endings. Because of the nerve endings, skin can feel touch, pressure, heat, cold, and pain. The dermis also contains hair follicles and two types of glands.

- **Hair follicles** are the structures where hairs originate. Hairs grow out of follicles, pass through the epidermis, and exit at the surface of the skin.
- **Sebaceous glands** produce an oily substance called sebum. Sebum is secreted into hair follicles and makes its way to the skin surface. It waterproofs the hair and skin and helps prevent them from drying out. Sebum also has antibacterial properties, so it inhibits the growth of microorganisms on the skin.
- **Sweat glands** produce the salty fluid called sweat, which contains excess water, salts, and other waste products. The glands have ducts that pass through the epidermis and open to the surface through pores in the skin.

Functions of the Skin

The skin has multiple roles in the body. Many of these roles are related to homeostasis. The skin's main functions are preventing water loss from the body and serving as a barrier to the entry of microorganisms. In addition, melanin in the skin blocks UV light and protects deeper layers from its damaging effects.

The skin also helps regulate body temperature. When the body is too warm, sweat is released by the sweat glands and spreads over the skin surface. As the sweat evaporates, it cools the body. Blood vessels in the skin also dilate, or widen, when the body is too warm. This allows more blood to flow through the skin, bringing body heat to the

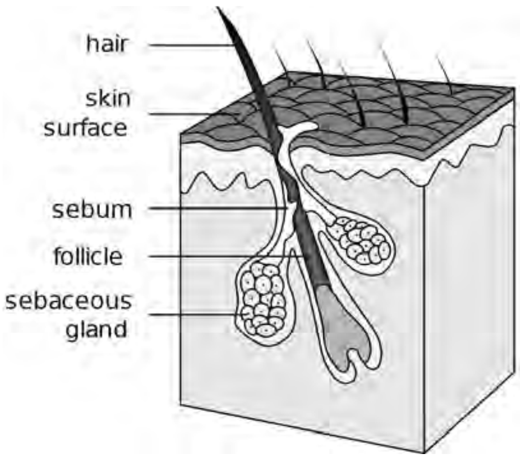


FIGURE 21.21
Structures of the Dermis. The dermis contains most of the structures found in skin.

surface, where it radiates into the environment. When the body is too cool, sweat glands stop producing sweat, and blood vessels in the skin constrict, or narrow, thus conserving body heat.

Skin Problems

In part because it is exposed to the environment, the skin is prone to injury and other problems. Two common problems of the skin are acne and skin cancer (see **Figure** 21.22).

- Acne is a condition in which red bumps called pimples form on the skin due to a bacterial infection. It affects more than 85 percent of teens and may continue into adulthood. The underlying cause of acne is excessive secretion of sebum, which plugs hair follicles and makes them good breeding grounds for bacteria. At the following link, you can watch an animation showing how acne develops: http://www.youtube.com/watch?v=11I7ONVqcc0.
- Skin cancer is a disease in which skin cells grow out of control. It is caused mainly by excessive exposure to UV light. People with lighter skin are at greater risk of developing skin cancer because they have less melanin to block harmful UV radiation. The best way to prevent skin cancer is to avoid UV exposure by using sunscreen and wearing protective clothing.

Nails and Hair

In addition to the skin, the integumentary system includes the nails and hair. Like the skin, these organs help the body maintain homeostasis.

Nails

Fingernails and toenails consist of specialized epidermal cells that are filled with keratin. The keratin makes them tough and hard, which is important for the functions they serve. Fingernails prevent injury by forming protective plates over the ends of the fingers. They also enhance sensation by acting as a counterforce to the sensitive fingertips when objects are handled.

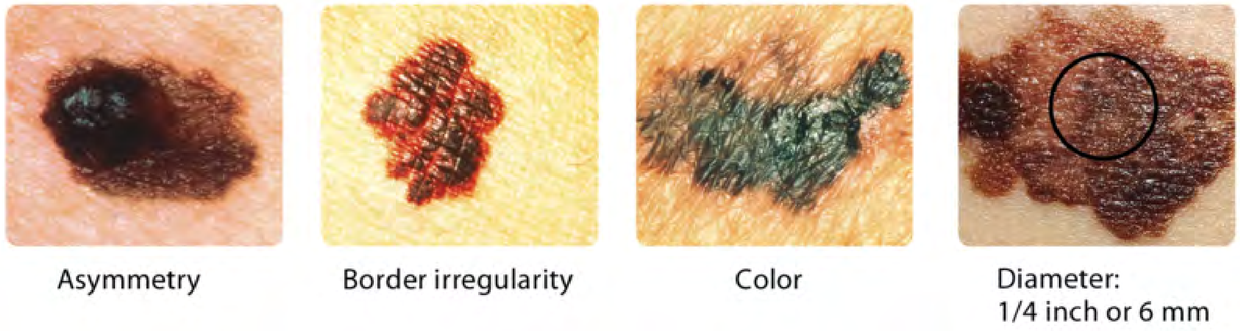


FIGURE 21.22
ABCDs of Skin Cancer. A brown spot on the skin is likely to be a harmless mole but it could be a sign of skin cancer. Unlike moles skin cancers are generally asymmetrical have irregular borders may be very dark in color and may have a relatively great diameter.

Hair

Hair is a fiber that is found only in mammals. Its main component is keratin. A hair shaft consists of dead, keratin-filled cells that overlap each other like the shingles on a roof (see **Figure** 21.23). Like roof shingles, the overlapping cells help shed water from the hair.

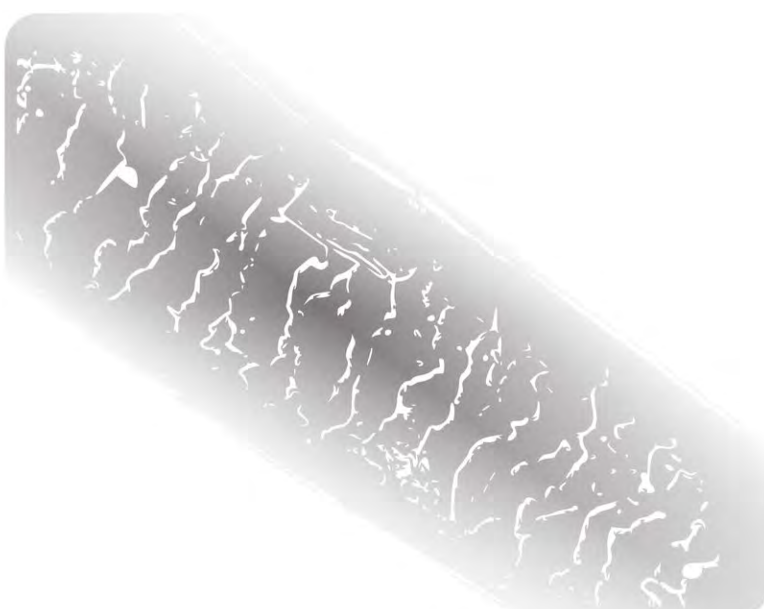


FIGURE 21.23
Shaft of Human Hair. This shaft of hair is magnified to show its overlapping cells.

Hair helps to insulate and protect the body. Head hair is especially important in preventing heat loss from the body. Eyelashes and eyebrows protect the eyes from water, dirt, and other irritants. Hairs in the nose trap dust particles and microorganisms in the air and prevent them from reaching the lungs. Hair also provides sensory input when objects brush against it or it sways in moving air.

Lesson Summary

- The skin consists of two layers: the epidermis, which contains mainly epithelial cells, and the dermis, which contains most of skin's other structures, including blood vessels, nerve endings, hair follicles, and glands.
- Skin protects the body from injury, water loss, and microorganisms. It also plays a major role in maintaining a stable body temperature. Common skin problems include acne and skin cancer.
- Nails and hair contain mostly keratin. They protect the body and enhance the sense of touch.

Lesson Review Questions

Recall

1. What organs make up the integumentary system?

2. Describe how new epidermal cells form, develop, and are shed from the body.

3. What is keratin? What role does it play in the organs of the integumentary system?

4. What is the function of the stratum corneum?

5. What causes acne?

Apply Concepts

6. Assume that you get a paper cut, but it doesn't bleed. How deep is the cut? How do you know?

7. Skin cancer has been increasing over recent decades. What could explain this? (*Hint:* What is the main cause of skin cancer?)

8. A certain disease causes the loss of all body hair. How might homeostasis of the body be disturbed by the absence of hair? (*Hint:* What are the functions of hair?)

Think Critically

9. Explain how melanin is related to skin color, vitamin D production, and skin cancer.

10. Explain how the skin helps the body maintain a stable temperature.

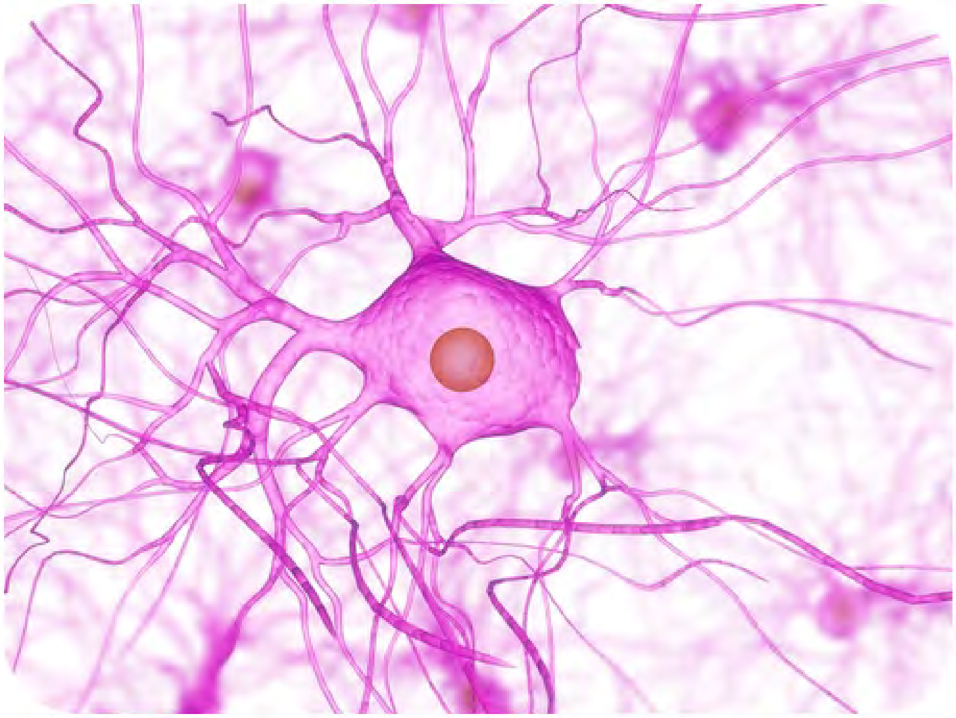
Points to Consider

In this lesson, you learned that the skin is the major organ that regulates body temperature. You also learned that acne is a common problem of the skin, especially in teens.

- What do you think causes sweat production and dilation of blood vessels when the body becomes too warm? Do you know which organ system signals these changes to occur?
- Why do you think acne occurs most often in teens? Which organ system might stimulate excessive sebum production in this age group?

CHAPTER 22 The Nervous and Endocrine Systems

CHAPTER OUTLINE



A spider web? Some sort of exotic bacteria? Maybe an illustration of a new species of jellyfish. This is actually a nerve cell, the cell of the nervous system. This cell sends electrical "sparks" that transmit signals throughout your body. In this chapter, you will learn more about nerve cells such as this one and their impressive abilities.

22.1 The Nervous System

Lesson Objectives

- Describe the structure of a neuron, and identify types of neurons.
- Explain how nerve impulses are transmitted.
- Identify parts of the central nervous system and their functions.
- Outline the divisions and subdivisions of the peripheral nervous system.
- Explain how sensory stimuli are perceived and interpreted.
- State how drugs affect the nervous system.
- Identify several nervous system disorders.

Vocabulary

action potential reversal of electrical charge across the membrane of a resting neuron that travels down the axon of the neuron as a nerve impulse

autonomic nervous system (ANS) division of the peripheral nervous system that controls involuntary activities not under conscious control such as heart rate and digestion

axon long extension of the cell body of a neuron that transmits nerve impulses to other cells

brain central nervous system organ inside the skull that is the control center of the nervous system

brain stem lowest part of the brain that connects the brain with the spinal cord and controls unconscious functions such as heart rate and breathing

cell body central part of a neuron that contains the nucleus and other cell organelles

central nervous system (CNS) one of two main divisions of the nervous system that includes the brain and spinal cord

cerebellum part of the brain below the cerebrum that coordinates body movements

dendrite extension of the cell body of a neuron that receives nerve impulses from other neurons

drug abuse use of a drug without the advice of a medical professional and for reasons not originally intended

drug addiction situation in which a drug user is unable to stop using a drug

interneuron type of neuron that carries nerve impulses back and forth between sensory and motor neurons

motor neuron type of neuron that carries nerve impulses from the central nervous system to muscles and glands

myelin sheath lipid layer around the axon of a neuron that allows nerve impulses to travel more rapidly down the axon

nerve one of many cable-like bundles of axons that make up the peripheral nervous system

nerve impulse electrical signal transmitted by the nervous system

nervous system human body system that carries electrical messages throughout the body

neuron nerve cell; structural and functional unit of the nervous system

neurotransmitter chemical that carries a nerve impulse from one nerve to another at a synapse

peripheral nervous system (PNS) one of two major divisions of the nervous system that consists of all the nervous tissue that lies outside the central nervous system

psychoactive drug drug that affects the central nervous system, generally by influencing the transmission of never impulses in the brain

resting potential difference in electrical charge across the plasma membrane of a neuron that is not actively transmitting a nerve impulse

sensory neuron type of neuron that carries nerve impulses from tissue and organs to the spinal cord and brain

sensory receptor specialized nerve cell that responds to a particular type of stimulus such as light or chemicals

somatic nervous system (SNS) division of the peripheral nervous system that controls voluntary, conscious activities and reflexes

spinal cord thin, tubular bundle of nervous tissue that extends from the brainstem down the back to the pelvis and connects the brain with the peripheral nervous system

synapse place where an axon terminal meets another cell

Introduction

A small child darts in front of your bike as you race down the street. You see the child and immediately react. You put on the brakes, steer away from the child, and yell out a warning—all in just a split second. How do you respond so quickly? Such rapid responses are controlled by your nervous system. The **nervous system** is a complex network of nervous tissue that carries electrical messages throughout the body (see **Figure** 22.1). To understand how nervous messages can travel so quickly, you need to know more about nerve cells.

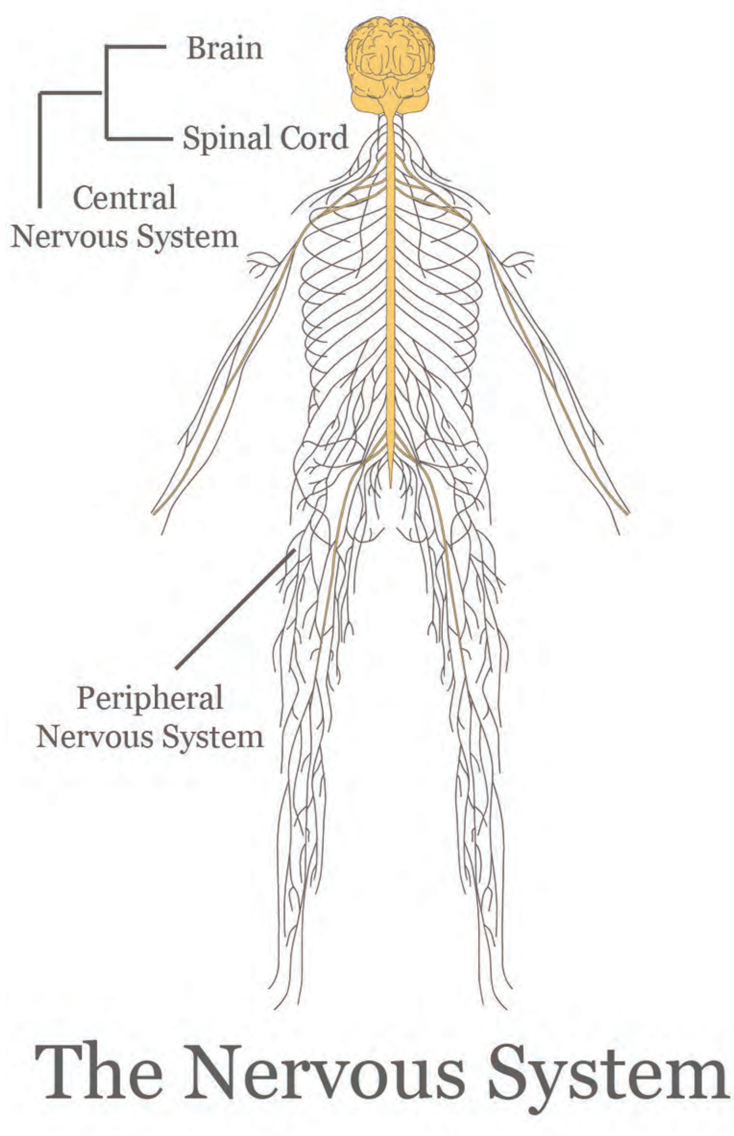


FIGURE 22.1
The human nervous system includes the brain and spinal cord *central nervous system* and nerves that run throughout the body *peripheral nervous system*.

Nerve Cells

Although the nervous system is very complex, nervous tissue consists of just two basic types of nerve cells: neurons and glial cells. **Neurons** are the structural and functional units of the nervous system. They transmit electrical signals, called **nerve impulses.** Glial cells provide support for neurons. For example, they provide neurons with nutrients and other materials.

Neuron Structure

As shown in **Figure** 22.2 , a neuron consists of three basic parts: the cell body, dendrites, and axon. You can watch an animation of the parts of a neuron at this link: http://www.garyfisk.com/anim/neuronparts.swf.

- The **cell body** contains the nucleus and other cell organelles.
- **Dendrites** extend from the cell body and receive nerve impulses from other neurons.
- The **axon** is a long extension of the cell body that transmits nerve impulses to other cells. The axon branches at the end, forming axon terminals. These are the points where the neuron communicates with other cells.

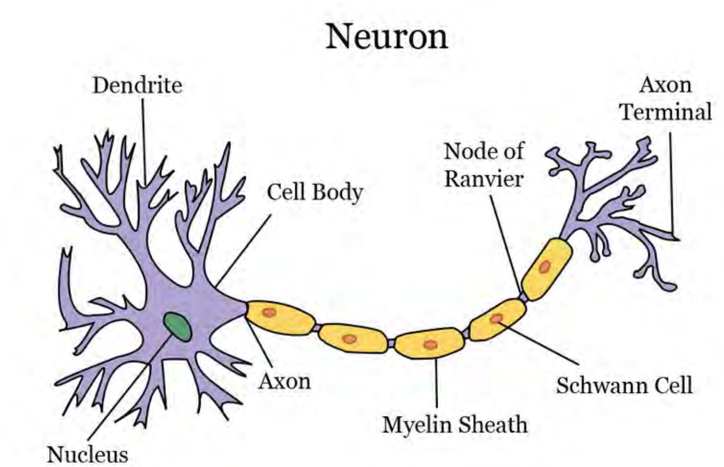
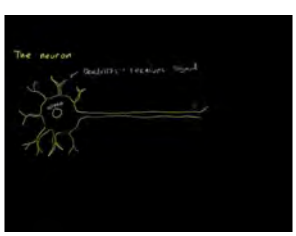


FIGURE 22.2
The structure of a neuron allows it to rapidly transmit nerve impulses to other cells.

The neuron is discussed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/39/ob5U8zPbAX4 (6:13).



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Myelin Sheath

The axon of many neurons has an outer layer called a **myelin sheath** (see **Figure** 22.2). Myelin is a lipid produced by a type of a glial cell known as a Schwann cell. The myelin sheath acts like a layer of insulation, similar to the plastic that encases an electrical cord. Regularly spaced nodes, or gaps, in the myelin sheath allow nerve impulses to skip along the axon very rapidly.

Types of Neurons

Neurons are classified based on the direction in which they carry nerve impulses.

- **Sensory neurons** carry nerve impulses from tissues and organs to the spinal cord and brain.
- **Motor neurons** carry nerve impulses from the brain and spinal cord to muscles and glands (see **Figure** 22.3).
- **Interneurons** carry nerve impulses back and forth between sensory and motor neurons.

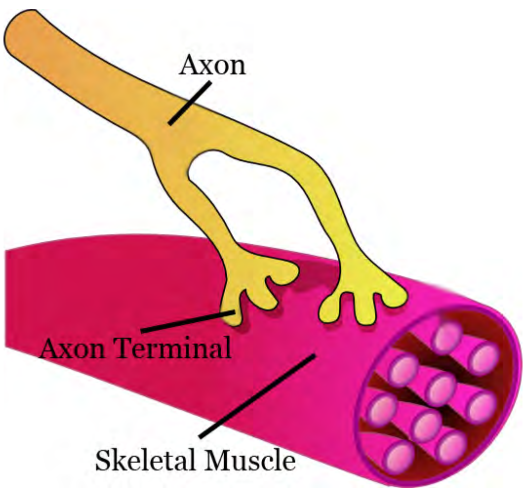


FIGURE 22.3
This axon is part of a motor neuron. It transmits nerve impulses to a skeletal muscle causing the muscle to contract.

Nerve Impulses

Nerve impulses are electrical in nature. They result from a difference in electrical charge across the plasma membrane of a neuron. How does this difference in electrical charge come about? The answer involves ions, which are electrically charged atoms or molecules.

Resting Potential

When a neuron is not actively transmitting a nerve impulse, it is in a resting state, ready to transmit a nerve impulse. During the resting state, the sodium-potassium pump maintains a difference in charge across the cell membrane (see **Figure** 22.4). It uses energy in ATP to pump positive sodium ions (Na^+) out of the cell and negative potassium ions (K^-) into the cell. As a result, the inside of the neuron is negatively charged, while the extracellular fluid surrounding the neuron is positively charged. This difference in electrical charge is called the **resting potential.**

Action Potential

A nerve impulse is a sudden reversal of the electrical charge across the membrane of a resting neuron. The reversal of charge is called an **action potential.** It begins when the neuron receives a chemical signal from another cell.

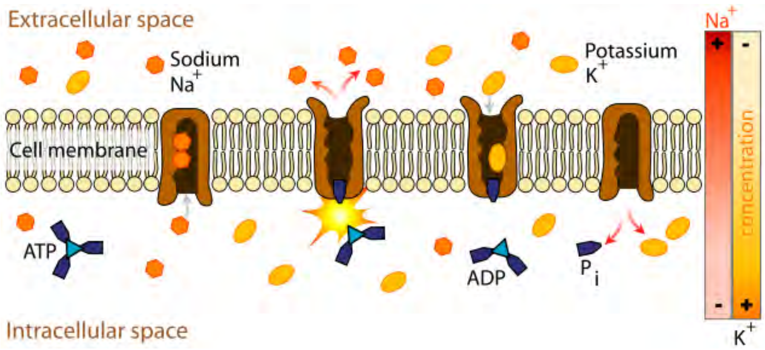


FIGURE 22.4
The sodium-potassium pump maintains the resting potential of a neuron.

The signal causes gates in the sodium-potassium pump to open, allowing positive sodium ions to flow back into the cell. As a result, the inside of the cell becomes positively charged and the outside becomes negatively charged. This reversal of charge ripples down the axon very rapidly as an electric current (see **Figure** 22.5). You can watch a detailed animation of an action potential at this link: http://outreach.mcb.harvard.edu/animations/actionpotential.swf.

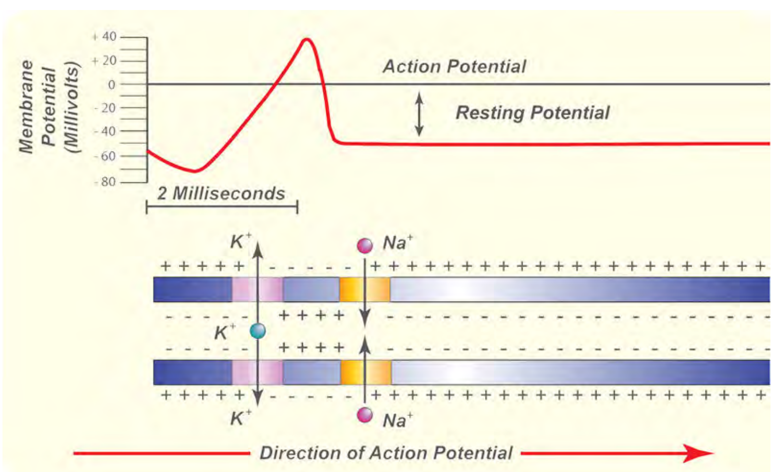
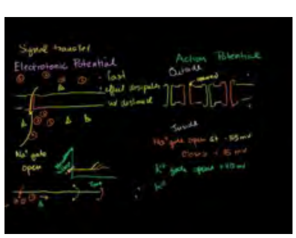


FIGURE 22.5
An action potential speeds along an axon in milliseconds.

In neurons with myelin sheaths, ions flow across the membrane only at the nodes between sections of myelin. As a result, the action potential jumps along the axon membrane from node to node, rather than spreading smoothly along the entire membrane. This increases the speed at which it travels.

The action potential is discussed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/42/gkQtRec2464 (18:53) and http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/43/7wgb7ggzFNs (12:04).



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You may choose to review the sodium-potassium pump (http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/40/C_H-ONQFjpQ) prior to watching the action potential videos.

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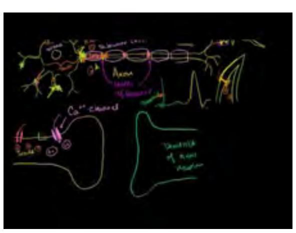
The Synapse

The place where an axon terminal meets another cell is called a **synapse**. The axon terminal and other cell are separated by a narrow space known as a synaptic cleft (see **Figure** 22.6). When an action potential reaches the axon terminal, the axon terminal releases molecules of a chemical called a **neurotransmitter**. The neurotransmitter molecules travel across the synaptic cleft and bind to receptors on the membrane of the other cell. If the other cell is a neuron, this starts an action potential in the other cell. You can view animations of neurotransmission at a synapse at the following links:

- http://outreach.mcb.harvard.edu/animations/synaptic.swf
- http://www.garyfisk.com/anim/neurotransmission.swf.

The synapse is further discussed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/44/Tbq-KZaXiL4.



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Central Nervous System

The nervous system has two main divisions: the central nervous system and the peripheral nervous system (see **Figure** 22.7). The **central nervous system (CNS)** includes the brain and spinal cord (see **Figure** 22.8). You can see an overview of the central nervous system at this link: http://vimeo.com/2024719.

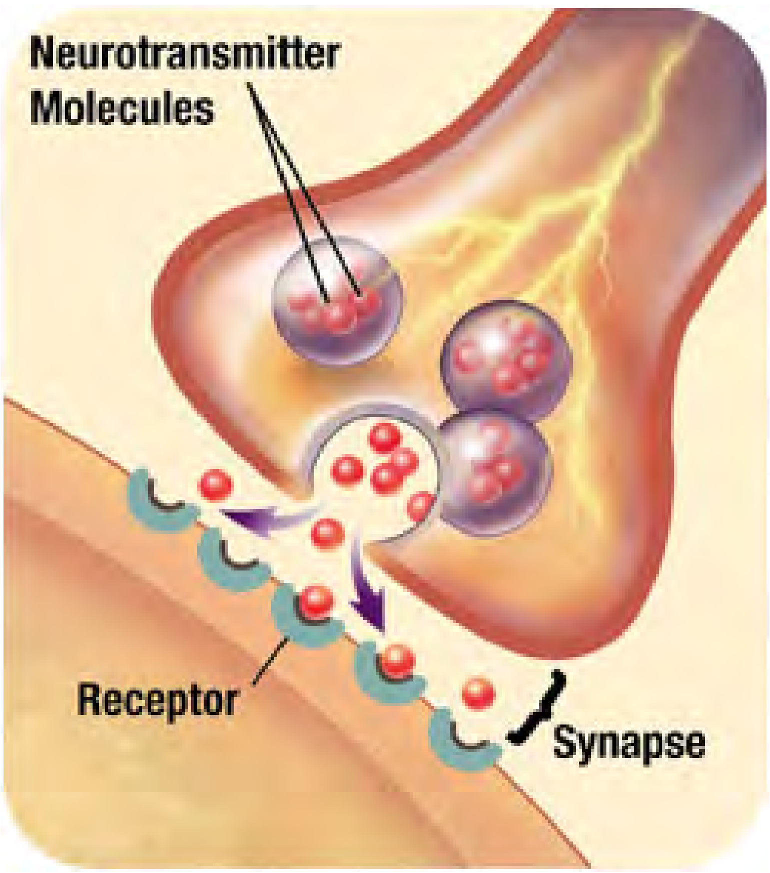

FIGURE 22.6

At a synapse neurotransmitters are released by the axon terminal. They bind with receptors on the other cell.

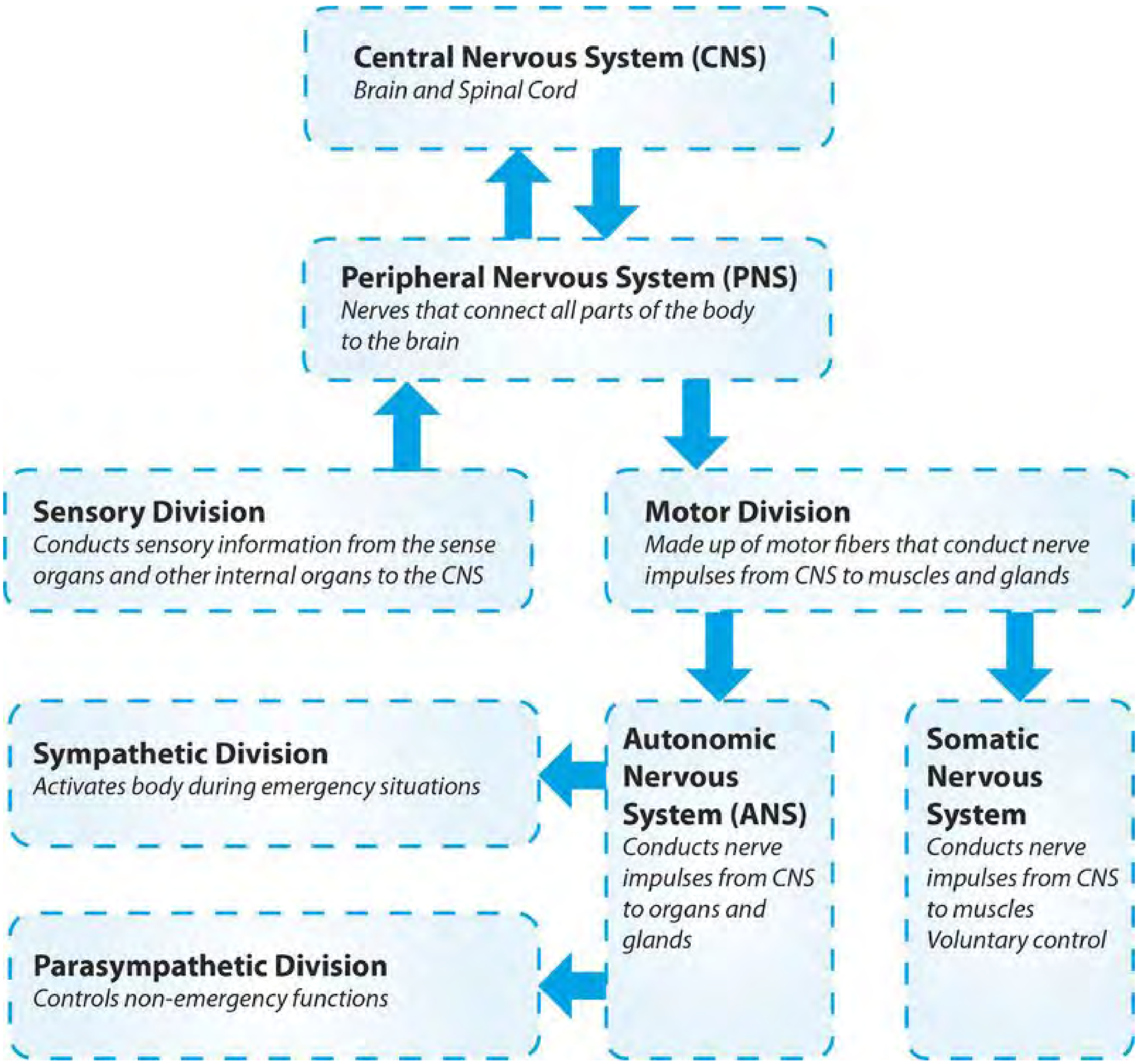

FIGURE 22.7

The two main divisions of the human nervous system are the central nervous system and the peripheral nervous system. The peripheral nervous system has additional divisions.

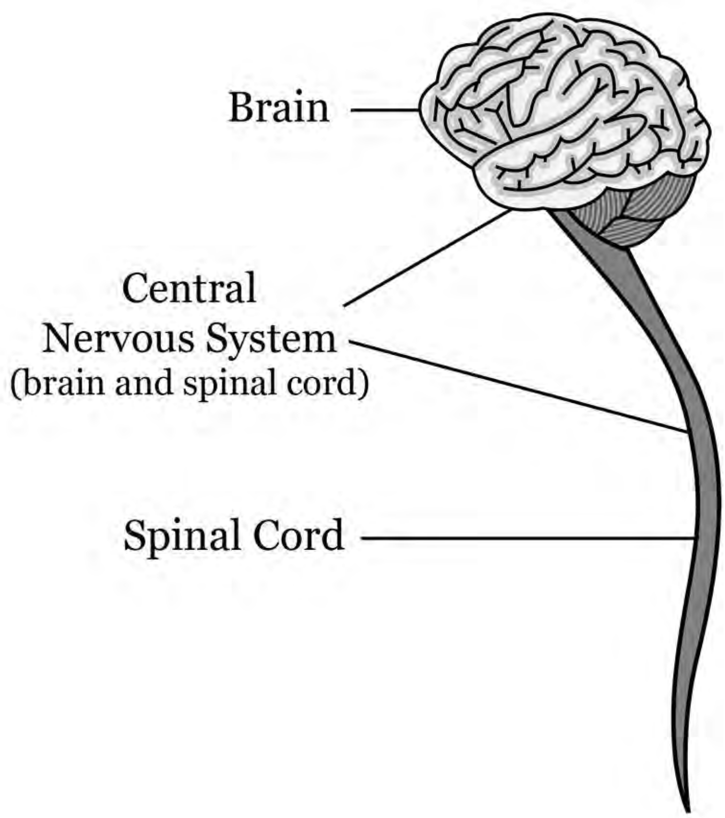

FIGURE 22.8
This diagram shows the components of the central nervous system.

The Brain

The **brain** is the most complex organ of the human body and the control center of the nervous system. It contains an astonishing 100 billion neurons! The brain controls such mental processes as reasoning, imagination, memory, and language. It also interprets information from the senses. In addition, it controls basic physical processes such as breathing and heartbeat. The brain has three major parts: the cerebrum, cerebellum, and brain stem. These parts are shown in **Figure** 22.9 and described in this section. For a video of the parts of the brain and their functions, go to this link: http://www.teachers.tv/video/13838.

You can also take interactive animated tours of the brain at these links:

- http://www.pbs.org/wnet/brain/3d/index.html
- http://www.garyfisk.com/anim/neuroanatomy.swf.

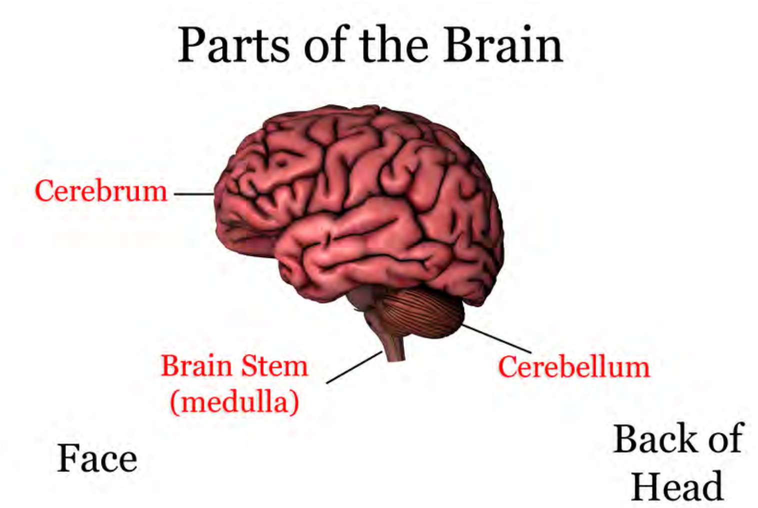

FIGURE 22.9
In this drawing assume you are looking at the left side of the head. This is how the brain would appear if you could look underneath the skull.

- The cerebrum is the largest part of the brain. It controls conscious functions such as reasoning, language, sight, touch, and hearing. It is divided into two hemispheres, or halves. The hemispheres are very similar but not identical to one another. They are connected by a thick bundle of axons deep within the brain. Each hemisphere is further divided into the four lobes shown in **Figure** 22.10 .
- The **cerebellum** is just below the cerebrum. It coordinates body movements. Many nerve pathways link the cerebellum with motor neurons throughout the body.
- The **brain stem** is the lowest part of the brain. It connects the rest of the brain with the spinal cord and passes nerve impulses between the brain and spinal cord. It also controls unconscious functions such as heart rate and breathing.

Spinal Cord

The **spinal cord** is a thin, tubular bundle of nervous tissue that extends from the brainstem and continues down the center of the back to the pelvis. It is protected by the vertebrae, which encase it. The spinal cord serves as an information superhighway, passing messages from the body to the brain and from the brain to the body.

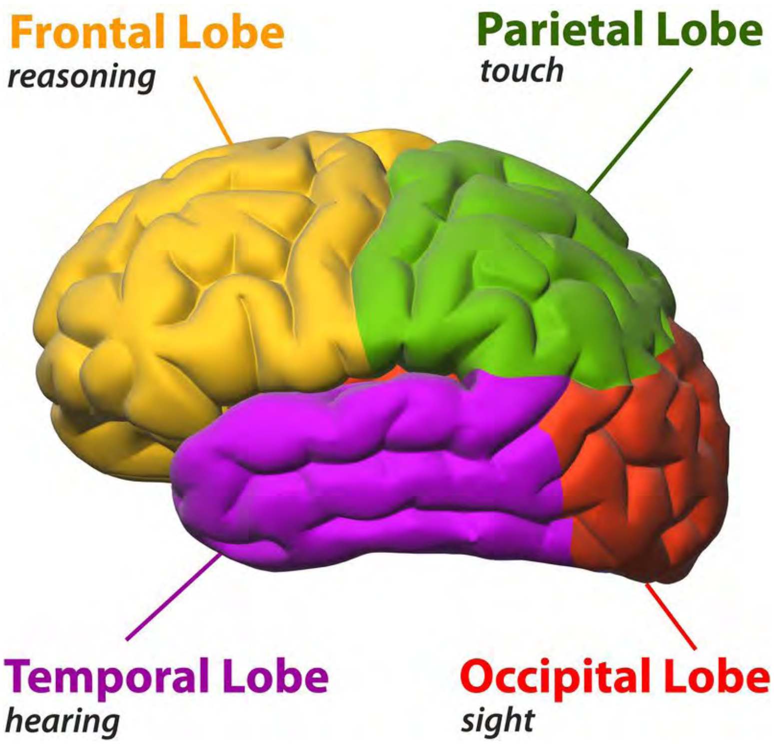

FIGURE 22.10

Each hemisphere of the cerebrum consists of four parts called lobes. Each lobe is associated with particular brain functions. Just one function of each lobe is listed here.

Peripheral Nervous System

The **peripheral nervous system (PNS)** consists of all the nervous tissue that lies outside the central nervous system. It is shown in yellow in **Figure** 22.11 . It is connected to the central nervous system by nerves. A **nerve** is a cable-like bundle of axons. Some nerves are very long. The longest human nerve is the sciatic nerve. It runs from the spinal cord in the lower back down the left leg all the way to the toes of the left foot. Like the nervous system as a whole, the peripheral nervous system also has two divisions: the sensory division and the motor division.

- The sensory division of the PNS carries sensory information from the body to the central nervous system. How sensations are detected and perceived is described in a later section of this lesson.
- The motor division of the PNS carries nerve impulses from the central nervous system to muscles and glands throughout the body. The nerve impulses stimulate muscles to contract and glands to secrete hormones. The motor division of the peripheral nervous system is further divided into the somatic and autonomic nervous systems.

Somatic Nervous System

The **somatic nervous system (SNS)** controls mainly voluntary activities that are under conscious control. It is made up of nerves that are connected to skeletal muscles. Whenever you perform a conscious movement—from signing your name to riding your bike—your somatic nervous system is responsible. The somatic nervous system also controls some unconscious movements called reflexes. A reflex is a very rapid motor response that is not directed by the brain. In a reflex, nerve impulses travel to and from the spinal cord in a reflex arc, like the one in **Figure** 22.12 . In this example, the person jerks his hand away from the flame without any conscious thought. It happens unconsciously because the nerve impulses bypass the brain.

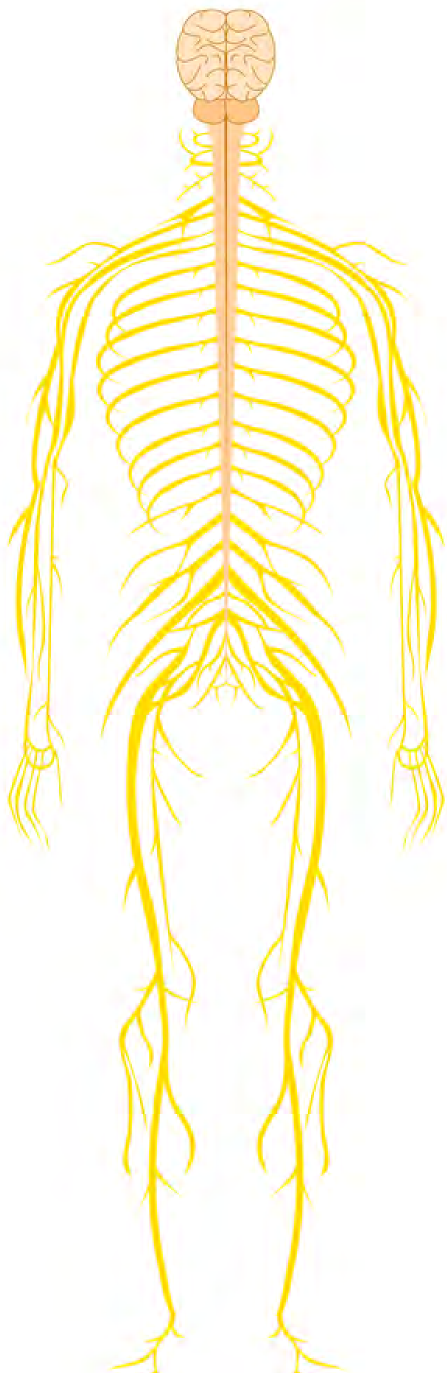

FIGURE 22.11

The nerves of the peripheral nervous system are shown in yellow in this image. Can you identify the sciatic nerve

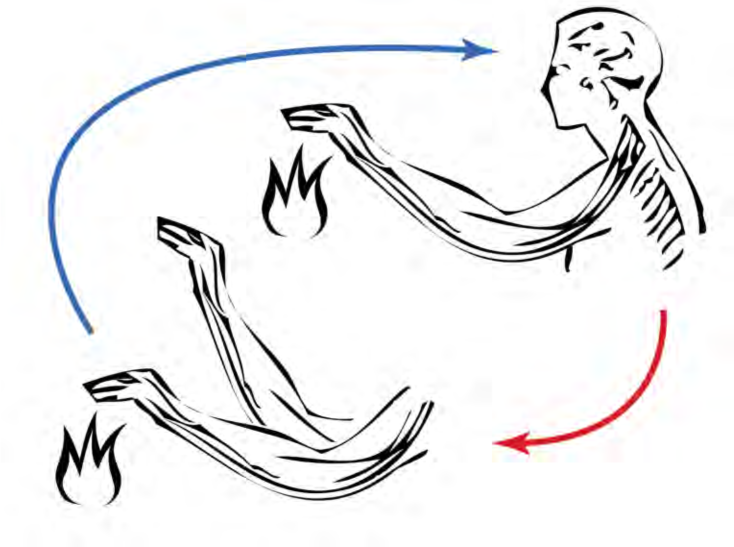

FIGURE 22.12

A reflex arc like this one enables involuntary actions. How might reflex responses be beneficial to the organism

Autonomic Nervous System

All other involuntary activities not under conscious control are the responsibility of the **autonomic nervous system (ANS)**. Nerves of the ANS are connected to glands and internal organs. They control basic physical functions such as heart rate, breathing, digestion, and sweat production. The autonomic nervous system also has two subdivisions: the sympathetic division and the parasympathetic division. You can watch an animation comparing these two subdivisions at this link: http://www.garyfisk.com/anim/autonomicns.swf.

- The sympathetic division deals with emergency situations. It prepares the body for "fight or flight." Do you get clammy palms or a racing heart when you have to play a solo or give a speech? Nerves of the sympathetic division control these responses.
- The parasympathetic division controls involuntary activities that are not emergencies. For example, it controls the organs of your digestive system so they can break down the food you eat.

The Senses

The sensory division of the PNS includes several sense organs—the eyes, ears, mouth, nose, and skin. Each sense organ has special cells, called **sensory receptors**, that respond to a particular type of stimulus. For example, the nose has sensory receptors that respond to chemicals, which we perceive as odors. Sensory receptors send nerve impulses to sensory nerves, which carry the nerve impulses to the central nervous system. The brain then interprets the nerve impulses to form a response.

Sight

Sight is the ability to sense light, and the eye is the organ that senses light. Light first passes through the cornea of the eye, which is a clear outer layer that protects the eye (see **Figure** 22.13). Light enters the eye through an opening called the pupil. The light then passes through the lens, which focuses it on the retina at the back of the eye. The retina contains light receptor cells, like those in the photograph on the first page of this chapter. These cells send nerve impulses to the optic nerve, which carries the impulses to the brain. The brain interprets the impulses and "tells" us what we are seeing. To learn more about the eye and the sense of sight, you can go to the link below. Be sure to take the quick quiz at the end of the animation. http://www.wisc-online.com/objects/ViewObject.aspx?ID=AP14304

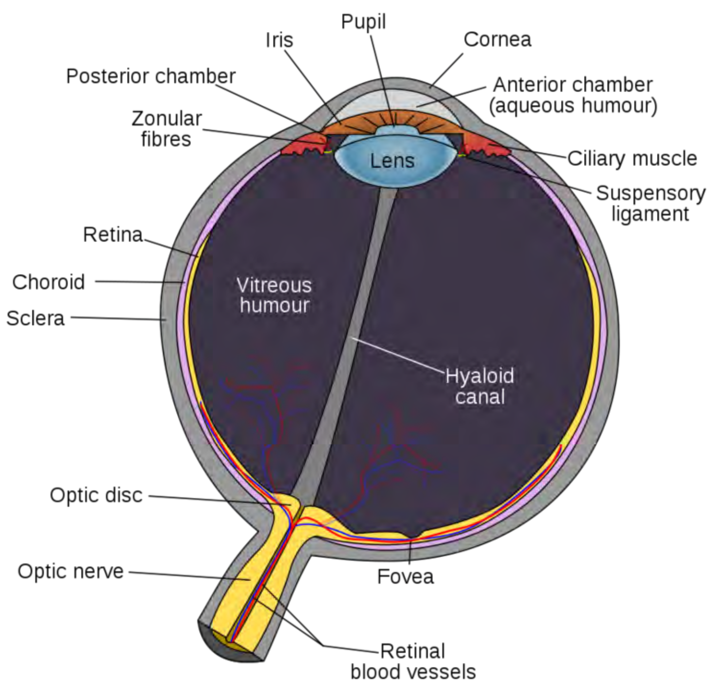

FIGURE 22.13
The eye is the organ that senses light and allows us to see.

Hearing

Hearing is the ability to sense sound waves, and the ear is the organ that senses sound. Sound waves enter the auditory canal and travel to the eardrum (see **Figure** 22.14). They strike the eardrum and make it vibrate. The vibrations then travel through several other structures inside the ear and reach the cochlea. The cochlea is a coiled tube filled with liquid. The liquid moves in response to the vibrations, causing tiny hair cells lining the cochlea to bend. In response, the hair cells send nerve impulses to the auditory nerve, which carries the impulses to the brain. The brain interprets the impulses and "tells" us what we are hearing.

Balance

The ears are also responsible for the sense of balance. Balance is the ability to sense and maintain body position. The semicircular canals inside the ear (see **Figure** 22.14) contain fluid that moves when the head changes position. Tiny hairs lining the semicircular canals sense movement of the fluid. In response, they send nerve impulses to the vestibular nerve, which carries the impulses to the brain. The brain interprets the impulses and sends messages to the peripheral nervous system. This system maintains the body's balance by triggering contractions of skeletal muscles as needed.

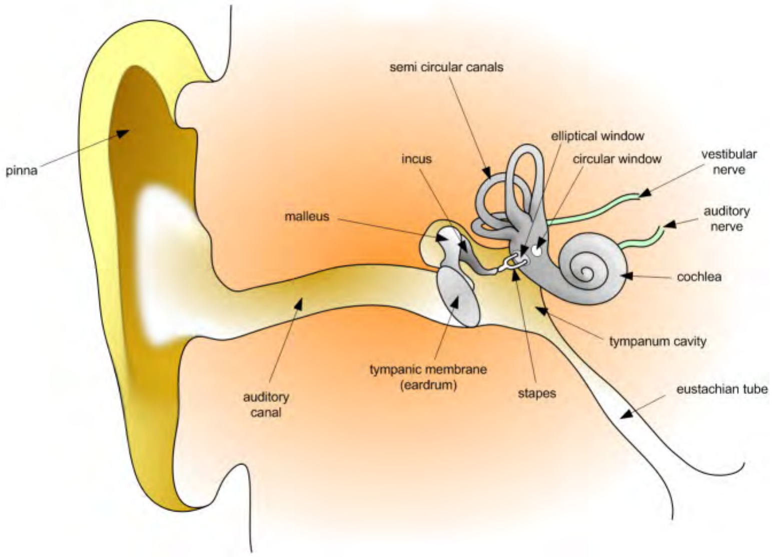

FIGURE 22.14
The ear is the organ that senses sound waves and allows us to hear. It also senses body position so we can keep our balance.

Taste and Smell

Taste and smell are both abilities to sense chemicals. Like other sense receptors, both taste and odor receptors send nerve impulses to the brain, and the brain "tells" use what we are tasting or smelling. Taste receptors are found in tiny bumps on the tongue called taste buds (see **Figure** 22.15). There are separate taste receptors for sweet, salty, sour, bitter, and meaty tastes. The meaty taste is called *umami*. You can learn more about taste receptors and the sense of taste by watching the animation at the following link: http://www.bbc.co.uk/science/humanbody/body/factfiles/taste/taste_ani_f5.swf.

FIGURE 22.15
Taste buds on the tongue contain taste receptor cells.

Odor receptors line the passages of the nose (see **Figure** 22.16). They sense chemicals in the air. In fact, odor receptors can sense hundreds of different chemicals. Did you ever notice that food seems to have less taste when you have a stuffy nose? This occurs because the sense of smell contributes to the sense of taste, and a stuffy nose interferes with the ability to smell.

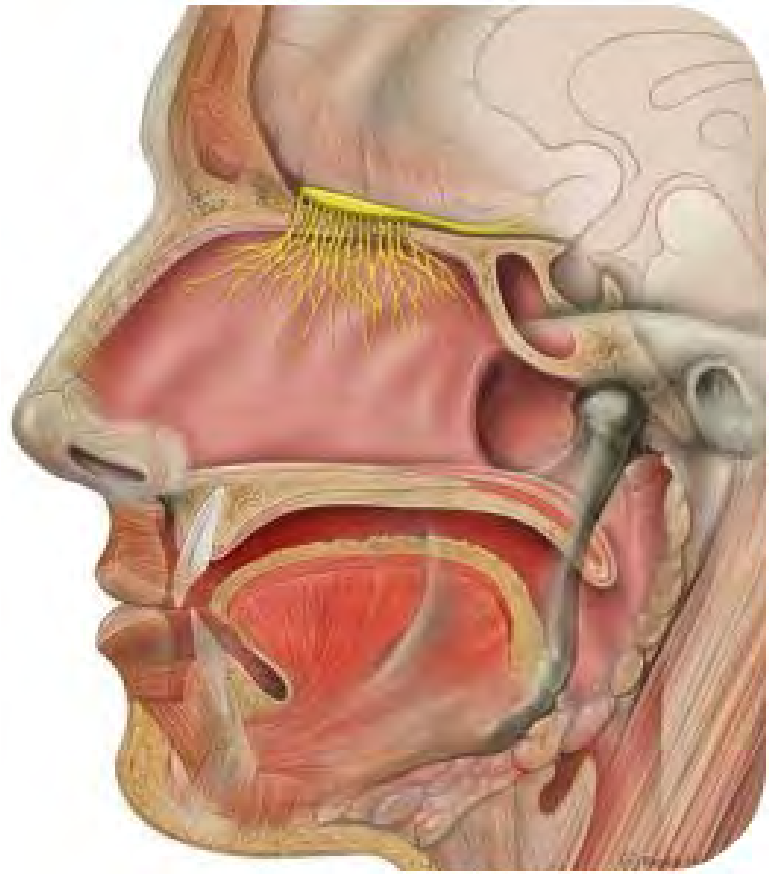

FIGURE 22.16
Odor receptors. Odor receptors and their associated nerves *in yellow* line the top of the nasal passages.

Touch

Touch is the ability to sense of pressure. Pressure receptors are found mainly in the skin. They are especially concentrated on the tongue, lips, face, palms of the hands, and soles of the feet. Some touch receptors sense differences in temperature or pain. How do pain receptors help maintain homeostasis? (Hint: What might happen if we couldn't feel pain?) See http://www.youtube.com/watch?v=xRkPNwqm0mM (0.51) for a summary.

KQED: The Flavor of Food: Smell Taste Touch

Did you know that about 95 percent of what we think is taste is actually smell? Or that the way we perceive flavor comes from a complex relationship between our senses, emotions and memories? As scientists decode how our taste and olfactory receptors work, top chefs are taking that knowledge and creating *science* in the kitchen. See the *Science of Taste* at http://www.kqed.org/quest/television/science-of-taste for more information.

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Drugs and the Nervous System

A drug is any chemical that affects the body's structure or function. Many drugs, including both legal and illegal drugs, are **psychoactive drugs**. This means that they affect the central nervous system, generally by influencing the transmission of nerve impulses. For example, some psychoactive drugs mimic neurotransmitters. At the link below, you can watch an animation showing how psychoactive drugs affect the brain. http://www.thirteen.org/closetohome/animation/neuron-main.html

Examples of Psychoactive Drugs

Caffeine is an example of a psychoactive drug. It is found in coffee and many other products (see **Table** 22.1). Caffeine is a central nervous system stimulant. Like other stimulant drugs, it makes you feel more awake and alert. Other psychoactive drugs include alcohol, nicotine, and marijuana. Each has a different effect on the central nervous system. Alcohol, for example, is a depressant. It has the opposite effects of a stimulant like caffeine.

TABLE 22.1: **Caffeine Content of Popular Products**

Product	Caffeine Content (mg)
Coffee (8 oz)	130
Tea (8 oz)	55
Cola (8 oz)	25
Coffee ice cream (8 oz)	60
Hot cocoa (8 oz)	10
Dark chocolate candy (1.5 oz)	30

Drug Abuse and Addiction

Psychoactive drugs may bring about changes in mood that users find desirable, so the 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**, in which the 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.

Disorders of the Nervous System

There are several different types of problems that can affect the nervous system.

- Vascular disorders involve problems with blood flow. For example, a stroke occurs when a blood clot blocks blood flow to part of the brain. Brain cells die quickly if their oxygen supply is cut off. This may cause paralysis and loss of other normal functions, depending on the part of the brain that is damaged.

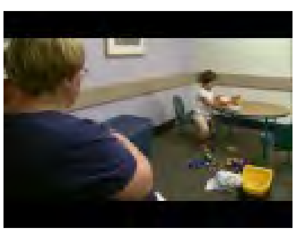
- Nervous tissue may become infected by microorganisms. Meningitis, for example, is caused by a viral or bacterial infection of the tissues covering the brain. This may cause the brain to swell and lead to brain damage and death.
- Brain or spinal cord injuries may cause paralysis and other disabilities. Injuries to peripheral nerves can cause localized pain or numbness.
- Abnormal brain functions can occur for a variety of reasons. Examples include headaches, such as migraine headaches, and epilepsy, in which seizures occur.
- Nervous tissue may degenerate, or break down. Alzheimer's disease is an example of this type of disorder, as is Amyotrophic lateral sclerosis, or ALS. ALS is also known as Lou Gehrig's disease. It leads to a gradual loss of higher brain functions.

KQED: Autism: Searching for Causes

Autism is a developmental disorder that appears in the first three years of life, and affects the brain's normal development of social and communication skills. Autism is a broad term given to a spectrum of disorders known as the autism spectrum disorders (ASDs). There are three types of ASDs: autistic disorder (also called "classic" autism), Asperger syndrome, and pervasive developmental disorder – not otherwise specified (PDD-NOS; also called "atypical autism").

Individuals with autistic disorder usually have significant language delays, social and communication challenges, and "unusual" behaviors and interests. Many people with autistic disorder also have intellectual disability. People with Asperger syndrome usually have some milder symptoms of autistic disorder. They might have social challenges and "unusual" behaviors and interests. However, they typically do not have problems with language or intellectual disability. People who meet some of the criteria for autistic disorder or Asperger syndrome, but not all, may be diagnosed with PDD-NOS. People with PDD-NOS usually have fewer and milder symptoms than those with autistic disorder. The symptoms might cause only social and communication challenges.

Today, many tens of thousands of children receive treatment for the most severe form of autism. This is a tremendous increase from 15 years ago, prompting officials to call the situation a public health crisis. Autism researchers are analyzing everything from saliva samples to carpet dust in hopes of cracking the autism mystery. See http://www.kqed.org/quest/television/autism-searching-for-causes for additional information.



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KQED: Alzheimer's Disease: Is the Cure in the Genes?

By 2050, as the population ages, 15 million Americans will suffer from Alzheimer's disease– triple today's number. But genetic studies may provide information leading to a cure. See http://www.kqed.org/quest/television/alzheimers-is-the-cure-in-the-genes for more information.

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In April 2011, an international analysis of genes of more than 50,000 people led to the discovery of five new genes that make Alzheimer's Disease more likely in the elderly and provide clues about what might start the Alzheimer's disease process and fuel its progress in a person's brain. See http://www.nytimes.com/2011/04/04/health/04alzheimer.html for additional information.

Lesson Summary

- Neurons are the structural and functional units of the nervous system. They consist of a cell body, dendrites, and axon. Neurons transmit nerve impulses to other cells. Types of neurons include sensory neurons, motor neurons, and interneurons.
- A nerve impulse begins when a neuron receives a chemical stimulus. The impulse travels down the axon membrane as an electrical action potential to the axon terminal. The axon terminal releases neurotransmitters that carry the nerve impulse to the next cell.
- The central nervous includes the brain and spinal cord. The brain is the control center of the nervous system. It controls virtually all mental and physical processes. The spinal cord is a long, thin bundle of nervous tissue that passes messages from the body to the brain and from the brain to the body.
- The peripheral nervous system consists of all the nervous tissue that lies outside the central nervous system. It is connected to the central nervous system by nerves. It has several divisions and subdivisions that transmit nerve impulses between the central nervous system and the rest of the body.
- Human senses include sight, hearing, balance, taste, smell, and touch. Sensory organs such as the eyes contain cells called sensory receptors that respond to particular sensory stimuli. Sensory nerves carry nerve impulses from sensory receptors to the central nervous system. The brain interprets the nerve impulses to form a response.
- Drugs are chemicals that affect the body's structure or function. Psychoactive drugs, such as caffeine and alcohol, affect the central nervous system by influencing the transmission of nerve impulses in the brain. Psychoactive drugs may be abused and lead to drug addiction.
- Disorders of the nervous system include blood flow problems such as stroke, infections such as meningitis, brain injuries, and degeneration of nervous tissue, as in Alzheimer's disease.

Lesson Review Questions

Recall

1. List and describe the parts of a neuron.
2. What do motor neurons do?
3. Define resting potential.
4. Name the organs of the central nervous system.
5. Which part of the brain controls conscious functions such as reasoning?
6. What are the roles of the brain stem?
7. Identify the two major divisions of the peripheral nervous system.
8. List five human senses.
9. What is a psychoactive drug? Give two examples.
10. Define drug abuse. When does drug addiction occur?

11. Identify three nervous system disorders.

Apply Concepts

12. Tony's dad was in a car accident in which his neck was broken. He survived the injury but is now paralyzed from the neck down. Explain why.

13. Multiple sclerosis is a disease in which the myelin sheaths of neurons in the central nervous system break down. What symptoms might this cause? Why?

Think Critically

14. Explain how resting potential is maintained and how an action potential occurs.

15. Compare and contrast the somatic and autonomic nervous systems.

Points to Consider

In this lesson, you learned that the nervous system enables electrical messages to be sent through the body very rapidly.

- Often, it's not necessary for the body to respond so rapidly. Can you think of another way the body could send messages that would travel more slowly? What about a way that makes use of the network of blood vessels throughout the body?
- Instead of electrical nerve impulses, what other way might messages be transmitted in the body? Do you think chemical molecules could be used to carry messages? How might this work?

22.2 The Endocrine System

Lesson Objectives

- List the glands of the endocrine system and their effects.
- Explain how hormones work by binding to receptors of target cells.
- Describe feedback mechanisms that regulate hormone secretion.
- Identify three endocrine system disorders.

Vocabulary

adrenal glands pair of endocrine glands located above the kidneys that secrete hormones such as cortisol and adrenaline

endocrine system human body system of glands that release hormones into the blood

gonads glands that secrete sex hormones and produce gametes; testes in males and ovaries in females

hypothalamus part of the brain that secretes hormones

pancreas gland near the stomach that secretes insulin and glucagon to regulate blood glucose and enzymes to help digest food

parathyroid glands a pair of small glands in the neck that secretes hormones that regulate blood calcium

pineal gland gland of the endocrine system that secretes the hormone melatonin that regulates sleep-wake cycles

pituitary gland master gland of the endocrine system that secretes many hormones, the majority of which regulate other endocrine glands

target cell type of cell on which a particular hormone has an effect because it has receptor molecules for the hormone

thyroid gland large endocrine gland in the neck that secretes hormones that control the rate of cellular metabolism throughout the body

Introduction

The nervous system isn't the only message-relaying system of the human body. The endocrine system also carries messages. The **endocrine system** is a system of glands that release chemical messenger molecules into the bloodstream. The messenger molecules are hormones. Hormones act slowly compared with the rapid transmission of electrical messages by the nervous system. They must travel through the bloodstream to the cells they affect, and this takes time. On the other hand, because endocrine hormones are released into the bloodstream, they travel throughout the body. As a result, endocrine hormones can affect many cells and have body-wide effects.

Glands of the Endocrine System

The major glands of the endocrine system are shown in **Figure** 22.17 . You can access a similar, animated endocrine system chart at the link below. http://www.abpischools.org.uk/page/modules/hormones/horm2.cfm

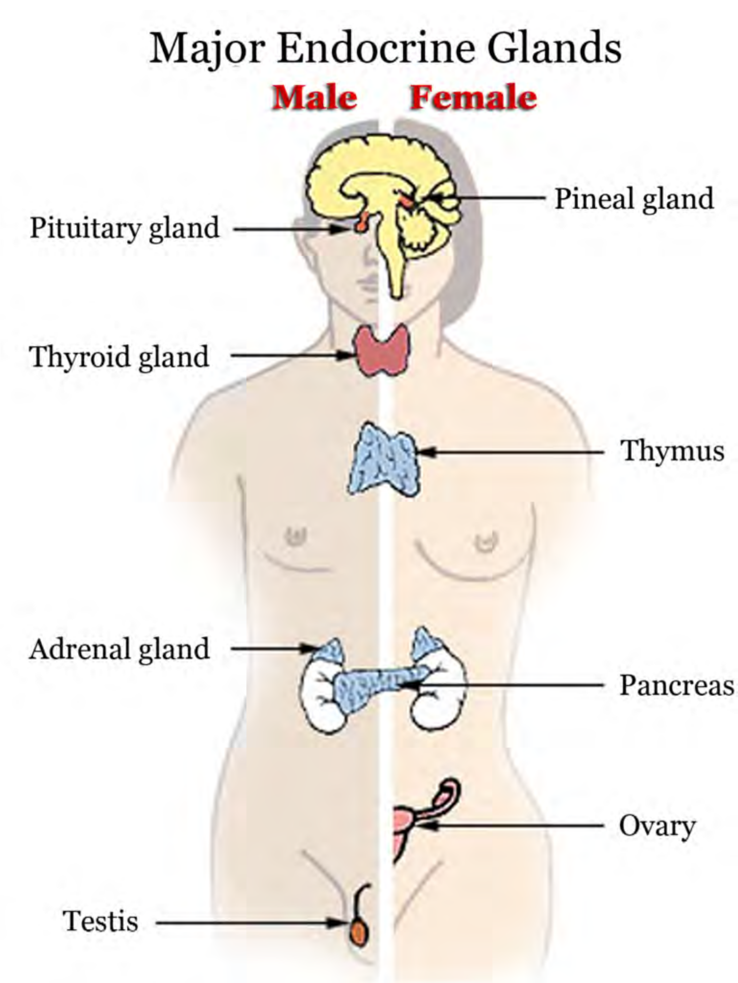


FIGURE 22.17
The glands of the endocrine system are the same in males and females except for the testes which are found only in males and ovaries which are found only in females.

Hypothalamus

The **hypothalamus** is actually part of the brain (see **Figure** 22.18), but it also secretes hormones. Some of its hormones that "tell" the pituitary gland 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. These hormones travel to the pituitary gland, which stores them until they are needed. The hormones include antidiuretic hormone and oxytocin.

- Antidiuretic hormone stimulates the kidneys to conserve water by producing more concentrated urine.
- Oxytocin stimulates the contractions of childbirth, among other functions.

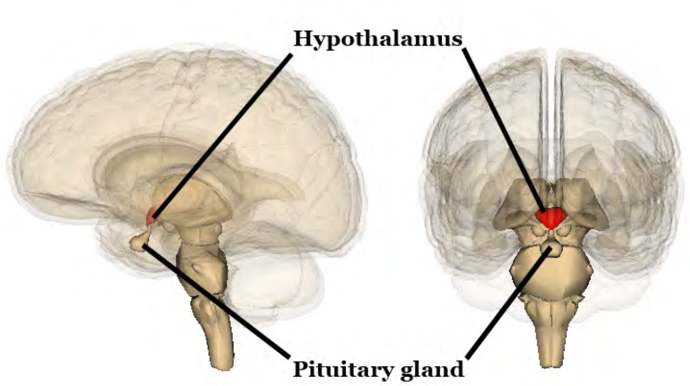


FIGURE 22.18
The hypothalamus and pituitary gland are located close together at the base of the brain.

Pituitary Gland

The pea-sized **pituitary gland** is attached to the hypothalamus by a thin stalk (see **Figure** 22.18). It consists of two bulb-like lobes. The posterior (back) lobe stores hormones from the hypothalamus. The anterior (front) lobe secretes pituitary hormones. Several pituitary hormones and their effects are listed in **Table** 22.2 . Most pituitary hormones control other endocrine glands. That's why the pituitary is often called the "master gland" of the endocrine system.

TABLE 22.2: Pituitary Hormones

Hormone	Target	Effect(s)
Adrenocorticotropic hormone (ACTH)	Adrenal glands	Stimulates the cortex of each adrenal gland to secrete its hormones
Thyroid-stimulating hormone (TSH)	Thyroid gland	Stimulates the thyroid gland to secrete thyroid hormone
Growth hormone (GH)	Body cells	Stimulates body cells to synthesize proteins and grow
Follicle-stimulating hormone (FSH)	Ovaries, testes	Stimulates the ovaries to develop mature eggs; stimulates the testes to produce sperm
Luteinizing hormone (LH)	Ovaries, testes	Stimulates the ovaries and testes to secrete sex hormones; stimulates the ovaries to release eggs

TABLE 22.2: (continued)

Hormone	Target	Effect(s)
Prolactin (PRL)	Mammary glands	Stimulates the mammary glands to produce milk

Other Endocrine Glands

Other glands of the endocrine system are described below. You can refer to **Figure** 22.17 to see where they are located.

- The **thyroid gland** is a large gland in the neck. Thyroid hormones increase the rate of metabolism in cells throughout the body. They control how quickly cells use energy and make proteins.
- The two **parathyroid glands** are located behind the thyroid gland. Parathyroid hormone helps keep the level of calcium in the blood within a narrow range. It stimulates bone cells to dissolve calcium in bone matrix and release it into the blood.
- The **pineal gland** is a tiny gland located at the base of the brain. It secretes the hormone melatonin. This hormone controls sleep-wake cycles and several other processes.
- The **pancreas** is located near the stomach. Its hormones include insulin and glucagon. These two hormones work together to control the level of glucose in the blood. Insulin causes excess blood glucose to be taken up by the liver, which stores the glucose as glycogen. Glucagon stimulates the liver to break down glycogen into glucose and release it back into the blood. The pancreas also secretes digestive enzymes into the digestive tract.
- The two **adrenal glands** are located above the kidneys. Each gland has an inner and outer part. The outer part, called the cortex, secretes hormones such as cortisol, which helps the body deal with stress, and aldosterone, which helps regulate the balance of minerals in the body. The inner part of each adrenal gland, called the medulla, secretes fight-or-flight hormones such as adrenaline, which prepare the body to respond to emergencies. For example, adrenaline increases the amount of oxygen and glucose going to the muscles. You can see an animation of this response at http://www.abpischools.org.uk/page/modules/hormones/horm8.cfm?coSiteNavigation_allTopic=1.
- The **gonads** secrete sex hormones. The 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 are involved in the changes of puberty. They also control the production of gametes by the gonads.

How Hormones Work

Endocrine hormones travel throughout the body in the blood. However, each hormone affects only certain cells, called target cells. A **target cell** is the type of cell on which a hormone has an effect. A target cell is affected by a particular hormone because it has receptor proteins that are specific to that hormone. A hormone travels through the bloodstream until it finds a target cell with a matching receptor it can bind to. When the hormone binds to a receptor, it causes a change within the cell. Exactly how this works depends on whether the hormone is a steroid hormone or a non-steroid hormone. At the link below, you can watch an animation that shows how both types of hormones work. http://www.wisc-online.com/objects/ViewObject.aspx?ID=AP13704

Hormones are discussed at http://www.youtube.com/watch?v=HrMi4GikWwQ#38;feature=related (2:28).

Steroid Hormones

Steroid hormones are made of lipids, such as phospholipids and cholesterol. They are fat soluble, so they can diffuse across the plasma membrane of target cells and bind with receptors in the cytoplasm of the cell (see **Figure** 22.19). The steroid hormone and receptor form a complex that moves into the nucleus and influences the expression of genes. Examples of steroid hormones include cortisol and sex hormones.

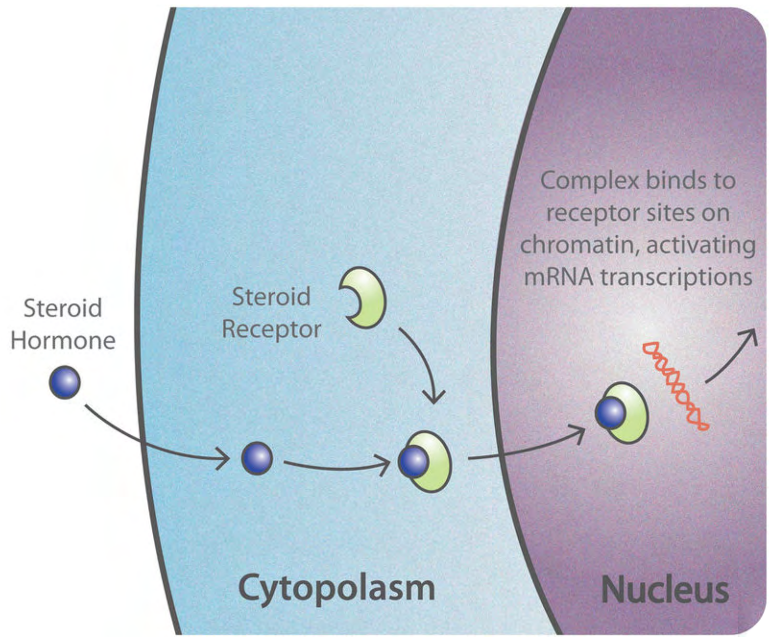


FIGURE 22.19
A steroid hormone crosses the plasma membrane of a target cell and binds with a receptor inside the cell.

Non-Steroid Hormones

Non-steroid hormones are made of amino acids. They are not fat soluble, so they cannot diffuse across the plasma membrane of target cells. Instead, a non-steroid hormone binds to a receptor on the cell membrane (see **Figure** 22.20). The binding of the hormone triggers an enzyme inside the cell membrane. The enzyme activates another molecule, called the second messenger, which influences processes inside the cell. Most endocrine hormones are non-steroid hormones, including insulin and thyroid hormones.

Hormone Regulation: Feedback Mechanisms

Hormones control many cell activities, so they are very important for homeostasis. But what controls the hormones themselves? Most hormones are regulated by feedback mechanisms. A feedback mechanism is a loop in which a product feeds back to control its own production. Most hormone feedback mechanisms involve negative feedback loops. Negative feedback keeps the concentration of a hormone within a narrow range.

Negative Feedback

Negative feedback occurs when a product feeds back to decrease its own production. This type of feedback brings things back to normal whenever they start to become too extreme. The thyroid gland is a good example of this

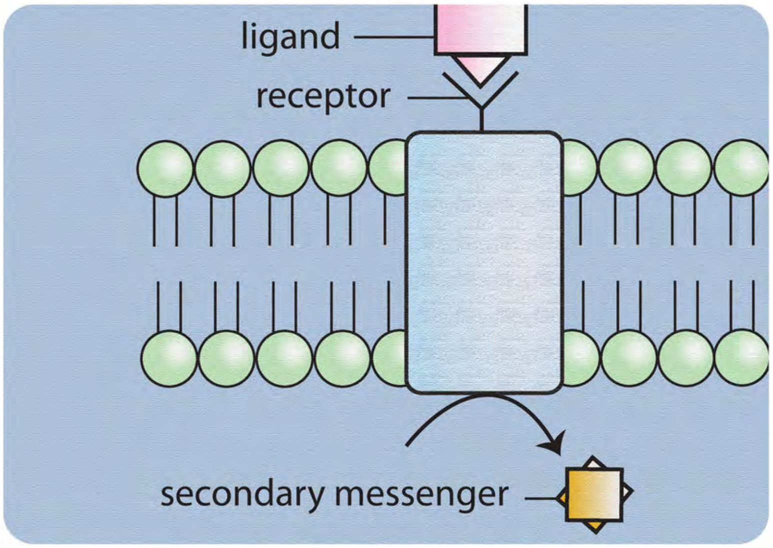


FIGURE 22.20
A non-steroid hormone binds with a receptor on the plasma membrane of a target cell. Then a secondary messenger affects cell processes.

type of regulation. It is controlled by the negative feedback loop shown in **Figure** 22.21 . You can also watch an animation of this process at the link below. http://biologyinmotion.com/thyroid/

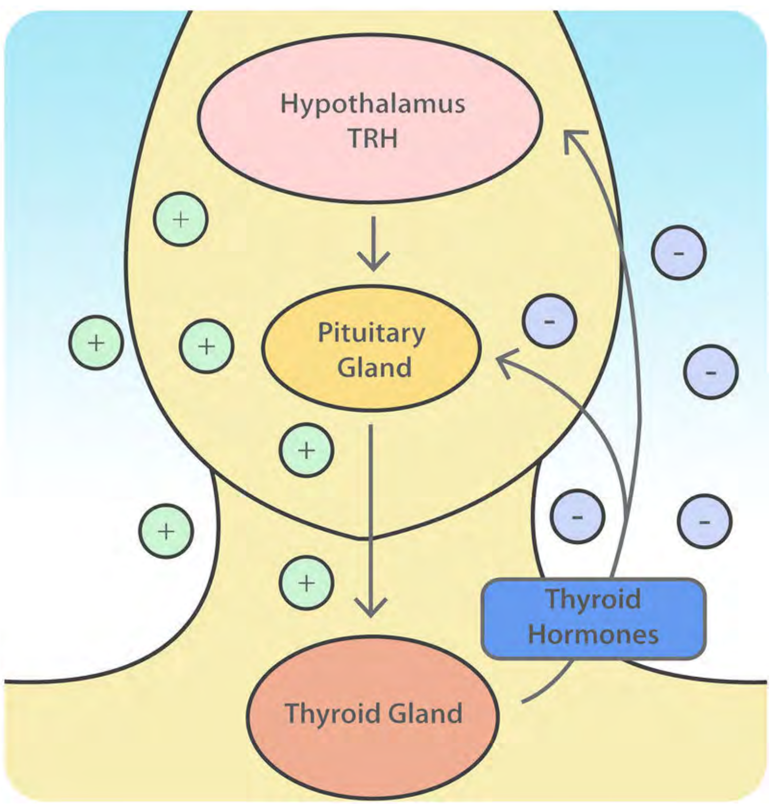


FIGURE 22.21
The thyroid gland is regulated by a negative feedback loop. The loop includes the hypothalamus and pituitary gland in addition to the thyroid.

Here's how thyroid regulation works. The hypothalamus secretes thyrotropin-releasing hormone, or TRH. TRH stimulates the pituitary gland to produce thyroid-stimulating hormone, or TSH. TSH, in turn, stimulates the thyroid gland to secrete its hormones. When the level of thyroid hormones is high enough, the hormones feedback to stop the hypothalamus from secreting TRH and the pituitary from secreting TSH. Without the stimulation of TSH, the thyroid gland stops secreting its hormones. Soon, the level of thyroid hormone starts to fall too low. What do you think happens next? This process is discussed at http://www.youtube.com/watch?v=Vae5CcaPN_8 (1:35).

Negative feedback also controls insulin secretion by the pancreas. You can interact with a feedback loop of this process at the link below. http://www.abpischools.org.uk/page/modules/hormones/horm6.cfm?coSiteNavigation_allTopic=1

Positive feedback

Positive feedback occurs when a product feeds back to increase its own production. This causes conditions to become increasingly extreme. An example of positive feedback is milk production by a mother for her baby. As the baby suckles, nerve messages from the nipple cause the pituitary gland to secrete prolactin. Prolactin, in turn, stimulates the mammary glands to produce milk, so the baby suckles more. This causes more prolactin to be secreted and more milk to be produced. This example is one of the few positive feedback mechanisms in the human body. What do you think would happen if milk production by the mammary glands was controlled by negative feedback instead?

Endocrine System Disorders

Diseases of the endocrine system are relatively common. An endocrine disease usually involves the secretion of too much or not enough hormone. When too much hormone is secreted, it is called hypersecretion. When not enough hormone is secreted, it is called hyposecretion.

Hypersecretion

Hypersecretion by an endocrine gland is often caused by a tumor. For example, a tumor of the pituitary gland can cause hypersecretion of growth hormone. If this occurs in childhood, it results in very long arms and legs and abnormally tall stature by adulthood. The condition is commonly known as gigantism (see **Figure** 22.22).

Hyposecretion

Destruction of hormone-secreting cells of a gland may result in not enough of a hormone being secreted. This occurs in Type 1 diabetes. In this case, the body's own immune system attacks and destroys cells of the pancreas that secrete insulin. A person with type 1 diabetes must frequently monitor the level of glucose in the blood (see **Figure** 22.23). If the level of blood glucose is too high, insulin is injected to bring it under control. If it is too low, a small amount of sugar is consumed.

Hormone Resistance

In some cases, an endocrine gland secretes a normal amount of hormone, but target cells do not respond to the hormone. Often, this is because target cells have because resistant to the hormone. Type 2 diabetes is an example of this type of endocrine disorder. In Type 2 diabetes, body cells do not respond to normal amounts of insulin. As a result, cells do not take up glucose and the amount of glucose in the blood becomes too high. This type of diabetes cannot be treated by insulin injections. Instead, it is usually treated with medication and diet.

FIGURE 22.22
Hypersecretion of growth hormone leads to abnormal growth often called gigantism.

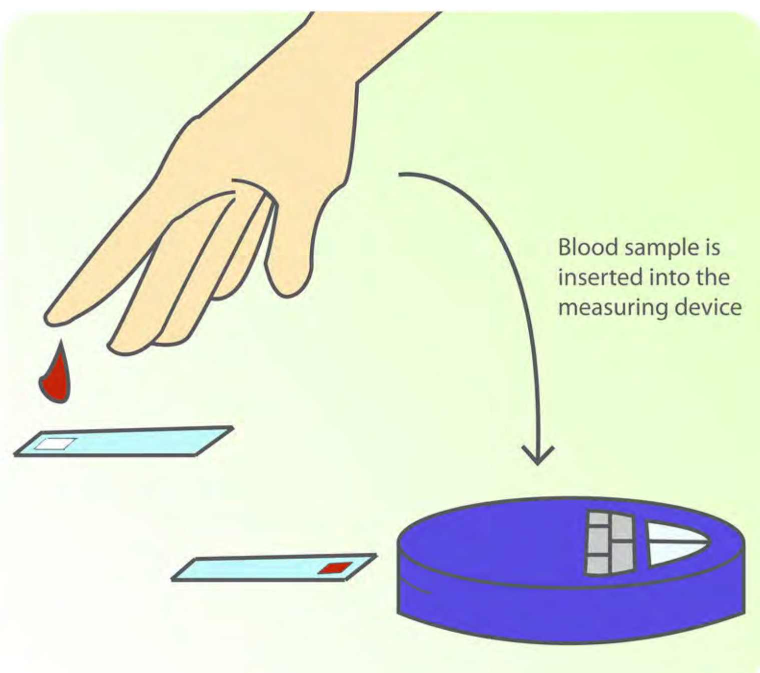


FIGURE 22.23
To measure the level of glucose in the blood a drop of blood is placed on a test strip which is read by a meter.

Lesson Summary

- The endocrine system consists of glands that secrete hormones into the bloodstream. It is regulated by a part of the brain called the hypothalamus, which also secretes hormones. The hypothalamus controls the pituitary gland, which is called the "master gland" of the endocrine system because its hormones regulate other endocrine glands. Other endocrine glands include the thyroid gland and pancreas.
- Hormones work by binding to protein receptors either inside target cells or on their plasma membranes. The binding of a steroid hormone forms a hormone-receptor complex that affects gene expression in the nucleus of the target cell. The binding of a non-steroid hormone activates a second messenger that affects processes within the target cell.
- Most hormones are controlled by negative feedback in which the hormone feeds back to decrease its own production. This type of feedback brings things back to normal whenever they start to become too extreme. Positive feedback is much less common because it causes conditions to become increasingly extreme.
- Endocrine system disorders usually involve the secretion of too much or not enough hormone. For example, a tumor of the adrenal gland may lead to excessive secretion of growth hormone, which causes gigantism. In Type 1 diabetes, the pancreas does not secrete enough insulin, which causes high levels of glucose in the blood.

Lesson Review Questions

Recall

1. Define hormone.

2. List the major glands of the endocrine system.

3. Name three pituitary hormones, and state how they affect their targets.

4. Define hypersecretion. Give an example of an endocrine disorder that involves hypersecretion.

Apply Concepts

5. Tasha had a thyroid test. Her doctor gave her an injection of TSH and 15 minutes later measured the level of thyroid hormone in her blood. What is TSH? Why do you think Tasha's doctor gave her an injection of TSH? How would this affect the level of thyroid hormone in her blood if her thyroid is normal?

6. After the thyroid test, Tasha's doctor said she has an underactive thyroid. What symptoms would you expect Tasha to have? Why?

Think Critically

7. Explain how the nervous system is linked with the endocrine system.

8. Compare and contrast how steroid and non-steroid hormones affect target cells.

9. Why are negative feedback mechanisms more common than positive feedback mechanisms in the human body? What might happen if an endocrine hormone such as thyroid hormone was controlled by positive instead of negative feedback?

10. Explain why a person with type 2 diabetes cannot be helped by insulin injections.

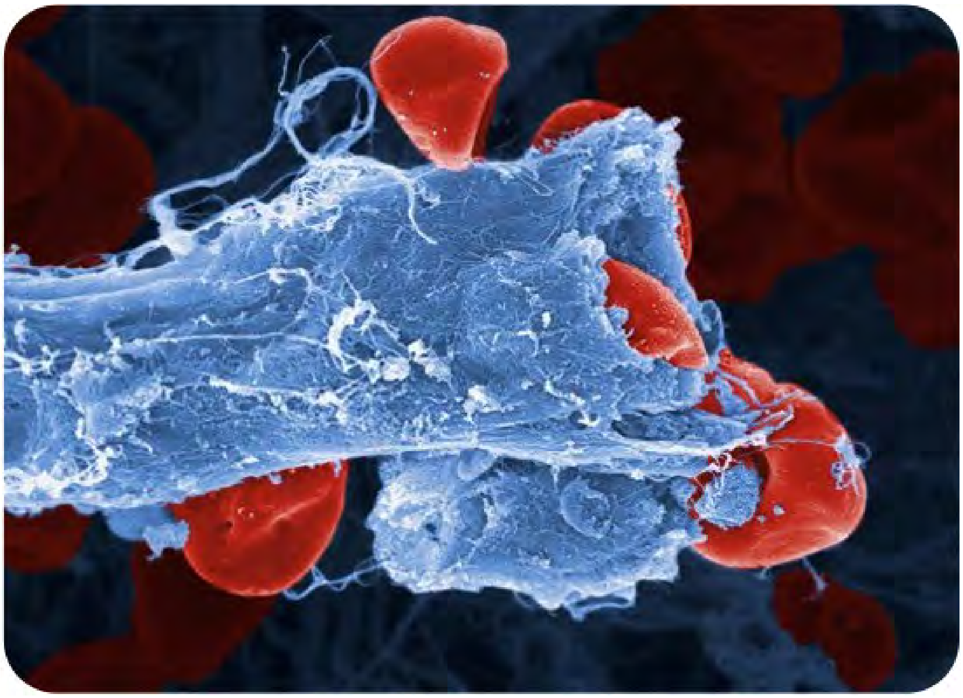
Points to Consider

In this lesson you learned that endocrine hormones can affect cells throughout the body because they travel in the blood through the circulatory system.

- Do you know what organs make up the circulatory system?
- Can you explain what causes blood to move through the system?

CHAPTER 23 The Circulatory, Respiratory, Digestive, and Excretory Systems

CHAPTER OUTLINE



This color-enhanced image was made with an electron microscope, so the objects it depicts are extremely small. Do you know what they are? This incredible photo shows red blood cells leaking out of a ruptured blood vessel.

Blood vessels are part of the circulatory system, the "highway" system of the human body that transports materials to all of its cells. Red blood cells carry some of these materials, so they are a little like trucks on a highway. In this chapter, you will learn more about capillaries, red blood cells, and other structures of the circulatory system.

23.1 The Circulatory System

Lesson Objectives

- Explain how the heart pumps blood throughout the body.
- Compare different types of blood vessels and their roles.
- Outline pathways of the pulmonary and systemic circulations.
- Define cardiovascular disease, and list its risk factors.
- Describe blood, blood components, and blood pressure.

Vocabulary

antigen molecule that the immune system identifies as foreign and responds to by forming antibodies

artery type of blood vessel that carries blood away from the heart toward the lungs or body

atherosclerosis condition in which plaque builds up inside arteries

blood fluid connective tissue that circulates throughout the body through blood vessels

blood pressure force exerted by circulating blood on the walls of blood vessels

blood type genetic characteristic associated with the presence or absence of antigens on the surface of red blood cells

capillary smallest type of blood vessel that connects very small arteries and veins

cardiovascular disease (CVD) any disease that affects the heart or blood vessels

circulatory system organ system consisting of the heart, blood vessels, and blood that transports materials around the body

heart attack blockage of blood flow to heart muscle tissues that may result in the death of cardiac muscle fibers

hypertension high blood pressure

plasma golden-yellow fluid part of blood that contains many dissolved substances and blood cells

platelet cell fragment in blood that helps blood clot

pulmonary circulation part of the circulatory system that carries blood between the heart and lungs

red blood cell type of cell in blood that contains hemoglobin and carries oxygen

systemic circulation part of the circulatory system that carries blood between the heart and body

vein type of blood vessel that carries blood toward the heart from the lungs or body

white blood cell type of cell in blood that defends the body against invading microorganisms or other threats in blood or extracellular fluid

Introduction

The **circulatory system** can be compared to a system of interconnected, one-way roads that range from superhighways to back alleys. Like a network of roads, the job of the circulatory system is to allow the transport of materials from one place to another. As described in **Figure** 23.1 , the materials carried by the circulatory system include hormones, oxygen, cellular wastes, and nutrients from digested food. Transport of all these materials is necessary to maintain homeostasis of the body. The main components of the circulatory system are the heart, blood vessels, and blood. Each of these components is described in detail below.

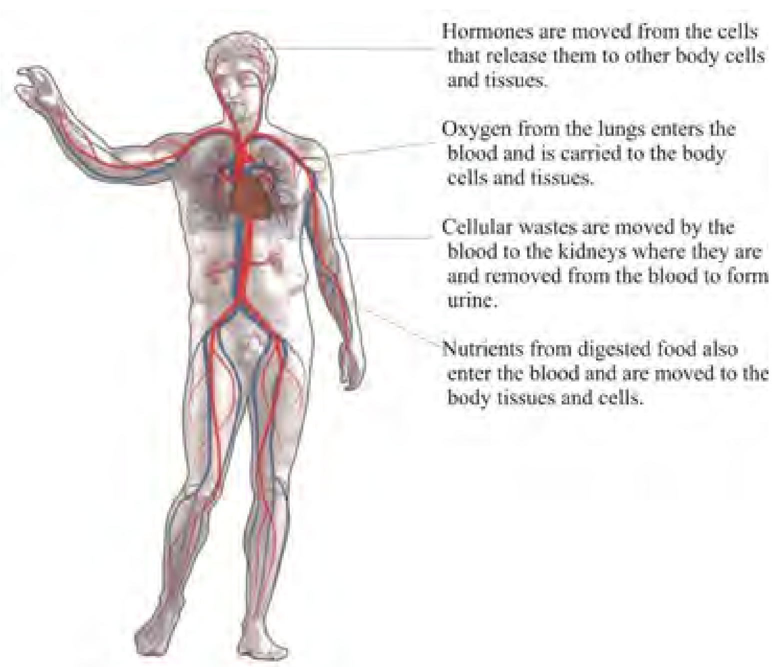


FIGURE 23.1
The function of the circulatory system is to move materials around the body.

The Heart

The heart is a muscular organ in the chest. It consists mainly of cardiac muscle tissue and pumps blood through blood vessels by repeated, rhythmic contractions. The heart has four chambers, as shown in **Figure** 23.2 : two upper atria (singular, atrium) and two lower ventricles. Valves between chambers keep blood flowing through the heart in just one direction. For an animation of the structures of the heart, go to this link: http://www.byrnehealthcare.com/animations/SutterAnatomy.htm.

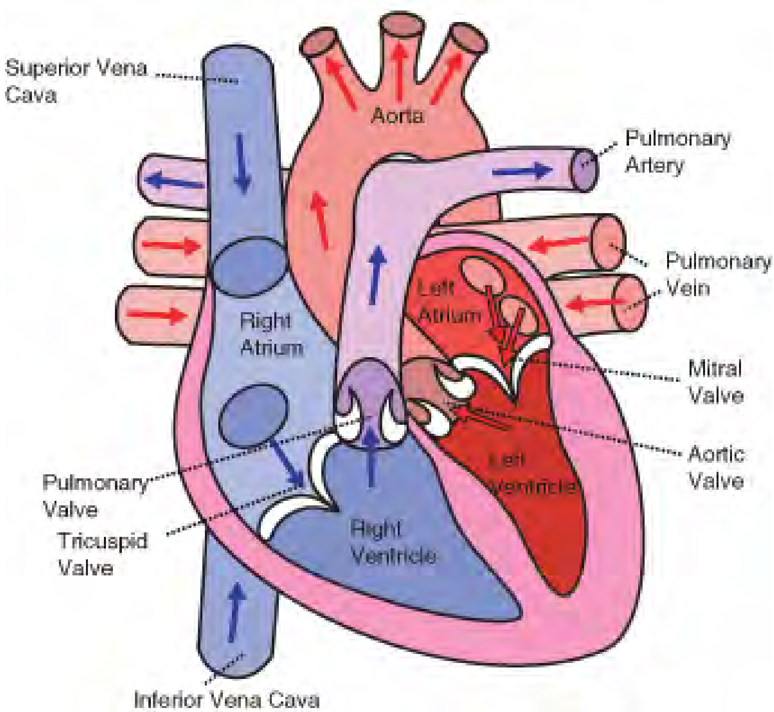


FIGURE 23.2

The chambers of the heart and the valves between them are shown here.

Blood Flow Through the Heart

Blood flows through the heart in two separate loops, which are indicated by the arrows in **Figure** 23.2 . You can also watch an animation of the heart pumping blood at this link: http://www.nhlbi.nih.gov/health/dci/Diseases/hhw/hhw_pumping.html.

a. Blood from the body enters the right atrium of the heart. The right atrium pumps the blood to the right ventricle, which pumps it to the lungs. This loop is represented by the blue arrows in **Figure** 23.2 .
b. Blood from the lungs enters the left atrium of the heart. The left atrium pumps the blood to the left ventricle, which pumps it to the body. This loop is represented by the red arrows in **Figure** 23.2 .

Heartbeat

Unlike skeletal muscle, cardiac muscle contracts without stimulation by the nervous system. Instead, specialized cardiac muscle cells send out electrical impulses that stimulate the contractions. As a result, the atria and ventricles normally contract with just the right timing to keep blood pumping efficiently through the heart. You can watch an animation to see how this happens at this link: http://www.nhlbi.nih.gov/health/dci/Diseases/hhw/hhw_electrical.html.

Blood Vessels

Blood vessels form a network throughout the body to transport blood to all the body cells. There are three major types of blood vessels: arteries, veins, and capillaries. All three are shown in **Figure** 23.3 and described below.

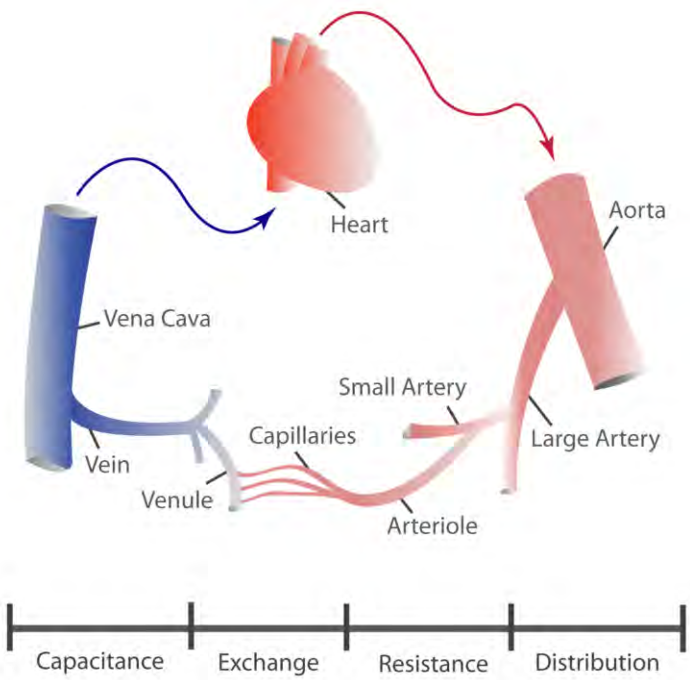


FIGURE 23.3
Blood vessels include arteries veins and capillaries.

- **Arteries** are muscular blood vessels that carry blood away from the heart. They have thick walls that can withstand the pressure of blood being pumped by the heart. Arteries generally carry oxygen-rich blood. The largest artery is the aorta, which receives blood directly from the heart.
- **Veins** are blood vessels that carry blood toward the heart. This blood is no longer under much pressure, so many veins have valves that prevent backflow of blood. Veins generally carry deoxygenated blood. The largest vein is the inferior vena cava, which carries blood from the lower body to the heart.
- **Capillaries** are the smallest type of blood vessels. They connect very small arteries and veins. The exchange of gases and other substances between cells and the blood takes place across the extremely thin walls of capillaries.

Blood Vessels and Homeostasis

Blood vessels help regulate body processes by either constricting (becoming narrower) or dilating (becoming wider). These actions occur in response to signals from the autonomic nervous system or the endocrine system. Constriction occurs when the muscular walls of blood vessels contract. This reduces the amount of blood that can flow through the vessels (see **Figure** 23.4). Dilation occurs when the walls relax. This increases blood flows through the vessels.

Constriction and dilation allow the circulatory system to change the amount of blood flowing to different organs.

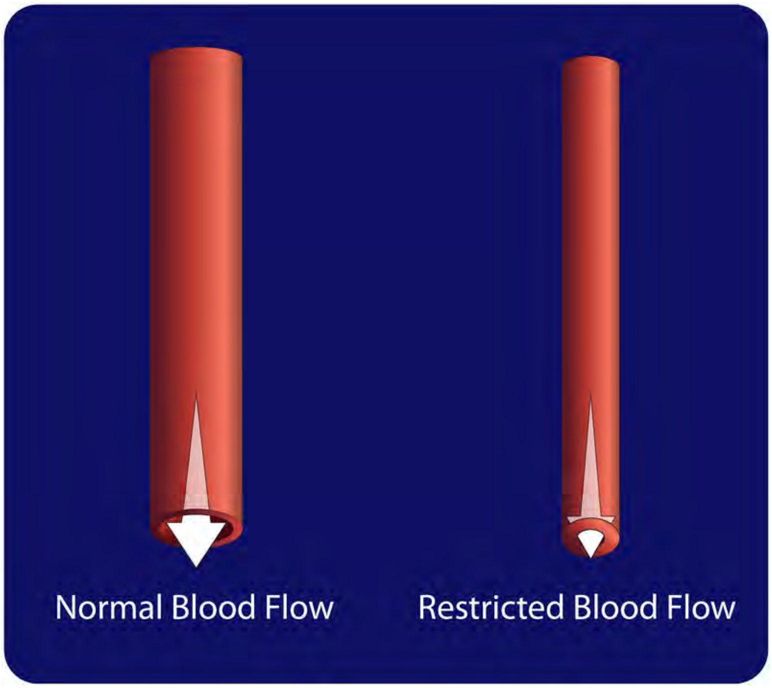


FIGURE 23.4
When a blood vessel constricts less blood can flow through it.

For example, during a fight-or-flight response, dilation and constriction of blood vessels allow more blood to flow to skeletal muscles and less to flow to digestive organs. Dilation of blood vessels in the skin allows more blood to flow to the body surface so the body can lose heat. Constriction of these blood vessels has the opposite effect and helps conserve body heat.

Blood Vessels and Blood Pressure

The force exerted by circulating blood on the walls of blood vessels is called **blood pressure**. Blood pressure is highest in arteries and lowest in veins. When you have your blood pressure checked, it is the blood pressure in arteries that is measured. High blood pressure, or **hypertension**, is a serious health risk but can often be controlled with lifestyle changes or medication. You can learn more about hypertension by watching the animation at this link: http://www.healthcentral.com/high-blood-pressure/introduction-47-115.html.

Pulmonary and Systemic Circulations

The circulatory system actually consists of two separate systems: pulmonary circulation and systemic circulation. You can watch animations of both systems at the following link. http://www.pbs.org/wnet/redgold/journey/phase2_a1.html

Pulmonary Circulation

Pulmonary circulation is the part of the circulatory system that carries blood between the heart and lungs (the term *pulmonary* means "of the lungs"). It is illustrated in **Figure** 23.5 . Deoxygenated blood leaves the right ventricle through pulmonary arteries, which transport it to the lungs. In the lungs, the blood gives up carbon dioxide and picks up oxygen. The oxygenated blood then returns to the left atrium of the heart through pulmonary veins.

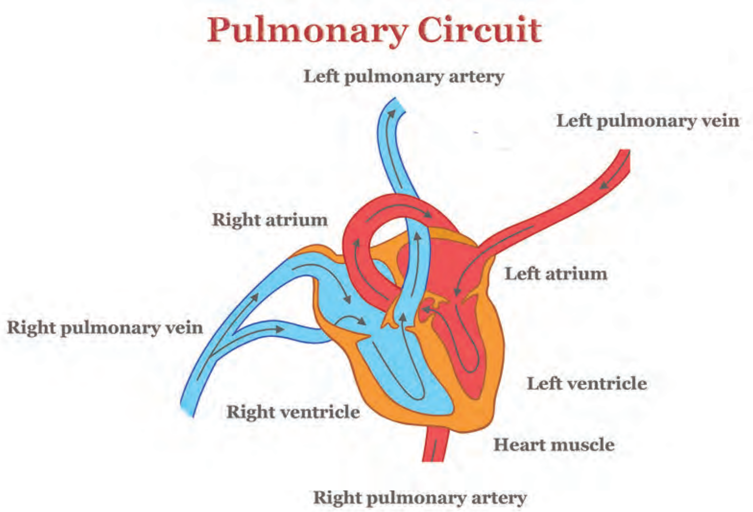


FIGURE 23.5
The pulmonary circulation carries blood between the heart and lungs.

Systemic Circulation

Systemic circulation is the part of the circulatory system that carries blood between the heart and body. It is illustrated in **Figure** 23.6 . Oxygenated blood leaves the left ventricle through the aorta. The aorta and other arteries transport the blood throughout the body, where it gives up oxygen and picks up carbon dioxide. The deoxygenated blood then returns to the right atrium through veins.

Cardiovascular Disease

Diseases of the heart and blood vessels, called **cardiovascular diseases (CVD)**, are very common. The leading cause of CVD is atherosclerosis.

Atherosclerosis

Atherosclerosis is the buildup of plaque inside arteries (see **Figure** 23.7). Plaque consists of cell debris, cholesterol, and other substances. Factors that contribute to plaque buildup include a high-fat diet and smoking. As plaque builds up, it narrows the arteries and reduces blood flow. You can watch an animation about atherosclerosis at these links: http://www.youtube.com/watch?v=fLonh7ZesKs and http://www.youtube.com/watch?v=qRK7-DCDKEA.

Coronary Heart Disease

Atherosclerosis of arteries that supply the heart muscle is called coronary heart disease. This disease may or may not have symptoms such as chest pain. As the disease progresses, there is an increased risk of heart attack. A **heart attack** occurs when the blood supply to part of the heart muscle is blocked and cardiac muscle fibers die. Coronary heart disease is the leading cause of death of adults in the U.S.

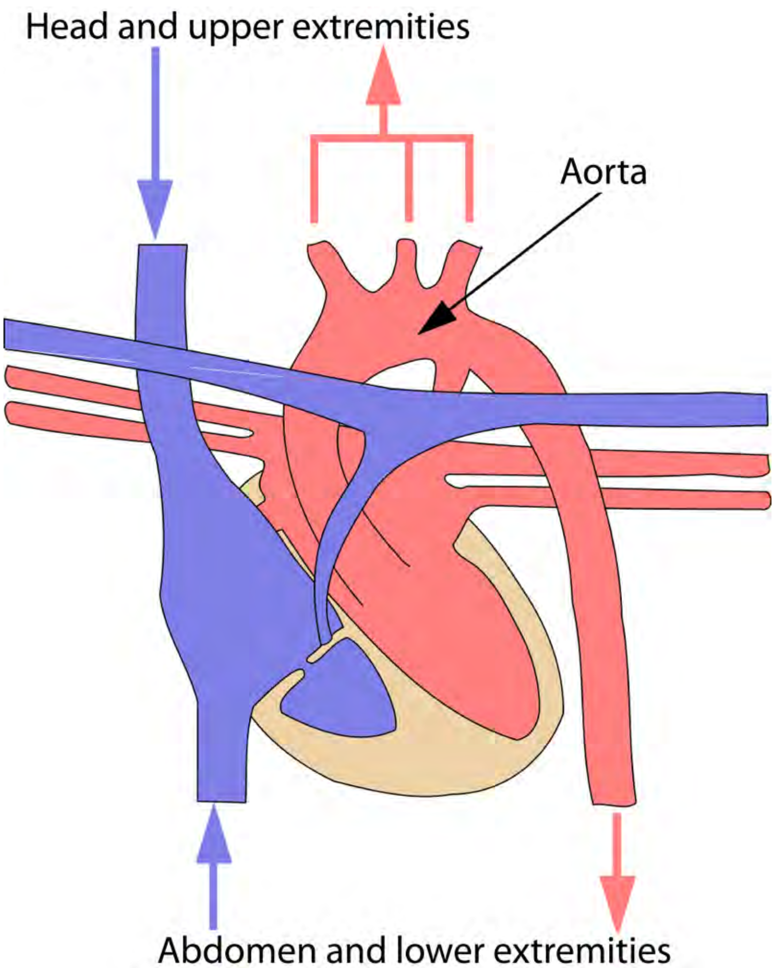


FIGURE 23.6

The systemic circulation carries blood between the heart and body.

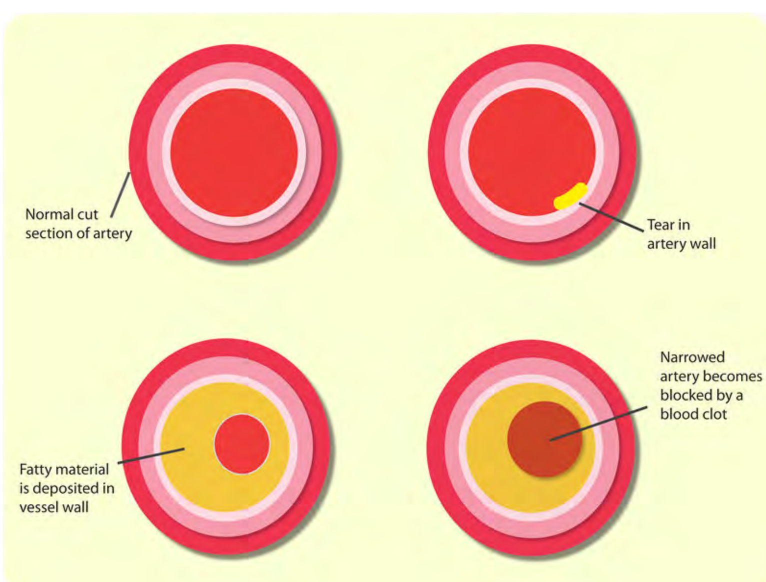


FIGURE 23.7

The fatty material inside the artery on the right is plaque. Notice how much narrower the artery has become. Less blood can flow through it than the normal artery.

Preventing Cardiovascular Disease

Many factors may increase the risk of developing coronary heart disease and other CVDs. The risk of CVDs increases with age and is greater in males than females at most ages. Having a close relative with CVD also increases the risk. These factors cannot be controlled, but other risk factors can, including smoking, lack of exercise, and high-fat diet. By making healthy lifestyle choices, you can reduce your risk of developing CVD.

Blood

Blood is a fluid connective tissue. It circulates throughout the body through blood vessels by the pumping action of the heart. Blood in arteries carries oxygen and nutrients to all the body's cells. Blood in veins carries carbon dioxide and other wastes away from the cells to be excreted. Blood also defends the body against infection, repairs body tissues, transports hormones, and controls the body's pH.

Composition of Blood

The fluid part of blood is called **plasma**. It is a watery golden-yellow liquid that contains many dissolved substances and blood cells. Types of blood cells in plasma include red blood cells, white blood cells, and platelets (see **Figure** 23.8). You can learn more about blood and its components by watching the animation *What Is Blood?* at this link: http://www.apan.net/meetings/busan03/materials/ws/education/demo-los/blood-rlo/whatisblood.swf.

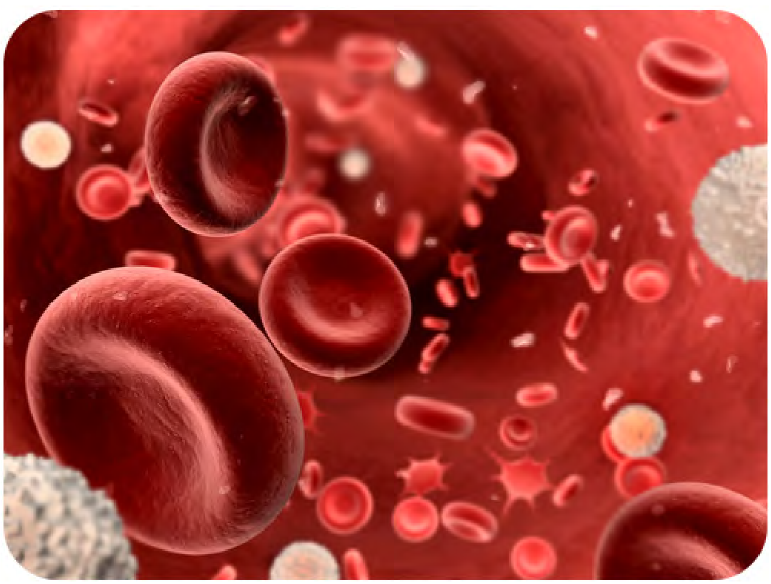
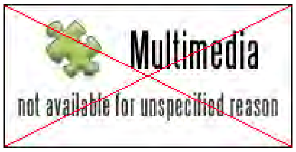


FIGURE 23.8

Cells in blood include red blood cells white blood cells and platelets.

- The trillions of **red blood cells** in blood plasma carry oxygen. Red blood cells contain hemoglobin, a protein with iron that binds with oxygen.
- **White blood cells** are generally larger than red blood cells but far fewer in number. They defend the body in various ways. For example, white blood cells called phagocytes swallow and destroy microorganisms and debris in the blood.
- **Platelets** are cell fragments involved in blood clotting. They stick to tears in blood vessels and to each other, forming a plug at the site of injury. They also release chemicals that are needed for clotting to occur.

An overview of red blood cells can be viewed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/36/fLKOBQ6cZHA (16:30).



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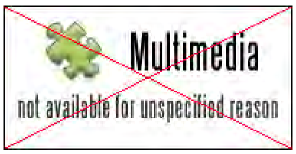
Hemoglobin is discussed in detail at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/38/LWtXthfG9_M (14:34).



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Blood Type

Blood type is a genetic characteristic associated with the presence or absence of certain molecules, called **antigens**, on the surface of red blood cells. The most commonly known blood types are the ABO and Rhesus blood types.

- ABO blood type is determined by two common antigens, often referred to simply as antigens A and B. A person may have blood type A (only antigen A), B (only antigen B), AB (both antigens), or O (no antigens).

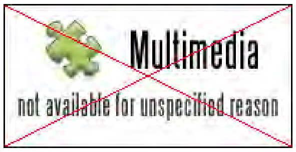
- Rhesus blood type is determined by one common antigen. A person may either have the antigen (Rh^+) or lack the antigen (Rh^-).

Blood type is important for medical reasons. A person who needs a blood transfusion must receive blood that is the same type as his or her own. Otherwise, the transfused blood may cause a potentially life-threatening reaction in the patient's bloodstream.

Lesson Summary

- The heart contracts rhythmically to pump blood to the lungs and the rest of the body. Specialized cardiac muscle cells trigger the contractions.
- Arteries carry blood away from the heart, veins carry blood toward the heart, and capillaries connect arteries and veins.
- The pulmonary circulation carries blood between the heart and lungs. The systemic circulation carries blood between the heart and body.
- A disease that affects the heart or blood vessels is called a cardiovascular disease (CVD). The leading cause of CVD is atherosclerosis, or the buildup of plaque inside arteries. Healthy lifestyle choices can reduce the risk of developing CVD.
- Blood is a fluid connective tissue that contains a liquid component called plasma. It also contains dissolved substances and blood cells. Red blood cells carry oxygen, white blood cells defend the body, and platelets help blood clot.

A summary of the circulatory system, blood cells and hemoglobin is available at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/37/QhiVnFvshZg (14:57).



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Lesson Review Questions

Recall

1. Describe how blood flows through the heart.

2. What controls heartbeat?

3. How do arteries differ from veins?

4. What is blood pressure? What is hypertension?

5. List factors that increase the risk of cardiovascular disease.

6. Identify three types of blood cells and their functions.

Apply Concepts

7. To take your pulse, you press your fingers against an artery near the surface of the body. What are you feeling and measuring when you take your pulse? Why can't you take your pulse by pressing your fingers against a vein?

8. People with type O blood are called "universal donors" because they can donate blood to anyone else, regardless of their ABO blood type. Explain why.

Think Critically

9. Compare and contrast the pulmonary and systemic circulations.

10. Explain the role of blood vessels in homeostasis.

Points to Consider

An important function of the circulatory system is transporting oxygen to cells.

- Do you know where blood gets the oxygen cells it needs?
- How do you think blood is able to give up its oxygen to cells?

23.2 The Respiratory System

Lesson Objectives

- Define respiration, and explain how it differs from cellular respiration.
- Identify the organs of the respiratory system.
- Outline the processes of ventilation, gas exchange, and gas transport.
- Describe the role of gas exchange in homeostasis.
- Explain how the rate of breathing is regulated.
- Identify diseases of the respiratory system.

Vocabulary

asthma respiratory system disease in which air passages of the lungs periodically become too narrow, making breathing difficult

emphysema lung disease, usually caused by smoking, in which walls of alveoli break down, so less gas can be exchanged in the lungs

larynx organ of the respiratory system between the pharynx and trachea that is also called the voice box because it allows the production of vocal sounds

lung organ of the respiratory system in which gas exchange takes place between the blood and the atmosphere

pharynx long, tubular organ that connects the mouth and nasal cavity with the larynx through which air and food pass

pneumonia disease in which the alveoli of the lungs become inflamed and filled with fluid as a result of infection or injury

respiration exchange of gases between the body and the outside air

respiratory system organ system that brings oxygen into the body and releases carbon dioxide into the atmosphere

trachea long, tubular organ of the respiratory system, also called the wind pipe, that carries air between the larynx and lungs

ventilation process of carrying air from the atmosphere into the lungs

Introduction

Red blood cells are like trucks that transport cargo on a highway system. Their cargo is oxygen, and the highways are blood vessels. Where do red blood cells pick up their cargo of oxygen? The answer is the lungs. The lungs are organs of the respiratory system. The **respiratory system** is the body system that brings air containing oxygen into the body and releases carbon dioxide into the atmosphere.

Respiration

The job of the respiratory system is the exchange of gases between the body and the outside air. This process, called **respiration**, actually consists of two parts. In the first part, oxygen in the air is drawn into the body and carbon dioxide is released from the body through the respiratory tract. In the second part, the circulatory system delivers the oxygen to body cells and picks up carbon dioxide from the cells in return. The use of the word *respiration* in relation to gas exchange is different from its use in the term *cellular respiration*. Recall that cellular respiration is the metabolic process by which cells obtain energy by "burning" glucose. Cellular respiration uses oxygen and releases carbon dioxide. Respiration by the respiratory system supplies the oxygen and takes away the carbon dioxide.

An overview of breathing is shown at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/35/SPGRkexI_cs (20:33).

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Organs of the Respiratory System

The organs of the respiratory system that bring air into the body are shown in **Figure** 23.9 . Refer to the figure as you read below about the passage of air through these organs. You can also watch a detailed animation of the respiratory system at this link: http://www.youtube.com/watch?v=HiT621PrrO0.

Journey of a Breath of Air

Take in a big breath of air through your nose. As you inhale, you may feel the air pass down your throat and notice your chest expand. Now exhale and observe the opposite events occurring. Inhaling and exhaling may seem like simple actions, but they are just part of the complex process of respiration, which includes these four steps:

a. Ventilation
b. Pulmonary gas exchange
c. Gas transport
d. Peripheral gas exchange

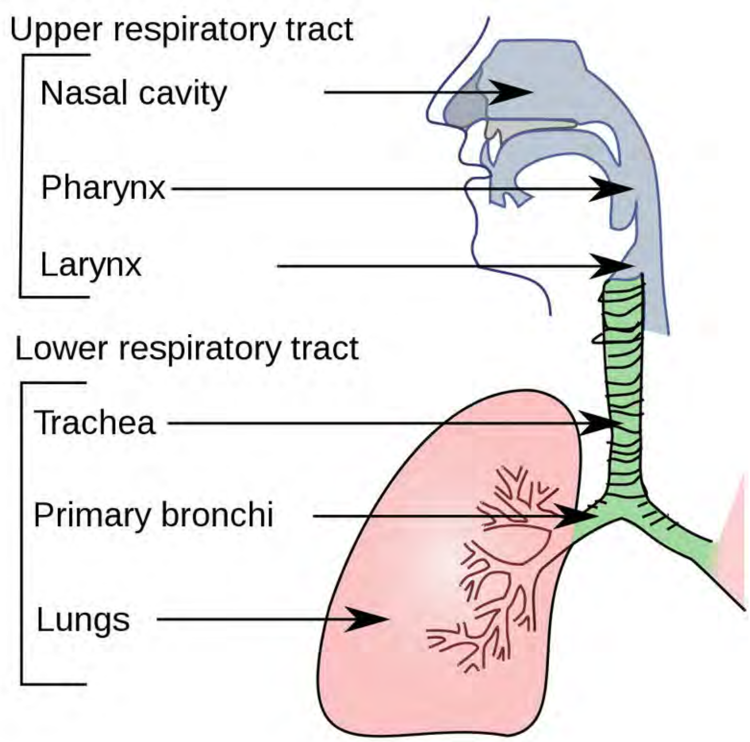


FIGURE 23.9
The organs of the respiratory system move air into and out of the body.

Ventilation

Respiration begins with **ventilation**. This is the process of moving air in and out of the lungs. The **lungs** are the organs in which gas exchange takes place between blood and air.

- Air enters the respiratory system through the nose. As the air passes through the nasal cavity, mucus and hairs trap any particles in the air. The air is also warmed and moistened so it won't harm delicate tissues of the lungs.
- Next, the air passes through the **pharynx**, a long tube that is shared with the digestive system. A flap of connective tissue called the epiglottis closes when food is swallowed to prevent choking.
- From the pharynx, air next passes through the **larynx**, or voice box. The larynx contains vocal cords, which allow us to produce vocal sounds
- After the larynx, air moves into the **trachea**, or wind pipe. This is a long tube that leads down to the chest.
- In the chest, the trachea divides as it enters the lungs to form the right and left bronchi. The bronchi contain cartilage, which prevents them from collapsing. Mucus in the bronchi traps any remaining particles in air. Tiny hairs called cilia line the bronchi and sweep the particles and mucus toward the throat so they can be expelled from the body.
- Finally, air passes from the bronchi into smaller passages called bronchioles. The bronchioles end in tiny air sacs called alveoli.

Pulmonary Gas Exchange

Pulmonary gas exchange is the exchange of gases between inhaled air and the blood. It occurs in the alveoli of the lungs. Alveoli (singular, alveolus) are grape-like clusters surrounded by networks of thin-walled pulmonary capillaries. After you inhale, there is a greater concentration of oxygen in the alveoli than in the blood of the pulmonary capillaries, so oxygen diffuses from the alveoli into the blood across the capillaries (see **Figure** 23.10). Carbon dioxide, in contrast, is more concentrated in the blood of the pulmonary capillaries than in the alveoli, so it diffuses in the opposite direction. This link has an animation of pulmonary gas exchange: http://www.youtube.com/watch?v=Z1h29R82mVc#38;NR=1.

Gas Transport

After the blood in the pulmonary capillaries becomes saturated with 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. Eventually, the blood travels into capillaries that supply body tissues. These capillaries are called peripheral capillaries.

Peripheral Gas Exchange

The cells of the body have a much lower concentration of oxygen than does the oxygenated blood in the peripheral capillaries. Therefore, oxygen diffuses from the peripheral capillaries into body cells. Carbon dioxide is produced by cells as a byproduct of cellular respiration, so it is more concentrated in the cells than in the blood of the peripheral capillaries. As a result, carbon dioxide diffuses in the opposite direction.

Back to the Lungs

The carbon dioxide from body cells travels in the blood from the peripheral capillaries to veins and then to the heart. The heart pumps the blood to the lungs, where the carbon dioxide diffuses into the alveoli. Then, the carbon dioxide passes out of the body through the other structures of the respiratory system, bringing the process of respiration full circle.

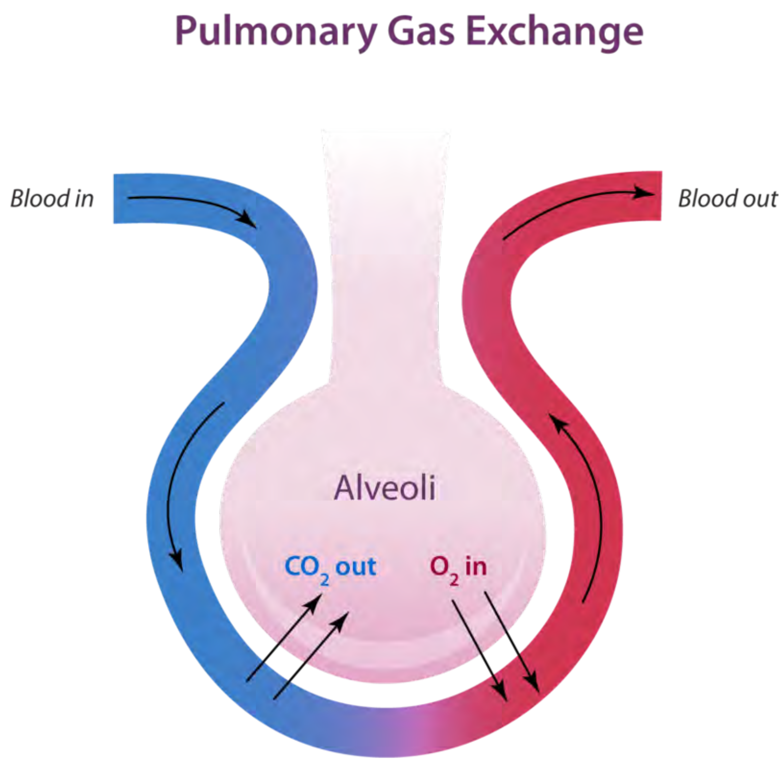


FIGURE 23.10
Alveoli are tiny sacs in the lungs where gas exchange takes place.

Gas Exchange and Homeostasis

Gas exchange is needed to provide cells with the oxygen they need for cellular respiration. Cells cannot survive for long without oxygen. Gas exchange is also needed to carry away carbon dioxide waste. Some of the carbon dioxide in the blood dissolves to form carbonic acid, which keeps blood pH within a normal range.

Blood pH may become unbalanced if the rate of breathing is too fast or too slow. When breathing is too fast, blood contains too little carbon dioxide and becomes too basic. When breathing is too slow, blood contains too much carbon dioxide and becomes too acidic. Clearly, to maintain proper blood pH, the rate of breathing must be regulated.

Regulation of Breathing

To understand how breathing is regulated, you first need to understand how breathing occurs.

How Breathing Occurs

Inhaling is an active movement that results from the contraction of a muscle called the diaphragm. The diaphragm is large, sheet-like muscle below the lungs (see **Figure** 23.11). When the diaphragm contracts, the ribcage expands and the contents of the abdomen move downward. This results in a larger chest volume, which decreases air pressure inside the lungs. With lower air pressure inside than outside the lungs, air rushes into the lungs. When the diaphragm relaxes, the opposite events occur. The volume of the chest cavity decreases, air pressure inside the lungs increases, and air flows out of the lungs, like air rushing out of a balloon. You can watch an animation showing how breathing occurs at this link: http://www.youtube.com/watch?v=hp-gCvW8PRY#38;feature=related.

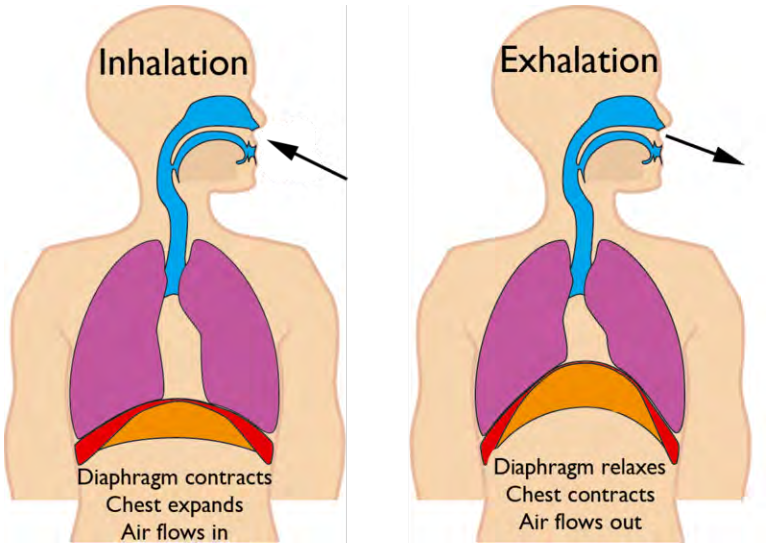


FIGURE 23.11
Breathing depends on contractions of the diaphragm.

Control of Breathing

The regular, rhythmic contractions of the diaphragm are controlled by the brain stem. It sends nerve impulses to the diaphragm through the autonomic nervous system. The brain stem monitors the level of carbon dioxide in the blood. If the level becomes too high, it "tells" the diaphragm to contract more often. Breathing speeds up, and the excess carbon dioxide is released into the air. The opposite events occur when the level of carbon dioxide in the blood becomes too low. In this way, breathing keeps blood pH within a narrow range.

Diseases of the Respiratory System

When you have a cold, your nasal passages may become so congested that it's hard to breathe through your nose. Many other diseases also affect the respiratory system, most of them more serious than the common cold. The following list includes just a sample of respiratory system diseases.

- **Asthma** is a disease in which the air passages of the lungs periodically become too narrow, often with excessive mucus production. This causes difficulty breathing, coughing, and chest tightness. An asthma attack may be triggered by allergens, strenuous exercise, stress, or other factors. You can learn more about asthma by watching the animation at this link: http://www.youtube.com/watch?v=S04dci7NTPk#38;feature=reated.

- **Pneumonia** is a disease in which some of the alveoli of the lungs fill with fluid so gas exchange cannot occur. Symptoms usually include coughing, chest pain, and difficulty breathing. Pneumonia may be caused by an infection or injury of the lungs.
- **Emphysema** is a lung disease in which walls of the alveoli break down so less gas can be exchanged in the lungs (see **Figure** 23.12). This causes shortness of breath. The damage to the alveoli is usually caused by smoking and is irreversible.

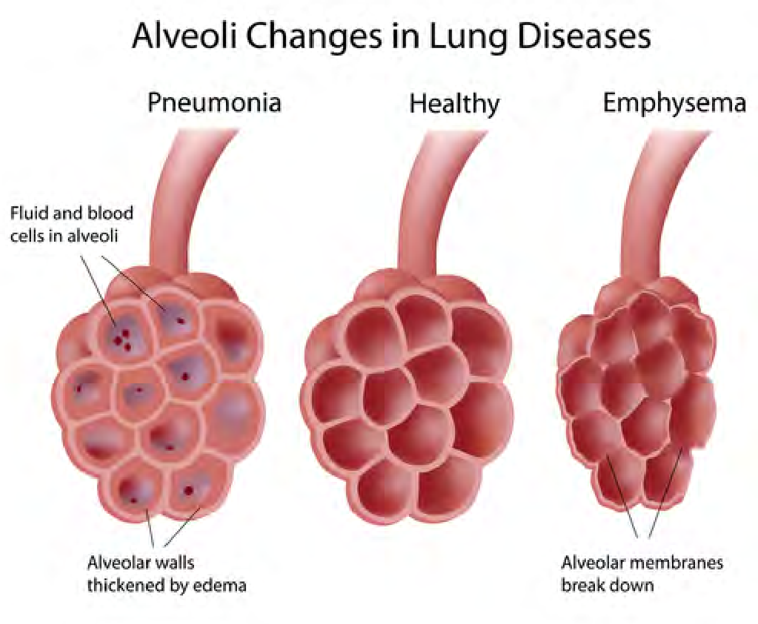


FIGURE 23.12
Pneumonia and emphysema are caused by damage to the alveoli of the lungs.

Cigarette Health Warnings

Beginning in September 2012, the U.S. Food and Drug Administration will require larger, more prominent cigarette health warnings on all cigarette packaging and advertisements in the United States. These warnings are a significant advancement in communicating the dangers of smoking. These new cigarette health warnings contains nine different warnings that will increase awareness of the specific health risks associated with smoking, such as death, addiction, lung disease, cancer, stroke and heart disease. These warnings include:

a. cigarettes are addictive
b. tobacco smoke can harm your children
c. cigarettes cause fatal lung disease
d. cigarettes cause cancer
e. cigarettes cause strokes and heart disease
f. smoking during pregnancy can harm your baby
g. smoking can kill you
h. tobacco smoke causes fatal lung disease in nonsmokers
i. quitting smoking now greatly reduces serious risks to your health.

See http://www.fda.gov/TobaccoProducts/Labeling/CigaretteWarningLabels/default.htm for additional information.

Lesson Summary

- Respiration is the process in which gases are exchanged between the body and the outside air. The lungs and other organs of the respiratory system bring oxygen into the body and release carbon dioxide into the atmosphere.

FIGURE 23.13
Cigarette warning labels unveiled on 6/21/2011 by the U.S. Food and Drug Administration.

- Respiration begins with ventilation, the process of moving air into and out of the lungs. Gas exchange in the lungs takes place in across the thin walls of pulmonary arteries in tiny air sacs called alveoli. Oxygenated blood is transported by the circulatory system from lungs to tissues throughout the body. Gas exchange between blood and body cells occurs across the walls of peripheral capillaries.
- Gas exchange helps maintain homeostasis by supplying cells with oxygen, carrying away carbon dioxide waste, and maintaining proper pH of the blood.
- Breathing occurs due to repeated contractions of a large muscle called the diaphragm. The rate of breathing is regulated by the brain stem. It monitors the level of carbon dioxide in the blood and triggers faster or slower breathing as needed to keep the level within a narrow range.
- Diseases of the respiratory system include asthma, pneumonia, and emphysema.

Lesson Review Questions

Recall

1. What is respiration? What is ventilation?
2. How is respiration different from cellular respiration?
3. Outline the pathway of a breath of air from the nose to the alveoli.
4. Describe how pulmonary gas exchange occurs.
5. Identify three diseases of the respiratory system, and state what triggers or causes each disease.

Apply Concepts

6. Sometimes people who are feeling anxious breathe too fast and become lightheaded. This is called hyperventilation. Hyperventilation can upset the pH balance of the blood, resulting in blood that is too basic. Explain why.

Think Critically

7. Compare and contrast pulmonary and peripheral gas exchange.
8. Explain why contraction of the diaphragm causes the lungs to fill with air.
9. Explain how the rate of breathing is controlled.

Points to Consider

Oxygen is just one substance transported by the blood. The blood also transports nutrients such as glucose.

- What are nutrients? What other substances do you think might be nutrients?
- Where do you think nutrients enter the bloodstream? How might this occur?

23.3 The Digestive System

Lesson Objectives

- Identify the organs and functions of the digestive system.
- Outline the roles of the mouth, esophagus, and stomach in digestion.
- Explain how digestion and absorption occur in the small intestine.
- List functions of the large intestine.
- Describe common diseases of the digestive system.
- Identify classes of nutrients and their functions in the human body.
- Explain how to use MyPyramid and food labels as tools for balanced eating.

Vocabulary

absorption process in which substances such as nutrients pass into the blood stream

bile fluid produced by the liver and stored in the gall bladder that is secreted into the small intestine to help digest lipids and neutralize acid from the stomach

body mass index (BMI) estimate of the fat content of the body calculated by dividing a person's weight (in kilograms) by the square of the person's height (in meters)

chemical digestion chemical breakdown of large, complex food molecules into smaller, simpler nutrient molecules that can be absorbed by the blood

digestion process of breaking down food into nutrients that can be absorbed by the blood

digestive system organ system that breaks down food, absorbs nutrients, and eliminates any remaining waste

eating disorder mental illness in which people feel compelled to eat in a way that causes physical, mental, and emotional health problems

elimination process in which waste passes out of the body

esophagus long, narrow digestive organ that passes food from the pharynx to the stomach

feces solid waste that remains after food is digested and is eliminated from the body through the anus

gall bladder sac-like organ that stores bile from the liver and secretes it into the duodenum of the small intestine

gastrointestinal (GI) tract organs of the digestive system through which food passes during digestion, including the mouth, esophagus, stomach, and small and large intestines

large intestine organ of the digestive system that removes water from food waste and forms feces

liver organ of digestion and excretion that secretes bile for lipid digestion and breaks down excess amino acids and toxins in the blood

macronutrient nutrient such as carbohydrates, proteins, lipids, or water that is needed by the body in relatively large amounts

mechanical digestion physical breakdown of chunks of food into smaller pieces by organs of the digestive system

micronutrient nutrient such as a vitamin or mineral that is needed by the body in relatively small amounts

mineral chemical element such as calcium or potassium that is needed in relatively small amounts for proper body functioning

MyPlate visual guideline for balanced eating, replacing MyPyramid in 2011

MyPyramid visual dietary guideline that shows the relative amounts of foods in different food groups that should be eaten each day

nutrient substance the body needs for energy, building materials, or control of body processes

obesity condition in which the body mass index is 30.0 kg/m^2 or greater

peristalsis rapid, involuntary, wave-like contraction of muscles that pushes food through the GI tract and urine through the ureters

small intestine long, narrow, tube-like organ of the digestive system where most chemical digestion of food and virtually all absorption of nutrients take place

stomach sac-like organ of the digestive system between the esophagus and small intestine in which both mechanical and chemical digestion take place

villi microscopic, finger-like projections in the mucous membrane lining the small intestine that form a large surface area for the absorption of nutrients

vitamin organic compound needed in small amounts for proper body functioning

Introduction

The respiratory and circulatory systems work together to provide cells with the oxygen they need for cellular respiration. Cells also need glucose for cellular respiration. Glucose is a simple sugar that comes from the food we eat. To get glucose from food, digestion must occur. This process is carried out by the digestive system.

Overview of the Digestive System

The **digestive system** consists of organs that break down food and absorb nutrients such as glucose. Organs of the digestive system are shown in **Figure** 23.14 . Most of the organs make up the gastrointestinal tract. The rest of the organs are called accessory organs.

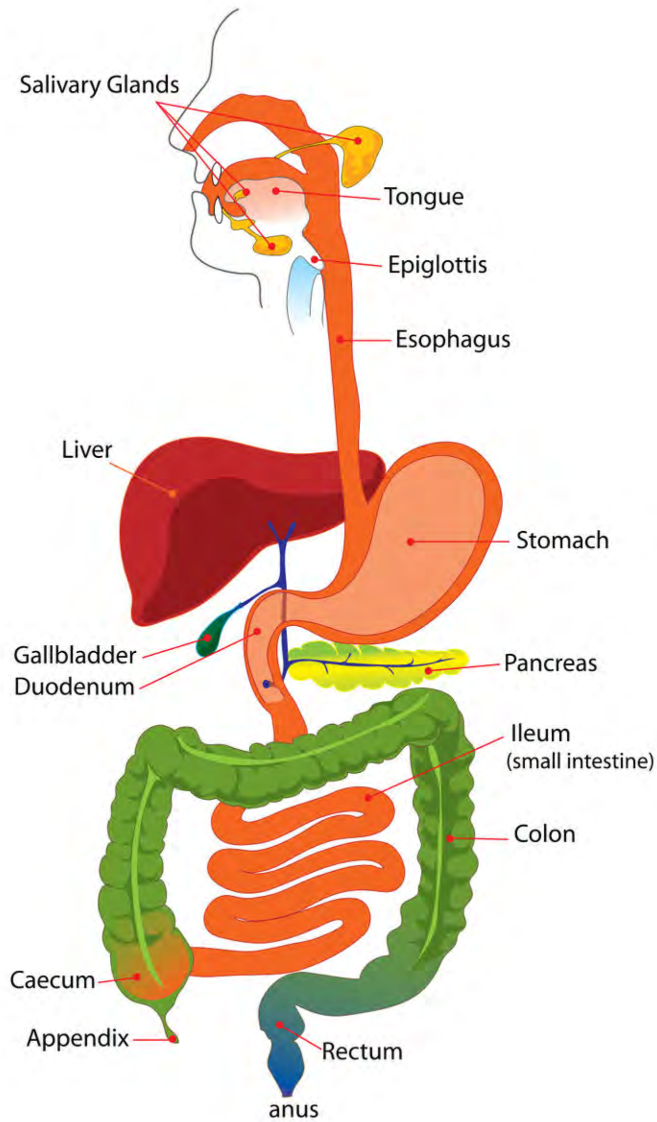
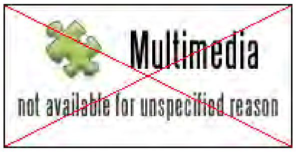


FIGURE 23.14
The digestive system includes organs from the mouth to the anus.



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The Gastrointestinal Tract

The **gastrointestinal (GI) tract** is a long tube that connects the mouth with the anus. It is more than 9 meters (30 feet) long in adults and includes the esophagus, stomach, and small and large intestines. Food enters the mouth, passes through the other organs of the GI tract, and then leaves the body through the anus. At the following link, you can watch an animation that shows what happens to food as it passes through the GI tract. http://www.youtube.com/watch?v=QtDgQjOGPJM.

The organs of the GI tract are lined with mucous membranes that secrete digestive enzymes and absorb nutrients. The organs are also covered by layers of muscle that enable peristalsis. **Peristalsis** is an involuntary muscle contraction that moves rapidly along an organ like a wave (see **Figure** 23.15). You can watch an animation of peristalsis at this link: http://en.wikipedia.org/wiki/File:Peristalsis.gif.

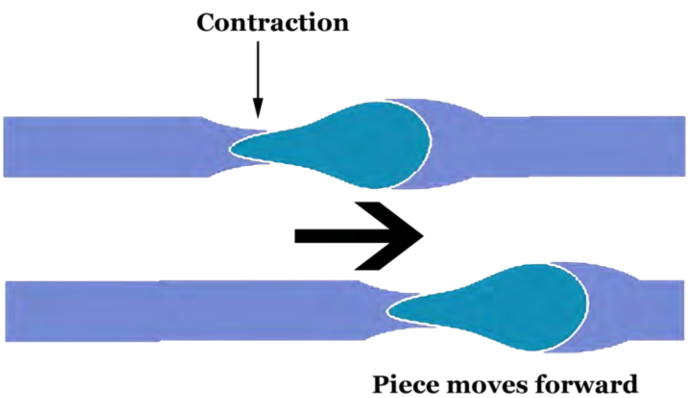

FIGURE 23.15

Peristalsis pushes food through the GI tract.

Accessory Organs of Digestion

Other organs involved in digestion include the liver, gall bladder, and pancreas. They are called accessory organs because food does not pass through them. Instead, they secrete or store substances needed for digestion.

Functions of the Digestive System

The digestive system has three main functions: digestion of food, absorption of nutrients, and elimination of solid food waste. **Digestion** is the process of breaking down food into components the body can absorb. It consists of two types of processes: mechanical digestion and chemical digestion.

- **Mechanical digestion** is the physical breakdown of chunks of food into smaller pieces. This type of digestion takes place mainly in the mouth and stomach.
- **Chemical digestion** is the chemical breakdown of large, complex food molecules into smaller, simpler nutrient molecules that can be absorbed by the blood. This type of digestion begins in the mouth and stomach but occurs mainly in the small intestine.

After food is digested, the resulting nutrients are absorbed. **Absorption** is the process in which substances pass into the bloodstream, where they can circulate throughout the body. Absorption of nutrients occurs mainly in the small intestine. Any remaining matter from food that cannot be digested and absorbed passes into the large intestine as waste. The waste later passes out of the body through the anus in the process of **elimination**.

The Start of Digestion: Mouth to Stomach

Does the sight or aroma 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 digestive enzymes by salivary glands inside the mouth. The major salivary enzyme is amylase. It begins the chemical digestion of carbohydrates by breaking down starch into sugar.

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The mouth also begins the process of mechanical digestion. Sharp teeth in the front of the mouth cut or tear food when you bite into it (see **Figure** 23.16). Broad teeth in the back of the mouth grind food when you chew. Food is easier to chew because it is moistened by saliva from the salivary glands. The tongue helps mix the food with saliva and also helps you swallow. After you swallow, the chewed food passes into the pharynx.

Esophagus

From the pharynx, the food moves into the esophagus. The **esophagus** is a long, narrow tube that passes food from the pharynx to the stomach by peristalsis. The esophagus has no other digestive functions. At the end of the esophagus, a muscle called a sphincter controls the entrance to the stomach. The sphincter opens to let food into the stomach and then closes again to prevent food from passing back into the esophagus.

Stomach

The **stomach** is a sac-like organ in which food is further digested both mechanically and chemically. (To see an animation of how the stomach digests food, go to the link below.) Churning movements of the stomach's thick, muscular walls complete the mechanical breakdown of food. The churning movements also mix food with digestive fluids secreted by the stomach. One of these fluids is hydrochloric acid. It kills bacteria in food and gives the stomach the low pH needed by digestive enzymes that work in the stomach. The main enzyme is pepsin, which chemically digests protein. See http://www.youtube.com/watch?v=URHBBE3RKEs#38;feature=related for additional information.

FIGURE 23.16
Teeth are important for mechanical digestion.

The stomach stores the partly digested food until the small intestine is ready to receive it. When the small intestine is empty, a sphincter opens to allow the partially digested food to enter the small intestine.

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Digestion and Absorption: The Small Intestine

The **small intestine** is a narrow tube about 7 meters (23 feet) long in adults. It is the site of most chemical digestion and virtually all absorption. The small intestine consists of three parts: the duodenum, jejunum, and ileum (see **Figure** 23.14).

Digestion in the Small Intestine

The duodenum is the first and shortest part of the small intestine. Most chemical digestion takes place here, and many digestive enzymes are active in the duodenum (see **Table** 23.1). Some are produced by the duodenum itself. Others are produced by the pancreas and secreted into the duodenum. To see animations about digestive enzymes in the duodenum, use these links: http://www.youtube.com/watch?v=bNMsNHqxszc#38;feature=related (0:40) and http://www.youtube.com/watch?v=IxNpXO8gGFM(2:45).

TABLE 23.1: Digestive Enzymes Active in the Duodenum

Enzyme	What It Digests	Where It Is Made
Amylase	carbohydrates	pancreas
Trypsin	proteins	pancreas
Lipase	lipids	pancreas, duodenum
Maltase	carbohydrates	duodenum
Peptidase	proteins	duodenum

The **liver** is an organ of both digestion and excretion. It produces a fluid called **bile**, which is secreted into the duodenum. Some bile also goes to the **gall bladder**, a sac-like organ that stores and concentrates bile and then secretes it into the small intestine. In the duodenum, bile breaks up large globules of lipids into smaller globules that are easier for enzymes to break down. Bile also reduces the acidity of food entering from the highly acidic stomach. This is important because digestive enzymes that work in the duodenum need a neutral environment. The pancreas contributes to the neutral environment by secreting bicarbonate, a basic substance that neutralizes acid.

Absorption in the Small Intestine

The jejunum is the second part of the small intestine, where most nutrients are absorbed into the blood. As shown in **Figure** 23.17 , the mucous membrane lining the jejunum is covered with millions of microscopic, fingerlike projections called **villi** (singular, villus). Villi contain many capillaries, and nutrients pass from the villi into the bloodstream through the capillaries. Because there are so many villi, they greatly increase the surface area for absorption. In fact, they make the inner surface of the small intestine as large as a tennis court! You can watch an animation of absorption across intestinal villi at this link: http://www.youtube.com/watch?v=P1sDOJM65Bc#38;feature=related.

FIGURE 23.17
This image shows intestinal villi greatly magnified. They are actually microscopic.

The ileum is the third part of the small intestine. A few remaining nutrients are absorbed here. Like the jejunum, the inner surface of the ileum is covered with villi that increase the surface area for absorption.

The Large Intestine and Its Functions

From the small intestine, any remaining food wastes pass into the large intestine. The **large intestine** is a relatively wide tube that connects the small intestine with the anus. Like the small intestine, the large intestine also consists of three parts: the cecum (or caecum), colon, and rectum. Follow food as it moves through the digestive system at http://www.youtube.com/watch?v=Uzl6M1YlU3w#38;feature=related (1:37).

The digestive system song *Where Will I Go* can be heard at http://www.youtube.com/watch?v=OYWVbt6t2mw#38;feature=related (3:27).

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Absorption of Water and Elimination of Wastes

The cecum is the first part of the large intestine, where wastes enter from the small intestine. The wastes are in a liquid state. As they passes through the colon, which is the second part of the large intestine, excess water is absorbed. The remaining solid wastes are called **feces**. Feces accumulate in the rectum, which is the third part of the large intestine. As the rectum fills, the feces become compacted. After a certain amount of feces accumulate, they are eliminated from the body. A sphincter controls the anus and opens to let feces pass through.

Bacteria in the Large Intestine

Trillions of bacteria normally live in the large intestine. Most of them are helpful. In fact, we wouldn't be able to survive without them. Some of the bacteria produce vitamins, which are absorbed by the large intestine. Other functions of intestinal bacteria include:

- Controlling the growth of harmful bacteria.
- Breaking down indigestible food components.
- Producing substances that help prevent colon cancer.
- Breaking down toxins before they can poison the body.

Diseases of the Digestive System

Many diseases can affect the digestive system. Three of the most common are food allergies, ulcers, and heartburn.

- Food allergies occur when the immune system reacts to substances in food as though they were harmful "foreign invaders." Foods that are most likely to cause allergies are pictured in **Figure** 23.18 . Symptoms of food allergies often include vomiting and diarrhea.

- Ulcers are sores in the lining of the stomach or duodenum that are usually caused by bacterial infections. Symptoms typically include abdominal pain and bleeding. You can see how stomach ulcers develop at this link: http://www.youtube.com/watch?v=4bXZRgJ-1fk.
- Heartburn is a painful burning sensation in the chest caused by stomach acid backing up into the esophagus. The stomach acid may eventually cause serious damage to the esophagus unless the problem is corrected.

FIGURE 23.18
These foods are the most common causes of food allergies.

KQED: Hepatitis C: The Silent Epidemic

Hepatitis C is a virus that causes cirrhosis of the liver and liver cancer. It's the leading cause for liver transplants in the U.S., and an estimated 4 million Americans have the disease. Current treatments are difficult to tolerate and are often ineffective, but recent breakthroughs from scientists may soon produce a cure for the disease that claims more than 10,000 American lives each year. See http://www.kqed.org/quest/television/hepatitis-c-the-silent-epidemic for additional information.

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Food and Nutrients

Did you ever hear the saying, "You are what you eat"? It's not just a saying. It's actually true. What you eat plays an important role in your health. Eating a variety of the right types of foods promotes good health and provides energy for growth and activity. This is because healthful foods are rich in nutrients. **Nutrients** are substances the body needs for energy, building materials, and control of body processes. There are six main classes of nutrients: carbohydrates, proteins, lipids, water, vitamins, and minerals. These six classes are categorized as macronutrients or micronutrients depending on how much of them the body needs.

Macronutrients

Nutrients the body needs in relatively large amounts are called **macronutrients**. They include carbohydrates, proteins, lipids, and water. All macronutrients except water can be used by the body for energy. (The energy in food is measured in a unit called a Calorie.) The exact amount of each macronutrient that an individual needs depends on many factors, including gender and age. Recommended daily intakes by teens of three macronutrients are shown in **Table** 23.2 . Based on your gender and age, how many grams of proteins should you eat each day?

TABLE 23.2: Recommended Intakes of Macronutrients

Gender/Age	Carbohydrates (g/day)	Proteins (g/day)	Water (L/day) (includes water in food)
Males 9–13 years	130	34	2.4
Males 14-18 years	130	52	3.3
Females 9-13 years	130	34	2.1
Females 14-18 years	130	46	2.3

- Carbohydrates include sugars, starches, and fiber. Sugars and starches are used by the body for energy. One gram of carbohydrates provides 4 Calories of energy. Fiber, which is found in plant foods, cannot be digested but is needed for good health.
- Dietary proteins are broken down during digestion to provide the amino acids needed for protein synthesis. Any extra proteins in the diet not needed for this purpose are used for energy or stored as fat. One gram of proteins provides 4 Calories of energy.
- Lipids provide the body with energy and serve other vital functions. One gram of lipids provides 9 Calories of energy. You need to eat small amounts of lipids for good health. However, large amounts can be harmful, especially if they contain saturated fatty acids from animal foods.
- Water is essential to life because biochemical reactions take place in water. Most people can survive only a few days without water.

Micronutrients

Nutrients the body needs in relatively small amounts are called **micronutrients**. They include vitamins and minerals. **Vitamins** are organic compounds that are needed by the body to function properly. Several vitamins are described in **Table** ref table|table:vitamins|below. Vitamins play many roles in good health, ranging from maintaining good vision to helping blood clot. Vitamin B12 is produced by bacteria in the large intestine. Vitamin D is synthesized by the skin when it is exposed to UV light. Most other vitamins must be obtained from foods like those listed in **Table** 23.3 .

TABLE 23.3: Vitamins

Vitamin	Function	Good Food Sources
A	good vision	carrots, spinach
B12	normal nerve function	meat, milk
C	making connective tissue	oranges, red peppers
D	healthy bones and teeth	salmon, eggs
E	normal cell membranes	vegetable oils, nuts
K	blood clotting	spinach, soybeans

Minerals are chemical elements that are essential for body processes. They include calcium, which helps form strong bones and teeth, and potassium, which is needed for normal nerve and muscle function. Good sources of minerals include green leafy vegetables, whole grains, milk, and meats. Vitamins and minerals do not provide energy, but they are still essential for good health. The needed amounts generally can be met with balanced eating. However, people who do not eat enough of the right foods may need vitamin or mineral supplements.

Balanced Eating

Balanced eating is a way of eating that promotes good health. It means eating the right balance of different foods to provide the body with all the nutrients it needs. Fortunately, you don't need to measure and record the amounts of different nutrients you each day in order to balance your eating. Instead, you can use MyPlate and food labels.

MyPyramid and MyPlate

MyPyramid shows the relative amounts of foods in different food groups you should eat each day (see **Figure** 23.19). You can visit the MyPyramid Web site (http://www.mypyramid.gov) to learn more about MyPyramid and customize it for your own gender, age, and activity level.

Each food group represented by a colored band in MyPyramid is a good source of nutrients. The key in **Figure** 23.19 shows the food group each band represents. The wider the band, the more you should eat from that food group. The white tip of MyPyramid represents foods that should be eaten only once in awhile, such as ice cream and potato chips. They contain few nutrients and may contribute excess Calories to the diet. The figure "walking" up the side of MyPyramid represents the role of physical activity in balanced eating. Regular exercise helps you burn any extra energy that you consume in foods and provides many other health benefits. You should be active for about an hour a day most days of the week. The more active you are, the more energy you will use.

In June 2011, the United States Department of Agriculture replaced My Pyramid with **MyPlate.** MyPlate depicts the relative daily portions of various food groups. See http://www.choosemyplate.gov/ for further information.

The following guidelines accompany MyPlate:

1. Balancing Calories

- Enjoy your food, but eat less.
- Avoid oversized portions.

2. Foods to Increase

- Make half your plate fruits and vegetables.
- Make at least half your grains whole grains.
- Switch to fat-free or low-fat (1%) milk.

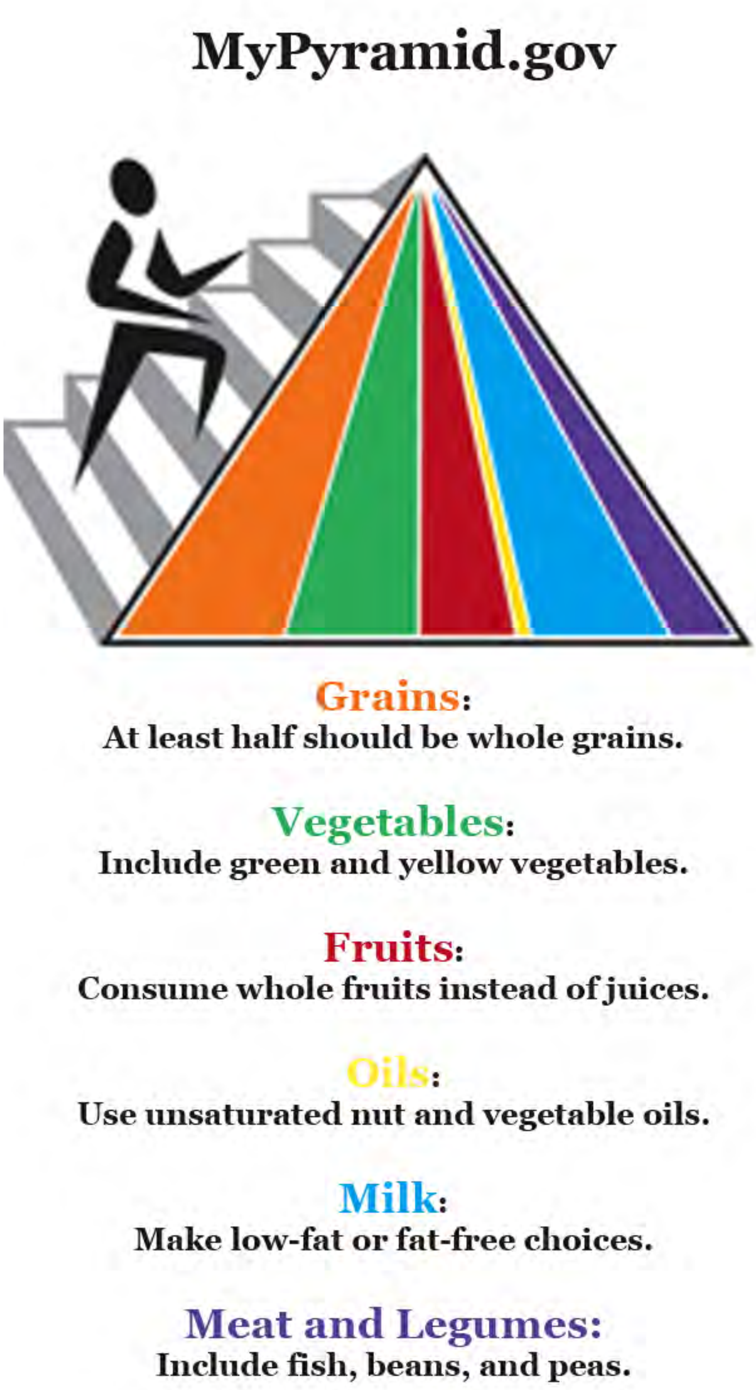


FIGURE 23.19

MyPyramid is a visual guideline for balanced eating.

FIGURE 23.20
MyPlate is a visual guideline for balanced eating replacing MyPyramid in 2011.

3. Foods to Reduce

- Compare sodium in foods like soup, bread, and frozen meals [U+2015] and choose the foods with lower numbers.
- Drink water instead of sugary drinks.

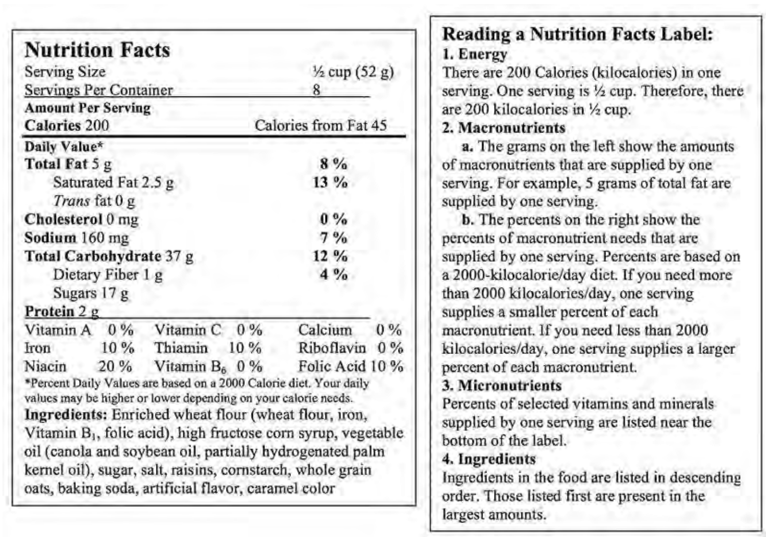
Food Labels

Packaged foods are required by law to carry a nutrition facts label, like the one in **Figure** 23.21 . The labels show the nutrient content and ingredients of foods. Reading labels can help you choose foods that are high in nutrients you need more of (such as proteins) and low in nutrients you need less of (such as fats).

You should also look for ingredients such as whole grains, vegetables, and fruits. Avoid foods that contain processed ingredients, such as white flour or white rice. Processing removes nutrients. As a result, processed foods generally supply fewer nutrients than whole foods, even when they have been enriched or fortified with added nutrients.

Weight Gain and Obesity

Any unused energy in food—whether it comes from carbohydrates, proteins, or lipids—is stored in the body as fat. An extra 3,500 Calories of energy results in the storage of almost half a kilogram (1 pound) of stored body fat. People who consistently consume more food energy then they need may become obese. **Obesity** occurs when the body mass index is 30.0 kg/m^2 or greater. **Body mass index (BMI)** is an estimate of the fat content of the body. It is calculated by dividing a person's weight (in kilograms) by the square of the person's height (in meters). Obesity increases the risk of health problems such as type 2 diabetes and hypertension.



Nutrition Facts

Serving Size	½ cup (52 g)
Servings Per Container	8
Amount Per Serving	
Calories 200	Calories from Fat 45
Daily Value*	
Total Fat 5 g	**8 %**
Saturated Fat 2.5 g	**13 %**
Trans fat 0 g	
Cholesterol 0 mg	**0 %**
Sodium 160 mg	**7 %**
Total Carbohydrate 37 g	**12 %**
Dietary Fiber 1 g	**4 %**
Sugars 17 g	
Protein 2 g	

Vitamin A	0 %	Vitamin C	0 %	Calcium	0 %
Iron	10 %	Thiamin	10 %	Riboflavin	0 %
Niacin	20 %	Vitamin B_6	0 %	Folic Acid	10 %

*Percent Daily Values are based on a 2000 Calorie diet. Your daily values may be higher or lower depending on your calorie needs.

Ingredients: Enriched wheat flour (wheat flour, iron, Vitamin B_1, folic acid), high fructose corn syrup, vegetable oil (canola and soybean oil, partially hydrogenated palm kernel oil), sugar, salt, raisins, cornstarch, whole grain oats, baking soda, artificial flavor, caramel color

Reading a Nutrition Facts Label:

1. Energy

There are 200 Calories (kilocalories) in one serving. One serving is ½ cup. Therefore, there are 200 kilocalories in ½ cup.

2. Macronutrients

a. The grams on the left show the amounts of macronutrients that are supplied by one serving. For example, 5 grams of total fat are supplied by one serving.

b. The percents on the right show the percents of macronutrient needs that are supplied by one serving. Percents are based on a 2000-kilocalorie/day diet. If you need more than 2000 kilocalories/day, one serving supplies a smaller percent of each macronutrient. If you need less than 2000 kilocalories/day, one serving supplies a larger percent of each macronutrient.

3. Micronutrients

Percents of selected vitamins and minerals supplied by one serving are listed near the bottom of the label.

4. Ingredients

Ingredients in the food are listed in descending order. Those listed first are present in the largest amounts.

FIGURE 23.21

Nutrition facts labels like this one can help you make good food choices.

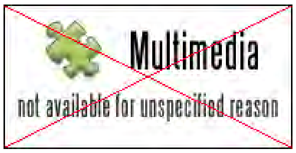
Eating Disorders

Some people who are obese have an eating disorder, called binge eating disorder, in which they compulsively overeat. An **eating disorder** is a mental illness in which people feel compelled to eat in a way that causes physical, mental, and emotional health problems. Other eating disorders include anorexia nervosa and bulimia nervosa. Treatments for eating disorders include counseling and medication.

Lesson Summary

- The digestive system consists of organs that break down food, absorb nutrients, and eliminate waste. The breakdown of food occurs in the process of digestion.
- Digestion consists of mechanical and chemical digestion. Mechanical digestion occurs in the mouth and stomach. Chemical digestion occurs mainly in the small intestine. The pancreas and liver secrete fluids that aid in digestion.
- Virtually all absorption of nutrients takes place in the small intestine, which has a very large inner surface area because it is covered with millions of microscopic villi.
- The absorption of water from digestive wastes and the elimination of the remaining solid wastes occur in the large intestine. The large intestine also contains helpful bacteria.
- Digestive system diseases include food allergies, ulcers, and heartburn.
- Nutrients are substances that the body needs for energy, building materials, and control of body processes. Carbohydrates, proteins, lipids, and water are nutrients needed in relatively large amounts. Vitamins and minerals are nutrients needed in much smaller amounts.
- Balanced eating promotes good health. MyPyramid and food labels are two tools that can help you choose the right foods for balanced eating. Eating too much and exercising too little can lead to weight gain and obesity. Some people who are obese have an eating disorder. Eating disorders are mental illnesses that require treatment by health professionals.

Interactive Puzzles



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Lesson Review Questions

Recall

1. What organs make up the gastrointestinal tract? What are the accessory organs of digestion?
2. Describe peristalsis and its role in digestion.
3. Define mechanical and chemical digestion.
4. Describe functions of the stomach.
5. Where are most nutrients absorbed?

6. What role do villi play in absorption?
7. How do bacteria in the large intestine help keep us healthy?
8. Describe two diseases of the digestive system.
9. What is an eating disorder? Give an example.

Apply Concepts

10. Assume that a person has a disease that prevents the pancreas from secreting digestive enzymes. Explain how digestion might be affected.
11. Aleesha weighs 80 kg and is 1.6 m tall. What is her body mass index? Is she obese?

Think Critically

12. Compare and contrast macronutrients and micronutrients.
13. Explain how to use MyPyramid and food labels to choose foods for balanced eating.

Points to Consider

In this lesson, you learned that the large intestine eliminates solid wastes that are left after digestion occurs.

- Wastes are also produced when cells break down nutrients for energy and building materials. How do you think these wastes are removed from the body? Do you think they are eliminated by the large intestine as well?
- Might there be other ways to remove wastes from the body? What about liquid wastes and excess water?

23.4 The Excretory System

Lesson Objectives

- Define excretion, and identify organs of the excretory system.
- Explain how the urinary system filters blood and excretes wastes.
- Describe the roles of the kidneys in homeostasis.
- Identify kidney diseases, and describe dialysis.

Vocabulary

bladder hollow, sac-like organ that stores urine until it is excreted from the body

dialysis medical procedure in which blood is filtered through a machine in patients with kidney failure

excretion process of removing wastes and excess water from the body

excretory system organ system that removes wastes and excess water from the body and includes the kidneys, large intestine, liver, skin, and lungs

kidney failure loss of the ability of nephrons of the kidney to function fully

nephron structural and functional unit of the kidney that filters blood and forms urine

ureter muscular, tube-like organ of the urinary system that moves urine by peristalsis from a kidney to the bladder

urethra muscular, tube-like organ of the urinary system that carries urine out of the body from the bladder; in males, it also carries sperm out of the body

urinary system organ system that includes the kidneys and is responsible for filtering waste products and excess water from the blood and excreting them from the body

urination process in which urine leaves the body through a sphincter at the end of the urethra

urine liquid waste product of the body that is formed by the kidneys and excreted by the other organs of the urinary system

Introduction

If you exercise on a hot day, you are likely to lose a lot of water in sweat. Then, for the next several hours, you may notice that you do not pass urine as often as normal and that your urine is darker than usual. Do you know why this happens? Your body is low on water and trying to reduce the amount of water lost in urine. The amount of water lost in urine is controlled by the kidneys, the main organs of the excretory system.

Excretion

Excretion is the process of removing wastes and excess water from the body. It is one of the major ways the body maintains homeostasis. Although the kidneys are the main organs of excretion, several other organs also excrete wastes. They include the large intestine, liver, skin, and lungs. All of these organs of excretion, along with the kidneys, make up the **excretory system**. This lesson focuses on the role of the kidneys in excretion. The roles of the other excretory organs are summarized below:

- The large intestine eliminates solid wastes that remain after the digestion of food.
- The liver breaks down excess amino acids and toxins in the blood.
- The skin eliminates excess water and salts in sweat.
- The lungs exhale water vapor and carbon dioxide.

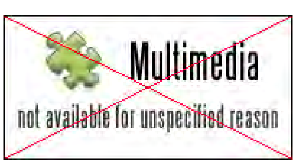
Urinary System

The kidneys are part of the **urinary system**, which is shown in **Figure** 23.22 . The main function of the urinary system is to filter waste products and excess water from the blood and excrete them from the body.

Kidneys and Nephrons

The kidneys are a pair of bean-shaped organs just above the waist. A cross-section of a kidney is shown in **Figure** 23.23 . The function of the kidney is to filter blood and form urine. **Urine** is the liquid waste product of the body that is excreted by the urinary system. **Nephrons** are the structural and functional units of the kidneys. A single kidney may have more than a million nephrons!

The kidney and nephron are discussed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/57/cc8sUv2SuaY (18:38).



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Additional information about the nephron is shown at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/58/czY5nyvZ7cU.

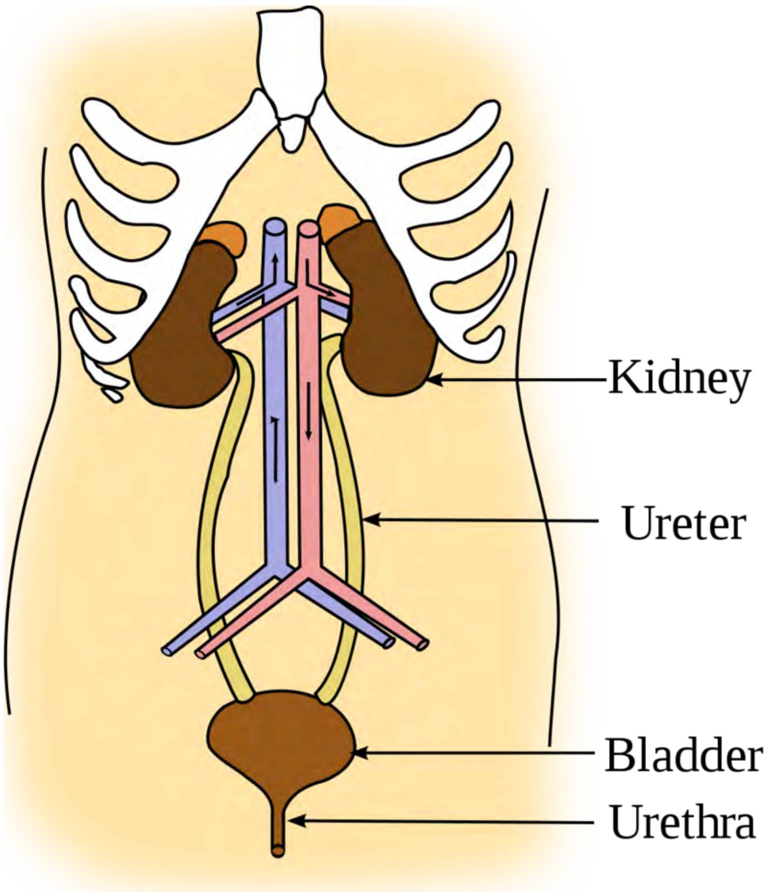


FIGURE 23.22
The kidneys are the chief organs of the urinary system.

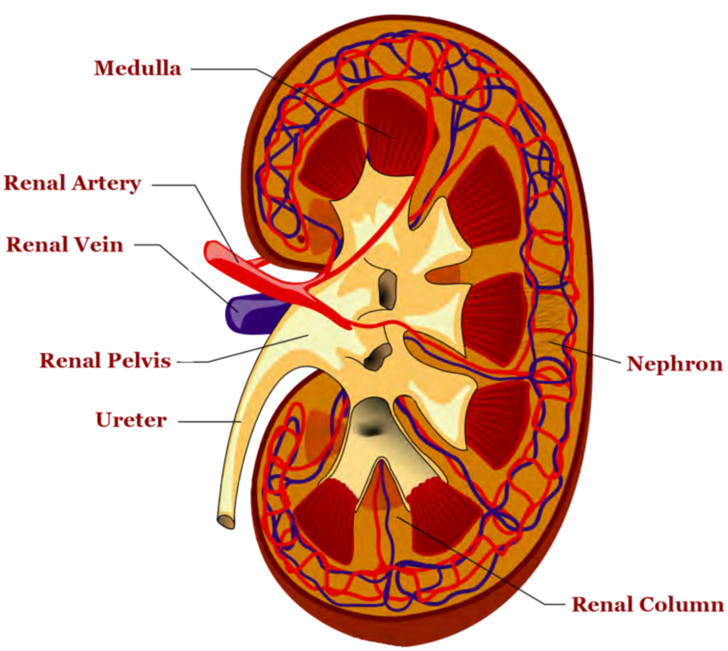
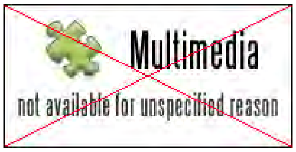


FIGURE 23.23
Each kidney is supplied by a renal artery and renal vein.



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Filtering Blood and Forming Urine

As shown in **Figure** 23.24 , each nephron is like a tiny filtering plant. It filters blood and forms urine in the following steps:

a. Blood enters the kidney through the renal artery, which branches into capillaries. When blood passes through capillaries of the glomerulus of a nephron, blood pressure forces some of the water and dissolved substances in the blood to cross the capillary walls into Bowman's capsule.
b. The filtered substances pass to the renal tubule of the nephron. In the renal tubule, some of the filtered substances are reabsorbed and returned to the bloodstream. Other substances are secreted into the fluid.
c. The fluid passes to a collecting duct, which reabsorbs some of the water and returns it to the bloodstream. The fluid that remains in the collecting duct is urine.

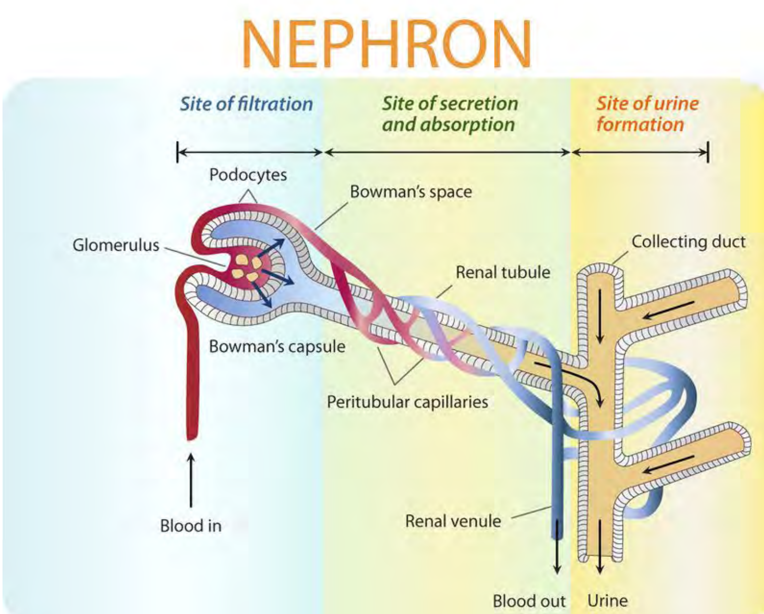


FIGURE 23.24

The parts of a nephron and their functions are shown in this diagram.

Excretion of Urine

From the collecting ducts of the kidneys, urine enters the **ureters**, two muscular tubes that move the urine by peristalsis to the bladder (see **Figure** 23.22). The **bladder** is a hollow, sac-like organ that stores urine. When the bladder is about half full, it sends a nerve impulse to a sphincter to relax and let urine flow out of the bladder and into the urethra. The **urethra** is a muscular tube that carries urine out of the body. Urine leaves the body through another sphincter in the process of **urination**. This sphincter and the process of urination are normally under conscious control.

Kidneys and Homeostasis

The kidneys play many vital roles in homeostasis. They filter all the blood in the body many times each day and produce a total of about 1.5 liters of urine. The kidneys control the amount of water, ions, and other substances in the blood by excreting more or less of them in urine. The kidneys also secrete hormones that help maintain homeostasis. Erythropoietin, for example, is a kidney hormone that stimulates bone marrow to produce red blood cells when more are needed.

The kidneys themselves are also regulated by hormones. For example, antidiuretic hormone from the hypothalamus stimulates the kidneys to produce more concentrated urine when the body is low on water. Homeostasis and feedback mechanisms are discussed in the following two videos: http://www.youtube.com/watch?v=FTkwJuazIwA#38;p=5D2D42394C49020A#38;playnext=1#38;index=3 (8:24) and http://www.youtube.com/watch?v=kIVix1O6qEI#38;p=5D2D42394C49020A#38;index=5 (8:40).

Kidney Disease and Dialysis

A person can live a normal, healthy life with just one kidney. 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.

- Kidney stones are mineral crystals that form in urine inside the kidney. They may be extremely painful. If they block a ureter, they must be removed so urine can leave the kidney and be excreted.
- Bacterial infections of the urinary tract, especially the bladder, are very common. Bladder infections can be treated with antibiotics prescribed by a doctor. If untreated, they may lead to kidney damage.
- Uncontrolled diabetes may damage capillaries of nephrons. As a result, the kidneys lose much of their ability to filter blood. This is called **kidney failure**. The only cure for kidney failure is a kidney transplant, but it can be treated with dialysis. **Dialysis** is a medical procedure in which blood is filtered through a machine (see **Figure** 23.25).

Lesson Summary

- Excretion is the process of removing wastes and excess water from the body. It is one of the major ways the body maintains homeostasis. Organs of excretion make up the excretory system. They include the kidneys, large intestine, liver, skin, and lungs.
- The kidneys filter blood and form urine. They are part of the urinary system, which also includes the ureters, bladder, and urethra.
- Each kidney has more than a million nephrons, which are the structural and functional units of the kidney. Each nephron is like a tiny filtering plant.
- The kidneys maintain homeostasis by controlling the amount of water, ions, and other substances in the blood. They also secrete hormones that have other homeostatic functions.
- Kidney diseases include kidney stones, infections, and kidney failure due to diabetes. Kidney failure may be treated with dialysis.

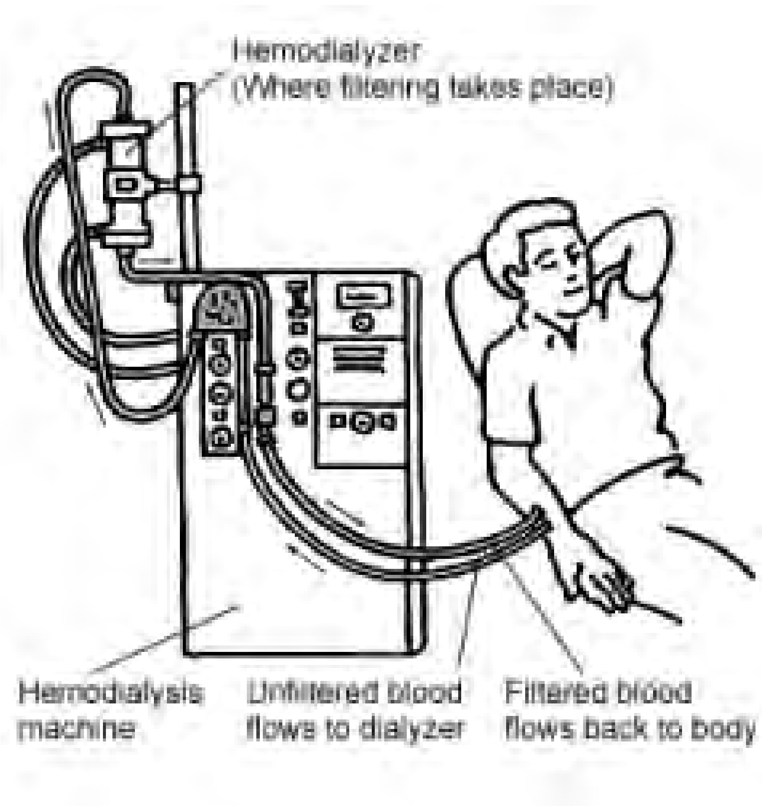


FIGURE 23.25

A dialysis machine filters a patient&#8217 s blood.

Lesson Review Questions

Recall

1. What is excretion?
2. List organs of the excretory system and their functions.
3. Describe how nephrons filter blood and form urine.
4. State the functions of the ureters, bladder, and urethra.

Apply Concepts

5. Tom was seriously injured in a car crash. As a result, he had to have one of his kidneys removed. Does Tom need dialysis? Why or why not?

Think Critically

6. Explain how the kidneys maintain homeostasis.

Points to Consider

Infections caused by microorganisms may affect any of the organ systems described in this chapter. For example, you have just read that bacterial infections of the bladder are common.

- What defenses do you think the body has to keep out microorganisms?
- Do you know if there are other defenses against microorganisms if they manage to get inside the body?

CHAPTER 24 The Immune System and Disease

CHAPTER OUTLINE

Does this organism look like a space alien? A scary creature from a nightmare? In fact, it's a 1-cm long worm that lives in the human body and causes serious harm. It enters the body through a hair follicle of the skin when it's in a much smaller stage of its life cycle.

Like this worm, many other organisms can make us sick if they manage to enter our body. Fortunately for us, our immune system is able to keep out most such invaders. When you read this chapter, you'll learn how your immune system keeps you safe from harm—including from scary creatures like this!

24.1 Nonspecific Defenses

Lesson Objectives

- Describe the barriers that keep most pathogens out of the human body.
- Explain how the inflammatory response and nonspecific leukocytes help fight pathogens that enter the body.

Vocabulary

inflammatory response nonspecific response the body first makes to tissue damage or infection

leukocyte white blood cell produced by bone marrow to fight infections

mucous membrane epithelial tissue that lines inner body surfaces and body openings and produces mucus

mucus slimy substance produced by mucous membranes that traps pathogens, particles, and debris

pathogen disease-causing agent such as a bacterium, virus, fungus, or protozoan

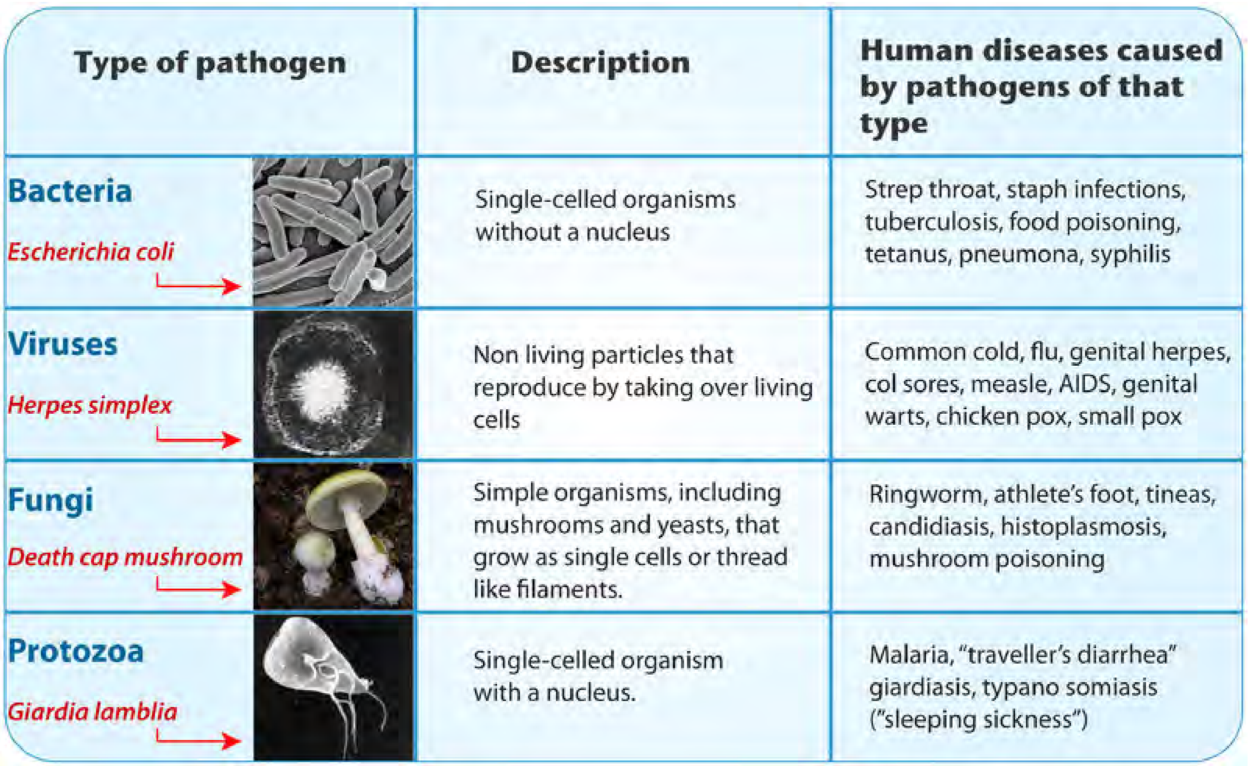
phagocytosis process in which leukocytes engulf and break down pathogens and debris

Introduction

The immune system protects the body from worms, germs, and other agents of harm. The immune system is like a medieval castle. The outside of the castle was protected by a moat and high stone walls. Inside the castle, soldiers were ready to fight off any invaders that managed to get through the outer defenses. Like a medieval castle, the immune system has a series of defenses. In fact, it has three lines of defense. Only pathogens that are able to get through all three lines of defense can harm the body.

The First Line of Defense

The body's first line of defense consists of different types of barriers that keep most pathogens out of the body. **Pathogens** are disease-causing agents, such as bacteria and viruses. These and other types of pathogens are described in **Figure** 24.1 . Regardless of the type of pathogen, however, the first line of defense is always the same.



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, pneumona, syphilis
Viruses *Herpes simplex*	Non living particles that reproduce by taking over living cells	Common cold, flu, genital herpes, col sores, measle, AIDS, genital warts, chicken 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, tineas, candidiasis, histoplasmosis, mushroom poisoning
Protozoa *Giardia lamblia*	Single-celled organism with a nucleus.	Malaria, "traveller's diarrhea" giardiasis, typano somiasis ("sleeping sickness")

FIGURE 24.1

Types of pathogens that commonly cause human diseases include bacteria viruses fungi and protozoa. Which type of pathogen causes the common cold Which type causes athlete&#8217 s foot

Mechanical Barriers

Mechanical barriers physically block pathogens from entering the body. The skin is the most important mechanical barrier. In fact, it is the single most important defense the body has. The outer layer of the skin is tough and very difficult for pathogens to penetrate. **Mucous membranes** provide a mechanical barrier at body openings. They also line the respiratory, GI, urinary, and reproductive tracts. Mucous membranes secrete **mucus**, a slimy substance that traps pathogens. The membranes also have hair-like cilia. The cilia sweep mucus and pathogens toward body openings where they can be removed from the body. When you sneeze or cough, pathogens are removed from the nose and throat (see **Figure** 24.2). Tears wash pathogens from the eyes, and urine flushes pathogens out of the urinary tract. You can watch the sweeping action of cilia at the following link: http://mcdb.colorado.edu/courses/2115/units/Other/mucus%20animation.swf.

FIGURE 24.2

A sneeze can expel many pathogens from the respiratory tract. That&#8217 s why you should always cover your mouth and nose and when you sneeze.

Chemical Barriers

Chemical barriers destroy pathogens on the outer body surface, at body openings, and on inner body linings. Sweat, mucus, tears, and saliva all contain enzymes that kill pathogens. Urine is too acidic for many pathogens, and semen contains zinc, which most pathogens cannot tolerate. In addition, stomach acid kills pathogens that enter the GI tract in food or water.

Biological Barriers

Biological barriers are living organisms that help protect the body. Millions of harmless bacteria live on the human skin. Many more live in the GI tract. The harmless bacteria use up food and space so harmful bacteria cannot grow.

The Second Line of Defense

If you have a cut on your hand, the break in the skin provides a way for pathogens to enter your body. Assume bacteria enter through the cut and infect the wound. These bacteria would then encounter the body's second line of defense.

Inflammatory Response

The cut on your hand may become red, warm, and swollen. These are signs of an **inflammatory response.** This is the first reaction of the body to tissue damage or infection. As explained in **Figure** 24.3 , the response is triggered by chemicals called cytokines and histamines, which are released when tissue is injured or infected. The chemicals communicate with other cells and coordinate the inflammatory response. You can see an animation of the inflammatory response at this link: http://www.sumanasinc.com/webcontent/animations/content/inflammatory.html.

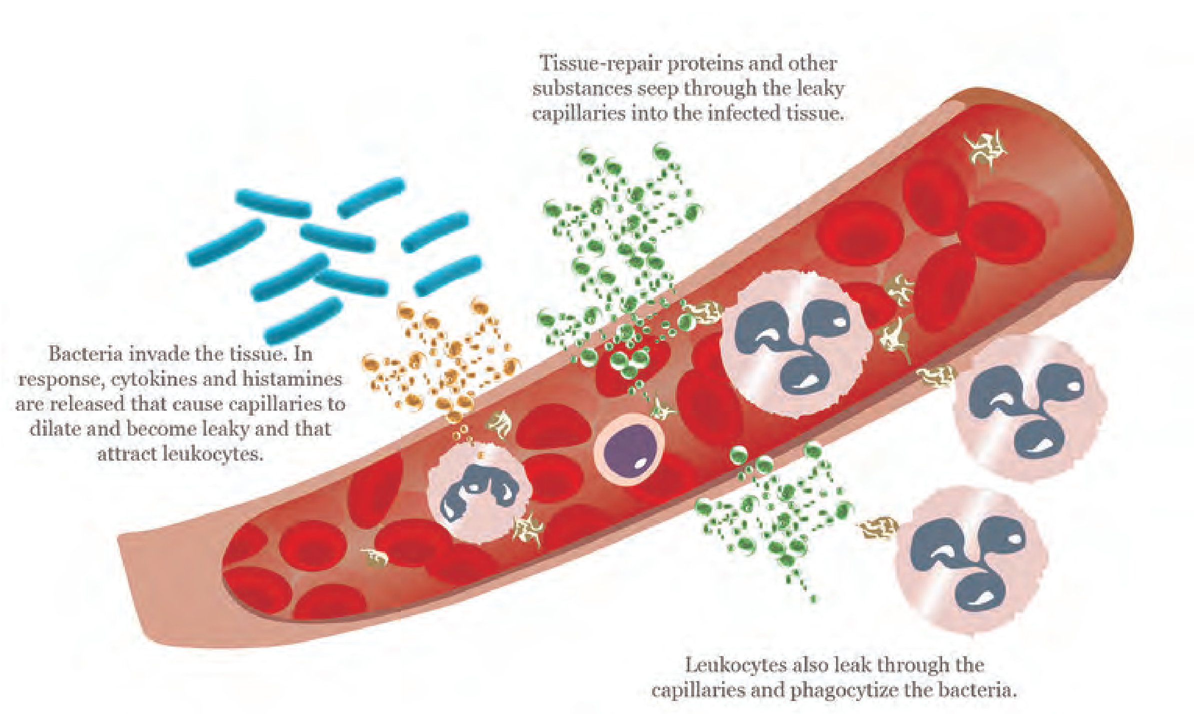


FIGURE 24.3
This drawing shows what happens during the inflammatory response. Why are changes in capillaries important for this response

The inflammatory response is discussed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/56/FXSuEIMrPQk.

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Leukocytes

The chemicals that trigger an inflammatory response attract leukocytes to the site of injury or infection. **Leukocytes** are white blood cells. Their role is to fight infections and get rid of debris. Leukocytes may respond with either a nonspecific or a specific defense.

- A nonspecific defense is the same no matter what type of pathogen is involved. An example of a nonspecific defense is **phagocytosis.** This is the process in which leukocytes engulf and break down pathogens and debris. It is illustrated in **Figure** 24.4 . You can also see an animation of phagocytosis at this link: http://www.sp.uconn.edu/ terry/Common/phago053.html.
- A specific defense is tailored to a particular pathogen. Leukocytes involved in this type of defense are described in the next lesson.

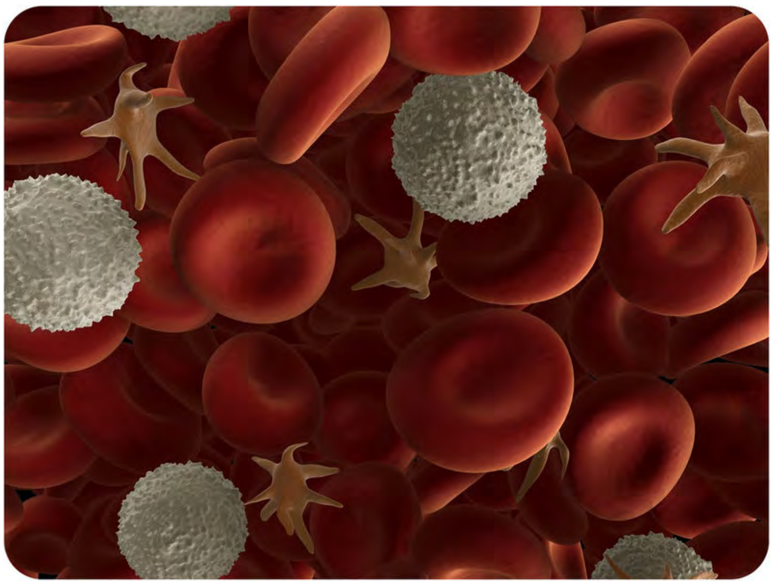

FIGURE 24.4

In this image leukocytes $white$ are attacking pathogens $star-shaped$.

A summary of the nonspecific defenses can be viewed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/49/O1N2rENXq_Y(16:20).

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Lesson Summary

- Barriers that keep out pathogens are the body's first line of defense. They include mechanical, chemical, and biological barriers.
- The second line of defense attacks pathogens that manage to enter the body. It includes the inflammatory response and phagocytosis by nonspecific leukocytes.

Review Questions

Recall

1. Identify three types of barriers in the body's first line of defense. Give an example of each type of barrier.
2. What is the body's second life of defense? When does it take effect?
3. Identify the roles of nonspecific leukocytes in the body's second line of defense.
4. State how phagocytosis helps defend the body from pathogens.
5. What is a nonspecific defense?

Apply Concepts

6. Jera cut her finger. The next day, the skin around the cut had become red and warm. Why are these signs of infection?

Think Critically

7. Explain how the inflammatory response helps fight an infection.

Points to Consider

The body's first and second lines of defense are the same regardless of the particular pathogen involved. The body's third line of defense is different. It tailors the response to the specific pathogen.

- How do you think the immune system can identify specific pathogens?
- How might a specific defense be different from a nonspecific defense? What mechanisms might be involved?

24.2 The Immune Response

Lesson Objectives

- Describe the lymphatic system and its roles in the immune response.
- List the steps that occur in a humoral immune response.
- Identify the roles of T cells in a cell-mediated immune response.
- Define immunity, and distinguish between active and passive immunity.

Vocabulary

active immunity ability to resist a pathogen that results when an immune response to the pathogen produces memory cells

antibody large, Y-shaped proteins produced by B cells that recognize and bind to antigens in a humoral immune response

B cell type of lymphocyte that fights infections by forming antibodies

cell-mediated immune response type of immune response in which T cells destroy cells that are infected with viruses

humoral immune response type of immune response in which B cells produce antibodies against antigens in blood and lymph

immune response specific defense against a particular pathogen

immunity ability to resist a pathogen due to memory lymphocytes or antibodies to the antigens the pathogen carries

immunization deliberate exposure of a person to a pathogen in order to provoke an immune response and the formation of memory cells specific to that pathogen

lymph fluid that leaks out of capillaries into spaces between cells and circulates in the vessels of the lymphatic system

lymphatic system system of the body consisting of organs, vessels, nodes, and lymph that produces lymphocytes and filters pathogens from body fluids

lymph node small structures located on lymphatic vessels where pathogens are filtered from lymph and destroyed by lymphocytes

lymphocyte type of leukocyte that is a key cell in the immune response to a specific pathogen

memory cell lymphocyte (B or T cell) that retains a "memory" of a specific pathogen after an infection is over and thus provides immunity to the pathogen

passive immunity type of immunity to a particular pathogen that results when antibodies are transferred to a person who has never been exposed to the pathogen

T cell type of lymphocyte involved in cell-mediated immunity in which cells infected with viruses are destroyed

Introduction

Like the immune systems of other vertebrates, the human immune system is adaptive. If pathogens manage to get through the body's first two lines of defense, the third line of defense takes over. The third line of defense is referred to as the **immune response.** This defense is specific to a particular pathogen, and it allows the immune system to "remember" the pathogen after the infection is over. If the pathogen tries to invade the body again, the immune response against that pathogen will be much faster and stronger. You can watch an overview of the immune response at this link: http://www.youtube.com/watch?v=G7rQuFZxVQQ#38;feature=related.

The types of immune responses is discussed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/50/rp7T4IItbtM.

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Lymphatic System

The immune response mainly involves the lymphatic system. The **lymphatic system** is a major part of the immune system. It produces leukocytes called lymphocytes. **Lymphocytes** are the key cells involved in the immune response. They recognize and help destroy particular pathogens in body fluids and cells. They also destroy certain cancer cells. You can watch an animation of the lymphatic system at this link: http://www.youtube.com/watch?v=qTXTDqvPnRk#38;feature=related.

Structures of the Lymphatic System

Figure 24.5 shows the structures of the lymphatic system. They include organs, lymph vessels, lymph, and lymph nodes. Organs of the lymphatic system are the bone marrow, thymus, spleen, and tonsils.

- Bone marrow is found inside many bones. It produces lymphocytes.
- The thymus is located in the upper chest behind the breast bone. It stores and matures lymphocytes.
- The spleen is in the upper abdomen. It filters pathogens and worn out red blood cells from the blood, and then lymphocytes in the spleen destroy them.

- The tonsils are located on either side of the pharynx in the throat. They trap pathogens, which are destroyed by lymphocytes in the tonsils.

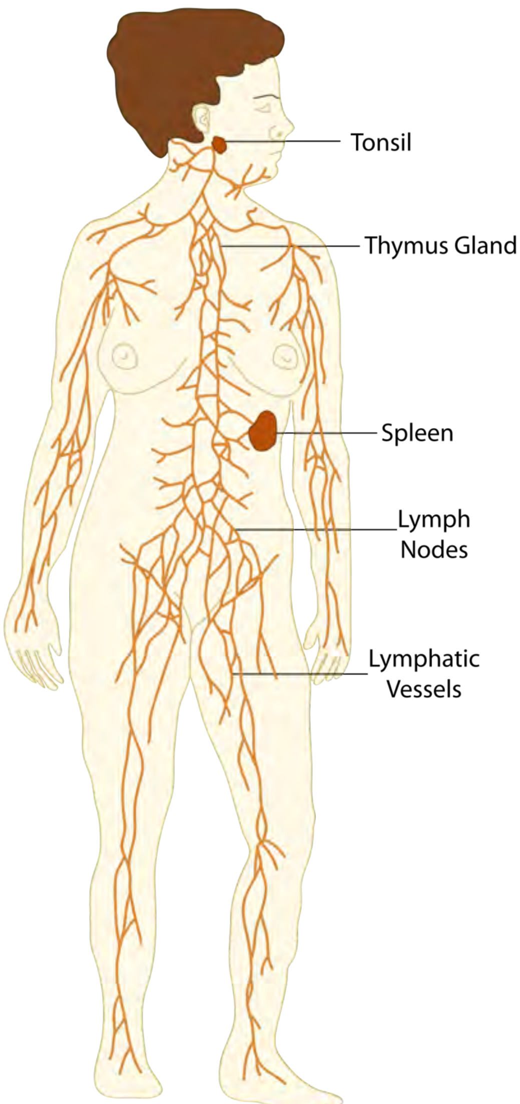


FIGURE 24.5
The lymphatic system consists of organs vessels and lymph.

Lymphatic Vessels and Lymph

Lymphatic vessels make up a body-wide circulatory system. The fluid they circulate is lymph. **Lymph** is a fluid that leaks out of capillaries into spaces between cells. As the lymph accumulates between cells, it diffuses into tiny lymphatic vessels. The lymph then moves through the lymphatic system from smaller to larger vessels. It finally drains back into the bloodstream in the chest. As lymph passes through the lymphatic vessels, pathogens are filtered out at small structures called **lymph nodes** (see **Figure** 24.5). The filtered pathogens are destroyed by lymphocytes.

Lymphocytes

The human body has as many as two trillion lymphocytes, and lymphocytes make up about 25% of all leukocytes. The majority of lymphocytes are found in the lymphatic system, where they are most likely to encounter pathogens.

The rest are found in the blood. There are two major types of lymphocytes, called **B cells** and **T cells.** These cells get their names from the organs in which they mature. B cells mature in bone marrow, and T cells mature in the thymus. Both B and T cells recognize and respond to particular pathogens.

Antigen Recognition

B and T cells actually recognize and respond to antigens on pathogens. Antigens are molecules that the immune system recognizes as foreign to the body. Antigens are also found on cancer cells and the cells of transplanted organs. They trigger the immune system to react against the cells that carry them. This is why a transplanted organ may be rejected by the recipient's immune system. How do B and T cells recognize specific antigens? They have receptor molecules on their surface that bind only with particular antigens. As shown in **Figure** 24.6 and in the animation at the link that follows, the fit between an antigen and a matching receptor molecule is like a key in a lock. http://www.youtube.com/watch?v=cL9KY_ECzfo

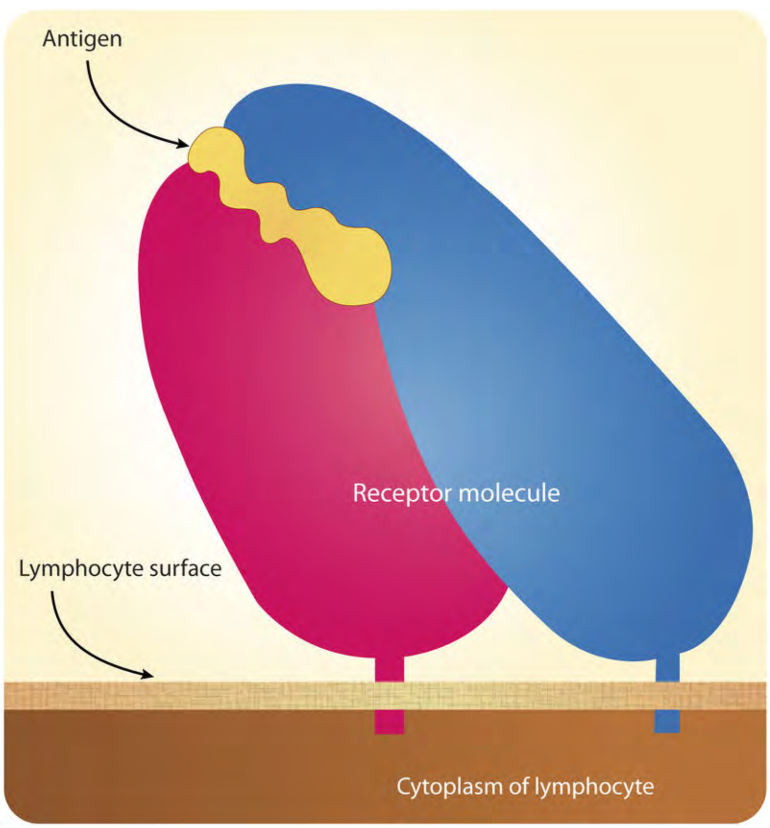


FIGURE 24.6
An antigen fits the matching receptor molecule like a key in a lock.

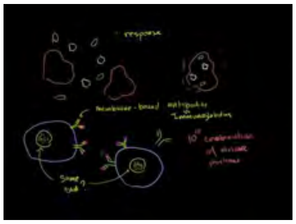
Humoral Immune Response

There are actually two types of immune responses: humoral and cell-mediated. The latter response is described later in this section. The **humoral immune response** involves mainly B cells and takes place in blood and lymph. You can watch an animation of the humoral immune response at the link below. http://www.cancerresearch.org/resources.aspx?id=586

B Cell Activation

B cells must be activated by an antigen before they can fight pathogens. This happens in the sequence of events shown in **Figure** 24.7 . First, a B cell encounters its matching antigen and engulfs it. The B cell then displays fragments of the antigen on its surface. This attracts a helper T cell (which is further discussed below). The helper T cell binds to the B cell at the antigen site and releases cytokines that "tell" the B cell to develop into a plasma cell.

B lymphocytes are further discussed at http://www.youtube.com/watch?v=Z36dUduOk1Y (14:13).



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Plasma Cells and Antibody Production

Plasma cells are activated B cells that secrete antibodies. **Antibodies** are large, Y-shaped proteins that recognize and bind to antigens. Plasma cells are like antibody factories, producing many copies of a single type of antibody. The antibodies travel throughout the body in blood and lymph. Each antibody binds to just one kind of antigen. When it does, it forms an antigen-antibody complex (see **Figure** 24.8). The complex flags the antigen-bearing cell for destruction by phagocytosis. The video at the following link shows how this happens: http://www.youtube.com/watch?v=lrYlZJiuf18#38;feature=fvw.

Memory Cells

Most plasma cells live for just a few days, but some of them live much longer. They may even survive for the lifetime of the individual. Long-living plasma cells are called **memory cells.** They retain a "memory" of a specific pathogen long after an infection is over. They help launch a rapid response against the pathogen if it invades the body again in the future.

Cell-Mediated Immune Response

The other type of immune response, the **cell-mediated immune response**, involves mainly T cells. It leads to the destruction of cells that are infected with viruses. Some cancer cells are also destroyed in this way. There are several different types of T cells involved in a cell-mediated immune response, including helper, cytotoxic, and regulatory T cells. You can watch an animation of this type of immune response at this link: http://www.cancerresearch.org/Resources.aspx?id=588.

T Cell Activation

All three types of T cells must be activated by an antigen before they can fight an infection or cancer. T cell activation is illustrated in **Figure** 24.9 . It begins when a B cell or nonspecific leukocyte engulfs a virus and displays its antigens. When the T cell encounters the matching antigen on a leukocyte, it becomes activated. What happens next depends on which type of T cell it is.

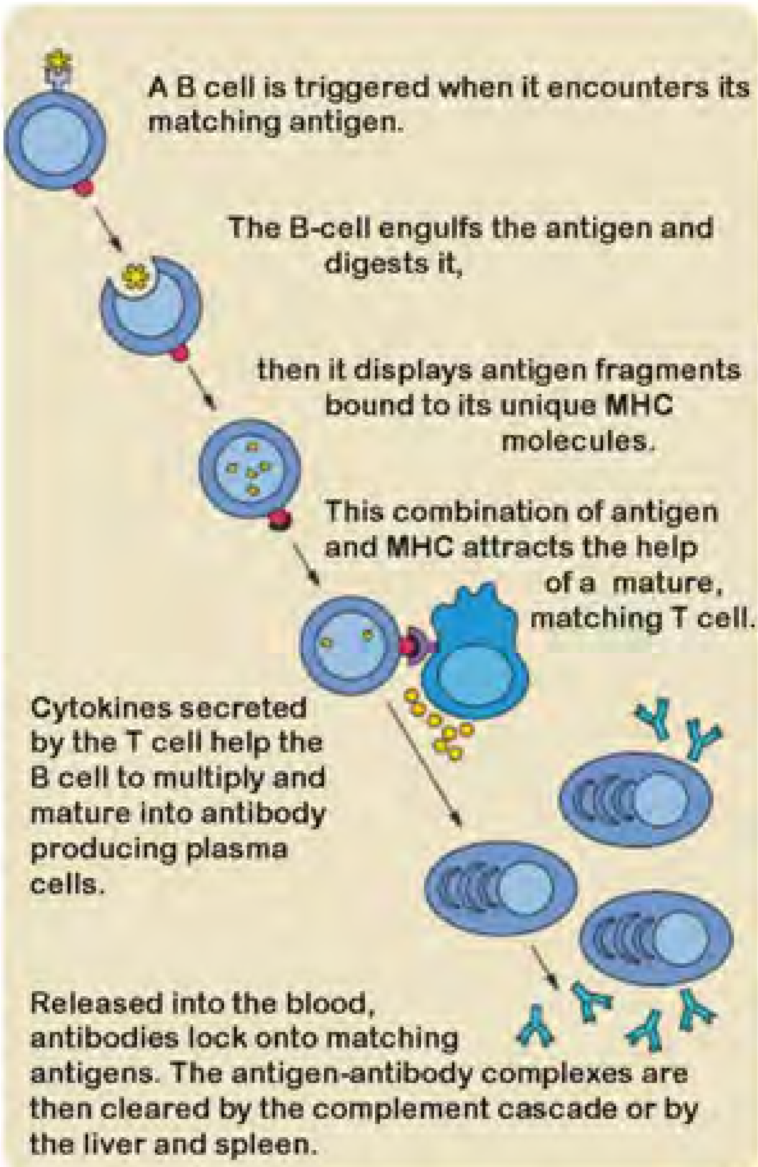

FIGURE 24.7

Activation of a B cell must occur before it can respond to pathogens. What role do T cells play in the activation process

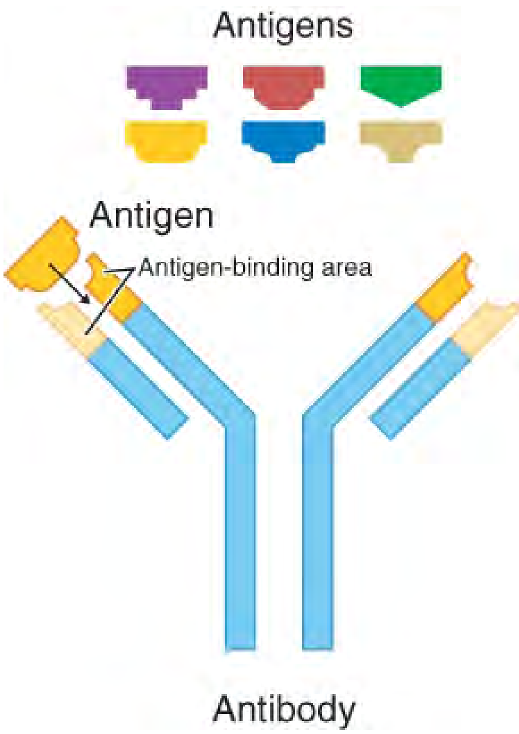

FIGURE 24.8
An antibody matches only one type of antigen.

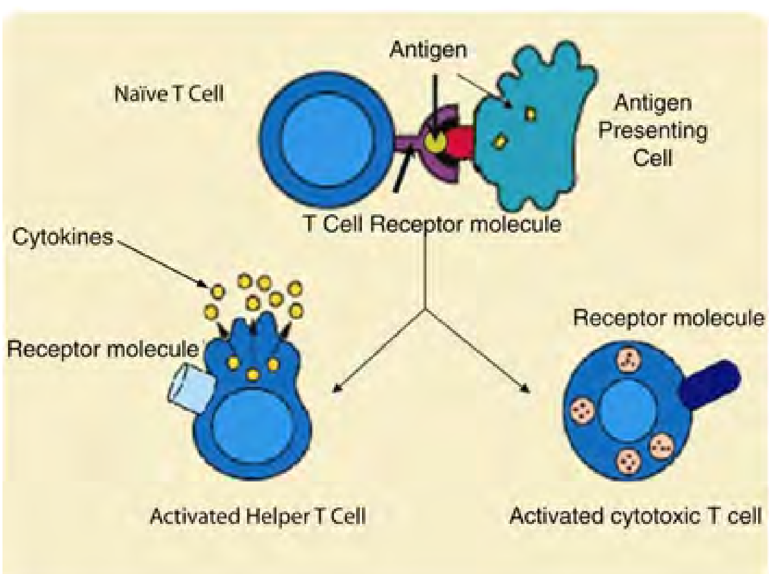

FIGURE 24.9
T cell activation requires another leukocyte to engulf a virus and display its antigen.

Helper T Cells

Helper T cells are like the "managers" of the immune response. They secrete cytokines, which activate or control the activities of other lymphocytes. Most helper T cells die out once a pathogen has been cleared from the body, but a few remain as memory cells. These memory cells are ready to produce large numbers of antigen-specific helper T cells like themselves if they are exposed to the same antigen in the future.

Helped T cells are discussed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/53/uwMYpTYsNZM.

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Cytotoxic T Cells

Cytotoxic T cells destroy virus-infected cells and some cancer cells. Once activated, a cytotoxic T cell divides rapidly and produces an "army" of cells identical to itself. These cells travel throughout the body "searching" for more cells to destroy. **Figure** 24.10 shows how a cytotoxic T cell destroys a body cell infected with viruses. The T cell releases toxins that form pores in the membrane of the infected cell. This causes the cell to burst, destroying both the cell and the viruses inside it. You can watch an animation of the actions of cytotoxic T cells at this link: http://www.youtube.com/watch?v=8buaiYBKl7U.

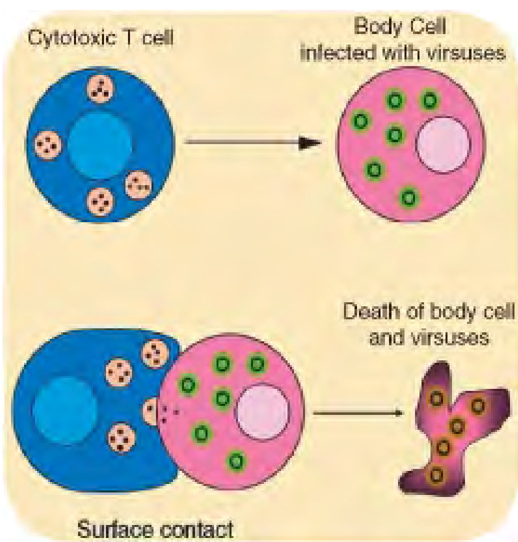

FIGURE 24.10

A cytotoxic T cell releases toxins that destroy an infected body cell and the viruses it contains.

After an infection has been brought under control, most cytotoxic T cells die off. However, a few remain as memory cells. If the same pathogen enters the body again, the memory cells mount a rapid immune response. They quickly produce many copies of cytotoxic T cells specific to the antigen of that pathogen.

Regulatory T Cells

Regulatory T cells are responsible for ending the cell-mediated immune response after an infection has been curbed. They also suppress T cells that mistakenly react against self antigens. What might happen if these T cells were not suppressed?

Immunity

Memory B and T cells help protect the body from re-infection by pathogens that infected the body in the past. Being able to resist a pathogen in this way is called **immunity.** Immunity can be active or passive.

Active Immunity

Active immunity results when an immune response to a pathogen produces memory cells. As long as the memory cells survive, the pathogen will be unable to cause a serious infection in the body. Some memory cells last for a lifetime and confer permanent immunity. Active immunity can also result from immunization. **Immunization** is the deliberate exposure of a person to a pathogen in order to provoke an immune response and the formation of memory cells specific to that pathogen. The pathogen is often injected. However, only part of a pathogen, a weakened form of the pathogen, or a dead pathogen is typically used. This causes an immune response without making the immunized person sick. This is how you most likely became immune to measles, mumps, and chicken pox. You can watch an animation showing how immunization brings about immunity at this link: http://www.biosolutions.info/2009/05/vaccination.html.

Passive Immunity

Passive immunity results when antibodies are transferred to a person who has never been exposed to the pathogen. Passive immunity lasts only as long as the antibodies survive in body fluids. This is usually between a few days and a few months. Passive immunity may be acquired by a fetus through its mother's blood. It may also be acquired by an infant though the mother's breast milk. Older children and adults can acquire passive immunity through the injection of antibodies.

Lesson Summary

- The body's third line of defense is the immune response. This involves the lymphatic system. This system filters pathogens from lymph and produces lymphocytes.
- Lymphocytes are the key cells in the immune response. They are leukocytes that become activated by a particular antigen. There are two major type of lymphocytes: B cells and T cells.
- Activated B cells produce antibodies to a particular antigen. Memory B cells remain in the body after the immune response is over and provide immunity to pathogens bearing the antigen.
- Activated T cells destroy certain cancer cells and cells infected by viruses. Memory T cells remain in the body after the immune response and provide antigen-specific immunity to the virus.
- Immunity is the ability to resist infection by a pathogen. Active immunity results from an immune response to a pathogen and the formation of memory cells. Passive immunity results from the transfer of antibodies to a person who has not been exposed to the pathogen.

A review of B cells and T cells is available at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/55/xaz5ftvZCyI(11:07).

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Review Questions

Recall

1. List three parts of the lymphatic system and their functions.
2. What are antigens, and how do lymphocytes "recognize" them?
3. How do plasma cells form, and how do they help fight pathogens?
4. Describe one way that cytotoxic T cells destroy cells infected with viruses.
5. What is immunity? What role do memory cells play in immunity?

Apply Concepts

6. If a disease destroyed a person's helper T cells, how might this affect the ability to launch an immune response?

Think Critically

7. Compare and contrast humoral and cell-mediated immune responses.
8. How is active immunity different from passive immunity? Why does active immunity last longer?
9. Explain how immunization prevents a disease such as measles, which is caused by a virus.

Points to Consider

Sometimes the immune system makes mistakes and things go wrong.

- What if the immune system responded to a harmless allergen as though it were a deadly pathogen? What might happen?
- What if the immune system responded to normal body cells as though they were foreign invaders? Would the immune system destroy the body cells?
- What if pathogens attacked and destroyed cells of the immune system itself? Would the immune system still be able to defend the body?

24.3 Immune System Diseases

Lesson Objectives

- Explain why allergies occur, and identify common allergens.
- Describe how autoimmune diseases affect the body.
- Define immunodeficiency, and list reasons for it.
- Explain how HIV is transmitted and how it causes AIDS.

Vocabulary

acquired immunodeficiency syndrome (AIDS) disorder characterized by frequent opportunistic infections that eventually develops in people who are infected with human immunodeficiency virus (HIV)

allergen any antigen that causes an allergy

allergy disease in which the immune system makes an inflammatory response to a harmless antigen

autoimmune disease type of disease, such as type 1 diabetes, in which the immune system attacks the body's cells as though they were pathogens

human immunodeficiency virus (HIV) virus transmitted through body fluids that infects and destroys helper T cells and eventually causes acquired immunodeficiency syndrome (AIDS)

immunodeficiency inability of the immune system to fight off pathogens that a normal immune system would be able to resist

Introduction

Your immune system usually protects you from pathogens and keeps you well. However, like any other body system, the immune system itself can develop problems. Sometimes it responds to harmless foreign substances as though they were pathogens. Sometimes it attacks the body's own cells. Certain diseases can also attack and damage the immune system and interfere with its ability to defend the body.

Allergies

An **allergy** is a disease in which the immune system makes an inflammatory response to a harmless antigen. Any antigen that causes an allergy is called an **allergen.** Allergens may be inhaled or ingested, or they may come into contact with the skin. Two common causes of allergies are shown in **Figure** 24.11 . Inhaling ragweed pollen may cause coughing and sneezing. Skin contact with oils in poison ivy may cause an itchy rash.

FIGURE 24.11
Ragweed and poison ivy are common causes of allergies. Are you allergic to these plants

The symptoms of allergies can range from mild to severe. Mild allergy symptoms are often treated with antihistamines. These are drugs that reduce or eliminate the effects of the histamines that cause allergy symptoms. The most severe allergic reaction is called anaphylaxis. This is a life-threatening response caused by a massive release of histamines. It requires emergency medical treatment. You can watch an animated video about how allergic reactions occur and how antihistamines can control them at this link: http://www.youtube.com/watch?v=y3bOgdvV-_M.

Autoimmune Diseases

Autoimmune diseases occur when the immune system fails to recognize the body's own molecules as "self," or belonging to the person. Instead, it attacks body cells as though they were dangerous pathogens. Some relatively common autoimmune diseases are listed in **Table** 24.1 . These diseases cannot be cured, although they can be treated to relieve symptoms and prevent some of the long-term damage they cause.

TABLE 24.1: Autoimmune Diseases

Name of Disease	Tissues Attacked by Immune System	Results of Immune System Attack
Rheumatoid arthritis	tissues inside joints	joint damage and pain
Type 1 diabetes	insulin-producing cells of the pancreas	inability to produce insulin, high blood sugar
Multiple sclerosis	myelin sheaths of central nervous system neurons	muscle weakness, pain, fatigue
Systemic lupus erythematosus	joints, heart, other organs	joint and organ damage and pain

Why does the immune system attack body cells? In some cases, it's because of exposure to pathogens that have antigens similar to the body's own molecules. When this happens, the immune system not only attacks the pathogens. It also attacks body cells with the similar molecules.

Immunodeficiency

Immunodeficiency occurs when the immune system is not working properly. As a result, it cannot fight off pathogens that a normal immune system would be able to resist. Rarely, the problem is caused by a defective gene. More often, it is acquired during a person's lifetime. Immunodeficiency may occur for a variety of reasons:

- The immune system naturally becomes less effective as people get older. This is why older people are generally more susceptible to disease.
- The immune system may be damaged by other disorders, such as obesity or drug abuse.
- Certain medications can suppress the immune system. This is an intended effect of drugs given to people with transplanted organs. In many cases, however, it is an unwanted side effect of drugs used to treat other diseases.
- Some pathogens attack and destroy cells of the immune system. An example is the virus known as HIV. It is the most common cause of immunodeficiency in the world today. Compromised immune systems are discussed at http://www.youtube.com/watch?v=usRofaZEteY (2:36).

HIV and AIDS

Human immunodeficiency virus (HIV) is a virus that attacks the immune system. An example of HIV is shown in **Figure** 24.12 . Many people infected with HIV eventually develop **acquired immune deficiency syndrome (AIDS).** This may not occur until many years after the virus first enters the body.

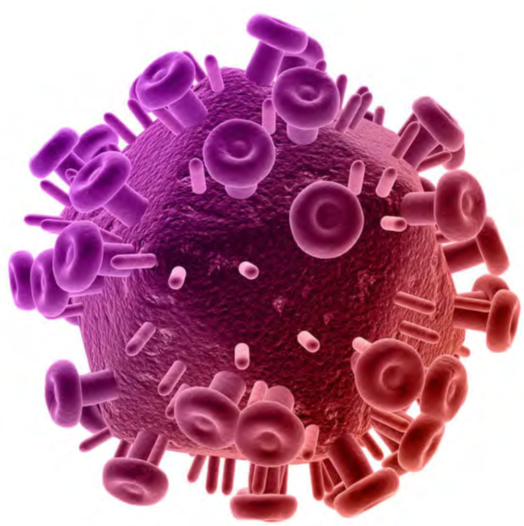


FIGURE 24.12
HIV is a virus that attacks cells of the immune system.

HIV Transmission

HIV is transmitted, or spread, through direct contact of mucous membranes or body fluids such as blood, semen, or breast milk. As shown in **Figure** 24.13 , transmission of the virus can occur through sexual contact or the use of contaminated hypodermic needles. It can also be transmitted through an infected mother's blood to her baby during late pregnancy or birth or through breast milk after birth. In the past, HIV was also transmitted through blood transfusions. Because donated blood is now screened for HIV, the virus is no longer transmitted this way.

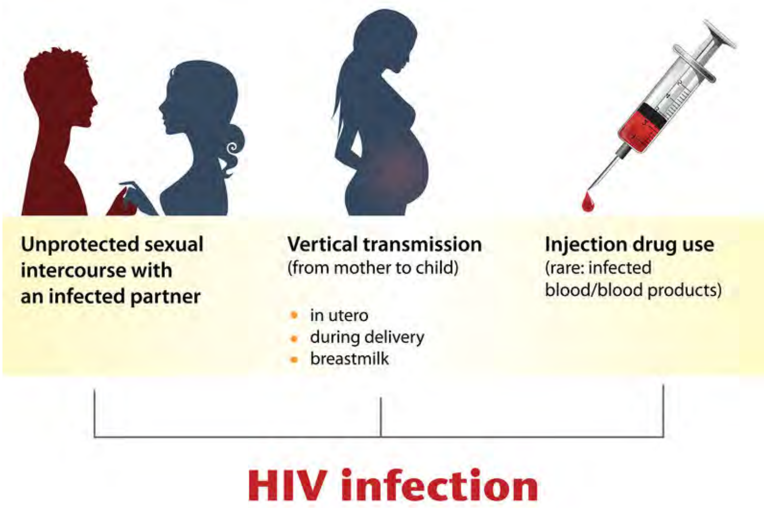


FIGURE 24.13
HIV may be transmitted in all of the ways shown here. Based on how HIV is transmitted what can people do to protect themselves from becoming infected What choices can they make to prevent infection

HIV and the Immune System

HIV infects and destroys helper T cells. As shown in **Figure** 24.14 , the virus injects its own DNA into a helper T cell and uses the T cell's "machinery" to make copies of itself. In the process the T cell is destroyed, and the virus copies go on to infect other helper T cells. You can watch an animation showing how HIV infects T cells at this link: http://www.youtube.com/watch?v=9leO28ydyfU.

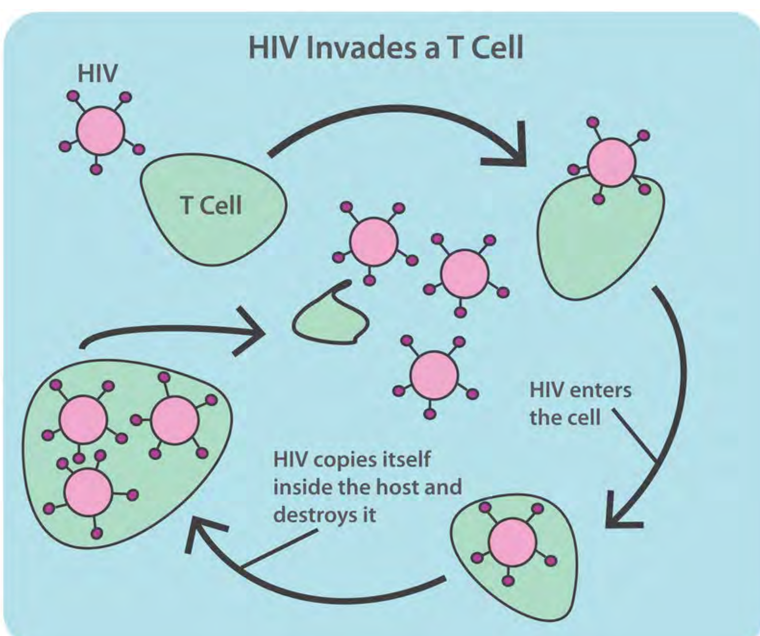


FIGURE 24.14
This diagram shows how HIV infects and destroys T cells.

HIV is able to evade the immune system and keep destroying T cells. This occurs in two ways:

- The virus frequently mutates and changes its surface antigens. This prevents antigen-specific lymphocytes

from developing that could destroy cells infected with the virus.
- The virus uses the plasma membranes of host cells to hide its own antigens. This prevents the host's immune system from detecting the antigens and destroying infected cells.

As time passes, the number of HIV copies keeps increasing, while the number of helper T cells keeps decreasing. The graph in **Figure** 24.15 shows how the number of T cells typically declines over a period of many years following the initial HIV infection. As the number of T cells decreases, so does the ability of the immune system to defend the body. As a result, an HIV-infected person develops frequent infections. Medicines can slow down the virus but not get rid of it, so there is no cure at present for HIV infections or AIDS. There also is no vaccine to immunize people against HIV infection, but scientists are working to develop one.

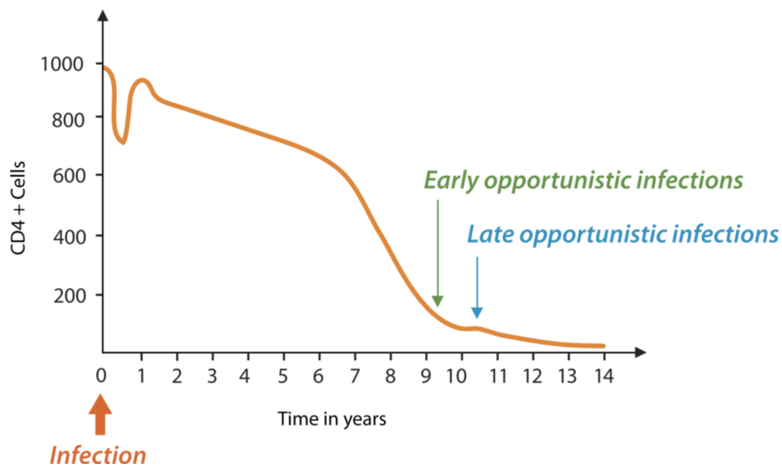


FIGURE 24.15
It typically takes several years after infection with HIV for the drop in T cells to cripple the immune system. What do you think explains the brief spike in T cells that occurs early in the HIV infection shown here

AIDS

AIDS is not a single disease but a set of diseases. It results from years of damage to the immune system by HIV. It occurs when helper T cells fall to a very low level and opportunistic diseases occur (see **Figure** 24.15). Opportunistic diseases are infections and tumors that are rare except in people with immunodeficiency. The diseases take advantage of the opportunity presented by people whose immune systems can't fight back. Opportunistic diseases are usually the direct cause of death of people with AIDS. You can watch a video showing when an HIV infection becomes AIDS at this link: http://www.youtube.com/watch?v=68I7JlVhuhY. AIDS and HIV were first identified in 1981. Scientists think that the virus originally infected monkeys but then jumped to human populations, probably sometime during the early to mid-1900s. This most likely occurred in West Africa, but the virus soon spread around the world (see **Figure** 24.16). Since then, HIV has killed more than 25 million people worldwide. The hardest hit countries are in Africa, where medicines to slow down the virus are least available. The worldwide economic toll of HIV and AIDS has also been enormous.

KQED: HIV Research: Beyond the Vaccine

Over the past 15 years, the number of people who die of AIDS each year in the United States has dropped by 70 percent. But AIDS remains a serious public health crisis among low-income African-Americans, particularly women. And in sub-Saharan Africa, the virus killed more than 1.6 million people in 2007. Innovative research approaches could lead to new treatments and possibly a cure for AIDS. HIV/AIDS has been described as a disease of poverty. Individuals with poor access to health care are less likely to see a doctor early on in their HIV infection,

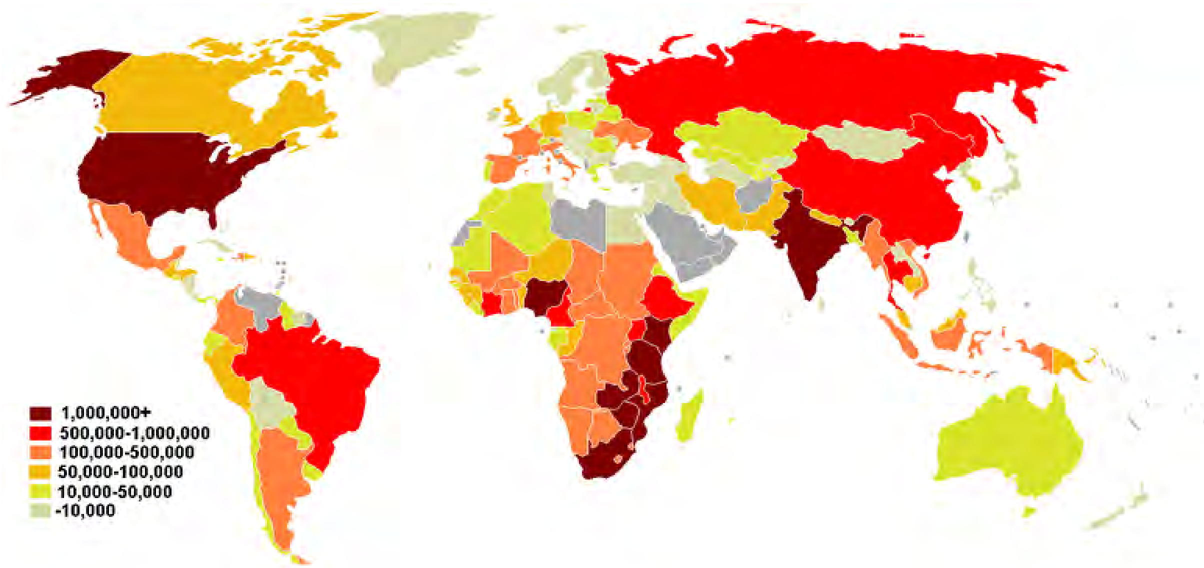
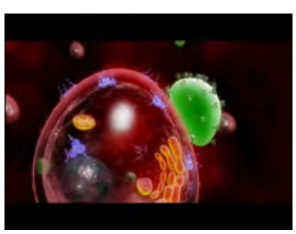


FIGURE 24.16

This map shows the number of people in different countries with HIV infections and AIDS in 2008. The rate of spread of the infection is higher Africa than in the U.S. yet the U.S. has a relatively large number of people with HIV infections and AIDS. Why might there be more survivors with HIV infections and AIDS in the U.S. than in Africa

and thus they may be more likely to transmit the infection. HIV is now the leading cause of death for African American women between 24 and 35 years old.

For patients who have access to drugs, infection with the virus ceased to be a death sentence in 1995, when combinations of drugs called highly active antiretroviral therapy (HAART) were developed. For some patients, drugs can reduce the amount of virus to undetectable levels. But some amount of virus always hides in the body's immune cells and attacks again if the patient stops taking their medication. Researchers are working on developing a drug to wipe out this hidden virus, which could mean the end of AIDS. See http://www.kqed.org/quest/television/hiv-research-beyond-the-vaccine for further information.



MEDIA

Click image to the left for more content.

Lesson Summary

- Allergies occur when the immune system makes an inflammatory response to a harmless antigen. An antigen that causes an allergy is called an allergen.
- Autoimmune diseases occur when the immune system fails to distinguish self from non-self. As a result, the immune system attacks the body's own cells.

- In an immunodeficiency disease, the immune system does not work normally. As a consequence, it cannot defend the body.
- HIV is a virus that attacks cells of the immune system and eventually causes AIDS. It is the chief cause of immunodeficiency in the world today.

Review Questions

Recall

1. What is an allergen? Give two examples.

2. Define anaphylaxis. What causes the symptoms of anaphylaxis?

3. What is an autoimmune disease? Name an example.

4. List three possible reasons for acquired immunodeficiency.

5. Identify two ways that HIV can be transmitted.

Apply Concepts

6. Rheumatic fever is caused by a virus that has antigens similar to molecules in human heart tissues. When the immune system attacks the virus, it may also attack the heart. What type of immune system disease is rheumatic fever? Explain your answer.

7. Draw a graph to show the progression of an untreated HIV infection. Include a line that shows how the number of HIV copies changes through time. Include another line that shows how the number of helper T cells changes through time.

Think Critically

8. Sometimes people with an allergy get allergy shots. They are injected with tiny amounts of the allergen that triggers the allergic reaction. The shots are repeated at regular intervals, and the amount of allergen that is injected each time gradually increases. How do you think this might help an allergy? Do you think this approach just treats allergy symptoms or might it cure the allergy?

9. Explain why opportunistic diseases are a sign of immunodeficiency.

Points to Consider

Pathogens such as HIV are not the only cause of human disease. Many other things in our environment can also make us sick.

- Can you think of other environmental factors that negatively affect human health? What about pollutants in the environment? What are their possible health effects?
- Viruses cause some types of cancer, but cancer is more often caused by other environmental dangers. What environmental factors might increase the risk of cancer? Do you know what causes skin cancer, for example, or lung cancer?

24.4 Environmental Problems and Human Health

Lesson Objectives

- Describe how carcinogens cause cancer and how cancer can be treated or prevented.
- Identify causes of air pollution and its effects on human health.
- Explain how bioterrorism threatens human health.

Vocabulary

Air Quality Index (AQI) assessment of the levels of pollutants in the outdoor air that is based on their human health effects

bioterrorism intentional release or spread of agents of disease

carcinogen anything that can cause cancer

Introduction

Besides pathogens, many other dangers in the environment may negatively affect human health. For example, air pollution can cause lung cancer. It can also make asthma and other diseases worse. Bioterrorism is another potential threat in the environment. It may poison large numbers of people or cause epidemics of deadly diseases.

Carcinogens and Cancer

A **carcinogen** is anything that can cause cancer. Cancer is a disease in which cells divide out of control. Most carcinogens cause cancer by producing mutations in DNA.

Types of Carcinogens

There are several different types of carcinogens. They include pathogens, radiation, and chemicals. Some carcinogens occur naturally. Others are produced by human actions.

- Viruses cause about 15 percent of all human cancers. For example, the virus called hepatitis B causes liver cancer.
- UV radiation is the leading cause of skin cancer. The radioactive gas known as radon causes lung cancer.

- Tobacco smoke contains dozens of carcinogens, including nicotine and formaldehyde. Exposure to tobacco smoke is the leading cause of lung cancer.
- Some chemicals that were previously added to foods, such as certain dyes, are now known to cause cancer. Cooking foods at very high temperatures also causes carcinogens to form (see **Figure** 24.17).

FIGURE 24.17
Barbecued foods are cooked at very high temperatures. This may cause carcinogens to form.

How Cancer Occurs

Mutations that lead to cancer usually occur in genes that control the cell cycle. These include tumor-suppressor genes and proto-oncogenes.

- Tumor-suppressor genes normally prevent cells with damaged DNA from dividing. Mutations in these genes prevent them from functioning normally. As a result, cells with damaged DNA are allowed to divide.
- Proto-oncogenes normally help control cell division. Mutations in these genes turn them into oncogenes. Oncogenes promote the division of cells with damaged DNA.

Cells that divide uncontrollably may form a tumor, or abnormal mass of cells. Tumors may be benign or malignant. Benign tumors remain localized and generally do not harm health. Malignant tumors are cancerous. There are no limits to their growth, so they can invade and damage neighboring tissues. Cells from malignant tumors may also break away from the tumor and enter the bloodstream. They are carried to other parts of the body, where new tumors may form. The most common and the most deadly cancers for U.S. adults are listed in **Table** 24.2 .

TABLE 24.2: **Cancers in U.S. Adults**

Gender	Most Common Types of Cancer after Skin Cancer (% of all cancers)	Most Common Causes of Cancer Deaths (% of all cancer deaths)
Males	prostate cancer (33%), lung cancer (13%)	lung cancer (31%), prostate cancer (10%)
Females	breast cancer (32%), lung cancer (12%)	lung cancer (27%), breast cancer (15%)

More cancer deaths in adult males and females are due to lung cancer than any other type of cancer. Lung cancer is most often caused by exposure to tobacco smoke. What might explain why lung cancer causes the most cancer deaths when it isn't the most common type of cancer?

Cancer Treatment and Prevention

Most cancers can be treated, and some can be cured. The general goal of treatment is to remove the tumor without damaging other cells. A cancer patient is typically treated in more than one way. Possible treatments include surgery, drugs (chemotherapy), and radiation. Early diagnosis and treatment of cancer lead to the best chance for survival. That's why it's important to know the following warning signs of cancer:

- change in bowel or bladder habits
- sore that does not heal
- unusual bleeding or discharge
- lump in the breast or elsewhere
- chronic indigestion or difficulty swallowing
- obvious changes in a wart or mole
- persistent coughing or hoarseness

Having one or more warning signs does not mean you have cancer, but you should see a doctor to be sure. Getting routine tests for particular cancers can also help detect cancers early, when chances of a cure are greatest. For example, getting the skin checked regularly by a dermatologist is important for early detection of skin cancer (see **Figure** 24.18).

You can take steps to reduce your own risk of cancer. For example, you can avoid exposure to carcinogens such as tobacco smoke and UV light. You can also follow a healthy lifestyle. Being active, eating a low-fat diet, and maintaining a normal weight can help reduce your risk of cancer.

Air Pollution and Illness

Almost 5 million people die each year because of air pollution. In fact, polluted air causes more deaths than traffic accidents. Air pollution harms the respiratory and circulatory systems. Both outdoor and indoor air can be polluted.

Outdoor Air Pollution

The **Air Quality Index (AQI)** is an assessment of the pollutants in the outdoor air based on their human health effects. The health risks associated with different values of AQI are shown in **Figure** 24.19 . When AQI is high, you should limit the time you spend outdoors. Avoiding exposure to air pollution can help limit its impact on your

FIGURE 24.18
Regular checkups with a dermatologist can detect skin cancers early. Why is early detection important

FIGURE 24.19
Air quality is especially important for sensitive people. They include people with asthma other respiratory illnesses and cardiovascular diseases.

health. People with certain health problems, including asthma, are very sensitive to the effects of air pollution. They need to be especially careful to avoid it.

AQI generally refers to the levels of ground-level ozone and particulates. Ozone is a gas that forms close to the ground when air pollutants are heated by sunlight. It is one of the main components of smog (see **Figure** 24.20). Smog also contains particulates. Particulates are tiny particles of solids or liquids suspended in the air. They are produced mainly by the burning of fossil fuels. The particles settle in airways and the lungs, where they cause damage.

FIGURE 24.20

Smog clouds the city of Los Angeles California. Visible air pollution in the form of smog is a sign that the air is unhealthy.

Indoor Air Pollution

Indoor air may be even more polluted than outdoor air. It may contain harmful substances such as mold, bacteria, and radon. It may also contain carbon monoxide. Carbon monoxide is a gas produced by furnaces and other devices that burn fuel. If it is inhaled, it replaces oxygen in the blood and quickly leads to death. Carbon monoxide is colorless and odorless, but it can be detected with a carbon monoxide detector like the one in **Figure** 24.21 .

Bioterrorism

Bioterrorism is the intentional release or spread of agents of disease. The agents may be viruses, bacteria, or toxins produced by bacteria. The agents may spread through the air, food, or water; or they may come into direct contact with the skin. Two of the best known bioterrorism incidents in the U.S. occurred early in this century:

a. In 2001, letters containing anthrax spores were mailed to several news offices and two U.S. Senate offices. A total of 22 people were infected, and 5 of them died of anthrax.
b. In 2003, a deadly toxin called ricin was detected in a letter addressed to the White House. The letter was intercepted at a mail-handling facility off White House grounds. Fortunately, the ricin toxin did not cause any illnesses or deaths.

FIGURE 24.21

A carbon monoxide detector warns you if the level of the gas is too high.

Lesson Summary

- A carcinogen is anything that causes cancer. Most carcinogens produce mutations in genes that control the cell cycle.
- Both outdoor and indoor air may contain pollutants that can cause human illness and death.
- Bioterrorism is the intentional release or spread of agents of disease.

Review Questions

Recall

1. What is a carcinogen?
2. How do most carcinogens cause cancer?
3. Identify three ways cancer can be treated.
4. List four warning signs of cancer.
5. Define bioterrorism.

Apply Concepts

6. How can you use the Air Quality Index to protect your health?

Think Critically

7. Explain why ground-level ozone is usually a worse problem in the summer than in the winter in North America.
8. Compare and contrast pollutants in outdoor and indoor air, including their effects on human health.

Points to Consider

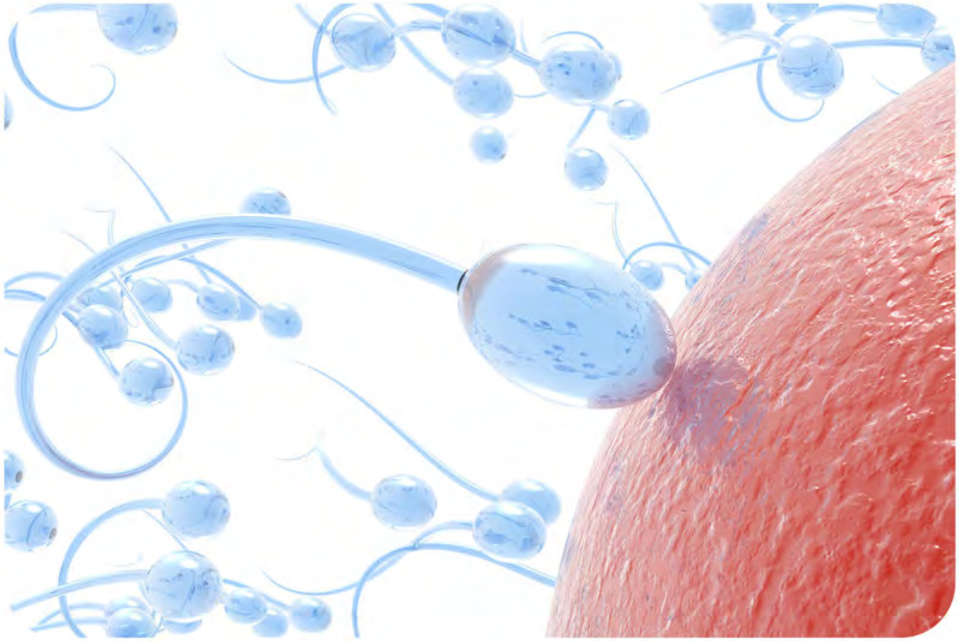
High levels of certain hormones can increase the risk of some types of cancer. For example, high levels of estrogen can increase the risk of breast cancer. Estrogen is a sex hormone.

- What are sex hormones? How do sex hormones normally affect the body?
- Do you think sex hormones might differ in males and females? Why?

Opening image courtesy of Bruce Wetzel/Harry Schaefer/National Cancer Institute (http://visualsonline.cancer.gov/details.cfm?imageid=1762), colorized by Sam McCabe, and is in the public domain.

CHAPTER 25 Reproduction and Human Development

CHAPTER OUTLINE



This image depicts a true wonder of nature. This tiny human sperm is penetrating a much larger egg. These two cells will unite to become a brand new human being. The process in which they unite is called fertilization. Do you know how sperm and egg cells are produced? When and where do they form? Do you know what will happen to the egg and sperm after they unite? How will the fertilized egg develop into a complete and very complex human being? You'll find answers to all of these questions when you read this chapter.

25.1 Male Reproductive System

Lesson Objectives

- Identify male reproductive structures and their functions.
- Explain how the male reproductive system develops.
- Describe how sperm are produced.

Vocabulary

adolescent growth spurt period of rapid growth that occurs during puberty

ejaculation muscle contractions that propel sperm from the epididymes and out through the urethra in males

epididymis (plural, epididymes) one of two male reproductive organs where sperm mature and are stored until they leave the body

luteinizing hormone (LH) pituitary gland hormone that stimulates the testes to secrete testosterone and the ovaries to secrete estrogen

penis male reproductive organ containing the urethra, through which sperm and urine pass out of the body

puberty period during which humans become sexually mature

reproductive system system of organs that produces gametes and secretes sex hormones

semen fluid containing sperm and gland secretions that nourish sperm and carry them through the urethra and out of the body

sex hormone chemical messenger that controls sexual development and reproduction

spermatogenesis process of producing sperm in the testes

testis one of two male reproductive organs that produces sperm and secretes testosterone

testosterone male sex hormone secreted by the testes

Introduction

The **reproductive system** in both males and females consists of structures that produce reproductive cells, or gametes, and secrete sex hormones. A gamete is a haploid cell that combines with another haploid gamete during fertilization. **Sex hormones** are chemical messengers that control sexual development and reproduction. The male reproductive system consists of structures that produce male gametes called sperm and secrete the male sex hormone **testosterone.**

Male Reproductive Structures

The main structures of the male reproductive system are shown in **Figure** 25.1 . Locate them in the figure as you read about them below. You can also watch an animation about male reproductive structures at this link: http://www.medindia.net/animation/male_reproductive_system.asp.

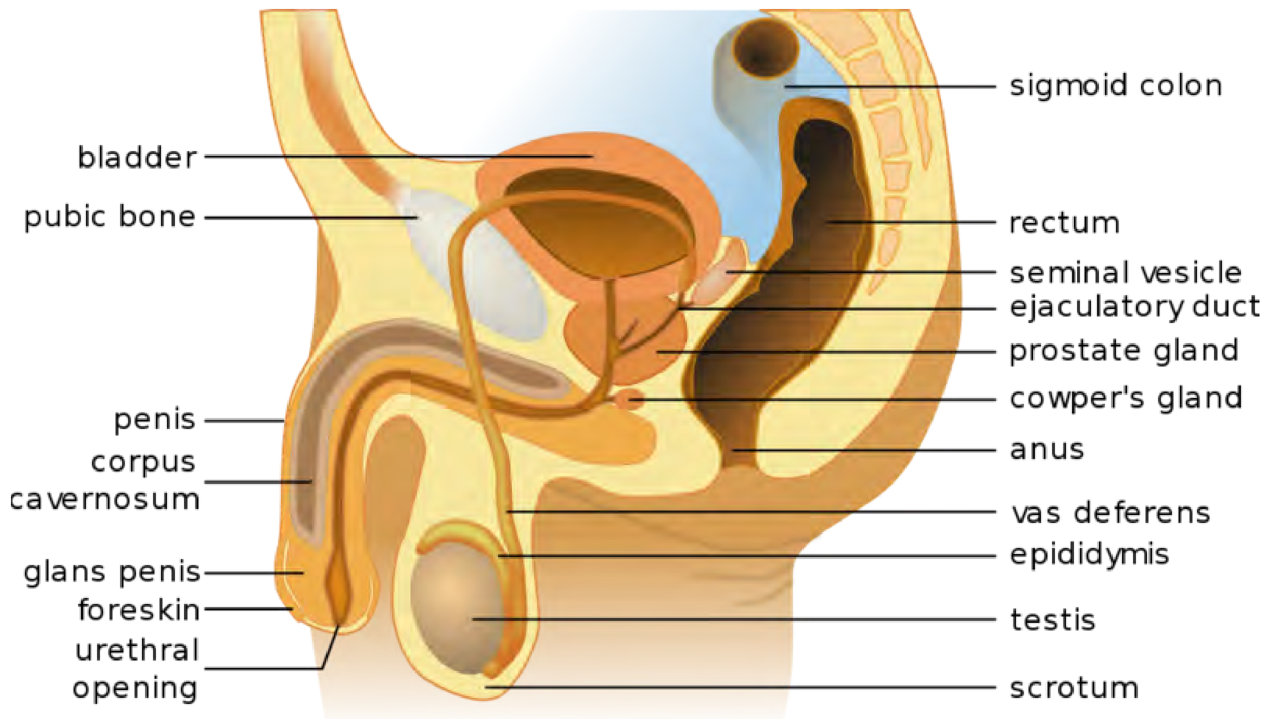


FIGURE 25.1

Male Reproductive Structures. Organs of the male reproductive system include the penis testes and epididymis. Several ducts and glands are also part of the system. Do you know the reproductive functions of any of these structures

Penis

The **penis** is an external genital organ with a long shaft and enlarged tip called the glans penis. The shaft of the penis contains erectile tissues that can fill with blood and cause an erection. When this occurs, the penis gets bigger and stiffer. The urethra passes through the penis. Sperm pass out of the body through the urethra. (During urination, the urethra carries urine from the bladder.)

Testes

The two **testes** (singular, testis) are located below the penis. They hang between the thighs in a sac of skin called the scrotum. Each testis contains more than 30 meters (90 feet) of tiny, tightly packed tubules called seminiferous tubules. These tubules are the functional units of the testes. They produce sperm and secrete testosterone.

Epididymis

The seminiferous tubules within each testis join to form the epididymis. The **epididymis** (plural, epididymes) is a coiled tube about 6 meters (20 feet) long lying atop the testis inside the scrotum. The functions of the epididymis are to mature and store mature sperm until they leave the body.

Ducts and Glands

In addition to these organs, the male reproductive system consists of a series of ducts and glands. Ducts include the vas deferens and ejaculatory ducts. They transport sperm from the epididymes to the urethra in the penis. Glands include the seminal vesicles and prostate gland. They secrete substances that become part of semen.

Semen

Semen is the fluid that carries sperm through the urethra and out of the body. In addition to sperm, it contains secretions from the glands. The secretions control pH and provide sperm with nutrients for energy.

Sexual Development in Males

The only obvious difference between boys and girls at birth is their reproductive organs. However, even the reproductive organs start out the same in both sexes.

Development Before Birth

In the first several weeks after fertilization, males and females are essentially the same except for their chromosomes. Females have two X chromosomes (XX), and males have an X and a Y chromosome (XY). Then, during the second month after fertilization, genes on the Y chromosome of males cause the secretion of testosterone. Testosterone stimulates the reproductive organs to develop into male organs. (Without testosterone, the reproductive organs always develop into female organs.) Although boys have male reproductive organs at birth, the organs are immature and not yet able to produce sperm or secrete testosterone.

Puberty and Its Changes

The reproductive organs grow very slowly during childhood and do not mature until puberty. **Puberty** is the period during which humans become sexually mature. In the U.S., boys generally begin puberty at about age 12 and complete it at about age 18. What causes puberty to begin? The hypothalamus in the brain "tells" the pituitary gland to secrete hormones that target the testes. The main pituitary hormone involved is **luteinizing hormone (LH).**

It stimulates the testes to secrete testosterone. Testosterone, in turn, promotes protein synthesis and growth. It brings about most of the physical changes of puberty, some of which are shown in **Figure** 25.2 . You can watch an animation of these and other changes that occur in boys during puberty at this link: http://www.bbc.co.uk/science/humanbody/body/interactives/lifecycle/teenagers/.

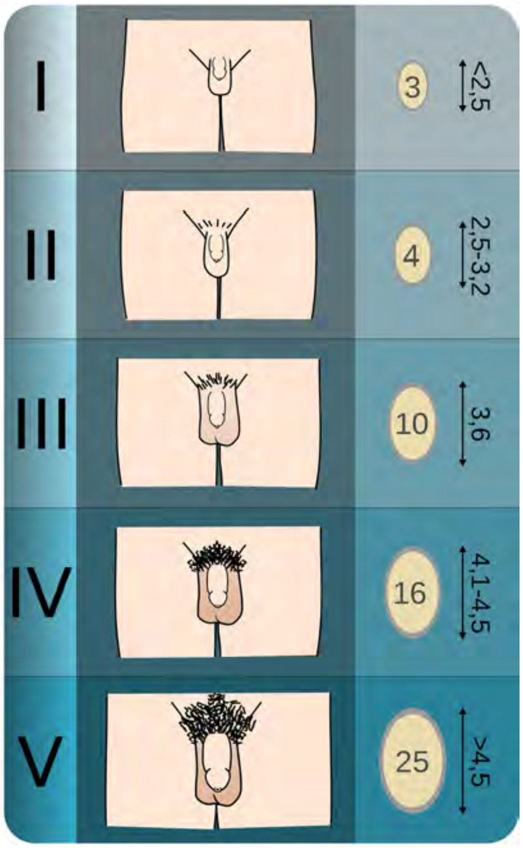


FIGURE 25.2

Some of the changes that occur in boys during puberty are shown in this figure. Pubic hair grows and the penis and testes both become larger.

Adolescent Growth Spurt

Another obvious change that occurs during puberty is rapid growth. This is called the **adolescent growth spurt.** In boys, it is controlled by testosterone. The rate of growth usually starts to increase relatively early in puberty. At its peak rate, growth in height is about 10 centimeters (almost 4 inches) per year in the average male. Growth generally remains rapid for several years. Growth and development of muscles occur toward the end of the growth spurt in height. Muscles may continue to develop and gain strength after growth in height is finished.

Production and Delivery of Sperm

A sexually mature male produces an astounding number of sperm—typically, hundreds of millions each day! Sperm production usually continues uninterrupted until death, although the number and quality of sperm decline during later adulthood.

Spermatogenesis

The process of producing mature sperm is called **spermatogenesis.** Sperm are produced in the seminiferous tubules of the testes and become mature in the epididymis. The entire process takes about 9 to 10 weeks. You can watch an animation of spermatogenesis at this link: http://wps.aw.com/bc_martini_eap_4/40/10469/2680298.cw/content/index.html. If you look inside the seminiferous tubule drawing shown in **Figure** 25.3 , you can see cells in various stages of spermatogenesis. The tubule is lined with spermatogonia, which are diploid, sperm-producing cells. Surrounding the spermatogonia are other cells. Some of these other cells secrete substances to nourish sperm, and some secrete testosterone, which is needed for sperm production.

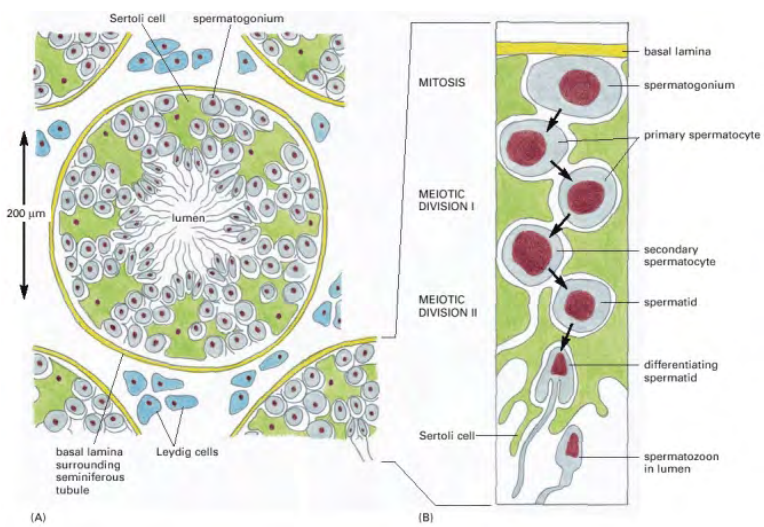


FIGURE 25.3

Seminiferous Tubule. This drawing shows an enlarged cross section of a seminiferous tubule.

Spermatogonia lining the seminiferous tubule undergo mitosis to form primary spermatocytes, which are also diploid. The primary spermatocytes undergo the first meiotic division to form secondary spermatocytes, which are haploid. Spermatocytes make up the next layer of cells inside the seminiferous tubule. Finally, the secondary spermatocytes complete meiosis to form spermatids. Spermatids make up a third layer of cells in the tubule.

Sperm Maturation

After spermatids form, they move into the epididymis to mature into sperm, like the one shown in **Figure** 25.4 . The spermatids grow a tail and lose excess cytoplasm from the head. When a sperm is mature, the tail can rotate like a propeller, so the sperm can propel itself forward. Mitochondria in the connecting piece produce the energy needed for movement. The head of the mature sperm consists mainly of the nucleus, which carries copies of the father's chromosomes. The part of the head called the acrosome produces enzymes that help the head penetrate an egg.

Ejaculation

Sperm are released from the body during **ejaculation.** Ejaculation occurs when muscle contractions propel sperm from the epididymes. The sperm are forced through the ducts and out of the body through the urethra. As sperm travel through the ducts, they mix with fluids from the glands to form semen. Hundreds of millions of sperm are released with each ejaculation.

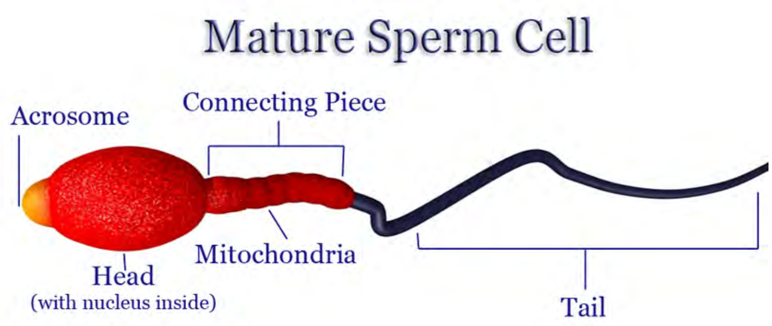


FIGURE 25.4
Mature Sperm Cell. A mature sperm cell has several structures that help it reach and penetrate an egg. These structures include the tail mitochondria and acrosome. How does each structure contribute to the sperm&#8217 s function

Lesson Summary

- The male reproductive system consists of structures that produce sperm and secrete testosterone. They include the penis, testes, and epididymes.
- The male reproductive system forms before birth but does not become capable of reproduction until it matures during puberty. Puberty lasts from about ages 12 to 18 years and is controlled by hormones.
- Sperm are produced in the testes in the process of spermatogenesis. They mature in the epididymes before being ejaculated from the body through the penis.

Lesson Review Questions

Recall

1. What are the two major roles of the male reproductive system?

2. Name two male reproductive organs and identify their functions.

3. List three physical changes that occur in males during puberty.

4. Outline the process of spermatogenesis. What cells are involved in the process?

5. Where do sperm mature and how do they leave the body?

Apply Concepts

6. Sexual dimorphism refers to differences between males and females of the same species. Applying what you read in this lesson, describe how human sexual dimorphism changes from fertilization to adulthood.

Think Critically

7. Explain how and why boys change so much during puberty.

8. If a man did not have functioning epididymes, predict how his sperm would be affected. How would this influence his ability to reproduce?

Points to Consider

By the time they finish puberty, males have developed the traits of mature adults of their own sex. Adult males differ from adult females in many ways. Many of the differences come about because females and males develop differently during puberty.

- How do you think females change during puberty?
- Do you know when females begin puberty? Do you think it's the same age as males?
- What hormones do you think control puberty in females?

25.2 Female Reproductive System

Lesson Objectives

- Identify female reproductive structures and their functions.
- Explain how the female reproductive system develops.
- Describe how eggs are produced.
- Outline the phases of the menstrual cycle.

Vocabulary

estrogen female sex hormone secreted by the ovaries

Fallopian tube one of two female reproductive organs that carry eggs from the ovary to the uterus and provide the site where fertilization usually takes place

follicle-stimulating hormone (FSH) pituitary gland hormone that stimulates the ovaries to secrete estrogen and follicles in the ovaries to mature

menarche beginning of menstruation; first monthly period in females

menopause period during which menstrual cycles slow down and eventually stop in middle adulthood

menstrual cycle monthly cycle of processes and events in the ovaries and uterus of a sexually mature human female

menstruation process in which the endometrium of the uterus is shed from the body during the first several days of the menstrual cycle; also called monthly period

oogenesis process of producing eggs in the ovary

ovulation release of a secondary oocyte from the uterus about half way through the menstrual cycle

vulva external female reproductive structures, including the labia and vaginal opening

Introduction

The female reproductive system consists of structures that produce female gametes called eggs and secrete the female sex hormone **estrogen.** The female reproductive system has several other functions as well:

a. It receives sperm during sexual intercourse.
b. It supports the development of a fetus.
c. It delivers a baby during birth.
d. It breast-feeds a baby after birth.

Female Reproductive Structures

The main structures of the female reproductive system are shown in **Figure** 25.5 . Most of the structures are inside the pelvic region of the body. Locate the structures in the figure as you read about them below. To watch an animation of the female reproductive system, go to this link: http://www.medindia.net/animation/female_reproductive_system.asp.

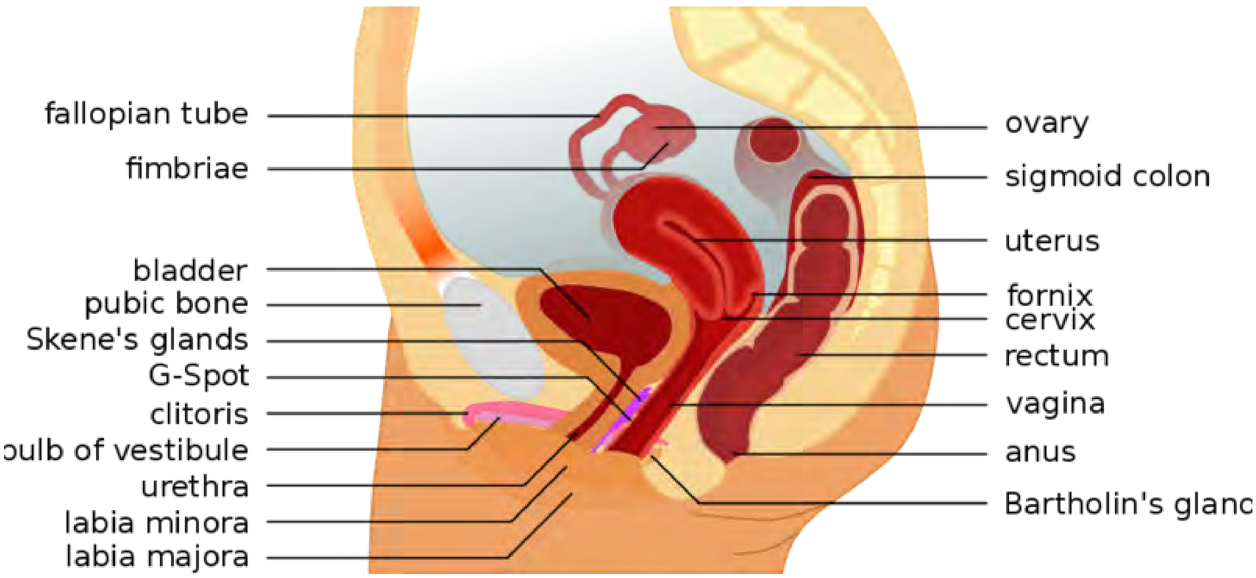


FIGURE 25.5
Female Reproductive Structures. Organs of the female reproductive system include the vagina uterus ovaries and fallopian tubes.

External Structures

The external female reproductive structures are referred to collectively as the **vulva.** They include the labia (singular, labium), which are the "lips" of the vulva. The labia protect the vagina and urethra, both of which have openings in the vulva.

Vagina

The vagina is a tube-like structure about 9 centimeters (3.5 inches) long. It begins at the vulva and extends upward to the uterus. It has muscular walls lined with mucous membranes. The vagina has two major reproductive functions. It receives sperm during sexual intercourse, and it provides a passageway for a baby to leave the mother's body during birth.

Uterus

The uterus is a muscular organ shaped like an upside-down pear. It has a thick lining of tissues called the endometrium. The lower, narrower end of the uterus is known as the cervix. The uterus is where a fetus grows and develops until birth. During pregnancy, the uterus can expand greatly to make room for the baby as it grows. During birth, contractions of the muscular walls of the uterus push the baby through the cervix and out of the body.

Ovaries

The two ovaries are small, egg-shaped organs that lie on either side of the uterus. They produce eggs and secrete estrogen. Each egg is located inside a structure called a follicle. Cells in the follicle protect the egg and help it mature.

Fallopian Tubes

Extending from the upper corners of the uterus are the two **fallopian tubes.** Each tube reaches (but is not attached to) one of the ovaries. The ovary end of the tube has a fringelike structure that moves in waves. The motion sweeps eggs from the ovary into the tube.

Breasts

The breasts are not directly involved in reproduction, but they nourish a baby after birth. Each breast contains mammary glands, which secrete milk. The milk drains into ducts leading to the nipple. A suckling baby squeezes the milk out of the ducts and through the nipple.

Sexual Development in Females

Female reproductive organs form before birth. However, as in males, the organs do not mature until puberty.

Development Before Birth

Unlike males, females are not influenced by the male sex hormone testosterone during embryonic development. This is because they lack a Y chromosome. As a result, females do not develop male reproductive organs. By the third month of fetal development, most of the internal female organs have formed. Immature eggs also form in the ovary before birth. Whereas a mature male produces sperm throughout his life, a female produces all the eggs she will ever make before birth.

Changes of Puberty

Like baby boys, baby girls are born with all their reproductive organs present but immature and unable to function. Female reproductive organs also grow very little until puberty. Girls begin puberty a year or two earlier than boys, at an average age of 10 years. Girls also complete puberty sooner than boys, in about 4 years instead of 6. Puberty in girls starts when the hypothalamus "tells" the pituitary gland to secrete hormones that target the ovaries. Two pituitary hormones are involved: luteinizing hormone (LH) and **follicle-stimulating hormone (FSH).** These hormones stimulate the ovary to produce estrogen. Estrogen, in turn, promotes growth and other physical changes of puberty. It stimulates growth and development of the internal reproductive organs, breasts, and pubic hair (see **Figure** 25.6

). You can watch an animation of these and other changes that girls experience during puberty at this link: http://www.bbc.co.uk/science/humanbody/body/interactives/lifecycle/teenagers/.

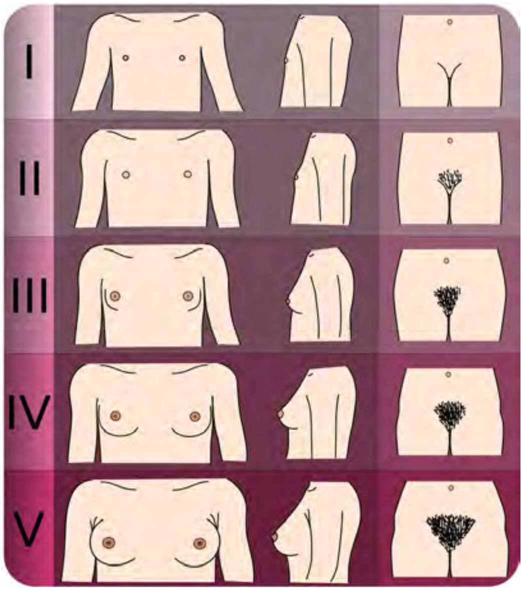


FIGURE 25.6
Changes in Females During Puberty. Two obvious changes of puberty in girls are growth and development of the breasts and pubic hair. The stages begin around age 10 and are completed by about age 14.

Adolescent Growth Spurt

Like boys, girls also go through an adolescent growth spurt. However, girls typically start their growth spurt a year or two earlier than boys (and therefore a couple of centimeters shorter, on average). Girls also have a shorter growth spurt. For example, they typically reach their adult height by about age 15. In addition, girls generally do not grow as fast as boys do during the growth spurt, even at their peak rate of growth. As a result, females are about 10 centimeters (about 4 inches) shorter, on average, than males by the time they reach their final height.

Menarche

One of the most significant changes in females during puberty is menarche. **Menarche** is the beginning of menstruation, or monthly periods. In U.S. girls, the average age of menarche is 12.5 years, although there is a lot of variation in this age. The variation may be due to a combination of genetic factors and environmental factors, such as diet.

Egg Production

At birth, a female's ovaries contain all the eggs she will ever produce. However, the eggs do not start to mature until she enters puberty. After menarche, one egg typically matures each month until a woman reaches middle adulthood.

Oogenesis

The process of producing eggs in the ovary is called **oogenesis.** Eggs, like sperm, are haploid cells, and their production occurs in several steps that involve different types of cells, as shown in **Figure** 25.7 . You can follow the process of oogenesis in the figure as you read about it below.

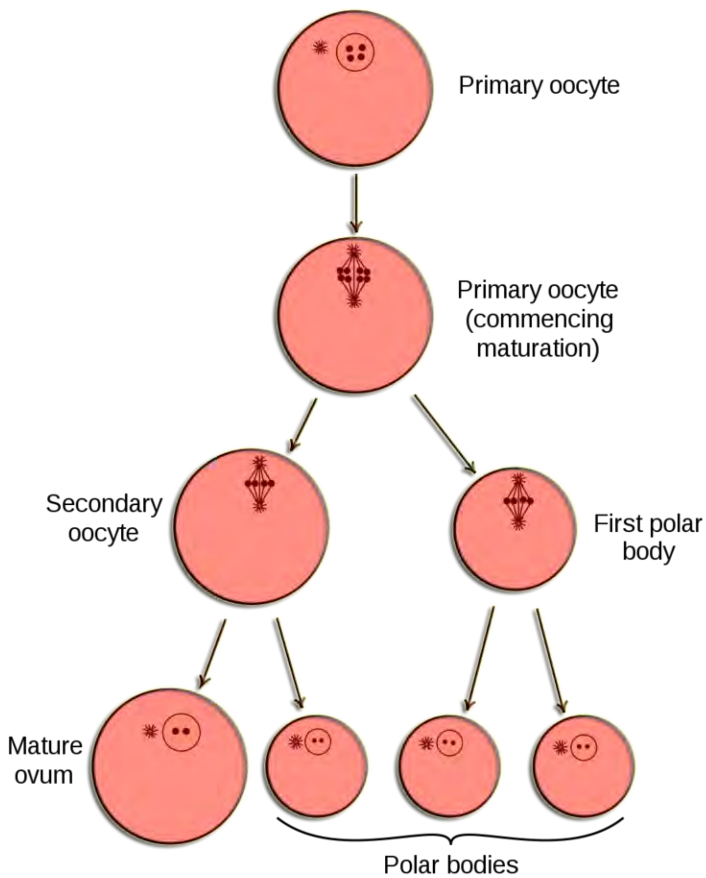


FIGURE 25.7

Oogenesis. Oogenesis begins before birth but is not finished until after puberty. A mature egg forms only if a secondary oocyte is fertilized by a sperm.

Oogenesis begins long before birth when an oogonium with the diploid number of chromosomes undergoes mitosis. It produces a diploid daughter cell called a primary oocyte. The primary oocyte, in turn, starts to go through the first cell division of meiosis (meiosis I). However, it does not complete meiosis until much later. The primary oocyte remains in a resting state, nestled in a tiny, immature follicle until puberty.

Maturation of a Follicle

Beginning in puberty, each month one of the follicles and its primary oocyte starts to mature (also see **Figure** 25.8). The primary oocyte resumes meiosis and divides to form a secondary oocyte and a smaller cell, called a polar body. Both the secondary oocyte and polar body are haploid cells. The secondary oocyte has most of the cytoplasm from the original cell and is much larger than the polar body.

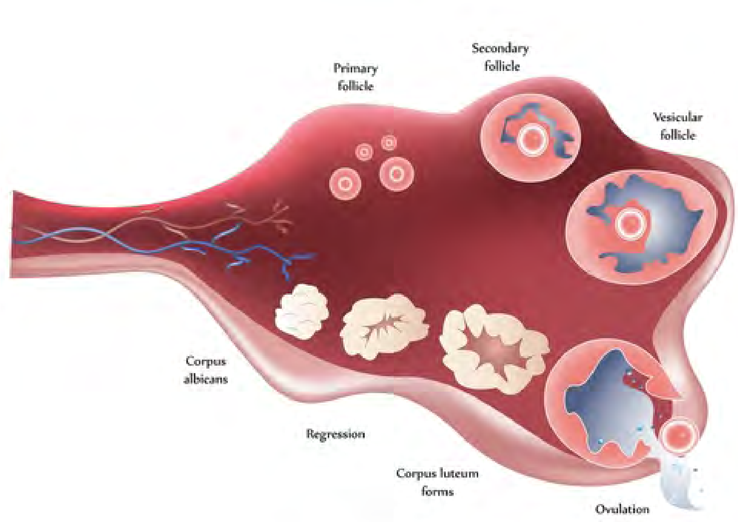


FIGURE 25.8

Maturation of a Follicle and Ovulation. A follicle matures and its primary oocyte $follicle$ resumes meiosis to form a secondary oocyte in the secondary follicle. The follicle ruptures and the oocyte leaves the ovary during ovulation. What happens to the ruptured follicle then

Ovulation and Fertilization

After 12–14 days, when the follicle is mature, it bursts open, releasing the secondary oocyte from the ovary. This event is called **ovulation** (see **Figure** 25.8). The follicle, now called a corpus luteum, starts to degenerate, or break down. After the secondary oocyte leaves the ovary, it is swept into the nearby fallopian tube by the waving, fringelike end (see **Figure** 25.9).

If the secondary oocyte is fertilized by a sperm as it is passing through the fallopian tube, it completes meiosis and forms a mature egg and another polar body. (The polar bodies break down and disappear.) If the secondary oocyte is not fertilized, it passes into the uterus as an immature egg and soon disintegrates. You can watch an animation of all these events and the hormones that control them at the link below. http://health.howstuffworks.com/adam-200017.htm

Menstrual Cycle

Ovulation is part of the **menstrual cycle**, which typically occurs each month in a sexually mature female unless she is pregnant. Another part of the cycle is the monthly period, or menstruation. **Menstruation** is the process in

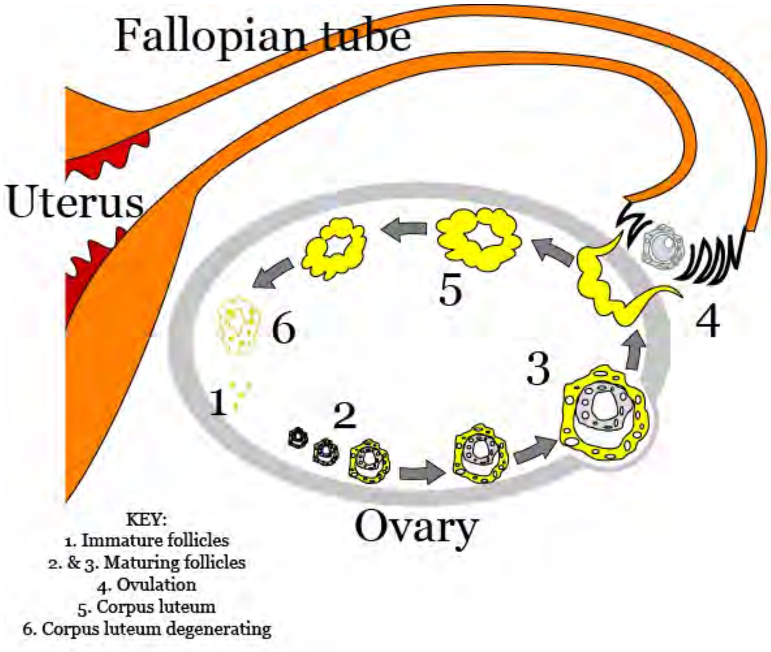


FIGURE 25.9
Egg Entering Fallopian Tube. After ovulation the fringelike end of the fallopian tube sweeps the oocyte inside of the tube where it begins its journey to the uterus.

which the endometrium of the uterus is shed from the body. The menstrual cycle is controlled by hormones from the hypothalamus, pituitary gland, and ovaries. For an interactive animation of the menstrual cycle, you can go this link: http://health.howstuffworks.com/adam-200132.htm

Phases of the Menstrual Cycle

As shown in **Figure** 25.10 , the menstrual cycle occurs in several phases. The cycle begins with menstruation. During menstruation, arteries that supply the endometrium of the uterus constrict. As a result, the endometrium breaks down and detaches from the uterus. It passes out of the body through the vagina over a period of several days.

After menstruation, the endometrium begins to build up again. At the same time, a follicle starts maturing in an ovary. Ovulation occurs around day 14 of the cycle. After it occurs, the endometrium continues to build up in preparation for a fertilized egg. What happens next depends on whether the egg is fertilized.

If the egg is fertilized, the endometrium will be maintained and help nourish the egg. The ruptured follicle, now called the corpus luteum, will secrete the hormone progesterone. This hormone keeps the endometrium from breaking down. If the egg is not fertilized, the corpus luteum will break down and disappear. Without progesterone, the endometrium will also break down and be shed. A new menstrual cycle thus begins.

Menopause

For most women, menstrual cycles continue until their mid- to late forties. Then women go through **menopause**, a period during which their menstrual cycles slow down and eventually stop, generally by their early fifties. After menopause, women can no longer reproduce naturally because their ovaries no longer produce eggs.

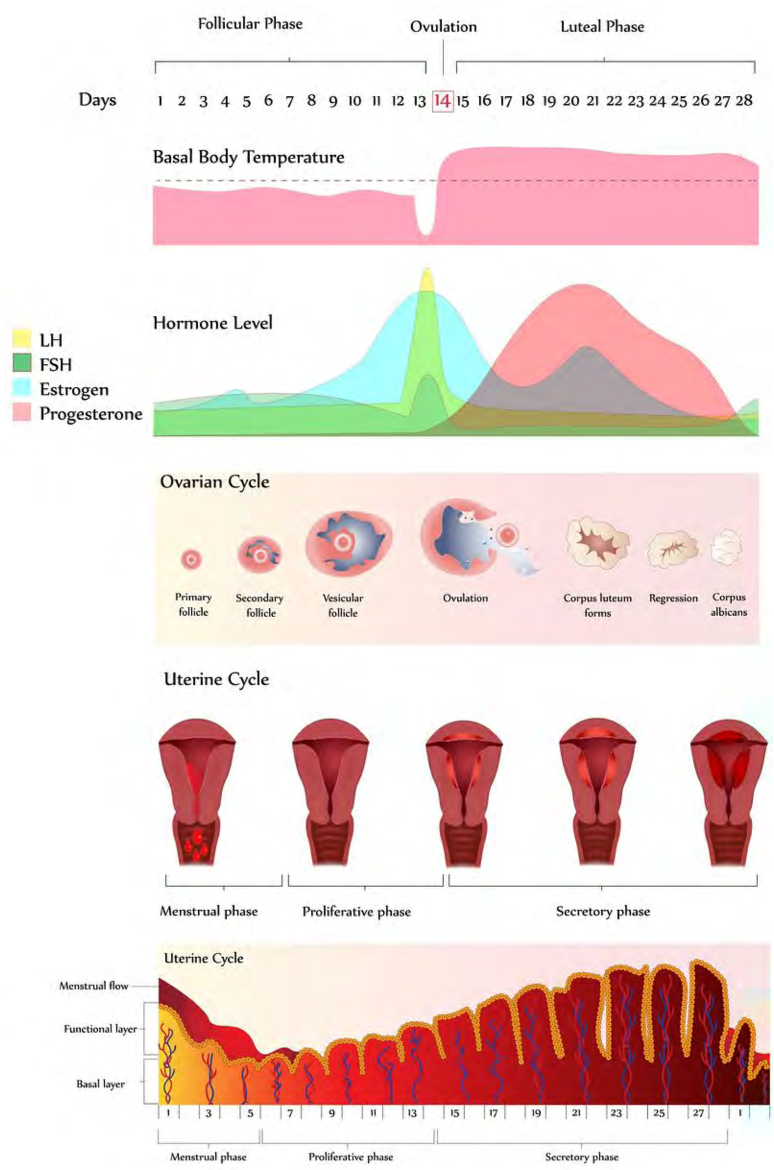


FIGURE 25.10

Phases of the Menstrual Cycle. The menstrual cycle occurs in the phases shown here.

Lesson Summary

- The female reproductive system consists of structures that produce eggs and secrete female sex hormones. They also provide a site for fertilization and enable the development and birth of a fetus. They include the vagina, uterus, ovaries, and fallopian tubes.
- Female reproductive organs form before birth. However, they do not mature until puberty.
- Immature eggs form in the ovaries before birth. Each month, starting in puberty, one egg matures and is released from the ovary. Release of an egg is called ovulation.
- The menstrual cycle includes events that take place in the ovary, such as ovulation. It also includes changes in the uterus, including menstruation. Menopause occurs when menstruation stops occurring, usually in middle adulthood.

Lesson Review Questions

Recall

1. List three general functions of the female reproductive system.

2. Describe the uterus, and state its role in reproduction.

3. State two ways that puberty differs in girls and boys.

4. Describe ovulation.

5. Define menstruation. What is the first menstrual period called?

6. What is menopause? When does it occur?

Apply Concepts

7. Create a flow chart showing the steps in which an oogonium develops into a mature egg.

8. Make a cycle diagram to represent the main events of the menstrual cycle in both the ovaries and the uterus, including the days when they occur.

Think Critically

9. Predict how blockage of both fallopian tubes would affect a woman's ability to reproduce naturally. Explain your answer.

10. Males and females are quite similar in height when they begin the adolescent growth spurt. Why are females about 10 centimeters shorter than males by adulthood?

11. Compare and contrast what happens in the menstrual cycle when the egg is fertilized with what happens when the egg is not fertilized.

Points to Consider

If an egg is fertilized by a sperm and implants in the uterus, the endometrium helps nourish it. However, as the new organism grows, it soon needs more nutrients than the endometrium can provide. These nutrients are provided by the mother's bloodstream.

- How do you think the fetus is able to obtain nutrients from the mother's blood? What structures and processes might be involved?
- The fetus also produces wastes. How do you think the wastes are excreted?

25.3 From Fertilization to Old Age

Lesson Objectives

- Outline the events that occur between fertilization and the embryonic stage.
- Explain how the embryo forms specialized cells and organs.
- Identify major events in the growth and development of the fetus.
- Explain the role of the placenta during fetal development.
- Describe pregnancy and childbirth.
- List milestones in growth and development from birth to adulthood.
- Describe the stages of adulthood, and explain why aging occurs.

Vocabulary

adolescence period of transition between the beginning of puberty and adulthood during which significant physical, mental, emotional, and social changes occur

amniotic sac enclosed membrane containing fluid that surrounds and protects a fetus

blastocyst fluid-filled ball of cells that develops a few days after fertilization in humans

differentiation process by which unspecialized cells become specialized into one of many different types of cells, such as neurons or epithelial cells

embryo stage of growth and development that occurs from implantation through the eighth week after fertilization in humans

fetus developing human organism between weeks 8 and 38 after fertilization

implantation process in which a blastocyst embeds in the endometrium lining the uterus

infancy first year of life after birth in humans

pregnancy carrying of one or more offspring from fertilization until birth

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 the uterus and enter a fallopian tube. This is where fertilization usually takes place.

Cleavage and Implantation

When a sperm penetrates the 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 all the chromosomes needed for a new human organism. Half the chromosomes come from the egg and half from the sperm.

Morula and Blastocyst Stages

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 by mitosis several times to form a ball of cells called a morula. The cell divisions are called cleavage. They increase the number of cells but not the overall size of the new organism. As more cell divisions occur, a fluid-filled cavity forms inside the ball of cells. At this stage, the ball of cells is called a **blastocyst.** The cells of the blastocyst form an inner cell mass and an outer cell layer, as shown in **Figure** 25.11 . The inner cell mass is called the embryoblast. These cells will soon develop into an embryo. The outer cell layer is called the trophoblast. These cells will develop into other structures needed to support and nourish the embryo.

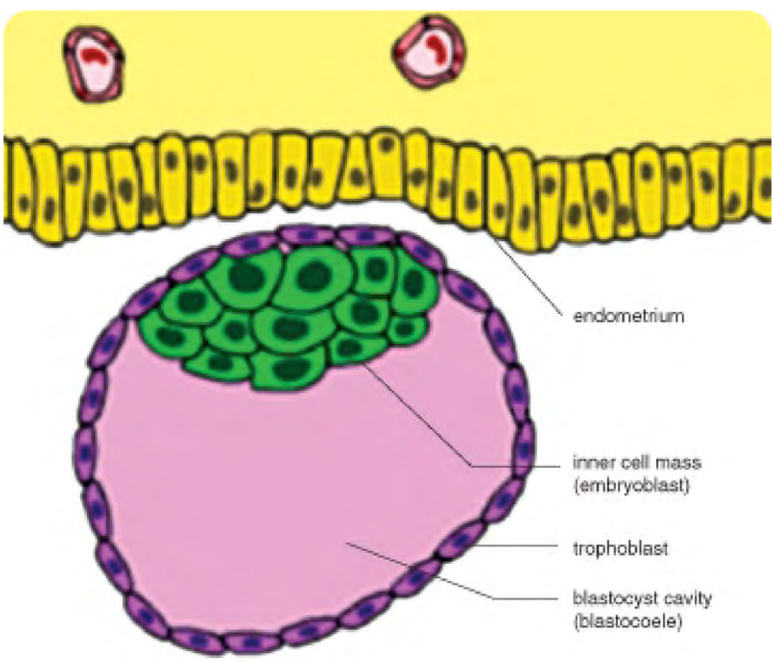


FIGURE 25.11
Blastocyst. The blastocyst consists of an outer layer of cells called the trophoblast and an inner cell mass called the embryoblast.

Implantation

The blastocyst continues down the fallopian tube and reaches the uterus about 4 or 5 days after fertilization. When the outer cells of the blastocyst contact cells of the endometrium lining the uterus, the blastocyst embeds in the endometrium. The process of embedding is called **implantation.** It generally occurs about a week after fertilization. You can watch an animation of a blastocyst implanting at this link: http://embryology.med.unsw.edu.au/notes/week2_3.htm

Growth and Development of the Embryo

After implantation occurs, the blastocyst is called an **embryo.** The embryonic stage lasts through the eighth week following fertilization. During this time, the embryo grows in size and becomes more complex. It develops specialized cells and tissues and starts to form most organs. For an interactive animation of embryonic development, go to this link: http://health.howstuffworks.com/adam-200129.htm.

Formation of Cell Layers

During the second week after fertilization, cells in the embryo migrate to form three distinct cell layers, called the ectoderm, mesoderm, and endoderm. Each layer will soon develop into different types of cells and tissues, as shown in **Figure** 25.12 .

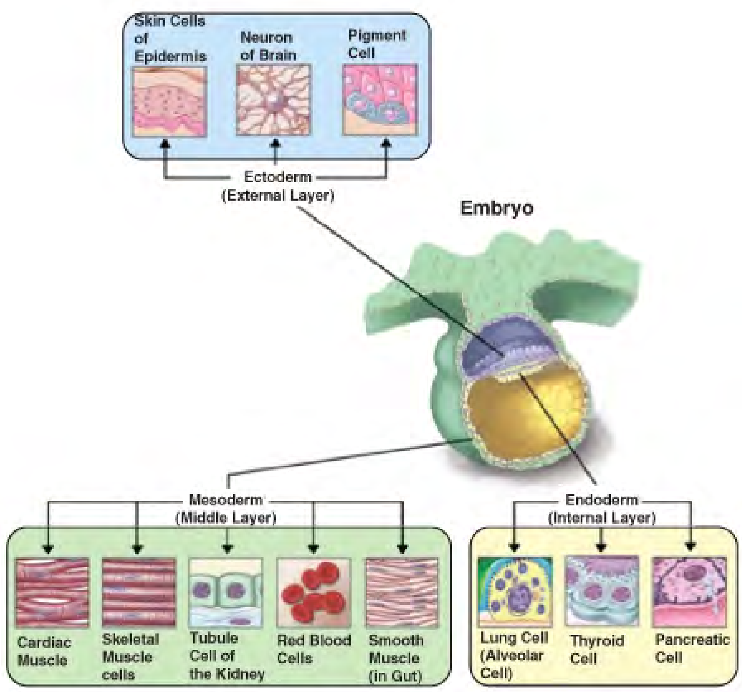


FIGURE 25.12

Cell Layers of the Embryo. The migration of cells into three layers occurs in the 2-week-old embryo. What organs eventually develop from the ectoderm cell layer Which cell layer develops into muscle tissues

Differentiation of Cells

A zygote is a single cell. How does a single cell develop into many different types of cells? During the third week after fertilization, the embryo begins to undergo cellular differentiation. **Differentiation** is the process by which unspecialized cells become specialized. As illustrated in **Figure** 25.13 , differentiation occurs as certain genes are expressed while other genes are switched off. Because of this process, cells develop unique structures and abilities that suit them for their specialized functions. You can explore cell differentiation by watching the video at this link: http://videos.howstuffworks.com/hsw/10313-the-cell-cell-differentiation-video.htm.

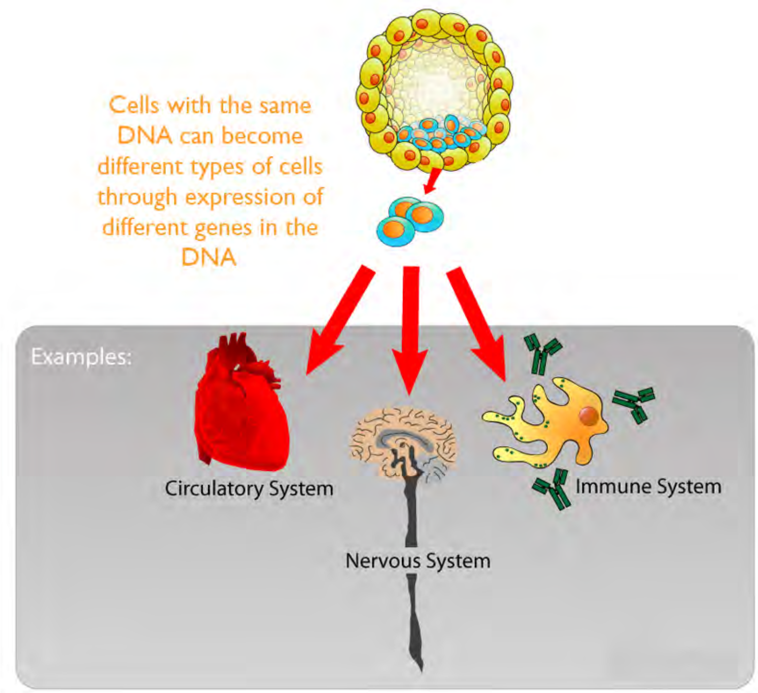


FIGURE 25.13
Cellular differentiation occurs in the 3-week-old embryo.

Organ Formation

After cells differentiate, all the major organs begin to form during the remaining weeks of embryonic development. A few of the developments that occur in the embryo during weeks 4 through 8 are listed in **Figure** 25.14 . As the embryo develops, it also grows in size. By the eighth week of development, the embryo is about 30 millimeters (just over 1 inch) in length. It may also have begun to move.

Growth and Development of the Fetus

From the end of the eighth week until birth, the developing organism is referred to as a **fetus.** Birth typically occurs at about 38 weeks after fertilization, so the fetal period generally lasts about 30 weeks. During this time, as outlined in **Figure** 25.15 , the organs complete their development. The fetus also grows rapidly in length and weight. For detailed videos of growth and development of the fetus birth, go to these links: http://www.youtube.com/watch?v=aR-Qa_LD2m4#38;#38;feature=related and http://www.youtube.com/watch?v=RS1ti23SUSw#38;feature=related.

By the 38th week, the fetus is fully developed and ready to be born (see **Figure** 25.16). A 38-week fetus normally ranges from 36 to 51 centimeters (14–20 inches) in length and weighs between 2.7 and 4.6 kilograms (about 6–10 pounds).

Placenta and Related Structures

The fetus could not grow and develop without oxygen and nutrients from the mother. Wastes from the fetus must also be removed in order for it to survive. The exchange of these substances between the mother and fetus occurs

FIGURE 25.14
Embryonic Development *Weeks* 4&#8211 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.*

FIGURE 25.15

Fetal Development *Weeks* 9&#8211 38. Organ development is completed and body size increases dramatically during weeks 9&#8211 38.

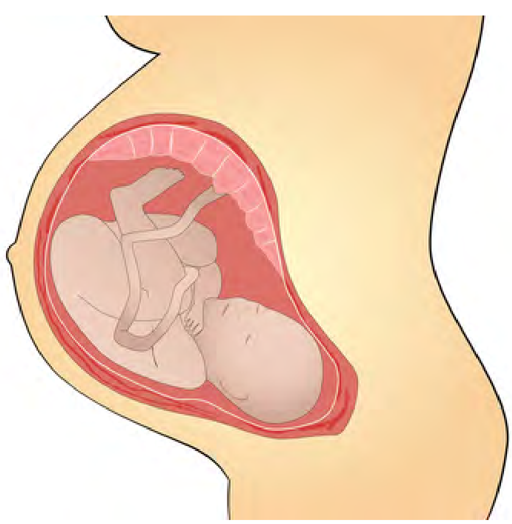


FIGURE 25.16

A 38-week-old fetus has completed development and will soon be born.

through the placenta.

Placenta

The placenta is a temporary organ that begins to form from the trophoblast layer of cells shortly after implantation. (For an animation showing how the placenta forms, go to link below.) The placenta continues to develop and grow to meet the needs of the growing fetus. A fully developed placenta, like the one in **Figure** 25.16 , is made up of a large mass of blood vessels from both the 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.

- http://health.howstuffworks.com/adam-200122.htm

The fetus is connected to the placenta through the umbilical cord, a tube that contains two arteries and a vein. Blood from the fetus enters the placenta through the umbilical arteries, exchanges gases and other substances with the mother's blood, and travels back to the fetus through the umbilical vein.

Amniotic Sac and Fluid

Attached to the placenta is the **amniotic sac**, an enclosed membrane that surrounds and protects the fetus (see **Figure** 25.16). 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 Childbirth

Pregnancy is the carrying of one or more offspring from fertilization until birth. It is the development of an embryo and fetus from the expectant mother's point of view.

The Mother's Role

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 must also provide all the nutrients and other substances needed for normal growth and development. Most nutrients are needed in greater amounts by a pregnant woman, but some are especially important, including folic acid (vitamin B9), calcium, iron, and omega-3 fatty acids.

Childbirth

Near the time of birth, the amniotic sac breaks in a gush of fluid. Labor usually begins within a day of this event. Labor involves contractions of the muscular walls of the uterus, which cause the cervix to dilate. 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 cannot exchange gases, so carbon dioxide quickly builds up in the baby's blood. This stimulates the brain to trigger breathing, and the newborn takes its first breath.

From Birth to Adulthood

For the first year after birth, a baby is called an infant. Childhood begins at age two and continues until adolescence. Adolescence is the last stage of life before adulthood.

Infancy

Infancy is the first year of life after birth. Infants are born with a surprising range of abilities. For example, they have well-developed senses of touch, hearing, and smell. They can also communicate their needs by crying. During their first year, they develop many other abilities, including those described below. For a video of major milestones in the first year of life, go to this link: http://www.youtube.com/watch?v=5_Ao_3hTS6I#38;feature=channel.

By 6 weeks after birth, infants typically start smiling (see **Figure** 25.17) and making vocal sounds. By 6 months, infants are babbling. They have also learned to sit and are starting to crawl. The deciduous (baby) teeth have started to come in. By 12 months, infants may be saying their first words. They usually can stand with help and may even have started to walk.

FIGURE 25.17
A baby&#8217 s first smile is an early milestone in infant development.

Infancy is the period of most rapid growth after birth. Growth is even faster during infancy that it is during puberty. By the end of the first year, the average baby is twice as long as it was at birth and three times as heavy.

Childhood

A toddler is a child aged 1 to 3 years. Children of this age are learning to walk, or "toddle." Growth is still relatively rapid during the toddler years but it has begun to slow down. During the next three years, children achieve many more milestones.

- By age 4, most children can run, climb stairs, and scribble with a crayon. They know many words and use simple sentences. The majority are also toilet trained.
- By age five, children are able to carry on conversations, recognize letters and words, and use a pencil to trace letters. They can usually tie their own shoelaces and may be learning to ride a bicycle, swing a bat, kick a ball and play other games (**Figure** 25.18).

- By age 6, most children begin losing their deciduous teeth, and their permanent teeth start coming in. They speak fluently and are learning to read and write. They spend more time with peers and develop friendships.

FIGURE 25.18
Five year olds can usually play various games.

Older children continue to grow slowly until they start the adolescent growth spurt during puberty. They also continue to develop mentally, emotionally, and socially. Think about all the ways you have changed since you were as young as the child in **Figure** 25.18 . What milestones of development did you achieve during these childhood years?

Adolescence

Adolescence is the period of transition between the beginning of puberty and adulthood. You learned about the physical changes of puberty earlier in this chapter. Adolescence is also a time of significant mental, emotional, and social changes. For example:

- Adolescents generally develop the ability to think abstractly.
- Adolescents may have mood swings because of surging hormones.
- Adolescents usually try to be more independent from their parents.
- Adolescents typically spend much of their time with peers.
- Adolescents may start to develop intimate relationships.

Adulthood and Aging

Adulthood does not have a definite starting point. A person may be physically mature by age 16 or 17 but not defined as an adult by law until older ages. In the U.S., you can't join the armed forces or vote until age 18. You can't buy or use alcohol or take on many legal and financial responsibilities until age 21.

Early Adulthood

Early adulthood coincides with the 20s and early 30s. During early adulthood, people generally form intimate relationships, both in friendship and love. Many people become engaged or marry during this time. Often they are completing their education and becoming established in a career. Health problems in young adults tend to be minor. The most common causes of death are homicides, car crashes, and suicides.

Middle Adulthood

Middle adulthood lasts from the mid-30s to the mid-60s. During this stage of life, many people raise a family and strive to attain career goals. They start showing physical signs of aging, such as wrinkles and gray hair. Typically, vision, strength, and reaction time start declining. Diseases such as type 2 diabetes, cardiovascular disease, and cancer are often diagnosed during this stage of life. These diseases are also the chief causes of death in middle adulthood.

Old Age

Old age begins in the mid-60s and lasts until the end of life. Most people over 65 have retired from work, freeing up their time for hobbies, grandchildren, and other interests. Stamina, strength, reflex time, and the senses all decline during old age, and the number of brain cells decreases as well. The immune system becomes less efficient, increasing the risk of serious illnesses such as cancer and pneumonia. Diseases such as Alzheimer's disease that cause loss of mental function also become more common.

Causes of Aging

Why do we decline in all these ways as we age? Generally, it's because cells stop dividing and die. There are at least two reasons why cells stop dividing:

a. Cells are programmed to divide only a set number of times.
b. Mutations accumulate in DNA, and cells with damaged DNA may not divide.

KQED: Embryonic Stem Cell Research

As we have seen in this lesson, you begin life as a single cell. By the time you were born, that cell had gone through millions of divisions. By adulthood, you're made up of approximately 100 trillion individual cells. There are about 200 different types of cells that make these 100 trillion cells, all all these cells work together to allow you to live. Each cell, or group of cells, has a specific task or specialty. Those specialties allow an organism to function.

During early development, embryonic stem cells are present. These are undifferentiated cells that have the potential to turn into any type of cell. This potential is what makes these cells very good candidates for medical treatments, such as treating individuals with heart disease. To learn more about stem cells, see http://www.kqed.org/quest/television/stem-cell-gold-rush.

Lesson Summary

- Fertilization is the union of a sperm and egg, resulting in the formation of a zygote. The zygote undergoes many cell divisions before it implants in the lining of the uterus.

- The embryonic stage begins with implantation. An embryo forms three distinct cell layers, and each layer develops into different types of cells and organs.
- The fetal stage begins about two months after fertilization and continues until birth. During this stage, organs continue to develop, and the fetus grows in size.
- The placenta allows nutrients and wastes to be exchanged between the mother and fetus. The fetus is connected to the placenta through the umbilical cord.
- A pregnant woman should avoid toxins and take in adequate nutrients for normal fetal growth and development. During childbirth, contractions of the uterus push the child out of the body.
- Growth and development are most rapid during infancy and slower throughout the rest of childhood until adolescence. Adolescence involves mental, emotional, and social changes in addition to the physical changes of puberty.
- During early adulthood, people form intimate relationships and start careers. Serious health problems start showing up in middle adulthood and old age. Aging occurs as cells lose their ability to divide.

Lesson Review Questions

Recall

1. What happens during fertilization? Where does it usually take place?
2. What is implantation? When does it occur?
3. Describe the role of the placenta in fetal development.
4. What causes the fetus to be pushed out of the uterus during birth?
5. When does adulthood begin?
6. Aging is associated with the death of cells. Give two reasons why cells die.

Apply Concepts

7. Make a flow chart of embryonic and fetal development.
8. Create a time line of milestones of growth and development from birth to adulthood.

Think Critically

9. Explain how the embryo forms specialized cells.
10. Why would an embryo be more susceptible than a fetus to damage by toxins?
11. Why is the umbilical cord cut before a newborn has started to breathe on its own?
12. Compare and contrast adolescence and puberty.

Points to Consider

Most diseases become more common as people grow older, but sexually transmitted diseases (STDs) are much more common in teens and young adults. These diseases are now usually called sexually transmitted infections (STIs).

- Can you name any STIs? Do you know how STIs spread?

- What might explain why STIs are so common in young people?

25.4 Sexually Transmitted Infections

Lesson Objectives

- Explain what causes STIs and how they can be prevented.
- Identify and describe three common bacterial STIs.
- Identify and describe three common viral STIs.

Vocabulary

chlamydia sexually transmitted bacterial infection that is the most common STI in the United States

genital herpes sexually transmitted infection caused by a herpes virus that is characterized by periodic outbreaks of blisters on the genitals

genital warts small, rough growths on the genitals caused by a sexually transmitted infection with human papillomavirus (HPV)

gonorrhea common sexually transmitted infection that is caused by bacteria

hepatitis B inflammation of the liver caused by infection with hepatitis B virus, which is often transmitted through sexual contact

human papilloma virus (HPV) sexually transmitted virus that causes genital warts and cervical cancer

sexually transmitted infection (STI) infection caused by a pathogen that spreads mainly through sexual contact; also known as sexually transmitted disease (STD)

syphilis sexually transmitted infection caused by bacteria that may eventually be fatal if untreated

trichomoniasis common sexually transmitted infection that is caused by protozoa

Introduction

A shocking statistic made headlines in 2008. A recent study had found that one in four teen girls in the U.S. had a sexually transmitted infection. A **sexually transmitted infection (STI)** (also known as a sexually transmitted disease, or STD) is an infection caused by a pathogen that spreads mainly through sexual contact. Worldwide, a million people a day become infected with STIs. The majority of them are under the age of 25. For a video about sexually transmitted infections, go to this link: http://www.youtube.com/watch?v=Bazh6p5rOFM.

Understanding Sexually Transmitted Infections

To be considered an STI, an infection must have only a small chance of spreading naturally in ways other than sexual contact. Some infections that can spread through sexual contact, such as the common cold, spread more commonly by other means. These infections are not considered STIs.

Pathogens that Cause STIs

STIs may be caused by several different types of pathogens, including protozoa, insects, bacteria, and viruses. For example: Protozoa cause an STI called **trichomoniasis.** The pathogen infects the vagina in females and the urethra in males, causing symptoms such as burning and itching. Trichomoniasis is common in young people. Pubic lice, like the one in **Figure** 25.19 , are insect parasites that are transmitted sexually. They suck the blood of their host and irritate the skin in the pubic area.

FIGURE 25.19
Public Louse. Public lice like this one are only about as big as the head of a pin.

Most STIs are caused by bacteria or viruses. Several of them are described below. Bacterial STIs can be cured with antibiotics. Viral STIs cannot be cured. Once you are infected with a viral STI, you are likely to be infected for life.

How STIs Spread

Most of the pathogens that cause STIs enter the body through mucous membranes of the reproductive organs. All sexual behaviors that involve contact between mucous membranes put a person at risk for infection. This includes vaginal, anal, and oral sexual behaviors. Many STIs can also be transmitted through body fluids such as blood, semen, and breast milk. Therefore, behaviors such as sharing injection or tattoo needles is another way these STIs can spread. Why are STIs common in young people? One reason is that young people often take risks. They may think, "It can't happen to me." They also may not know how STIs are spread, so they don't know how to protect themselves. In addition, young people may have multiple sexual partners.

Preventing STIs

The only completely effective way to prevent infection with STIs is to avoid sexual contact and other risky behaviors. Using condoms can lower the risk of becoming infected with STIs during some types of sexual activity. However, condoms are not foolproof. Pathogens may be present on areas of the body not covered by condoms. Condoms can also break or be used incorrectly.

Bacterial STIs

Many STIs are caused by bacteria. Some of the most common bacterial STIs are chlamydia, gonorrhea, and syphilis.

Chlamydia

Chlamydia is the most common STI in the U.S. As shown in the graph in **Figure** 25.20 , females are much more likely than males to develop chlamydia. Like most STIs, rates of chlamydia are highest in teens and young adults.

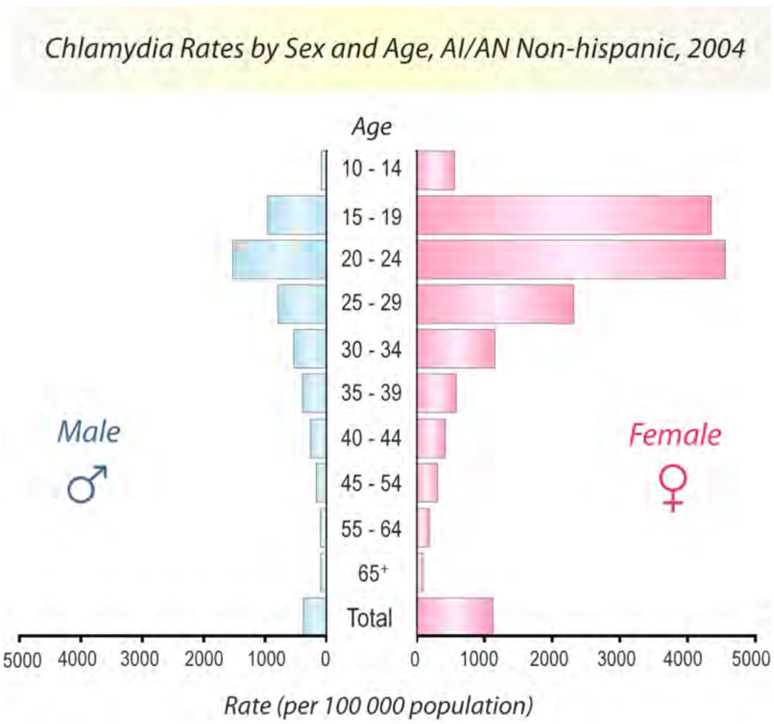


FIGURE 25.20
This graph shows the number of cases of chlamydia per 100 000 people in the U.S. in 2004. Which age group had the highest rates How much higher were the rates for females aged 15&#8211 19 than for males in the same age group

Symptoms of chlamydia may include a burning sensation during urination and a discharge from the vagina or penis. Chlamydia can be cured with antibiotics, but often there are no symptoms, so people do not seek treatment. Untreated chlamydia can lead to more serious problems, such as pelvic inflammatory disease (PID). This is an infection of the uterus, fallopian tubes, and/or ovaries. It can scar a woman's reproductive organs and make it difficult for her to become pregnant. To learn more about chlamydia, watch the video at this link: http://www.youtube.com/watch?v=qaazmU8YU7E#38;feature=fvw.

Gonorrhea

Gonorrhea is another common STI. Symptoms of gonorrhea may include painful urination and discharge from the vagina or penis. Gonorrhea usually can be cured with antibiotics, although the bacteria have developed resistance to many of the drugs. Gonorrhea infections may not cause symptoms, especially in females, so they often go untreated. Untreated gonorrhea can lead to PID in females. It can lead to inflammation of the reproductive organs in males as well.

Syphilis

Syphilis is less common than chlamydia or gonorrhea but more serious if untreated. Early symptoms of syphilis infection include a small sore on or near the genitals. The sore is painless and heals on its own, so it may go unnoticed. If treated early, most cases of syphilis can be cured with antibiotics. Untreated syphilis can cause serious damage to the heart, brain, and other organs. It may eventually lead to death.

Viral STIs

STIs caused by viruses include genital herpes, hepatitis B, genital warts, and HIV/AIDS, which is described in Chapter 24.

Genital Herpes

Genital herpes is an STI caused by a herpes virus. In the U.S., as many as one in four people are infected with the virus. Symptoms of genital herpes include painful blisters on the genitals (see **Figure** 25.21). The blisters usually go away on their own, but the virus remains in the body, causing periodic outbreaks of blisters throughout life. Outbreaks may be triggered by stress, illness, or other factors. A person with genital herpes is most likely to transmit the virus during an outbreak. To learn more about genital herpes, watch the video at this link: http://www.youtube.com/watch?v=eXK6GKe1kOw#38;feature=PlayList#38;p=1386BB276DFC6837#38;playnext_from=PL.

FIGURE 25.21
Genital Herpes Blisters. Blisters like these on the genitals are a sign of genital herpes.

Hepatitis B

Hepatitis B is inflammation of the liver caused by infection with the hepatitis B virus. In many people, the immune system quickly eliminates the virus from the body. However, in a small percentage of people, the virus remains in the body and continues to cause illness. It may eventually damage the liver and increase the risk of liver cancer, which is usually fatal.

Genital Warts and Cervical Cancer

Infections with the **human papillomavirus (HPV)** are very common. HPV may cause **genital warts**, which are small, rough growths on the genitals. It may also cause cancer of the cervix in females. A simple test, called a PAP test, can detect cervical cancer. If the cancer is detected early, it usually can be cured with surgery. There is also a vaccine to prevent infection with HPV. The vaccine is recommended for females aged 11 to 26 years.

Lesson Summary

- STIs are diseases caused by pathogens that spread through sexual contact. Abstinence from sexual activity and other risk behaviors is the only completely effective way to prevent the spread of STIs.
- Bacterial STIs include chlamydia, gonorrhea, and syphilis. These diseases usually can be cured with antibiotics.
- Viral STIs include genital herpes, hepatitis B, genital warts, and cervical cancer. These diseases cannot be cured, but some of them can be prevented with vaccines.

Lesson Review Questions

Recall

1. Describe how STIs spread.

2. What is the only completely effective way to prevent a sexually transmitted infection?

3. Identify three common STIs that are caused by bacteria.

4. Name and describe an STI caused by a virus.

Apply Concepts

5. Assume you are preparing a public service announcement (PSA) to explain to teens how and why to avoid STIs. List three facts you think it would be important to include for an informative and persuasive PSA.

Think Critically

6. Often, STIs do not cause symptoms. Why is it important to detect and treat STIs even when they do not cause symptoms?

7. Explain how a lack of symptoms might contribute to the spread of STIs.

8. Compare and contrast bacterial and viral STIs with regard to their treatment, cure, and prevention.

Points to Consider

From fertilization to old age, the human body is like a fantastic machine. It controls its own growth and development, protects itself from dangers in the outside world, and has amazing abilities to act, think, and feel. Like all living things, human beings are marvels of nature.

- What have you learned about human beings and other organisms by reading this book?
- Has studying biology given you a greater understanding and appreciation of the living world?

Chapter 26 Biology Glossary

Chapter Outline


Biology

26.1 A

abiotic factor nonliving aspect of the environment such as sunlight and soil

absolute dating carbon-14 or other method of dating fossils that gives an approximate age in years

absorption process in which substances such as nutrients pass into the blood stream

acid solution with a pH lower than 7

acid rain low-pH precipitation that forms with air pollution combines with water

acquired immunodeficiency syndrome (AIDS) disorder characterized by frequent opportunistic infections that eventually develops in people who are infected with human immunodeficiency virus (HIV)

action potential reversal of electrical charge across the membrane of a resting neuron that travels down the axon of the neuron as a nerve impulse

activation energy energy needed to start a chemical reaction

active immunity ability to resist a pathogen that results when an immune response to the pathogen produces memory cells

active transport movement of substances across a plasma membrane that requires energy

adaptation characteristic that helps living things survive and reproduce in a given environment

adaptive radiation process by which a single species evolves into many new species to fill available niches

adolescence period of transition between the beginning of puberty and adulthood during which significant physical, mental, emotional, and social changes occur

adolescent growth spurt period of rapid growth that occurs during puberty

adrenal glands pair of endocrine glands located above the kidneys that secrete hormones such as cortisol and adrenaline

aerobic respiration type of cellular respiration that requires oxygen

age-sex structure number of individuals of each sex and age in a population

aggression behavior that is intended to cause harm or pain

air pollution chemical substances and particles released into the air mainly by human actions such as burning fossil fuels

Air Quality Index (AQI) assessment of the levels of pollutants in the outdoor air that is based on their human health effects

alcoholic fermentation type of anaerobic respiration that includes glycolysis followed by the conversion of pyruvic acid to ethanol and carbon dioxide and the formation of NAD^+

algae (singular, alga) plant-like protists such as diatoms and seaweeds

algal bloom excessive growth of algae in bodies of water because of high levels of nutrients, usually from fertilizer in runoff

allele one of two or more different versions of the same gene

allele frequency how often an allele occurs in a gene pool relative to the other alleles for that gene

allergen any antigen that causes an allergy

allergy disease in which the immune system makes an inflammatory response to a harmless antigen

allopatric speciation evolution of a new species that occurs when some members of an original species become geographically separated from the rest of the species

alternation of generations change back and forth from one generation to the next between haploid gametophyte and diploid sporophyte stages in the life cycle of plants

alveoli (singular, alveolus) tiny sacs at the ends of bronchioles in the lungs where pulmonary gas exchange takes place

amoeboid type of protozoa, such as *Amoeba,* that moves with pseudopods

amino acid small molecule that is a building block of proteins

amniote animal that produces eggs with internal membranes that allow gases but not water to pass through so the embryo can breathe without drying out (reptile, bird, or mammal)

amniotic sac enclosed membrane containing fluid that surrounds and protects a fetus

amphibian ectothermic, tetrapod vertebrate that may live on land but must return to water in order to reproduce

anabolic reaction endothermic reaction in organisms

anaerobic respiration type of cellular respiration that does not require oxygen

analogous structure structure that is similar in unrelated organisms because it evolved to do the same job, not because it was inherited from a common ancestor

anaphase third phase of mitosis during which sister chromatids separate and move to opposite poles of the cell

angiosperm type of seed plant that produces seeds in the ovary of a flower

animal heterotrophic, multicellular eukaryote with cells that lack cell walls; member of the animal kingdom

animal behavior any way that animals interact with each other or the environment

Annelida invertebrate phylum of segmented worms such as earthworms

antheridia (singular, antheridium) male reproductive organs of the gametophyte generation of plants that produce motile sperm

antibiotic drug drug that kills bacteria and cures bacterial infections and diseases

antibiotic resistance ability to withstand antibiotic drugs that has evolved in some bacteria

antibody large, Y-shaped proteins produced by B cells that recognize and bind to antigens in a humoral immune response

antigen molecule that the immune system identifies as foreign and responds to by forming antibodies

aphotic zone area in aquatic biomes deeper than 200 meters

aquatic biome water-based biomes, defined by the availability of sunlight and the concentration of dissolved oxygen and nutrients in the water

aquifer underground layer of rock that stores water

arboreal of or pertaining to trees, as in arboreal, or tree-living, mammal

Archaea one of two prokaryote domains that includes organisms that live in extreme environments

archegonia (singular, archegonium) female reproductive organs of the gametophyte generation of plants that produce eggs

artery type of blood vessel that carries blood away from the heart toward the lungs or body

arthropod invertebrate in the phylum Arthropoda, characterized by a segmented body, hard exoskeleton, and jointed appendages

artificial selection process in which organisms evolve traits useful to humans because people select which individuals are allowed to reproduce and pass on their genes to successive generations

asexual reproduction reproduction that involves a single parent and results in offspring that are all genetically identical to the parent

asthma respiratory system disease in which air passages of the lungs periodically become too narrow, making breathing difficult

atherosclerosis condition in which plaque builds up inside arteries

athlete's foot infection of the skin between the toes by the fungus *Trichophyton*

ATP (adenosine triphosphate) energy-carrying molecule that cells use to power their metabolic processes

autoimmune disease type of disease, such as type 1 diabetes, in which the immune system attacks the body's cells as though they were pathogens

autonomic nervous system (ANS) division of the peripheral nervous system that controls involuntary activities not under conscious control such as heart rate and digestion

autosome chromosomes 1–22 in humans that contain genes for characteristics unrelated to sex

autotroph organism that makes its own food

axon long extension of the cell body of a neuron that transmits nerve impulses to other cells

26.2 B

Bacteria domain of prokaryotes, some of which cause human diseases

bark tissue that provides a rough, woody external covering on the stems of trees

base solution with a pH higher than 7

B cell type of lymphocyte that fights infections by forming antibodies

bilateral symmetry symmetry of a body plan in which there are distinct head and tail ends, so the body can be divided into two identical right and left halves

bile fluid produced by the liver and stored in the gall bladder that is secreted into the small intestine to help digest lipids and neutralize acid from the stomach

binary fission type of cell division that occurs in prokaryotic cells in which a parent cells divides into two identical daughter cells

binomial nomenclature method of naming species with two names, consisting of the genus name and species name

biochemical reaction chemical reaction that occurs inside the cells of living things

biodiversity the variety of life and its processes; including the variety of living organisms, the genetic differences among them, and the communities and ecosystems in which they occur

biofilm colony of prokaryotes that is stuck to a surface such as a rock or a host's tissue

biogeochemical cycle interconnected pathways through which water or a chemical element such as carbon is continuously recycled through the biotic and abiotic components of the biosphere

biogeography study of how and why plants and animals live where they do

biology science of life, study of life

biomass total mass of organisms at a trophic level

biome group of similar ecosystems with the same general type of physical environment

biosphere part of Earth where all life exists, including land, water, and air

biotechnology use of technology to change the genetic makeup of living things in order to produce useful products

bioterrorism intentional release or spread of agents of disease

biotic factor living aspects of the environment, including organisms of the same and different species

bird bipedal, endothermic, tetrapod vertebrate that lays amniotic eggs and has wings and feathers

bladder hollow, sac-like organ that stores urine until it is excreted from the body

blastocyst fluid-filled ball of cells that develops a few days after fertilization in humans

blood fluid connective tissue that circulates throughout the body through blood vessels

blood pressure force exerted by circulating blood on the walls of blood vessels

blood type genetic characteristic associated with the presence or absence of antigens on the surface of red blood cells

body mass index (BMI) estimate of the fat content of the body calculated by dividing a person's weight (in kilograms) by the square of the person's height (in meters)

bone hard tissue in most vertebrates that consists of a collagen matrix, or framework, filled in with minerals such a calcium

bone marrow soft connective tissue in spongy bone that produces blood cells

bone matrix rigid framework of bone that consists of tough protein fibers and mineral crystals

brain central nervous system organ inside the skull that is the control center of the nervous system

brain stem lowest part of the brain that connects the brain with the spinal cord and controls unconscious functions such as heart rate and breathing

bryophyte type of plant that lacks vascular tissues, such as a liverwort, hornwort, or moss

budding type of asexual reproduction in yeasts in which an offspring cell pinches off from the parent cell

26.3 C

Calvin cycle second stage of photosynthesis in which carbon atoms from carbon dioxide are combined, using the energy in ATP and NADPH, to make glucose

Cambrian explosion spectacular burst of new life that occurred at the start of the Paleozoic Era

cancer disease that occurs when the cell cycle is no longer regulated and cells divide out of control

candidiasis infection of the mouth or of the vagina in females that is caused by the yeast *Candida*

capillary smallest type of blood vessel that connects very small arteries and veins

capsid protein coat that surrounds the DNA or RNA of a virus particle

carbohydrate organic compound such as sugar or starch

carbon cycle interconnected pathways through which carbon is recycled through the biotic and abiotic components of the biosphere

carcinogen anything that can cause cancer

cardiac muscle involuntary, striated muscle found only in the walls of the heart

cardiovascular disease (CVD) any disease that affects the heart or blood vessels

carnivore consumer that eats animals

carrying capacity (K) largest population size that can be supported in an area without harming the environment

cartilage dense connective tissue that provides a smooth surface for the movement of bones at joints

catabolic reaction exothermic reaction in organisms

cell basic unit of structure and function of living things

cell body central part of a neuron that contains the nucleus and other cell organelles

cell cycle repeating series of events that a cell goes through during its life, including growth, DNA, synthesis, and cell division

cell division process in which a parent cell divides to form two daughter cells

cell-mediated immune response type of immune response in which T cells destroy cells that are infected with viruses

cell theory theory that all living things are made up of cells, all life functions occur within cells, and all cells come from already existing cells

cellular respiration process in which cells break down glucose and make ATP for energy

cell wall rigid layer that surrounds the plasma membrane of a plant cell and helps support and protect the cell

Cenozoic Era age of mammals that lasted from 65 million years ago to the present

central dogma of molecule biology doctrine that genetic instructions in DNA are copied by RNA, which carries them to a ribosome where they are used to synthesize a protein (DNA $\rightarrow$ RNA $\rightarrow$ protein)

central nervous system (CNS) one of two main divisions of the nervous system that includes the brain and spinal cord

central vacuole large saclike organelle in plant cells that stores substances such as water and helps keep plant tissues rigid

centromere region of sister chromatids where they are joined together

cephalization concentration of nerve tissue in one end of an animal, forming a head region

cerebellum part of the brain below the cerebrum that coordinates body movements

cerebrum largest part of the brain that controls conscious functions such as reasoning and sight

Chargaff's rules observations by Erwin Chargaff that concentrations of the four nucleotide bases differ among species; and that, within a species, the concentrations of adenine and thymine are always about the same and the concentrations of cytosine and guanine are always about the same

chemical bond force that holds molecules together

chemical digestion chemical breakdown of large, complex food molecules into smaller, simpler nutrient molecules that can be absorbed by the blood

chemical reaction process that changes some chemical substances into others

chemoautotroph producer that uses energy from chemical compounds to make food by chemosynthesis

chemosynthesis process of using the energy in chemical compounds to make food

chitin tough carbohydrate that makes up the cell walls of fungi and the exoskeletons of insects and other arthropods

chlamydia sexually transmitted bacterial infection that is the most common STI in the United States

chlorophyll green pigment in a chloroplast that absorbs sunlight in the light reactions of photosynthesis

chloroplast organelle in the cells of plants and algae where photosynthesis takes place

chordates consists of all animals with a notochord, dorsal hollow nerve cord, post-anal tail, and pharyngeal slits during at least some stage of their life

chromatid one of two identical copies of a chromosome that are joined together at a centromere before a cell divides

chromatin grainy material that DNA forms when it is not coiled into chromosomes

chromosomal alteration mutation that changes chromosome structure

chromosome coiled structure made of DNA and proteins containing sister chromatids that is the form in which the genetic material of a cell goes through cell division

cilia (singular, cilium) short, hairlike projections, similar to flagella, that allow some cells to move

ciliate type of protozoa, such as *Paramecium,* that moves with cilia

circadian rhythm regular change in biology or behavior that occurs in a 24-hour cycle

circulatory system organ system consisting of the heart, blood vessels, and blood that transports materials around the body

clade group of related organisms that includes an ancestor and all of its descendants

climate average weather in an area over a long period of time

climax community final stable stage of ecological succession that may be reached in an undisturbed community

cloaca body cavity with a single opening in amphibians, reptiles, and monotreme mammals that collects and excretes wastes from the digestive and excretory systems and gametes from the reproductive system

Cnidaria invertebrate phylum that includes animals such as jellyfish and corals that are characterized by radial symmetry, tissues, and a stinger called a nematocyst

codominance relationship between two alleles for the same gene in which both alleles are expressed equally in the phenotype of the heterozygote

codon group of three nitrogen bases in nucleic acids that makes up a code "word" of the genetic code and stands for an amino acid, start, or stop

coelom fluid-filled body cavity

coevolution process in which two interacting species evolve together, with each species influencing the other's evolution

commensalism symbiotic relationship in which one species benefits while the other species is not affected

community all of the populations of different species that live in the same area

compact bone dense outer layer of bone that is very hard and strong

comparative anatomy study of the similarities and differences in the structures of different species

comparative embryology study of the similarities and differences in the embryos of different species

competition relationship between living things that depend on the same resources in the same place and at the same time

competitive exclusion principle principle of ecology stating that two different species cannot occupy the same niche in the same place for very long

complementary base pair pair of nucleotide bases that bond together—either adenine and thymine (or uracil) or cytosine and guanine

complete digestive system digestive system consisting of a digestive tract and two body openings (mouth and anus)

compound substance with a unique, fixed composition that consists of two or more elements

condensation process in which water vapor changes to tiny droplets of liquid water

cone structure consisting of scales that bear naked seeds in the type of seed plants called gymnosperms

connective tissue tissue made up of cells that form the body's structure, such as bone and cartilage

consumer organism that consumes other organisms for food

cooperation type of animal behavior in which social animals live and work together for the good of the group

courtship animal behavior that is intended to attract a mate

cranium part of a vertebrate endoskeleton that encloses and protects the brain; also called the skull

crop sac-like structure in the digestive system of birds that stores and moistens food before it is digested

crossing-over exchange of genetic material between homologous chromosomes when they are closely paired during meiosis I

cuticle waxy, waterproof substance produced by epidermal cells of leaves, shoots, and other above-ground parts of plants to preven damage and loss of water by evaporation

cyanobacteria Gram-positive blue-green photosynthetic bacteria of the type that added oxygen to Earth's early atmosphere and evolved into chloroplasts of eukaryotic cells

cytokinesis splitting of the cytoplasm to form daughter cells when a cell divides

cytoplasm all of the material inside the plasma membrane of a cell (excluding organelles)

cytoskeleton structure of filaments and tubules in the cytoplasm that provides a cell with an internal framework

26.4 D

dead zone area in the ocean or other body of water where low oxygen levels from excessive growth of algae have killed all aquatic organisms

deciduous plant type of plant that seasonally loses its leaves to reduce water loss during the cold or dry season each year and grows new leaves later in the year

decomposer organism that breaks down the remains of dead organisms and other organic wastes

demographic transition changes in population that occurred in Europe and North America beginning in the 18^{th} century, in which death rates fell and population growth rates increased, followed by birth rates falling and population growth rates decreasing

dendrite extension of the cell body of a neuron that receives nerve impulses from other neurons

dependent variable variable in a scientific experiment that is affected by another variable, called the independent variable

deposit feeder animal that obtains organic matter for nutrition by eating soil or the sediments at the bottom of a body of water

dermal tissue type of plant tissue that covers the outside of a plant in a single layer of cells called the epidermis

dermis lower layer of the skin that is made of tough connective tissue and contains blood vessels, nerve endings, hair follicles, and glands

detritivore decomposer that consumes detritus

detritus substance composed of dead leaves, other plant remains, and animal feces that collects on the soil or at the bottom of a body of water

dialysis medical procedure in which blood is filtered through a machine in patients with kidney failure

diaphragm large, sheet-like muscle below the lungs that allows breathing to occur when it contracts and relaxes

differentiation process by which unspecialized cells become specialized into one of many different types of cells, such as neurons or epithelial cells

diffusion type of passive transport that does not require the help of transport proteins

digestion process of breaking down food into nutrients that can be absorbed by the blood

digestive system organ system that breaks down food, absorbs nutrients, and eliminates any remaining waste

diploid having two of each type of chromosome

directional selection type of natural selection for a polygenic trait in which one of two extreme phenotypes is selected for, resulting in a shift of the phenotypic distribution toward that extreme

dispersal movement of offspring away from their parents

disruptive selection type of natural selection for a polygenic trait in which phenotypes in the middle of the phenotypic distribution are selected against, resulting in two overlapping phenotypes, one at each end of the distribution

DNA (deoxyribonucleic acid) double-stranded nucleic acid that makes up genes and chromosomes

DNA replication process of copying of DNA prior to cell division

domain taxon in the revised Linnaean system that is larger and more inclusive than the kingdom

dominant allele allele that masks the presence of another allele for the same gene when they occur together in a heterozygote

dormancy state in which a plant slows down cellular activity and may shed its leaves

double helix double spiral shape of the DNA molecule

drug abuse use of a drug without the advice of a medical professional and for reasons not originally intended

drug addiction situation in which a drug user is unable to stop using a drug

26.5 E

eating disorder mental illness in which people feel compelled to eat in a way that causes physical, mental, and emotional health problems

echinoderms invertebrates such as sea stars and sand dollars that are characterized by a spiny endoskeleton, radial symmetry as adults, and a water vascular system

ecological succession changes through time in the numbers and types of species that make up the community of an ecosystem

ecology branch of biology that is the study of how living things interact with each other and with their environment

ecosystem all the living things in a given area together with the physical factors of the nonliving environment

ectoderm outer embryonic cell layer in animals

ectothermy regulation of body temperature from the outside through behavioral changes such as basking in the sun

egg female gamete

ejaculation muscle contractions that propel sperm from the epididymes and out through the urethra in males

electron transport chain series of electron-transport molecules that pass high-energy electrons from molecule to molecule and capture their energy

element pure substance that cannot be broken down into other types of substances

elimination process in which waste passes out of the body

embryo stage of growth and development that occurs from implantation through the eighth week after fertilization in humans

emigration movement of individuals out of a population

emphysema lung disease, usually caused by smoking, in which walls of alveoli break down, so less gas can be exchanged in the lungs

endocrine system human body system of glands that release hormones into the blood

endocytosis type of vesicle transport that moves substances into a cell

endoderm inner embryonic cell layer in animals

endoplasmic reticulum (ER) organelle in eukaryotic cells that helps make and transport proteins

endoskeleton internal skeleton that provides support and protection

endosperm stored food inside a plant seed

endospore spores that form inside prokaryotic cells when they are under stress, enclosing the DNA and helping it survive conditions that may kill the cell

endosymbiotic theory theory that eukaryotic organelles such as mitochondria evolved from ancient, free-living prokaryotes that invaded primitive eukaryotic cells

endothermic reaction chemical reaction that absorbs energy

endothermy regulation of body temperature from the inside through metabolic or other physical changes

energy ability to do work

enzyme protein that speeds up biochemical reactions

epidermis outer layer of skin that consists mainly of epithelial cells and lacks nerve endings and blood vessels

epididymis (plural, epididymes) one of two male reproductive organs where sperm mature and are stored until they leave the body

epiphyte plant that is adapted to grow on other plants and obtain moisture from the air

epistasis situation in which one gene affects the expression of another gene

epithelial tissue tissue made up of cells that line inner and outer body surfaces, such as skin

esophagus long, narrow digestive organ that passes food from the pharynx to the stomach

estrogen female sex hormone secreted by the ovaries

estuary a partly enclosed coastal body of water with one or more rivers or streams flowing into it, and with a free connection to the ocean

ethology branch of biology that studies animal behavior

eukaryote organism that has cells containing a nucleus and other organelles

eukaryotic cell cell that contains a nucleus and other organelles

evaporation process in which liquid water changes to water vapor

evergreen plant type of plant that keeps its leaves and stays green year-round

evidence any type of data that may be used to test a hypothesis

evolution change in the characteristics of living things over time, the change in species over time

exchange pool part of a biogeochemical cycle that holds an element or water for a short period of time

excretion process of removing wastes and excess water from the body

excretory system organ system that removes wastes and excess water from the body and includes the kidneys, large intestine, liver, skin, and lungs

exocytosis type of vesicle transport that moves substances out of a cell

exoskeleton non-bony skeleton that forms on the outside of the body of some invertebrates and provides protection and support

exothermic reaction chemical reaction that releases energy

exotic species species that is introduced (usually by human actions) into a new habitat where it may lack local predators and out-compete native species

experiment special type of scientific investigation that is performed under controlled conditions

exponential growth pattern of population growth in which a population starts out growing slowly but grows faster and faster as population size increases

extinction situation in which a species completely dies out and no members of the species remain

extremophile any type of Archaea that lives in an extreme environment, such as a very salty, hot, or acidic environment

26.6 F

facilitated diffusion diffusion with the help of transport proteins

Fallopian tube one of two female reproductive organs that carry eggs from the ovary to the uterus and provide the site where fertilization usually takes place

feces solid waste that remains after food is digested and is eliminated from the body through the anus

fermentation type of anaerobic respiration that includes glycolysis followed by the conversion of pyruvic acid to one or more other compounds and the formation of NAD^+

fertilization union of two gametes that produces a diploid zygote

fetus developing human organism between weeks 8 and 38 after fertilization

fibrous root threadlike root that makes up part of the fibrous root system of some plants

filter feeder animal that obtains organic matter for nutrition by filtering particles out of water

fish ectothermic, aquatic vertebrate with a streamlined body and gills for absorbing oxygen from water

fitness relative ability of an organism to survive and produce fertile offspring

flagella (singular, flagellum) long, thin protein extensions of the plasma membrane in most prokaryotic cells that help the cells move

flagellate type of protozoa, such as *Giardia,* that moves with flagella

flower structure in angiosperms consisting of male and female reproductive structures that attracts animal pollinators

follicle-stimulating hormone (FSH) pituitary gland hormone that stimulates the ovaries to secrete estrogen and follicles in the ovaries to mature

food organic molecules such as glucose that organisms use for chemical energy

food chain diagram that represents a single pathway through which energy and matter flow through an ecosystem

food web diagram that represents multiple intersecting pathways through which energy and matter flow through an ecosystem

fossil preserved remains or traces of organisms that lived in the past

fossil record the record of life as told by the study and analysis of fossils

frameshift mutation deletion or insertion of one or more nucleotides that changes the reading frame of the genetic material

freshwater biome aquatic biome such as a pond, lake, stream, or river in which the water contains little or no salt

fruit structure in many flowering plants that develops from the ovary and contains seeds

fungi (singular, fungus) kingdom in the domain Eukarya that includes molds, mushrooms, and yeasts

26.7 G

Galápagos Islands group of 16 small volcanic islands in the Pacific Ocean 966 kilometers (600 miles) off the west coast of South America, where Darwin made some of his most important observations during his voyage on the *HMS Beagle*

gall bladder sac-like organ that stores bile from the liver and secretes it into the duodenum of the small intestine

gamete reproductive cell produced during meiosis that has the haploid number of chromosomes

gametogenesis development of haploid cells into gametes such as sperm and egg

gametophyte haploid generation in the life cycle of a plant that results from asexual reproduction with spores and that produces gametes for sexual reproduction

gastrointestinal (GI) tract organs of the digestive system through which food passes during digestion, including the mouth, esophagus, stomach, and small and large intestines

gene unit of DNA on a chromosome that is encoded with the instructions for a single protein

gene cloning process of isolating and making copies of a gene

gene expression use of a gene to make a protein

gene flow change in allele frequencies that occurs when individuals move into or out of a population

gene pool all the genes of all the members of a population

generalist organism that can consume many different types of food

gene theory theory that the characteristics of living things are controlled by genes that are passed from parents to offspring

gene therapy way to cure genetic disorders by inserting normal genes into cells with mutant genes

genetic code universal code of three-base codons that encodes the genetic instructions for the amino acid sequence of proteins

genetic disorder disease caused by a mutation in one or a few genes

genetic drift a random change in allele frequencies that occurs in a small population

genetic engineering using biotechnology to change the genetic makeup of an organism

genetics the science of heredity

genetic trait characteristic that is encoded in DNA

genetic transfer method of increasing genetic variation in prokaryotes that involves cells "grabbing" stray pieces of DNA from their environment or exchanging DNA directly with other cells

genital herpes sexually transmitted infection caused by a herpes virus that is characterized by periodic outbreaks of blisters on the genitals

genital warts small, rough growths on the genitals caused by a sexually transmitted infection with human papillomavirus (HPV)

genotype alleles an individual inherits at a particular genetic locus

genus taxon above the species in the Linnaean classification system; group of closely related species

geologic time scale time line of Earth based on major events in geology, climate, and the evolution of life

germination early growth and development of a plant embryo in a seed

germline mutation mutation that occur in gametes

giardiasis disease caused by *Giardia* protozoa that spreads through contaminated food or water

gills organs in aquatic organisms composed of thin filaments that absorb oxygen from water

gizzard food-grinding organ in the digestive system of birds and some other animals that may contain swallowed stones

global warming recent rise in Earth's average surface temperature generally attributed to an increased greenhouse effect

glucose simple carbohydrate with the chemical formula $C_6H_{12}O_6$ that is the nearly universal food for life

glycolysis first stage of cellular respiration in which glucose is split, in the absence of oxygen, to form two molecules of pyruvate (pyruvic acid) and two (net) molecules of ATP

Golgi apparatus organelle in eukaryotic cells that processes proteins and prepares them for use both inside and outside the cell

gonads glands that secrete sex hormones and produce gametes; testes in males and ovaries in females

gonorrhea common sexually transmitted infection that is caused by bacteria

gradualism model of the timing of evolution in which evolutionary change occurs at a slow and steady pace

Gram-negative bacteria type of bacteria that stain red with Gram stain and have a thin cell wall with an outer membrane

Gram-positive bacteria type of bacteria that stain purple with Gram stain and have a thick cell wall without an outer membrane

grana within the chloroplast, consists of sac-like membranes, known as thylakoid membranes

greenhouse effect natural feature of Earth's atmosphere that occurs when gases in the atmosphere radiate the sun's heat back down to Earth's surface, making Earth's temperature far warmer than it otherwise would be

ground tissue type of plant tissue making up most of the interior of the roots and stems of plants that carries out basic metabolic functions and provides support and storage

groundwater water that exists in the ground either in the soil or in rock layers below the surface

growing season period of time each year when it is warm enough and wet enough for plants to grow

gymnosperm type of seed plant that produces bare seeds in cones

26.8 H

habitat physical environment in which a species lives and to which it has become adapted

habitat loss destruction or disruption of Earth's natural habitats, most often due to human actions such as agriculture, forestry, mining, and urbanization

hair follicle structure in the dermis of skin where a hair originates

haploid having only one chromosome of each type

Hardy-Weinberg theorem founding principle of population genetics that proves allele and genotype frequencies do not change in a population that meets the conditions of no mutation, no migration, large population size, random mating, and no natural selection

heart muscular organ in the chest that that pumps blood through blood vessels when it contracts

heart attack blockage of blood flow to heart muscle tissues that may result in the death of cardiac muscle fibers

hepatitis B inflammation of the liver caused by infection with hepatitis B virus, which is often transmitted through sexual contact

herbivore consumer that eats producers such as plants or algae

heterotroph organism that gets food by consuming other organisms

heterozygote organism that inherits two different alleles for a given gene

homeobox gene gene that codes of regulatory proteins that control gene expression during development

homeostasis process of maintaining a stable environment inside a cell or an entire organism

homologous chromosomes pair of chromosomes that have the same size and shape and contain the same genes

homologous structure structure that is similar in related organisms because it was inherited from a common ancestor

homozygote organism that inherits two alleles of the same type for a given gene

host species that is harmed in a parasitic relationship

human genome all of the DNA of the human species

Human Genome Project international science project that sequenced all 3 billion base pairs of the human genome

human immunodeficiency virus (HIV) virus transmitted through body fluids that infects and destroys helper T cells and eventually causes acquired immunodeficiency syndrome (AIDS)

human papilloma virus (HPV) sexually transmitted virus that causes genital warts and cervical cancer

humoral immune response type of immune response in which B cells produce antibodies against antigens in blood and lymph

hybrid offspring that results from a cross between two different types of parents

hydrogen bond type of chemical bond that forms between molecules: found between water molecules

hydrostatic skeleton type of internal support in an animal body that results from the pressure of fluid within the body cavity known as the coelom

hypertension high blood pressure

hyphae (singular, hypha) thread-like filaments that make up the body of a fungus and consist of one or more cells surrounded by a tubular cell wall

hypothalamus part of the brain that secretes hormones

hypothesis possible answer to a scientific question; must be falsifiable

26.9 I

immigration movement of individuals into a population

immune response specific defense against a particular pathogen

immune system body system that consists of skin, mucous, membranes, and other tissues and organs that defends the body from pathogens and cancer

immunity ability to resist a pathogen due to memory lymphocytes or antibodies to the antigens the pathogen carries

immunization deliberate exposure of a person to a pathogen in order to provoke an immune response and the formation of memory cells specific to that pathogen

immunodeficiency inability of the immune system to fight off pathogens that a normal immune system would be able to resist

implantation process in which a blastocyst embeds in the endometrium lining the uterus

incomplete digestive system digestive system that consists of a digestive cavity and a single opening that serves as both mouth and anus

incomplete dominance relationship between the alleles for a gene in which one allele is only partly dominant to the other allele so an intermediate phenotype results

incubation period of bird reproduction when one or both parents sit on, or brood, the eggs in order to keep them warm until they hatch

independent assortment independent segregation of chromosomes to gametes during meiosis

independent variable variable in a scientific experiment that is manipulated by the researcher to investigate its affect on another variable, called the dependent variable

infancy first year of life after birth in humans

inflammatory response nonspecific response the body first makes to tissue damage or infection

inheritance of acquired characteristics mistaken idea of Jean Baptiste Lamarck that evolution occurs through the inheritance of traits that an organism develops in its own life time

innate behavior behavior closely controlled by genes that occurs naturally, without learning or practice, in all members of a species whenever they are exposed to a certain stimulus; also called instinctive behavior

instinct ability of an animal to perform a behavior the first time it is exposed to the proper stimulus

integumentary system human body system that includes the skin, nails, and hair

interneuron type of neuron that carries nerve impulses back and forth between sensory and motor neurons

interphase stage of the eukaryotic cell cycle when the cell grows, synthesizes DNA, and prepares to divide

interspecific competition relationship between organisms of different species that strive for the same resources in the same place

intertidal zone in marine biomes, the narrow strip along the coastline that is covered by water at high tide and exposed to air at low tide

intraspecific competition relationship between organisms of the same species that strive for the same resources in the same place

invertebrate animal that lacks a vertebral column, or backbone

26.10 J

joint place where two or more bones of the skeleton meet

26.11 K

kelp multicellular seaweed that may grow as large as a tree and occurs in forests found throughout the ocean in temperate and arctic climates

keratin tough, fibrous protein in skin, nails, and hair

keystone species species that plays an especially important role in its community so that major changes in its numbers affect the populations of many other species in the community

kidney main organ of the excretory system that filters blood and forms urine

kidney failure loss of the ability of nephrons of the kidney to function fully

kingdom largest and most inclusive taxon in the original Linnaean classification system

Krebs cycle second stage of aerobic respiration in which two pyruvate (pyruvic acid) molecules from the first stage react to form ATP, NADH, and $FADH_2$

species in which population growth is controlled by density-dependent factors and population size is generally at or near carrying capacity

26.12 L

lactation production of milk for an offspring by mammary glands, which occurs in all female mammals after giving birth or laying eggs

lactic acid fermentation type of anaerobic respiration that includes glycolysis followed by the conversion of pyruvic acid to lactic acid and the formation of NAD^+

lancelets members of the subphylum Cephalochordata

large intestine organ of the digestive system that removes water from food waste and forms feces

larva (plural, larvae) juvenile stage that occurs in the life cycle of many invertebrates, fish, and amphibians and that differs in form and function from the adult stage

larynx organ of the respiratory system between the pharynx and trachea that is also called the voice box because it allows the production of vocal sounds

last universal common ancestor (LUCA) hypothetical early cell (or group of cells) that gave rise to all subsequent life on Earth

latency period of dormancy of a virus inside a living body that may last for many years

law of independent assortment Mendel's second law stating that factors controlling different characteristics are inherited independently of each other

law of segregation Mendel's first law stating that the two factors controlling a characteristics separate and go to different gametes

learning change in behavior that occurs as a result of experience

leukocyte white blood cell produced by bone marrow to fight infections

lichen mutualistic relationship between a fungus and a cyanobacterium or green alga

life cycle series of stages a sexually reproducing organism goes through from one generation to the next

ligament band of fibrous connective tissue that holds bones together

light reactions first stage of photosynthesis in which light energy from the sun is captured and changed into chemical energy that is stored in ATP and NADPH

lignin tough, hydrophobic carbohydrate molecule that stiffens and waterproofs vascular tissues of plants

linkage map map that shows the positions of genes on a chromosome based on the frequency of crossing-over between the genes

linked genes genes that are located on the same chromosome

Linnaean classification system system of classifying organisms based on observable physical traits; consists of a hierarchy of taxa, fro the kingdom to the species

lipid organic compound such as fat or oil

liver organ of digestion and excretion that secretes bile for lipid digestion and breaks down excess amino acids and toxins in the blood

locus position of a gene on a chromosome

logistic growth pattern of population growth in which growth slows and population size levels off as the population approaches the carrying capacity

lung organ of the respiratory system in which gas exchange takes place between the blood and the atmosphere

luteinizing hormone (LH) pituitary gland hormone that stimulates the testes to secrete testosterone and the ovaries to secrete estrogen

lymph fluid that leaks out of capillaries into spaces between cells and circulates in the vessels of the lymphatic system

lymphatic system system of the body consisting of organs, vessels, nodes, and lymph that produces lymphocytes and filters pathogens from body fluids

lymph node small structures located on lymphatic vessels where pathogens are filtered from lymph and destroyed by lymphocytes

lymphocyte type of leukocyte that is a key cell in the immune response to a specific pathogen

26.13 M

macroevolution evolutionary change that occurs over geologic time above the level of the species

macronutrient nutrient such as carbohydrates, proteins, lipids, or water that is needed by the body in relatively large amounts

malaria disease caused by *Plasmodium* protozoa and transmitted by mosquitoes in tropical and subtropical regions of the world

mammal endothermic, tetrapod vertebrate that lays amniotic eggs and has mammary glands (in females) and hair or fur

mammary gland gland in female mammals that produces milk for offspring

mantle layer of tissue that lies between the shell and body of a mollusk and forms a cavity, called the mantle cavity, that pumps water for filter feeding

marine biome aquatic biome in the salt water of the ocean

marsupial therian mammal in which the embryo is born at an early, immature stage and completes its development outside the mother's body in a pouch on her belly

mass extinction extinction event in which many if not most species abruptly disappear from Earth

matter anything that takes up space and has mass

mechanical digestion physical breakdown of chunks of food into smaller pieces by organs of the digestive system

medusa (plural, medusae) basic body plan in cnidarians such as jellyfish that is bell-shaped and typically motile

meiosis type of cell division in which the number of chromosomes is reduced by half and four haploid cells result

melanin brown pigment produced by melanocytes in the skin that gives skin most of its color and prevents UV light from penetrating the skin

memory cell lymphocyte (B or T cell) that retains a "memory" of a specific pathogen after an infection is over and thus provides immunity to the pathogen

menarche beginning of menstruation; first monthly period in females

menopause period during which menstrual cycles slow down and eventually stop in middle adulthood

menstrual cycle monthly cycle of processes and events in the ovaries and uterus of a sexually mature human female

menstruation process in which the endometrium of the uterus is shed from the body during the first several days of the menstrual cycle; also called monthly period

meristem type of plant tissue consisting of undifferentiated cells that can continue to divide and differentiate and from which plants grow in length or width

mesoderm embryonic cell layer in many animals that is located between the endoderm (inner cell layer) and ectoderm (outer cell layer)

mesophyll specialized tissue inside plant leaves where photosynthesis takes place

Mesozoic Era age of dinosaurs that lasted from 245–65 million years ago

messenger RNA (mRNA) type of RNA that copies genetic instructions from DNA in the nucleus and carries them to the cytoplasm

metabolism sum of all the biochemical reactions in an organism

metamorphosis process in which a larva undergoes a major transformation to change into the adult form, which occurs in amphibians, arthropods, and other invertebrates

metaphase second phase of mitosis during which chromosomes line up at the equator of the cell

microevolution evolutionary change that occurs over a relatively short period of time within a population or species

micronutrient nutrient such as a vitamin or mineral that is needed by the body in relatively small amounts

migration regular movement of individuals or populations each year during certain seasons, usually to find food, mates, or other resources

mineral chemical element such as calcium or potassium that is needed in relatively small amounts for proper body functioning

mitochondria (singular, mitochondrion) organelle in eukaryotic cells that makes energy available to the cell in the form of ATP molecules

mitosis process in which the nucleus of a eukaryotic cell divides

model representation of part of the real world

molecular clock using DNA (or proteins) to measure how long it has been since related species diverged from a common ancestor

Mollusca phylum of invertebrates that are generally characterized by a hard outer shell, a mantle, and a feeding organ called a radula

molting process in which an animal sheds and replaces the outer covering of the body, such as the exoskeleton in arthropods

monosaccharide simple sugar such as glucose that is a building block of carbohydrates

monotreme type of mammal that reproduces by laying eggs

motility the ability to move

motor neuron type of neuron that carries nerve impulses from the central nervous system to muscles and glands

mucous membrane epithelial tissue that lines inner body surfaces and body openings and produces mucus

mucus slimy substance produced by mucous membranes that traps pathogens, particles, and debris

multiple allele trait trait controlled by one gene with more than two alleles

muscle fiber long, thin muscle cell that has the ability to contract, or shorten

muscle tissue tissue made up of cells that can contract; includes smooth, skeletal, and cardiac muscle tissue

muscular system human body system that includes all the muscles of the body

mutagen environmental factors that causes mutations

mutation change in the sequence of bases in DNA or RNA

mutualism type of symbiotic relationship in which both species benefit

mycelium body of a fungus that consists of a mass of threadlike filaments called hyphae

mycorrhiza mutualistic relationship between a plant and a fungus that grows in or on its roots

myelin sheath lipid layer around the axon of a neuron that allows nerve impulses to travel more rapidly down the axon

MyPlate visual guideline for balanced eating, replacing MyPyramid in 2011

MyPyramid visual dietary guideline that shows the relative amounts of foods in different food groups that should be eaten each day

26.14 N

natural resource something supplied by nature that helps support life

natural selection evolutionary process in which some living things produce more offspring than others so the characteristics of organisms change over time

nature-nurture debate debate over the extent to which genes (nature) or experiences in a given environment (nurture) control traits such as animal behaviors

nectar sweet, sugary liquid produced by the flowers of many angiosperms to attract animal pollinators

Nematoda phylum of invertebrates called roundworms, which have a pseudocoelom and complete digestive system

neocortex layer of nerve cells covering the cerebrum of the mammalian brain that plays an important role in many complex brain functions

nephron structural and functional unit of the kidney that filters blood and forms urine

nerve one of many cable-like bundles of axons that make up the peripheral nervous system

nerve impulse electrical signal transmitted by the nervous system

nervous system human body system that carries electrical messages throughout the body

nervous tissue tissue made up of neurons, or nerve cells, that carry electrical messages

neuron nerve cell; structural and functional unit of the nervous system

neurotransmitter chemical that carries a nerve impulse from one nerve to another at a synapse

niche role of a species in its ecosystem that includes all the ways the species interacts with the biotic and abiotic factors of the ecosystem

nitrogen cycle interconnected pathways through which nitrogen is recycled through the biotic and abiotic components of the biosphere

nitrogen fixation process of changing nitrogen gas to nitrates that is carried out by nitrogen-fixing bacteria in the soil or in the roots of legumes

nondisjunction failure of replicated chromosomes to separate during meiosis II, resulting in some gametes with a missing chromosome and some with an extra chromosome

nonrenewable resource natural resource that exists in a fixed amount and can be used up

notochord stiff support rod that runs from one end of the body to the other in animals called chordates

nucleic acid organic compound such as DNA or RNA

nucleotide small molecule containing a sugar, phosphate group, and base that is a building block of nucleic acids

nucleus (plural, nuclei) organelle inside eukaryotic cells that contains most of the cell's DNA and acts as the control center of the cell

nutrient substance the body needs for energy, building materials, or control of body processes

26.15 O

obesity condition in which the body mass index is 30.0 kg/m^2 or greater

observation anything that is detected with the senses

omnivore consumer that eats both plants and animals

oogenesis process of producing eggs in the ovary

open circulatory system type of circulatory system in which blood flows not only through blood vessels but also through a body cavity

operator a region of an operon where regulatory proteins bind

operon region of prokaryotic DNA that consists of a promoter, an operator, and one or more genes that encode proteins needed for a specific function

organ structure composed of more than one type of tissue that performs a particular function

organelle structure within the cytoplasm of a cell that is enclosed within a membrane and performs a specific job

organic compound compound found in living things that contains mainly carbon

organism an individual living thing

organ system group of organs that work together to do a certain job

osmosis diffusion of water molecules across a membrane

ossification process in which mineral deposits replace cartilage and change it into bone

osteoblast type of bone cell that makes new bone cells and secretes collagen

osteoclast type of bone cell that dissolves minerals in bone and releases them back into the blood

osteocyte type of bone cell that regulates mineral homeostasis by directing the uptake of minerals from the blood and the release of minerals back into the blood as needed

ovary one of two female reproductive organs that produces eggs and secretes estrogen

ovipary type of reproduction in which an embryo develops within an egg outside the mother's body

ovovivipary type of reproduction in which an embryo develops inside an egg within the mother's body but in which the mother provides no nourishment to the developing embryo in the egg

ovulation release of a secondary oocyte from the uterus about half way through the menstrual cycle

ozone hole hole in the ozone layer high in the atmosphere over Antarctica caused by air pollution destroying ozone

26.16 P

paleontologist scientist who finds and studies fossils to learn about evolution and understand the past

Paleozoic Era age of “old life” from 544–245 million years ago that began with the Cambrian explosion and ended with the Permian extinction

pancreas gland near the stomach that secretes insulin and glucagon to regulate blood glucose and enzymes to help digest food

parasite species that benefits in a parasitic relationship

parasitism symbiotic relationship in which one species benefits while the other species is harmed

parathyroid glands a pair of small glands in the neck that secretes hormones that regulate blood calcium

passive immunity type of immunity to a particular pathogen that results when antibodies are transferred to a person who has never been exposed to the pathogen

passive transport movement of substances across a plasma membrane that does not require energy

pathogen disease-causing agent such as a bacterium, virus, fungus, or protozoan

pedigree chart showing how a trait is passed from generation to generation within a family

penis male reproductive organ containing the urethra, through which sperm and urine pass out of the body

periosteum tough, fibrous membrane that covers the outer surface of bone

peripheral nervous system (PNS) one of two major divisions of the nervous system that consists of all the nervous tissue that lies outside the central nervous system

peristalsis rapid, involuntary, wave-like contraction of muscles that pushes food through the GI tract and urine through the ureters

Permian extinction extinction at the end of the Paleozoic Period that was the biggest mass extinction the world had ever seen until then

petal outer parts of flowers that are usually brightly colored to attract animal pollinators

pH scale that is used to measure acidity

phagocytosis process in which leukocytes engulf and break down pathogens and debris

pharmacogenomics field that is tailoring medical treatments to fit our genetic profiles

pharynx long, tubular organ that connects the mouth and nasal cavity with the larynx through which air and food pass

phenotype characteristics of an organism that depend on how the organism's genotype is expressed

phloem type of vascular tissue in a plant that transports food from photosynthetic cells to other parts of the plant

phospholipid bilayer double layer of phospholipid molecules that makes up a plasma membrane

photic zone area in an aquatic biome that extends to a maximum depth of 200 meters

photoautotroph producer that uses energy from sunlight to make food by photosynthesis

photosynthesis process of using the energy in sunlight to make food (glucose)

photosystem group of molecules, including chlorophyll, in the thylakoid membrane of a chloroplast that captures light energy

phylogenetic tree diagram that shows how species are related to each other through common ancestors

phylogeny evolutionary history of a group of related organisms

phytoplankton bacteria and algae that use sunlight to make food

pineal gland gland of the endocrine system that secretes the hormone melatonin that regulates sleep-wake cycles

pioneer species type of species that first colonizes a disturbed area

pistil female reproductive structure of a flower that consists of a stigma, style, and ovary

pituitary gland master gland of the endocrine system that secretes many hormones, the majority of which regulate other endocrine glands

placenta temporary organ that consists of a large mass of maternal and fetal blood vessels through the mother's and fetus's blood exchange substances

placental mammal therian mammal in which a placenta develops during pregnancy to sustain the fetus while it develops inside the mother's uterus

plant multicellular eukaryote with chloroplasts, cell walls made of cellulose, and specialized reproductive organs

plasma golden-yellow fluid part of blood that contains many dissolved substances and blood cells

plasma membrane thin coat of lipids (phospholipids) that surrounds and encloses a cell

plasmid small, circular piece of DNA in a prokaryotic cell

platelet cell fragment in blood that helps blood clot

Platyhelminthes invertebrate phylum of flatworms that are characterized by a flat body because they lack a coelom or pseudocoelom

pleiotropy situation in which a single gene affects more than one trait

pneumonia disease in which the alveoli of the lungs become inflamed and filled with fluid as a result of infection or injury

point mutation change in a single nucleotide base in the genetic material

polarity difference in electrical charge between different parts of the same molecule

pollen tiny grains that bear the male gametes of seed plants and transfer sperm to female reproductive structures

pollination fertilization in plants in which pollen is transferred to female gametes in an ovary

polygenic characteristic characteristic, or trait, controlled by more than one gene, each of which may have two or more alleles

polymerase chain reaction (PCR) biotechnology process that makes many copies of a gene or other DNA segment

polynucleotide chain of nucleotides that alone or with another such chain makes up a nucleic acid

polyp basic body plan in cnidarians such as jellyfish that is tubular in shape and typically sessile

polypeptide chain of amino acids that alone or with other such chains makes up a protein

polysaccharide chain of monosaccharides that makes up a complex carbohydrate such as starch

population all the organisms of the same species that live in the same area

population density average number of individuals in a population per unit of area or volume

population distribution describes how the individuals are distributed, or spread throughout their habitat

population genetics science focusing on evolution within populations that is the area of overlap between evolutionary theory and Mendelian genetics

population growth rate (r) how fast a population changes in size over time

population pyramid bar graph that represents the age-structure of a population

Porifera invertebrate phylum of sponges, which have a non-bony endoskeleton and are sessile as adults

precipitation water that falls from clouds in the atmosphere to Earth's in the form of rain, snow, sleet, hail, or freezing rain

predation relationship in which members of one species consume members of another species

predator species that consumes another in a predator-prey relationship

prediction statement that tells what will happen under certain conditions

pregnancy carrying of one or more offspring from fertilization until birth

prey species that is consumed by another in a predator-prey relationship

primary succession change in the numbers and types of species that live in a community that occurs in an area that has never before been colonized

probability the likelihood, or chance, than a certain event will occur

producer organism that produces food for itself and other organisms

product substance that forms as the result of a chemical reaction

prokaryote single-celled organism that lacks a nucleus

prokaryotic cell cell without a nucleus that is found in single-celled organisms

promoter region of a gene where a RNA polymerase binds to initiate transcription of the gene

prophase first phase of mitosis during which chromatin condense into chromosomes, the nuclear envelope breaks down, centrioles separate, and a spindle begins to form

protein organic compound made up of amino acids

protein synthesis process in which cells make proteins that includes transcription of DNA and translation of mRNA

protist kingdom in the domain Eukarya that includes all eukaryotes except plants, animals, and fungi

protozoa (singular, protozoan) animal-like protists such as *Amoeba* and *Paramecium*

pseudocoelom partial, fluid-filled cavity inside the body of some invertebrates

pseudopod temporary, foot-like extension of the cytoplasm that some cells use for movement or feeding

psychoactive drug drug that affects the central nervous system, generally by influencing the transmission of never impulses in the brain

puberty period during which humans become sexually mature

pulmonary circulation part of the circulatory system that carries blood between the heart and lungs

punctuated equilibrium model of the timing of evolution in which long periods of little evolutionary change are interrupted by bursts of rapid evolutionary change

Punnett square chart for determining the expected percentages of different genotypes in the offspring of two parents

pupa life cycle stage of many insects that occurs between the larval and adult stages and during which the insect is immobile, may be encased within a cocoon, and changes into the adult form

26.17 Q

26.18 R

radial symmetry symmetry of a body plan in which there is a distinct top and bottom but not distinct head and tail ends, so the body can be divided into two halves like a pie

reactant starting material in a chemical reaction

recessive allele allele that is masked by the presence of another allele for the same gene when they occur together in a heterozygote

recombinant DNA DNA that results when DNA from two organisms is combined

red blood cell type of cell in blood that contains hemoglobin and carries oxygen

reflex rapid motor response to a sensory stimulus in which nerve impulses travel in an arc that includes the spinal cord but not the brain

regeneration regrowing of tissues, organs, or limbs that have been lost or damaged

regulatory element region of DNA where a regulatory protein binds

regulatory protein protein that regulates gene expression

relative dating method of dating fossils by their location in rock layers; determines which fossils are older or younger but not their age in years

renewable resource natural resource that can be replenished by natural processes as quickly as humans use it

reproduction process by which living things give rise to offspring

reproductive system system of organs that produces gametes and secretes sex hormones

reptile ectothermic, tetrapod vertebrate that lays amniotic eggs; includes crocodiles, lizards, snakes, and turtles

reservoir part of a biogeochemical cycle that holds an element or water for a long period of time

respiration exchange of gases between the body and the outside air

respiratory system organ system that brings oxygen into the body and releases carbon dioxide into the atmosphere

resting potential difference in electrical charge across the plasma membrane of a neuron that is not actively transmitting a nerve impulse

rhizoid hair-like structure in a nonvascular plant that absorbs water and minerals and anchors the plant to a surface

ribosomal RNA type of RNA that helps form ribosomes and assemble proteins

ribosome organelle inside all cells where proteins are made

ringworm skin infection caused by the fungus *Trichophyton* that causes a characteristic ring-shaped rash

RNA (ribonucleic acid) single-stranded nucleic acid that helps make proteins

RNA world hypothesis hypothesis that RNA was the first organic molecule to evolve and that early life was based on RNA, rather than DNA or protein

root hair tiny hairlike structure that extends from an epidermal cell of a plant root and increases the surface area for absorption

root system all the roots of a plant, including primary roots and secondary roots

species in which population growth is rapid but death rates are high so population size is generally below the carrying capacity

runoff precipitation that falls on land and flows over the surface of the ground

26.19 S

saprotroph decomposer such as a fungus or protozoan that feeds on any remaining organic matter that is left after other decomposers do their work

saturated fatty acid molecule in lipids in which carbon atoms are bonded to as many hydrogen atoms as possible

sauropsid type of early amniote that evolved during the Carboniferous Period and eventually gave rise to dinosaurs, reptiles, and birds

scavenger decomposer that consumers the soft tissues of dead animals

science distinctive way of gaining knowledge about the natural world that tries to answer questions with evidence and logic

scientific investigation plan for asking questions and testing possible answers

scientific law statement describing what always happens under certain conditions in nature

scientific method the process of a scientific investigation

scientific theory broad explanation that is widely accepted as true because it is supported by a great deal of evidence

sebaceous gland gland in the dermis of skin that produces sebum, an oily substance that waterproofs the skin and hair

secondary succession change in the numbers and types of species that live in a community that occurs in an area that was previously colonized but has been disturbed

seed structure produced by a seed plant that contains an embryo and food supply enclosed within a tough coat

seed coat tough covering of a seed that protects the embryo and keeps it from drying out until conditions are favorable for germination

segmentation division of an animal body into multiple segments

semen fluid containing sperm and gland secretions that nourish sperm and carry them through the urethra and out of the body

sensory neuron type of neuron that carries nerve impulses from tissue and organs to the spinal cord and brain

sensory receptor specialized nerve cell that responds to a particular type of stimulus such as light or chemicals

sepal part of a flower that helps protect it while it is still in bud

sessile of or relating to an animal that is unable to move from place to place

sex chromosome X or Y chromosome (in humans)

sex hormone chemical messenger that controls sexual development and reproduction

sex-linked gene gene located on a sex chromosome

sex-linked trait traits controlled by a gene located on a sex chromosome

sexual dimorphism differences between the phenotypes of males and females of the same species

sexually transmitted infection (STI) infection caused by a pathogen that spreads mainly through sexual contact; also known as sexually transmitted disease (STD)

sexual reproduction type of reproduction that involves the fertilization of gametes produced by two parents and produces genetically variable offspring

sixth mass extinction current mass extinction caused primarily by habitat loss due to human actions

skeletal muscle voluntary, striated muscle that is attached to bones of the skeleton and helps the body move

skeletal system human body system that consists of all the bones of the body as well as cartilage and ligaments

sliding filament theory theory that explains muscle contraction by the sliding of myosin filaments over actin filaments within muscle fibers

slime mold fungus-like protist commonly found on rotting logs and other decaying organic matter

small intestine long, narrow, tube-like organ of the digestive system where most chemical digestion of food and virtually all absorption of nutrients take place

smooth muscle involuntary, nonstriated muscle that is found in the walls of internal organs such as the stomach

social animal animal that lives in a society

society close-knit group of animals of the same species that live and work together

sodium-potassium pump type of active transport in which sodium ions are pumped out of the cell and potassium ions are pumped into the cell with the help of a carrier protein and energy from ATP

soil mixture of eroded rock, minerals, organic matter, and other materials that is essential for plant growth and forms the foundation of terrestrial ecosystems

solution mixture that has the same composition throughout

somatic mutation mutation that occurs in cells of the body other than gametes

somatic nervous system (SNS) division of the peripheral nervous system that controls voluntary, conscious activities and reflexes

spawning depositing large numbers of gametes in the same place and at the same time by fish or amphibians

specialization evolution of different adaptations in competing species, which allows them to live in the same area without competing

speciation process by which a new species evolves

species group of organisms that are similar enough to mate together and produce fertile offspring

sperm male gamete

spermatogenesis process of producing sperm in the testes

spermatophyte type of plant that reproduces by producing seeds

spinal cord thin, tubular bundle of nervous tissue that extends from the brainstem down the back to the pelvis and connects the brain with the peripheral nervous system

spongy bone light, porous inner layer of bone that contains bone marrow

sporangium (plural, sporangia) structure on a plant of the sporophyte generation that produces spores for asexual reproduction

sporophyte diploid generation in the life cycle of a plant that results from sexual reproduction with gametes and that produces spores for asexual reproduction

sporozoa (singular, sporozoan) type of protozoa that cannot move as adults

stabilizing selection type of natural selection for a polygenic trait in which phenotypes at both extremes of the phenotypic distribution are selected against, resulting in a narrowing of the range of phenotypic variation

stamen male reproductive structure of a flower that consists of a stalk-like filament and a pollen-producing anther

stimulus something that triggers a behavior

stomach sac-like organ of the digestive system between the esophagus and small intestine in which both mechanical and chemical digestion take place

stomata (singular, stoma) tiny pore in the epidermis of a plant leaf that controls transpiration and gas exchange with the air

stroma space outside the thylakoid membranes of a chloroplast where the Calvin cycle of photosynthesis takes place

sublimation process in which ice and snow change directly to water vapor

survivorship curve graph that represents the individuals still alive at each age in a population

sustainable use use of resources in a way that meets the needs of the present and also preserves the resources for the use of future generations

sweat gland gland in the dermis of skin that produces the salty fluid called sweat, which excretes wastes and helps cool the body

swim bladder balloon-like internal organ in most fish that can be used to move up or down through the water column by changing the amount of gas it contains

symbiosis close relationship between organisms of different species in which at least one of the organisms benefits from the relationship

sympatric speciation evolution of a new species that occurs when without geographic separation first occurring between members of an original species

synapse place where an axon terminal meets another cell

synapsid type of early amniote that evolved during the Carboniferous Period and eventually gave rise to mammals

synthetic biology field of biology involved in engineering new functions from living systems

syphilis sexually transmitted infection caused by bacteria that may eventually be fatal if untreated

systemic circulation part of the circulatory system that carries blood between the heart and body

26.20 T

taproot single, thick primary root that characterizes the root system of some plants

target cell type of cell on which a particular hormone has an effect because it has receptor molecules for the hormone

TATA box regulatory element that is part of the promoter of most eukaryotic genes

taxa a grouping of organisms in a classification system such as the Linnaean system; for example, species or genus

taxonomy science of classifying organisms

T cell type of lymphocyte involved in cell-mediated immunity in which cells infected with viruses are destroyed

telophase last stage of mitosis during which chromosomes uncoil to form chromatin, the spindle breaks down, and new nuclear membranes form

tendon tough connective tissue that attaches skeletal muscle to bones of the skeleton

terrestrial biome a biome of or pertaining to land, as in terrestrial ecosystem

testis (plural, testes) one of two male reproductive organs that produces sperm and secretes testosterone

testosterone male sex hormone secreted by the testes

tetrapod vertebrate with four legs (amphibian, reptile, bird, or mammal)

therapsid type of extinct organism that lived during the Permian Period and gave rise to mammals

therian mammal viviparous mammal that may be either a marsupial or placental mammal

thylakoid membrane membrane in a chloroplast where the light reactions of photosynthesis occur

thyroid gland large endocrine gland in the neck that secretes hormones that control the rate of cellular metabolism throughout the body

tissue group of cells of the same kind that perform a particular function in an organism

trachea long, tubular organ of the respiratory system, also called the wind pipe, that carries air between the larynx and lungs

tracheophyte type of plant that has vascular tissues, such as a seed plant or flowering plant

transcription process in which genetic instructions in DNA are copied to form a complementary strand of mRNA

transfer RNA (tRNA) type of RNA that brings amino acids to ribosomes where they are joined together to form proteins

transgenic crop crop that has been genetically modified with new genes that code for traits useful to humans

translation process in which genetic instructions in mRNA are "read" to synthesize a protein

transpiration process in which plants give off water vapor from photosynthesis through tiny pores, called stomata, in their leaves

transport protein protein in a plasma membrane that helps other substances cross the membrane

trichomoniasis common sexually transmitted infection that is caused by protozoa

trilobite oldest known arthropod, which is now extinct and known only from numerous fossils

trophic level feeding position in a food chain or food web, such as producer, primary consumer, or secondary consumer

tropism turning by an organism or part of an organism toward or away from an environmental stimulus

tumor abnormal mass of cells that may be cancerous

tunicates members of the subphylum Urochordata are tunicates (also called sea squirts)

26.21 U

unsaturated fatty acid molecule in lipids in which some carbon atoms are bonded to other groups of atoms rather than to hydrogen atoms

ureter muscular, tube-like organ of the urinary system that moves urine by peristalsis from a kidney to the bladder

urethra muscular, tube-like organ of the urinary system that carries urine out of the body from the bladder; in males, it also carries sperm out of the body

urinary system organ system that includes the kidneys and is responsible for filtering waste products and excess water from the blood and excreting them from the body

urination process in which urine leaves the body through a sphincter at the end of the urethra

urine liquid waste product of the body that is formed by the kidneys and excreted by the other organs of the urinary system

uterus (plural, uteri) female reproductive organ in therian mammals where an embryo or fetus grows and develops until birth

26.22 V

vaccine substance containing modified pathogens that does not cause disease but provokes an immune response and results in immunity to the pathogen

vacuole large saclike organelle that stores and transports materials inside a cell

vagina female reproductive organ that receives sperm during sexual intercourse and provides a passageway for a baby to leave the mother's body during birth

vascular tissue type of tissue in plants that transports fluids through the plant; includes xylem and phloem

vector organism such as an insect that spreads pathogens from host to host

vegetative reproduction asexual reproduction in plants using nonreproductive tissues such as leaves, stems, or roots

vein type of blood vessel that carries blood toward the heart from the lungs or body

ventilation process of carrying air from the atmosphere into the lungs

vertebrae (singular, vertebra) repeating bony units that make up the vertebral column of vertebrates

vertebral column bony support structure that runs down the back of a vertebrate animal; also called a backbone

vertebrate animal with a vertebral column, or backbone

vesicle small saclike organelle that stores and transports materials inside a cell

vesicle transport type of active transport in which substances are carried across the cell membrane by vesicles

vestigial structure structure such as the human tailbone or appendix that evolution has reduced in size because it is no longer used

villi (singular, villus) microscopic, finger-like projections in the mucous membrane lining the small intestine that form a large surface area for the absorption of nutrients

virion individual virus particle that consists of nucleic acid within a protein capsid

virus tiny, nonliving particle that contains DNA but lacks other characteristics of living cells

vitamin organic compound needed in small amounts for proper body functioning

vivipary type of reproduction in which an embryo develops within, and is nourished by, the mother's body

vulva external female reproductive structures, including the labia and vaginal opening

26.23 W

water cycle interconnected pathways through which water is recycled through the biotic and abiotic components of the biosphere

water mold fungus-like protist commonly found in moist soil and surface water

weed plant that is growing where people do not want it

wetland area that is saturated with water or covered by water for at least one season of the year

white blood cell type of cell in blood that defends the body against invading microorganisms or other threats in blood or extracellular fluid

26.24 X

xerophyte plant that is adapted to a very dry environment

X-linked gene gene located on the X chromosome

X-linked trait trait controlled by a gene located on the X chromosome

xylem type of vascular tissue in a plant that transports water and dissolved nutrients from roots to stems and leaves

26.25 Y

26.26 Z

zooplankton tiny animals that feed on phytoplankton

zygospore diploid spore in fungi that is produced by the fusion of two haploid parent cells

zygote diploid cell that forms when two haploid gametes unite during fertilization