

Part 3: Biology

Chapter 15: The Basic Unit of Life—The Cell

Chapter 16: Genetics

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Chapter 21: Ecology



I've learned in my study of biology that this little leaf is on Earth. No other leaf, in the present, past, or future, c

same. Likewise for no two identical trees, no two identical ladybug, no two identical human faces—no two identical bit of life on Earth is unique. Yet all of Earth's living things know one another and have many things in common. What a We'll learn that and more as we explore biology, the st

Chapter 15

The Basic Unit of Life—The



15.1 Characteristics of Life

INTEGRATED SCIENCE 15A: CHEMISTRY: *The*
that Make Up Life 

15.2 The Two Types of Cells: Prokaryotic and Eukar

HISTORY OF SCIENCE: *Cell Theory* □

INTEGRATED SCIENCE 15B: PHYSICS: *The Microscopic World* □

15.3 Tour of a Eukaryotic Cell □

15.4 The Cell Membrane □

15.5 Transport Into and Out of Cells □

MATH CONNECTION: *Why Does Diffusion Limit Cell Size?* □

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15.7 How Cells Reproduce □

SCIENCE AND SOCIETY: *Henrietta Lacks and Immortal Cells* □

15.8 How Cells Use Energy □

INTEGRATED SCIENCE 15C: CHEMISTRY: *ATP and Energy Reactions in Cells* □

INTEGRATED SCIENCE 15D: PHYSICS AND CHEMISTRY: *Photosynthesis* □

TECHNOLOGY: *Artificial Leaves* □

INTEGRATED SCIENCE 15E: CHEMISTRY: *Cell and Fermentation* □

IT'S A rock. Or wait—could it be a well-disguised stone juicy crab to come near? We know a living thing when our eyes fool us sometimes. But what, exactly, is a living thing? All living things share characteristics that differentiate them from non-living things? Do they all reproduce? Use energy? Evolve? Are they all made up of one or more cells? What are cells? How do they function? How do cells make new cells? How do cells obtain energy? How do we take advantage of this process when we bake bread or beer? How do plant cells use sunlight, air, and water to grow? and how is this process the basis of life as we know it? In this chapter, we will explore the nature of life and the world of the cell.

15.1 Characteristics of Life

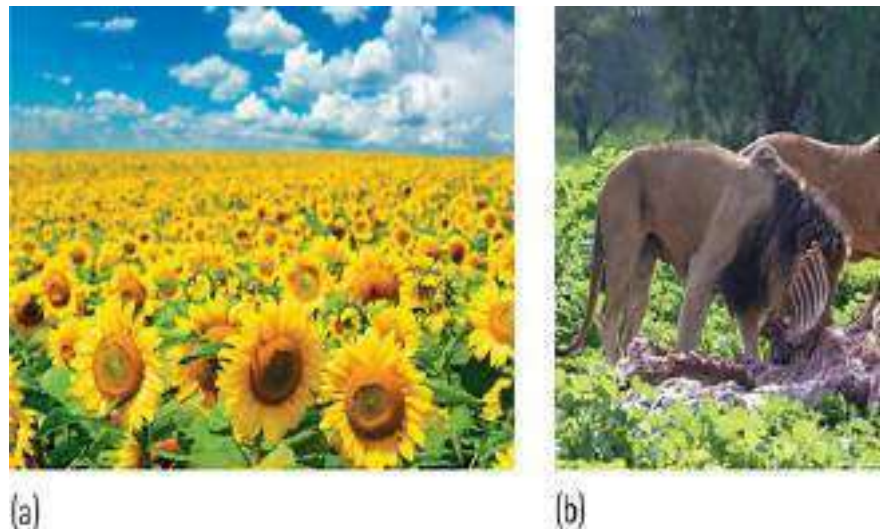
Learning Objective

List and describe the characteristics of living things.

Biology is the study of life and living organisms. But what is an organism? What distinguishes living things from nonliving things?

Living things share certain characteristics. For one thing, they use energy. Living things, such as the sunflowers and lions in Figure 15.1, obtain energy from the environment and convert it into other forms of energy for their own use. Plants take electromagnetic energy from the sun and convert it into chemical energy, which they can use to grow and reproduce. Plants and leaves use this energy to power photosynthesis. Animals eat, converting the chemical energy they get from food into chemical energy, which they store in their bodies. This chemical energy is eventually converted again into kinetic energy and heat as animals crawl, or fly, or grow. Of course, the laws in which living things convert energy are consistent with the laws of physics. This means, first, that energy is always conserved. Second, that in any energy conversion, some energy is lost to the environment as heat.

Figure 15.1



Living things take energy from the environment and convert it into different forms of energy. (a) Sunflowers convert energy from sunlight into chemical energy, which can be used to build tissues or store energy. (b) Lions convert the chemical energy stored in food into mechanical energy for activity, or use it for growth and reproduction.

Unifying Concept

The Law of Conservation of Energy [Section 4.10](#)

The Second Law of Thermodynamics [Section 6.5](#)

Another characteristic of living things is that they develop over time. When chicks hatch, they are small and covered with downy feathers. Over time, they grow bigger, and their downy feathers are replaced by stiff adult feathers ([Figure 15.2](#)).

Figure 15.2



Living things develop and grow over time.

Living things maintain themselves. They generate structures and leaves or skin and bones, and they repair damage to those structures. When you scrape your knee, your blood is bleeding, and the wounded skin scabs over and heals. Living things maintain their internal environment, keeping it stable in

changing external conditions. Whether it is freezing cold or hot, your body temperature stays right around 37°C (98.6°F).

Living things have the capacity to reproduce. They make exact or inexact copies of themselves. **Figure 15.3** shows ways living things reproduce, asexually and sexually. In *asexual reproduction*, a living organism reproduces all by itself, dividing into two. Bacteria typically reproduce asexually. In *sexual reproduction*, organisms form special sex cells, such as sperm and eggs, which develop into new individuals. Humans, penguins, beetles, and many other organisms reproduce sexually.

Figure 15.3



(a)



(b)

Living things have the capacity to reproduce. (a) Bacteria asexually by dividing. (b) Penguins reproduce sexually.

Finally, living things are parts of populations that evolve and do not remain constant from one generation to the next but change over time. Often, populations change in response to their environment. During the Industrial Revolution, when cities became polluted and blackened with soot, peppered moth populations evolved. Dark-winged moths became more common, while light-winged moths became less common. After antipollution laws were passed and cities cleaned up, light-winged moths again became more common.

Check Yourself

Interactive

Question 1

Check Answer

Question 2

Check Answer

Question 1

Cars are not living things. Which characteristics of living organisms do they have and which are they lacking?

Check Answer

Cars are not living things. Which characteristics of living organisms do they have and which are they lacking?

Answer: Cars use energy, converting the energy in gasoline into motion. They can be able to argue that cars “develop” over time, acquiring nicks and scratches and wearing down the treads on their tires. However, cars do not mate, do not reproduce, and do not evolve.

Question 2

Integrated Science 15A: Chemistry

The Big Molecules that Make Us

Learning Objective

Describe the structure and functions of the four major types of molecules that make up living things: proteins, carbohydrates, lipids, and nucleic acids.

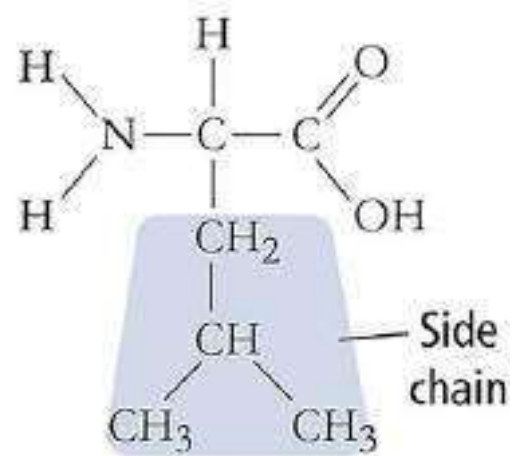
Living things are made up of four main types of macromolecules, or “big molecules.” Some of them are already familiar to you if you’ve heard that proteins grow or if you’ve ever “carbo-loaded” before a long run. The four main types of macromolecules in living organisms are proteins, carbohydrates, lipids, and nucleic acids. They are called macromolecules because each of these “big” molecules consists of multiple smaller molecules joined together.

Proteins perform a wide range of functions in living organisms. The protein keratin provides structural support in the form of skin, hair, and feathers. Insulin acts as a hormone, enabling one type of cell in the body to communicate with other types. Actin and myosin are proteins that allow muscles to contract. Hemoglobin, a protein in red blood cells, transports oxygen to body tissues. Antibodies, called antibodies, protect the body from disease. Enzymes, known as digestive enzymes, break down food during digestion.

What are proteins? Proteins are folded chains of amino acid molecules called *amino acids*. All amino acids include a central carbon (C) atom bonded to an amino group (NH₂), a carboxyl group (COOH), a hydrogen atom (H), and a side chain.

that varies from one amino acid to another. The α -leucine is shown in **Figure 15.4**. Although only 20 amino acids are found in living organisms, they combine together and folded in practically countless ways to form proteins with unique three-dimensional structures. Proteins are able to perform such a wide variety of functions

Figure 15.4



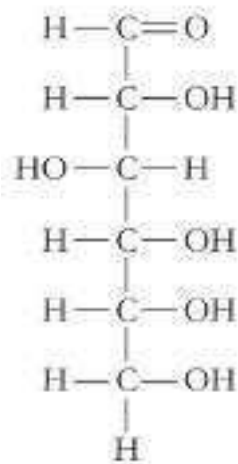
Leucine

Proteins perform a wide range of functions in living organisms, including providing structure. For example, hair is primarily made of protein. Leucine is one of the 20 amino acids that make up proteins.

Carbohydrates store energy in living organisms: sugars, such as glucose (Figure 15.5) and fructose.

carbohydrates. More complex carbohydrates are chains of simple sugars. Starch and glycogen—the energy-storage substances in plants and animals—consist of linked glucose molecules. Carbohydrates have structural functions. Cellulose, found in plants, is a structural carbohydrate built from glucose molecules. It is the most abundant organic compound in the world. Carbohydrates are made up of carbon, hydrogen, and oxygen atoms, generally in the form of $(\text{CH}_2\text{O})_n$.

Figure 15.5



Glucose

Carbohydrates, such as sugar, store energy in living

Glucose is an example of a carbohydrate.


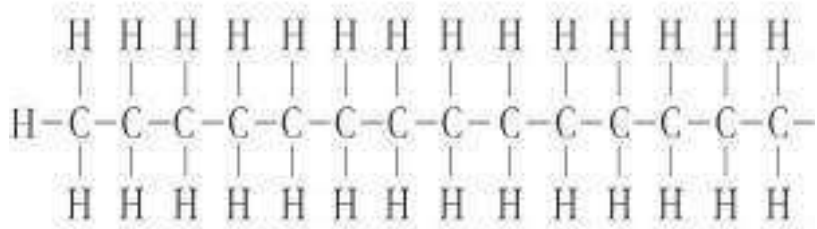
Lipids  serve diverse functions in living organisms. In oils, lipids are used by many living organisms to store energy. Lipids store energy much more efficiently than carbohydrates; that is, 1 gram of fat or oil contains a lot more energy than 1 gram of carbohydrate. For this reason, lipids are used for long-term energy storage by many organisms. Lipids also have structural functions as well; for example, phospholipids are a major component of cell membranes. One of the most famous lipids is cholesterol, which the body uses to make such hormones as estrogen and testosterone. Lipids have a variety of chemical structures, but many include fatty acids—strings of hydrocarbons (carbon and hydrogen atoms) with a carboxyl (COOH) group at one end—as a major component (see [Figure 15.6](#)). Lipids are hydrophobic; that is, they are not soluble in water.

Figure 15.6



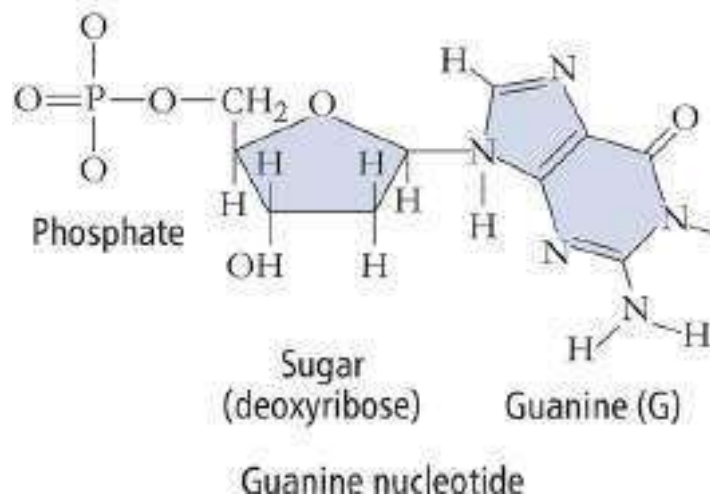
Palmitic acid

Lipids store energy, provide structure, or perform functions in living organisms. Palmitic acid is a lipid found in butter.

The role of the fourth type of macromolecule, **nucleic acid**, is to store genetic information in living organisms. Genes are made up of nucleic acids. Nucleic acids are made of smaller units called nucleotides. A *nucleotide* is made of a sugar molecule, a phosphate group, and a nitrogenous base. The two kinds of nucleic acids found in living organisms are *deoxyribonucleic acid* (DNA) and *ribonucleic acid* (RNA). DNA consists of two nucleic acid strands twisted into a double helix.

is why it is sometimes called a double helix. There are four kinds of nucleotides in DNA—adenine, cytosine, guanine (see [15.7](#)), and thymine, or A, C, G, and T for short. All genetic information in living organisms is expressed using this letter alphabet.

Figure 15.7



Nucleic acids store genetic information in living organisms. The guanine shown here is one of the four nucleotides in DNA.

Figure 15.8



Geckos store fat in their tails.

Check Yourself

Interactive

Question 1

Check Answer

Question 2

Check Answer

Question 1

Gecko lizards store fat in their tails (Figure 15.8), using this energy to survive during lean periods. What is the advantage of storing energy as fat rather than as carbohydrate?

Check Answer

Gecko lizards store fat in their tails (Figure 15.8), using this energy to survive during lean periods. What is the advantage of storing energy as fat rather than as carbohydrate?

Answer: A gram of fat contains more energy than a gram of carbohydrate. By storing the energy as fat, geckos can keep the energy supply the same without weighing themselves down. If they stored the energy as carbohydrate, they would need a much heavier tail.

Question 2

Living organisms contain thousands of different kinds of proteins. How is it possible to make so many different kinds of proteins from only 20 amino acids?

15.2 The Two Types of Cell

Prokaryotic and Eukaryotic

Learning Objective

Describe the key differences between the two basic types of cells—prokaryotic and eukaryotic.

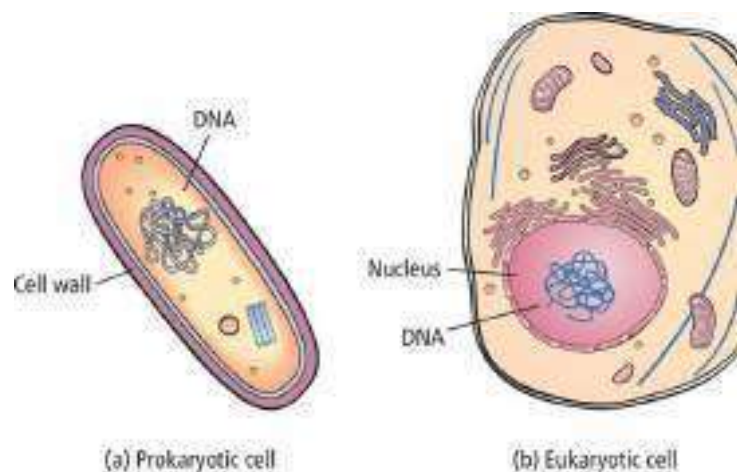
Now that you know what molecules living organisms are made of, let's look at living things themselves. **Cells** are the basic units of life in the same way that atoms are the basic units of matter. All living organisms are made up of one or more cells.* Organisms made up of one cell are *unicellular*—bacteria are unicellular. Organisms made up of many cells are *multicellular*.

You yourself have about 37 trillion cells in your body, and the things they do is amazing. Right now, muscle cells are contracting to move your eyeballs as you follow the text on this page, sensory cells are taking in the shapes of the letters, cells in your ears are hearing the sounds, red blood cells are carrying oxygen to all the other cells in your body, and digestive cells are making the enzymes that v

your last snack. And some extremely impressive cells—your brain—are producing your thoughts about how an

Two distinct types of cells are found in different living organisms: prokaryotic cells and eukaryotic cells. They are distinguished by the presence or absence of a **nucleus**, a structure that contains the cell's DNA. *Prokaryotic cells* do not have a nucleus (the prefix "pro" refers to "before" and *karyote* refers to "nut" or "nucleus"). *Eukaryotic cells* (the prefix "eu" refers to "true" or "nucleus") have a nucleus as well as other structures not found in prokaryotic cells. Organisms with prokaryotic cells are called **prokaryotes**, and organisms with eukaryotic cells are called **eukaryotes**. Figure 15.9 compares typical prokaryotic and eukaryotic cells.

Figure 15.9



(a) Prokaryotic cells have no nucleus. (b) Eukaryotic cell.


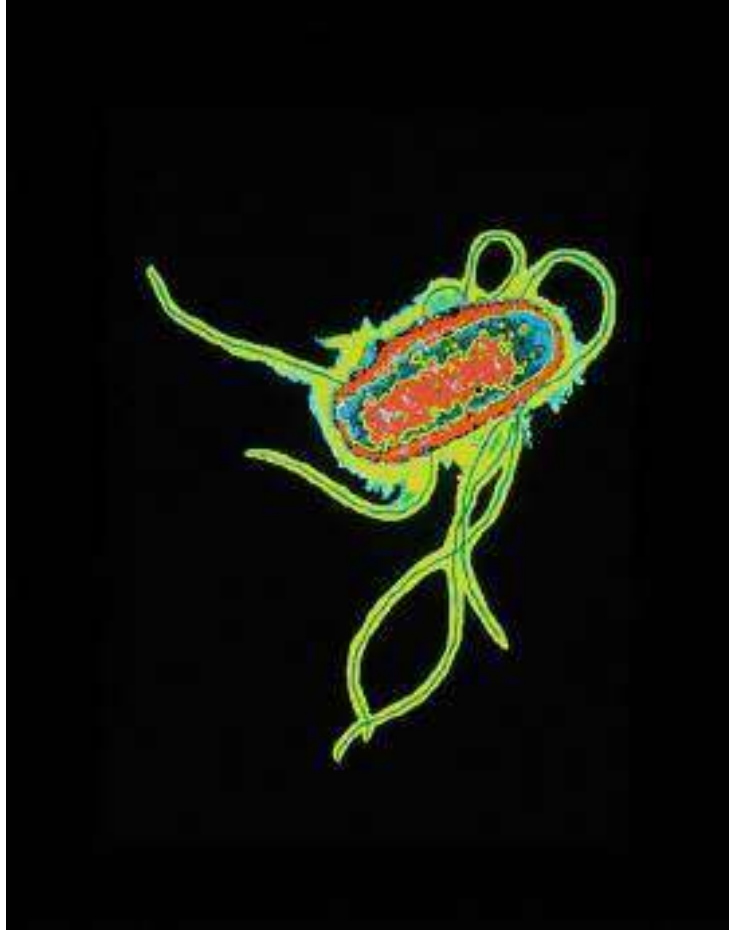
Prokaryotes have existed on Earth far longer than eukaryotes. Prokaryotes first evolved 3.5 to 4 billion years ago and have been living things on Earth for several billion years. Prokaryotes consist of two major lineages, the bacteria and the archaea. Prokaryotes are unicellular organisms and are very small, ranging from about 1 to 10 micrometers (10^{-6} meter) in diameter. Their structure is very different from that of eukaryotes. The DNA of prokaryotes is found in a single circular structure and is not contained within a nucleus. Most prokaryotes have an outer *cell wall* that helps protect the cell. The prokaryote *Escherichia coli*, which lives in the human digestive tract and is one of the most common organisms in the world, is shown in [Figure 15.10](#) .

Figure 15.10



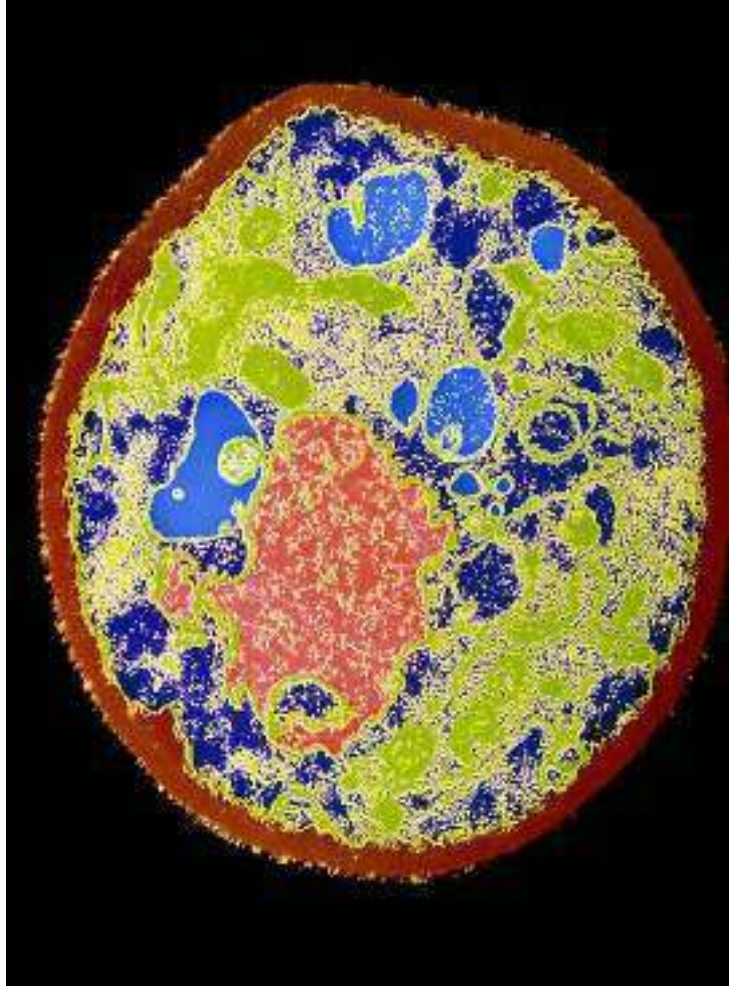
Escherichia coli (commonly referred to as *E. coli*) is a prokaryotic bacterium found in the human digestive tract.

You just learned that you are made up of about 30 trillion eukaryotic cells. But did you know that you have just as many prokaryotic bacteria living in your body right now as you do eukaryotic cells—that they are—for the most part—friendly!

Eukaryotes first appeared about 2 billion years ago. Eukaryotes can be single-celled, like prokaryotes, or they can be composed of many cells.

The fungus known as baker's yeast, commonly used in brewing, is a single-celled eukaryote (Figure 15.11). Unlike multicellular eukaryotes, eukaryotes include all animals and protists. Eukaryotic cells have their DNA inside a nucleus. In addition, the DNA of eukaryotic cells is found in linear, circular, **chromosomes**. Eukaryotic cells also have **organelles**, structures that perform specific functions. Finally, eukaryotic cells are larger than prokaryotic cells. Prokaryotic cells measure 0.1 to 10 micrometers, eukaryotic cells measure 10 to 100 micrometers. Some eukaryotic cells are even larger than that.

Figure 15.11



Saccharomyces cerevisiae, commonly known as baker's yeast, is a single-celled eukaryote. The red area at the center of the cell is the nucleus.

An egg yolk is a single cell. That makes the ostrich egg yolk the largest cell in the world, which measures 10 to 15 centimeters in diameter.

Ostrich eggs may be the largest cells in the world. The longest cells are the longest. The longest cell in the human body is a neuron that runs all the way from the spinal cord to the tip of your nose. You can try this cell out right now by wiggling your nose.

Check Yourself

Interactive

Question
Check Answer
Question

Which of the following organisms are prokaryotes and which are eukaryotes? A bacterium that causes tuberculosis, a humpback whale, a honeybee.


Check Answer

Which of the following organisms are prokaryotes and which are eukaryotes? A bacterium that causes tuberculosis, a humpback whale, a honeybee.
Answer: The tuberculosis bacterium, like all bacteria, is a prokaryote.

History of Science

Cell Theory

Cell theory, the idea that the cell is the basic unit of life, took several centuries in the making. In 1665, Robert Hooke, an English scientist, coined the term *cell* and published his description of cells in his book *Micrographia*. Hooke's discovery of cells was a major step in the development of cell theory.



a piece of cork under a microscope and saw a set of boxlike chambers. He called these chambers “cells” because they reminded him of monks’ cells. We now know the chambers Hooke saw were not actually living cell walls that remain in dried plant matter.

It was not until the 1800s that the central importance of the cell was established. In 1838, careful studies of plant tissue led the German scientist Matthias Schleiden to conclude that all plants are made of cells. The following year, another German scientist, Theodor Schwann, came to the same conclusion for animals. The cell theory was finally completed in 1858 when German scientist Rudolph Virchow observed that all cells come from other living cells.

In summary, the cell theory says:

1. All living things are made up of one or more cells.
2. All cells come from other cells.



Robert Hooke examined cork under a microscope and saw small chambers he called "cells." This is Hooke's original drawing of what he saw.

Integrated Science 15B: Principles of Science

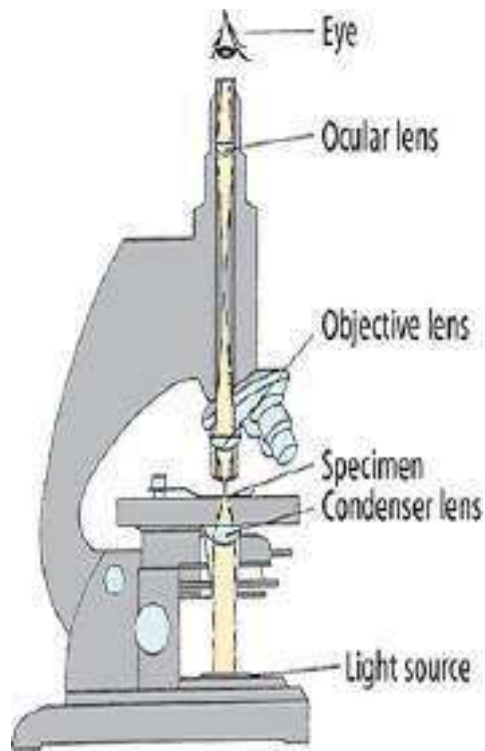
The Microscope

Learning Objective

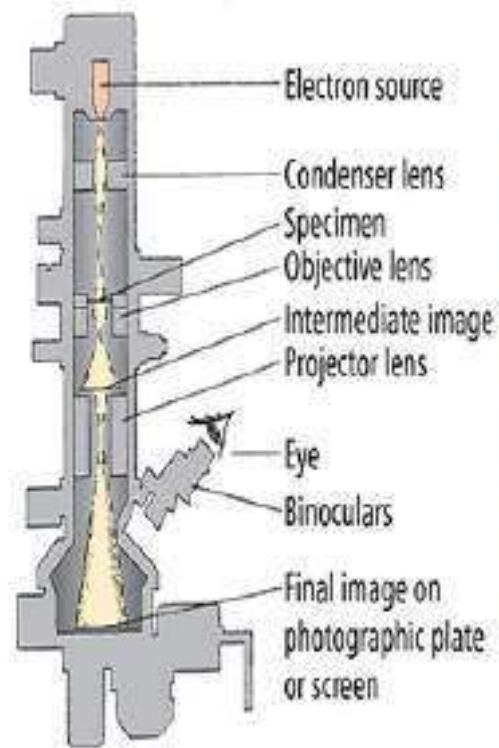
Explain how light and electron microscopes work, describing the uses of each for biology.

Microscopes are high-tech magnifying glasses that let us see very small objects with a fine level of detail. Complicated microscope, the light microscope, has been around for centuries. In fact, Robert Hooke discovered the first animal cells while using one. Light microscopes work by shining visible light through a specimen and then through two lenses. The lenses refract, or bend, the light in order to produce a magnified image of the specimen (Figure 15.12).

Figure 15.12



(a)



(b)

Microscopes enable us to examine objects that are beyond the human eye to see. (a) Light microscopes use lenses to bend light and magnify specimens. The photo shows cells seen through a light microscope. The small green structures inside the cells are plant structures called chloroplasts. Electron microscopes use electric and magnetic fields to bend and magnify specimens. This is an electron micrograph of a leaf in cross-section. Chloroplasts can be seen inside the cells.

Light microscopes are able to resolve objects on the order of a micrometer (10^{-6} meter) in size. This means that two objects closer together than 10^{-6} meter appear as a single object. The resolving power of the human eye is about $1/10$ that of a light microscope (10^{-4} meter.) This is because diffraction blurs the image. If the size of an object is about the same as the wavelength of light, the image is blurred. Furthermore, if an object is *smaller* than the wavelength of light, no structure can be seen at all. The entire image is blurred due to diffraction. No amount of magnification or better microscope design can overcome this fundamental limit.

With a resolving power of 10^{-6} meter, light microscopes allow us to view cells and to make out the larger features of cells.

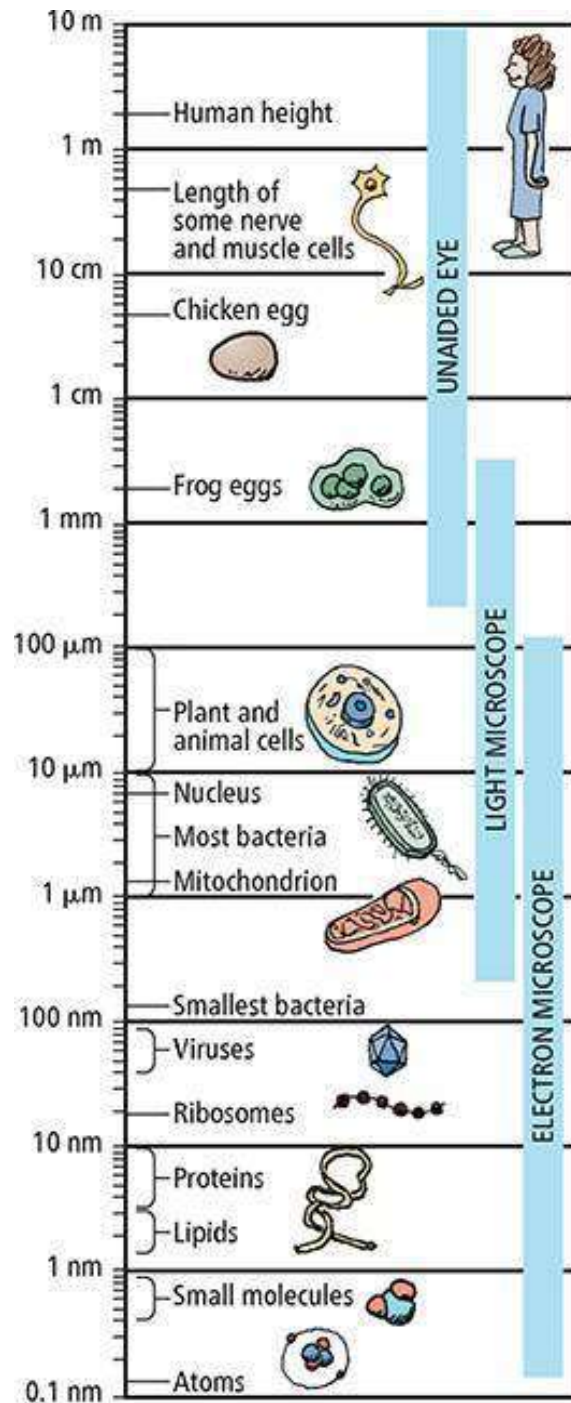
them, such as the nucleus. However, they do not to see smaller cellular structures in detail.

Unifying Concept

Waves [Section 8.1](#)

To get around this problem, scientists illuminate objects with electron beams rather than with light. Light has wave properties, and, compared with light waves, electron beams have extremely short wavelengths, allowing them to resolve much smaller objects. In an electron microscope, electric and magnetic fields, rather than optical lenses, are used to focus electron beams ([Figure 15.12b](#)). Electron microscopes are able to resolve objects about a nanometer (10^{-9} meter) in size, which covers just about every scale of biological interest ([Figure 15.13](#)).

Figure 15.13



Measurement equivalents

1 meter (m) = 100 cm = 1,000 mm = about 39.4 inches
 1 centimeter (cm) = 10^{-2} (1/100) meter (m) = about 0.4 inch
 1 millimeter (mm) = 10^{-3} (1/1,000) m = 1/10 cm
 1 micrometer (μm) = 10^{-6} m
 1 nanometer (nm) = 10^{-9} m

Microscopes allow us to look into the world of the
Depending on the size of a feature, the naked eye
microscope, or an electron microscope may be us

There are two types of electron microscopes. Sc
electron microscopes create a three-dimensiona
surface of a specimen (see [Figure 15.12b](#)). Tran
electron microscopes image thin sections throug

Check Yourself

Interactive

Question

Check Answer

Question

Tiny bacteria called mycoplasmas have diameters as small as 0.
they be studied with light microscopes? With electron microsc

Check Answer

Tiny bacteria called mycoplasmas have diameters as small as 0.
they be studied with light microscopes? With electron microsc

Answer: Mycoplasmas are too small to be examined with light

* Viruses, which possess some of the characteristics of life and straddle th
and nonliving, are not composed of cells.

15.3 Tour of a Eukaryotic Cell

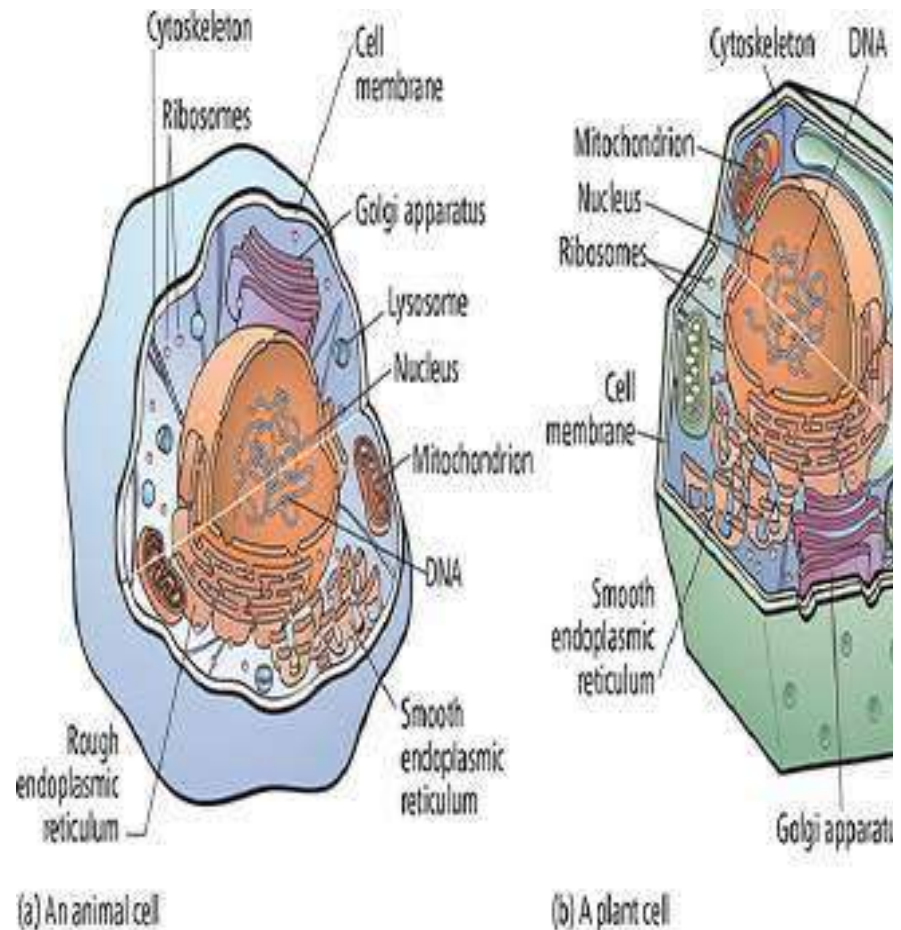
Learning Objective

Describe the main features of eukaryotic cells.

You, your tulips, and your dog are all eukaryotes, organisms made of eukaryotic cells. In fact, most of the living things we encounter on Earth—on a global basis—all the plants, animals, and fungi—are eukaryotes.

All eukaryotic cells are surrounded by a cell membrane. The cell membrane separates the inside of the cell from the outside. It is responsible for controlling what goes into and out of the cell. Some cells also have a rigid cell wall outside the cell membrane made of cellulose and other materials. The cell wall helps to protect and support the cell.

Figure 15.14



Eukaryotic cells have a cell membrane, a nucleus, and many organelles. (a) This is an animal cell. The lysosomes are not found in plant cells. (b) This is a plant cell. Plants have a cell wall outside the cell membrane, a large central vacuole, and other features that are absent from animal cells.

Eukaryotic cells have a nucleus, a structure within the cell that contains the cell's DNA. The nucleus is surrounded by a double membrane. A large portion of the cell that is inside the cell membrane but outside the nucleus is the cytoplasm.

nucleus is called the cell's cytoplasm ⓘ. The cytoplasm contains fibers of the *cytoskeleton*, which helps the cell hold its shape.

The cytoplasm of eukaryotic cells contains many organelles attached to the cytoskeleton. These are called organelles. Each organ of the body, each performs a specific function in an organelle, except for the ribosomes, is also surrounded by a membrane. Let's consider the organelles one at a time. *Ribosomes* assemble proteins. Some ribosomes are suspended in the cytoplasm. These make proteins that will remain inside the cell. Some ribosomes are attached to an organelle called the *rough endoplasmic reticulum*. These ribosomes assemble proteins that will be used in the cell membrane or be exported from the cell. The rough endoplasmic reticulum appears "rough" because of the ribosomes on its surface. The *smooth endoplasmic reticulum* assembles membrane proteins. The smooth endoplasmic reticulum on the cell, may have additional functions. For example, the smooth endoplasmic reticulum of liver cells detoxifies drugs and alcohol. The *Golgi apparatus* is sometimes described as the "post office" of the cell. It receives products from the endoplasmic reticulum, modifies them, and packages them for transport within or out of the cell. *Lysosomes* are involved in the garbage disposals of a cell. These organelles break down waste materials, such as damaged or worn-out organelles. Cells also contain small, spherical structures called *vacuoles*.

cells of the immune system use lysosomes to destroy the pathogens they have engulfed. *Vacuoles* are sacs surrounded by membranes and usually have a single large vacuole that can be used to store water and other materials. In flowers, vacuoles store the pigments that give them their color. Animal cells typically have smaller vacuoles, some called *vesicles*, that are used to hold or transport a wide array of substances. For example, neurons have many vesicles that contain the neurotransmitters used to communicate with other neurons. **Mitochondria** are organelles that break down organic molecules to obtain energy in a form that can be used for cellular work. In plants, organelles called **chloroplasts** capture energy from sunlight and use it to build organic molecules. **Table 15.1** summarizes the major organelles and features of eukaryotic cells.

Only plant cells have chloroplasts, but both plant and animal cells have mitochondria.

Table 15.1 Major Features of Eukaryotic Cells

Nucleus	Contains the cell's DNA
Ribosome	Assembles proteins for the cell
Rough endoplasmic reticulum	Assembles proteins destined either to the cell membrane or to leave the cell
Smooth endoplasmic reticulum	Assembles membranes and performs specific functions in specific cells
Golgi apparatus	Receives products from the endoplasmic reticulum and packages them for transport
Lysosome	Breaks down organic material
Mitochondrion	Obtains energy for the cell to use
Chloroplast	In plant cells, captures energy from sunlight to build organic molecules
Cytoskeleton	Helps cell hold its shape

15.4 The Cell Membrane

Learning Objective

Describe the structure and function of the cell membrane.

The cell membrane defines a cell's boundary, separating the cell from the outside. One of its main functions is to serve as a gatekeeper, controlling what goes into the cell and out of the cell. To understand how the cell membrane performs this function, let's look at its structure. The three primary components of the cell membrane are phospholipids, proteins, and short carbohydrates.

Phospholipids are part hydrophilic and part hydrophobic. You have probably noticed how oil and water separate after they have been mixed together. The oil floats on top of the water in a distinct layer, rather than mixing with the water (Figure 15.15). This is because oil is *hydrophobic*, or "water-fearing" (*Hydrophobic* literally means "afraid of water.") The opposite of hydrophobic is *hydrophilic*, or soluble in water. (*Hydrophilic* means "loves water.") Phospholipids have hydrophilic "heads" and hydrophobic "tails" (Figure 15.16). The hydrophilic heads are drawn to the watery environment inside and outside the cell.

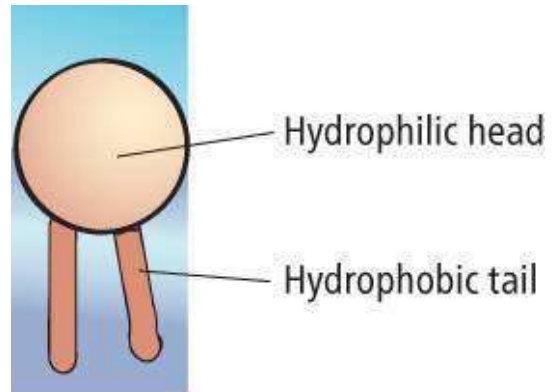
hydrophobic tails naturally try to avoid it. The result is phospholipids form a double layer, or bilayer, with the pointing inward and the hydrophilic heads pointing out (15.17). You can think of the phospholipids as making the heads as two slices of bread and the tails as the pea

Figure 15.15



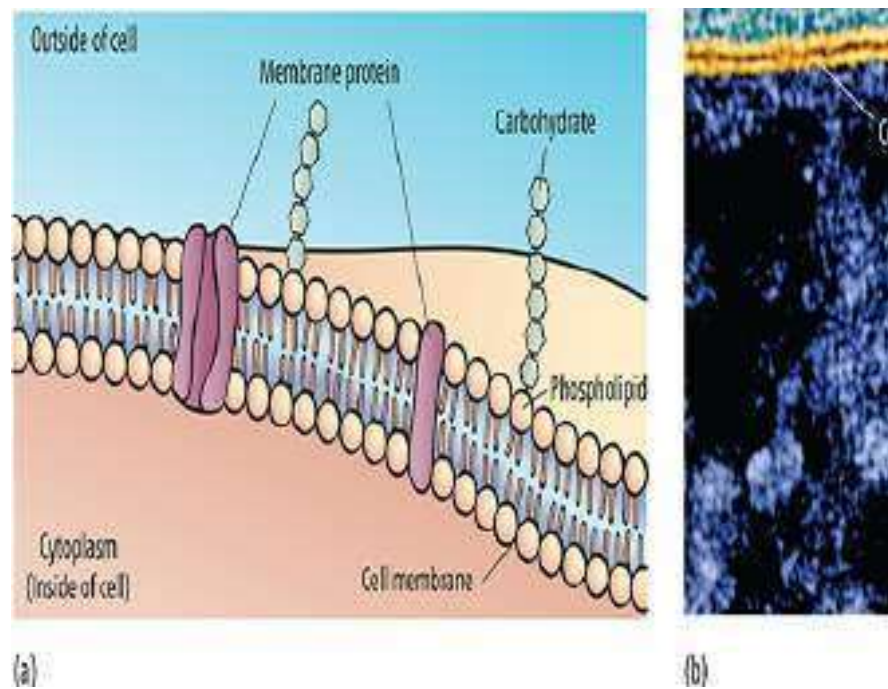
Water and oil do not mix when they are combined.

Figure 15.16



A phospholipid has a hydrophilic head and hydrophobic

Figure 15.17



(a) The cell membrane includes a phospholipid bilayer, tails pointed inward and hydrophilic heads pointing to and outside of the cell. Proteins are embedded in the membrane. Short carbohydrates are attached to the outside of the membrane.

photograph of a cell membrane shows the double layer. The hydrophilic heads are shown in yellow and the hydrophobic tails shown in red.

The cell membrane also includes a large number of *membrane proteins* embedded like toothpicks in the phospholipid sandwich. Membrane proteins serve a variety of functions: They help cells communicate with other cells, control transport into and out of cells, and join cells to one another. Because different cells have different functions, membrane proteins also differ from one cell type to another.

Short carbohydrates are attached to the membrane proteins and phospholipids on the outside surface of the cell. These carbohydrates play an important role in cell recognition, the ability to distinguish one cell from another. For example, certain immune-system cells use short carbohydrates to identify foreign cells, such as diseased cells and bacteria.

Because the cell membrane includes a mosaic of phospholipids and proteins, and because the phospholipids and many membrane proteins slide freely around the cell surface, the cell membrane is

as *fluid mosaic*. The fluidity of the cell membrane is essential to control the movement of materials into and out of the cell.

15.5 Transport Into and Out

Learning Objective

Describe the different ways molecules move into cells.

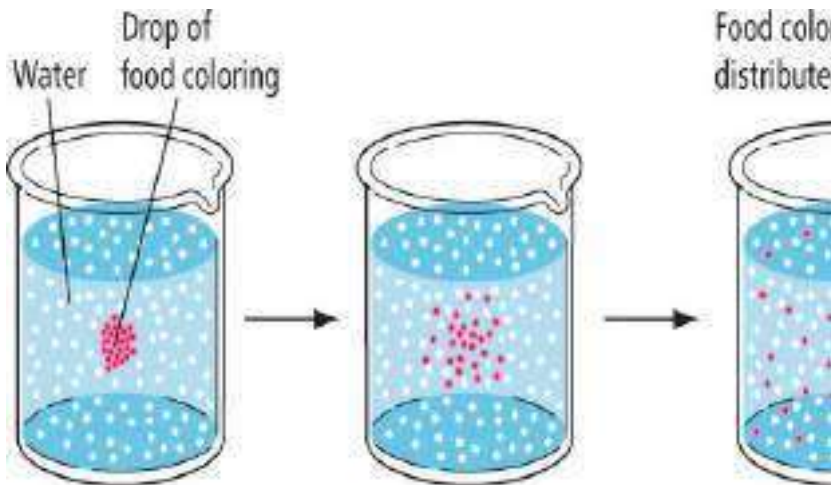
Cells need to take in a variety of resources, including water and organic molecules. Cells also generate wastes that they must remove. Now that we know the structure of the cell membrane, we can see how it performs the essential task of controlling how things move in and out of cells. Transport across the cell membrane occurs in several different ways—through diffusion, facilitated diffusion, active transport, endocytosis, and exocytosis.

Diffusion

Some molecules are able to cross the phospholipid bilayer of the cell membrane directly. Hydrophobic molecules, such as oxygen and carbon dioxide, can pass directly through the double layer of hydrophobic tails. Certain small hydrophilic molecules-

can also cross the cell membrane this way. What governs the movement of substances into and out of cells? A process known as diffusion is the movement of molecules from an area of high concentration to an area of low concentration—that is, down a concentration gradient. This is a direct result of the second law of thermodynamics, which states that natural systems tend to move from concentrated states to less concentrated states. A familiar example of diffusion is the way a drop of food coloring spreads in a beaker of water (Figure 15.18).

Figure 15.18



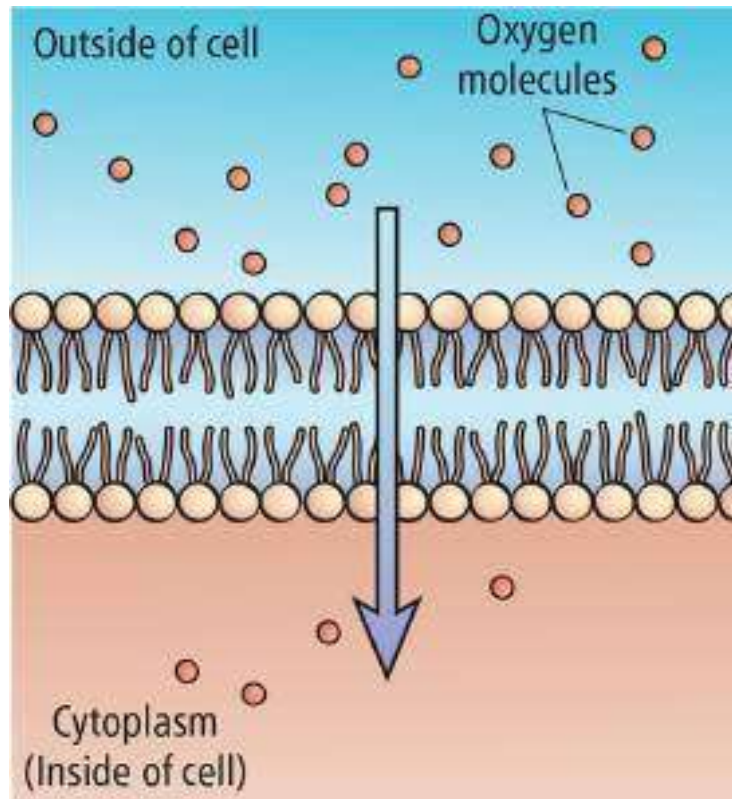
A drop of food coloring diffuses in a beaker of water. Oxygen molecules diffuse from where they are more concentrated to where they are less concentrated. Eventually, the water becomes uniform in color.

Unifying Concept

The Second Law of Thermodynamics **Section 6.5**

Let's look at how molecules diffuse across the cell membrane. For example, consider how oxygen diffuses from the fluid spaces outside cells into the cells themselves (**Figure 15.19**). Oxygen molecules are found both inside and outside the cell, and they move around randomly. Sometimes an oxygen molecule drifts from outside the cell into the cell, and sometimes an oxygen molecule drifts from inside the cell to outside the cell. However, because there is a higher concentration of oxygen molecules outside the cell than inside, the net effect of diffusion is to move oxygen molecules into the cell. (Note that there are fewer oxygen molecules inside cells because cells use up oxygen in cellular respiration, which we will discuss later in this chapter.)

Figure 15.19



Molecules that diffuse freely across the cell membrane : movement from an area of higher concentration to an a concentration.

Diffusion works best over small distances. Because of th processes that depend on diffusion require very thin str of our capillaries are very thin so that oxygen can diffus our blood to our tissues. Processes that depend on diffu large surface areas. The intricate branching of our lung: surface area so that a lot of oxygen can diffuse into the that amphibians get much of their oxygen from diffusio



can you develop a hypothesis for why the giant salamander
15.20  has such wrinkly skin?

Figure 15.20

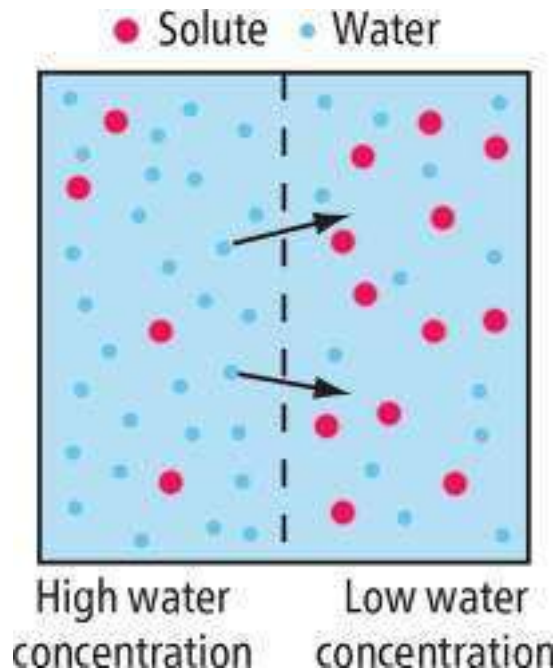


The Chinese giant salamander is the largest amphibian. These salamanders live in streams and obtain oxygen from across their wrinkly skin.

The diffusion of water has a special name—*osmosis*. Like water diffuses from an area with a high concentration of water molecules to an area with a low concentration of water molecules. A low concentration of water molecules means a lower concentration of solute and vice versa, another way to say this is that diffusion occurs from an area of lower solute concentration to an area of higher solute concentration (Figure 15.21 ). This is important because

water flow is important to all cells—with too much water they burst; with too little, they shrivel.

Figure 15.21



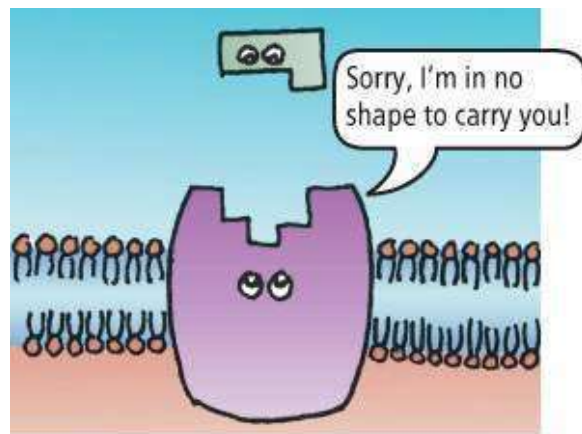
In osmosis, water molecules move from an area of low solute concentration to an area of higher solute concentration. Solute molecules cannot cross the barrier, but the water

Facilitated Diffusion

Many of the molecules that cells need, including ions and hydrophilic molecules such as proteins and carbohydrates,

freely across the phospholipid bilayer of the cell membrane. How do these molecules get into and out of cells? They use special gates in the cell membrane. These gates are membrane proteins called *transport proteins*. Transport proteins are very specific about the molecules they carry across the cell membrane. A molecule fits into its transport protein way a key fits into a lock—only the right key will work in the lock (Figure 15.22).

Figure 15.22

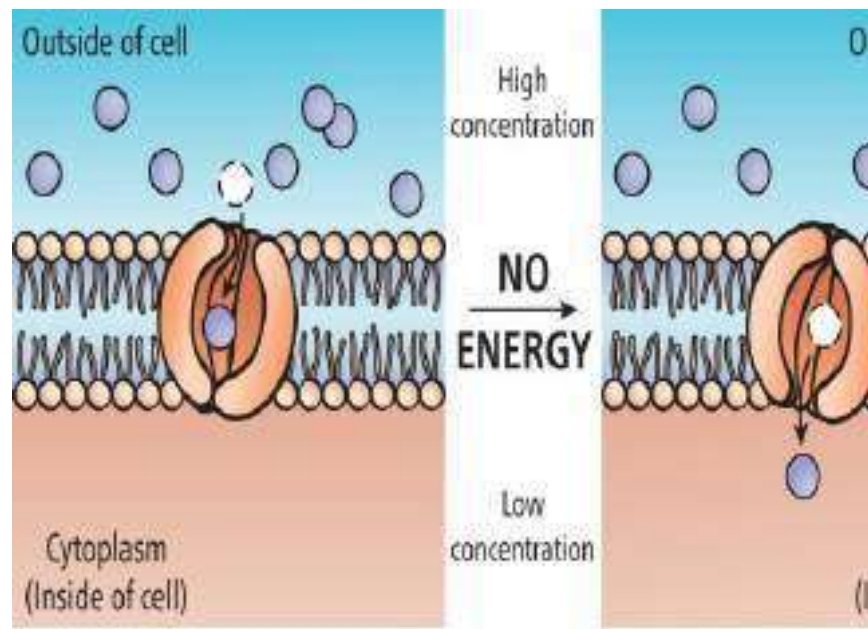


Transport proteins and the molecules they transport fit like a lock and key.

In *facilitated diffusion*, a transport protein moves molecules down their concentration gradient, from an area of high concentration to an area of low concentration (Figure 15.23). One example of facilitated diffusion is the transport of glucose across the cell membrane.

the movement of the sugar glucose (the basic fuel that provides energy) into red blood cells. Water, in addition to diffusing through the phospholipid bilayer, can also use facilitated diffusion across the cell membrane. The transport proteins used by water are called Aquaporins allow water to move more quickly across the membrane than it can through diffusion alone. Like diffusion, facilitated diffusion requires no energy from the cell. For this reason, diffusion and facilitated diffusion are both examples of passive transport.

Figure 15.23



In facilitated diffusion, molecules move from an area of high concentration to an area of low concentration using a transport protein.

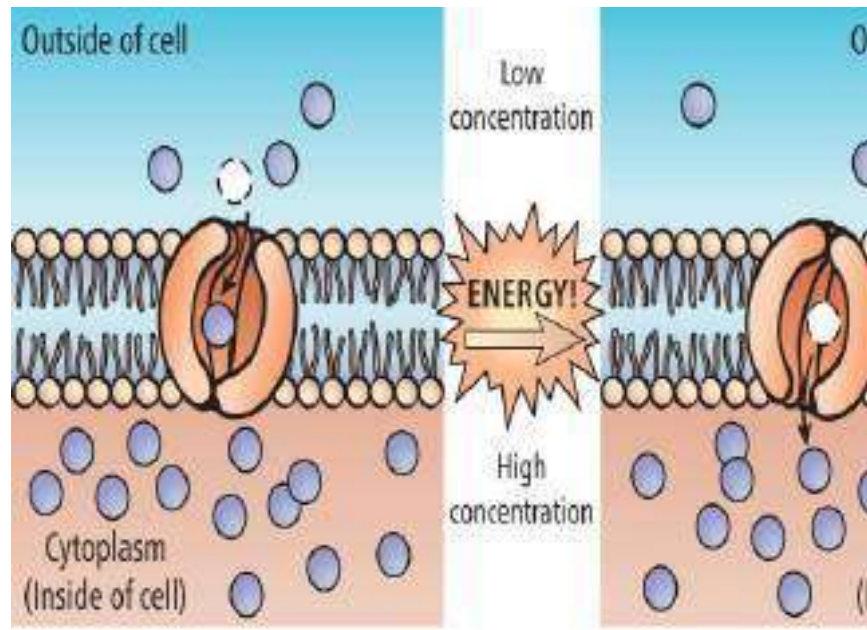
Active Transport

In active transport, a transport protein moves molecules against a concentration gradient, from an area of low concentration to an area of high concentration (Figure 15.24). In this case, the second law of thermodynamics tells us that energy is required, since molecules do not move spontaneously from more diffuse states to more ordered states. Active transport is used to move many organic molecules, including most proteins, into cells. Active transport is also used to maintain the concentration of many ions inside and outside cells. For example, in active transport, the movement of sodium and potassium ions by the sodium-potassium pump, is described later in this chapter.

Unifying Concept

The Second Law of Thermodynamics [Section 6.5](#)

Figure 15.24



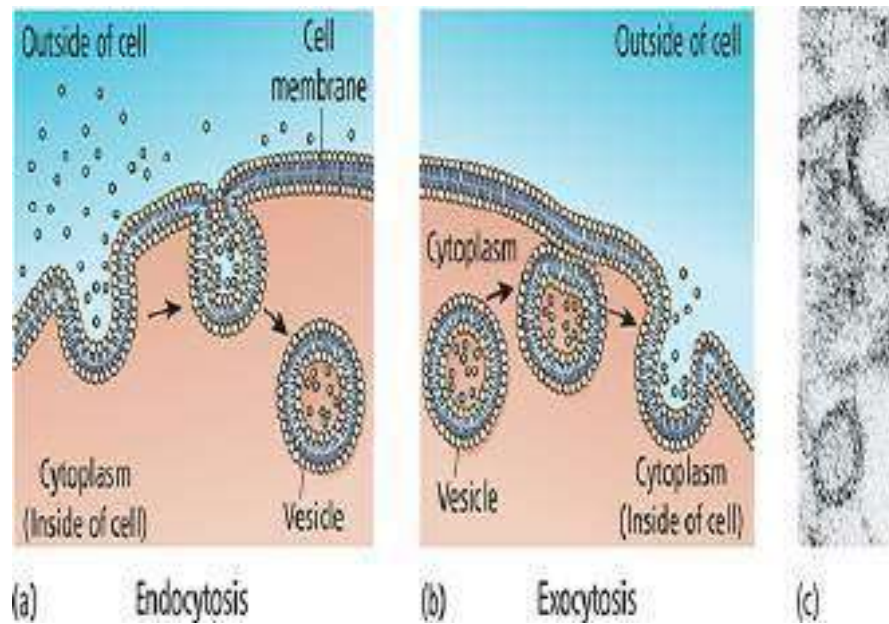
In active transport, molecules move from an area of low concentration to an area of high concentration—that is, against a concentration gradient. This requires both a transport protein and energy from the cell.

Endocytosis and Exocytosis

Larger amounts of material can be moved into and out of a cell through endocytosis and exocytosis (Figure 15.25). In endocytosis, the cell membrane folds inward and pinches off, enclosing the material within a vesicle inside the cell. Endocytosis is used by cells of the human immune system to engulf invading bacteria. In exocytosis, the opposite process occurs—a vesicle fuses with the cell membrane and dumps its contents outside the cell.

endocrine cells use exocytosis to release hormones into the bloodstream. Neurotransmitters—the chemicals that neurons use to send signals—also are released through exocytosis.

Figure 15.25



(a) In endocytosis, a portion of the cell membrane pinches off to form a vesicle that brings materials into the cell. (b) In exocytosis, a vesicle inside the cell fuses with the cell membrane, dumping its contents into the cell. (c) This photo shows vesicles dumping their contents through exocytosis.

Check Yourself



Question

Check Answer

Question

Insects don't have lungs. Instead, they get oxygen from a series of tubules in their bodies that are connected to the outside air. Oxygen travels through the tubules to reach their tissues. Can you use this information to explain why a mosquito could never grow to be 12 feet tall?

Check Answer

Insects don't have lungs. Instead, they get oxygen from a series of tubules in their bodies that are connected to the outside air. Oxygen travels through the tubules to reach their tissues. Can you use this information to explain why a mosquito could never grow to be 12 feet tall?

Answer: Because diffusion works well only at small distances.

Math Connection

Why Does Diffusion Limit the Size of Cells?

Cells rely on diffusion to obtain many crucial resources. The amount of any given resource that a cell needs usually depends on the cell's volume. The larger the volume, the more resources the cell needs. But, the rate at which molecules diffuse into the cell depends on the cell's surface area—the total area of the cell membrane. For diffusion to work well, a cell needs to have a large surface area relative to its volume. What does this mean for the size of cells?

Let's look at how well diffusion works in cells of different sizes. We'll assume that cells are spherical. The surface area of a sphere is $4\pi r^2$, where π is the constant equal to approximately 3.14 and r is the radius of the sphere. The volume of a sphere is $\frac{4}{3}\pi r^3$. Let's look at how surface area compares to volume in three cells with radii of 1, 2, and 3 micrometers, respectively. For a cell with a radius of 1 micrometer,

$$\frac{\text{Surface area}}{\text{Volume}} = \frac{4\pi r^2}{\frac{4}{3}\pi r^3} = \frac{4\pi(1)^2}{\frac{4}{3}\pi(1)^3} = \frac{4\pi}{\frac{4}{3}\pi}$$

That is, the amount of surface area the cell has is three times the volume of the cell. For a cell with a radius of 2 micrometers,

$$\frac{\text{Surface area}}{\text{Volume}} = \frac{4\pi r^2}{\frac{4}{3}\pi r^3} = \frac{4\pi(2)^2}{\frac{4}{3}\pi(2)^3} = \frac{4\pi(4)}{\frac{4}{3}\pi(8)}$$

For a cell with a radius of 3 micrometers,

$$\frac{\text{Surface area}}{\text{Volume}} = \frac{4\pi r^2}{\frac{4}{3}\pi r^3} = \frac{4\pi(3)^2}{\frac{4}{3}\pi(3)^3} = \frac{4\pi(9)}{\frac{4}{3}\pi(27)}$$

What's happening here? Even though a cell's surface area increases as it gets bigger, its volume increases even more quickly. Bigger cells have a *smaller* surface-area-to-volume ratio, making it harder for them to meet their needs through diffusion. For this reason, it was long thought that bacteria, which rely on diffusion to obtain nutrients, could not grow very large. The discovery of two giant species of bacteria—large enough to be visible to the naked eye—was startling. A close examination of these organisms reveals how they do it. One giant, *Thiomargarita namibiensis*, has all its cytoplasm in a thin layer just beneath the cell membrane. Most of the interior of the cell is occupied by a large central vacuole. The other giant, *Epulopiscium fishelsoni*, has a highly wrinkled cell membrane. The wrinkles increase the surface area available for diffusion. In order to use diffusion effectively for nutrient transport, these species have evolved ways of compensating for their large size.

Problem

The smallest bacteria, called mycoplasmas, are only about 0.1 micrometer long, and the largest bacterium is the giant *Thiomargarita namibiensis* mentioned

radius close to 500 micrometers. What is the surface area to-volume ratio for each of these?

Solution

For the mycoplasma:

$$\begin{aligned}\frac{\text{Surface area}}{\text{Volume}} &= \frac{4\pi r^2}{\frac{4}{3}\pi r^3} = \frac{4\pi}{\frac{4}{3}\pi} \\ &= \frac{4\pi (0.01)}{\frac{4}{3}\pi (0.001)} =\end{aligned}$$

For the giant bacteria:

$$\begin{aligned}\frac{\text{Surface area}}{\text{Volume}} &= \frac{4\pi r^2}{\frac{4}{3}\pi r^3} = \frac{4\pi(50)}{\frac{4}{3}\pi(5)} \\ &= \frac{4\pi (250,000)}{\frac{4}{3}\pi (125,000,000)} =\end{aligned}$$

15.6 Cell Communication

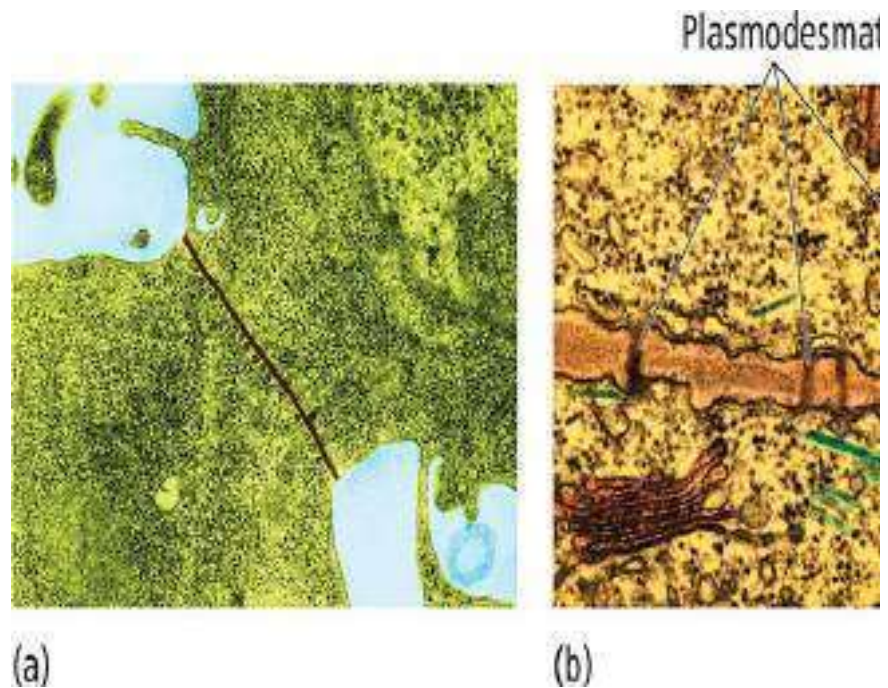
Learning Objective

Explain how cells can send chemical messages to other cells.

The cells of multicellular organisms communicate with one another in order to coordinate their activities. The “messages” they send are in the form of molecules. For example, nerve cells send special messages to muscle cells, telling the muscle cells to contract. The pituitary gland sends a different molecule, called growth hormone, to many cells throughout the body, telling them to grow and divide.

In animals and plants, special structures allow very local communication directly from one cell to an adjacent cell ([Figure 15.26](#)). In animals, these structures are gap junctions, tiny channels between adjacent cells. Gap junctions are found in almost every cell in the body. In muscle cells, communication via gap junctions allows muscle cells to contract simultaneously to produce the heartbeat. Plasmodesma are found in plants and serve a function similar to gap junctions in animal cells. Plasmodesma are slender threads of cytoplasm that link adjacent plant cells.

Figure 15.26

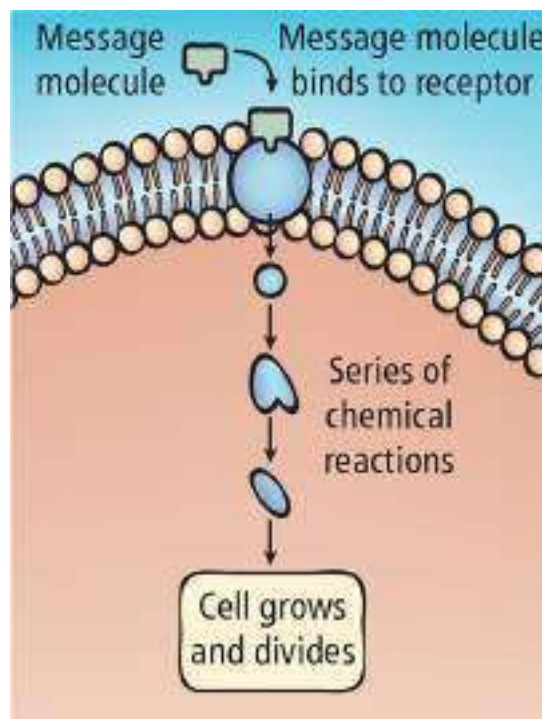


(a) Gap junctions are tiny channels between adjacent animal cells. These channels allow small molecules to pass. This photo shows a gap junction between two rat cells. (b) This photo shows plasmodesmata, which are passages that link the cytoplasm of adjacent plant cells. (The dark, branching elements are part of the cytoskeleton, and the large red structure is the Golgi apparatus.)

Message molecules may also travel through the bloodstream to reach target cells. When a message molecule reaches a target cell, it binds to a protein called a *receptor*. Some receptors are membrane proteins, and others are inside the cell. Receptors are extremely specific; they bind only to certain message molecules. This is because a message molecule

receptor fit together like a key in a lock—only the right work. This lock-and-key fit also means that only cells with appropriate receptors will “receive” and respond to specific molecules. The binding of a message molecule to its receptor starts a series of chemical reactions that results ultimately in the response to the message. As just one example, a cell may receive a message that tells it to grow and divide (Figure 15.27).

Figure 15.27



A cell receives a message when a message molecule binds to its cell membrane. This begins a chain reaction that leads to the response to the message. In this case, the cell responds by growing and dividing.

Problems with cell communication can be dangerous. In cells, a problem in the communication process causes the "grow and divide" message continuously and divide out

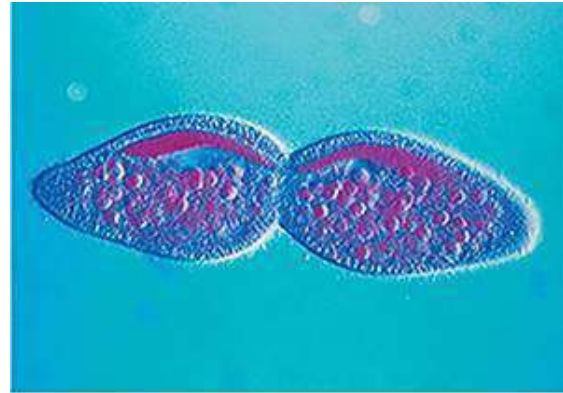
15.7 How Cells Reproduce

Learning Objective

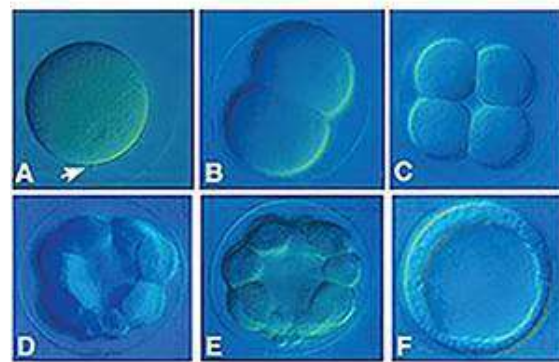
Describe the process of cell division.

Cells reproduce by dividing. Cell division allows single-celled organisms to reproduce themselves and multicellular organisms to grow and maintain their tissues (Figure 15.28).

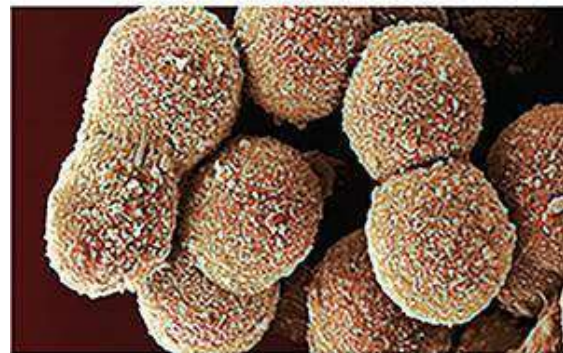
Figure 15.28



(a)



(b)



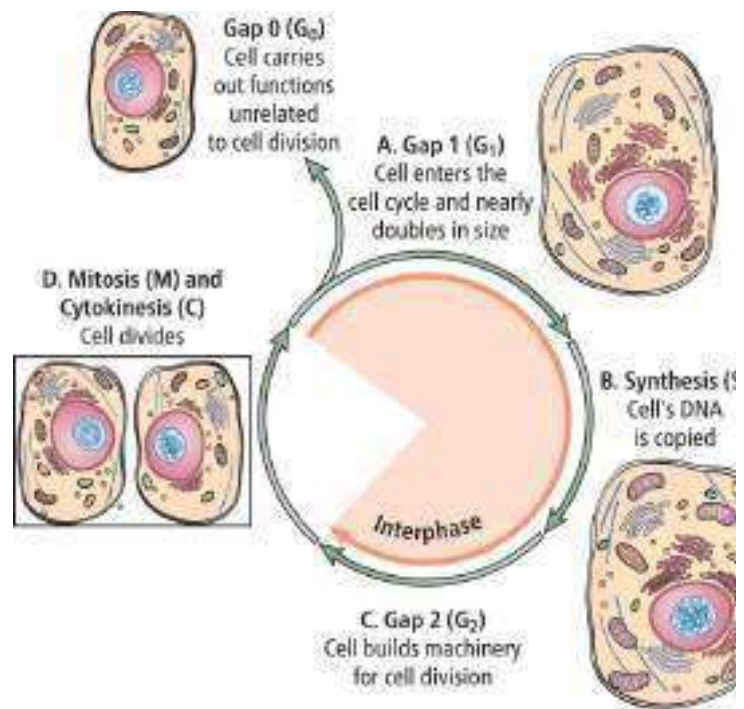
(c)

Cell division is essential for reproduction, growth and maintenance. (a) A paramecium, a single-celled organism, is shown dividing into two. (b) The early development of a sea urchin involves multiple divisions of the fertilized egg. A fertilized egg has divided several times to produce this early embryo, which

(c) Cell division in the liver produces new cells to replace old cells.

Mitosis is a form of cell division in which one parent cell divides to produce two daughter cells, each of which contains the same genetic information as the parent cell. Cells that are preparing to divide enter the cell cycle, which is shown in **Figure 15.29**. The cell cycle is divided into four phases: gap 1, synthesis, gap 2, and mitosis and cytokinesis. Gap 1, synthesis, and gap 2 are collectively known as interphase. During interphase, the cell makes the necessary preparations for division. During mitosis and cytokinesis, the cell divides.

Figure 15.29



The cell cycle has four stages. (A) During gap 1, the cell double its original size. (B) During synthesis, an exact c DNA is made. (C) During gap 2, the cell builds the mac for mitosis. (D) During mitosis and cytokinesis, the cell

During gap 1 (G₁), a cell prepares to divide by growing double its original size. All the important components c including the mitochondria and other organelles, also c (Calling this stage a “gap” is a little misleading in that it nothing is going on. In fact, important events occur dur stages. They are gaps only from the point of view of sor exclusively on whether the cell’s DNA is doing anything;

During synthesis (S), the cell creates an exact copy of it—its DNA. We will look at how DNA is duplicated in C

During gap 2 (G₂), the cell builds the machinery necessary for division. This includes the structures that will separate the genetic material and divide the cell into two daughter

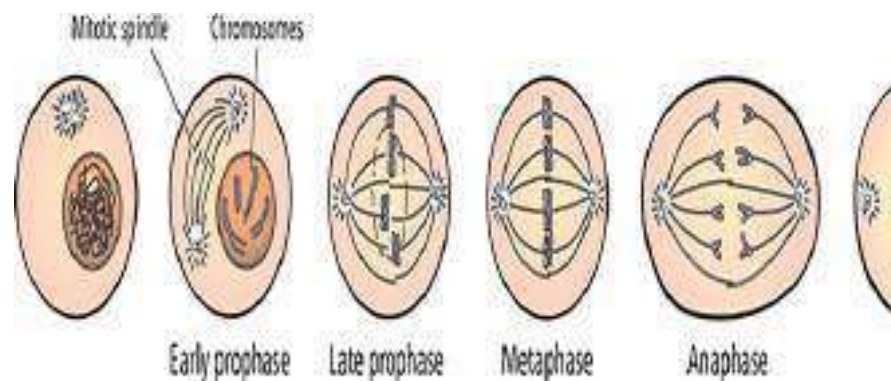
Mnemonics are little sayings that help us remember. Here's a mnemonic for the cell cycle: "Go, Sally, Bake a Cake!" (Gap 1, Synthesis, Gap 2, Mitosis and Cytokinesis)



During mitosis and cytokinesis (M), the cell divides. Mitosis is the division of the nucleus, which takes place in four steps, (Figure 15.30). During *prophase*, the normally loosely packed chromosomes condense and the membranes surrounding

break down. The condensed chromosomes each consist of two sister chromatids attached at a point called the centromere. The mitotic spindle also forms during prophase. The mitotic spindle is a series of fibers that attach to the duplicated chromosomes and pull them apart, separating the genetic material between the two daughter cells. During metaphase, the chromosomes line up at the equatorial plane, the plane through the imaginary “equator” of the cell. During anaphase, the sister chromatids are pulled apart by the shortening of the spindle fibers and move to opposite poles of the cell. During telophase, the nuclear membranes form around each set of chromosomes, and the chromosomes return to their loosely packed state. The process of mitosis is followed by *cytokinesis*, the division of the cytoplasm to form two separate daughter cells.

Figure 15.30



During mitosis, the nucleus divides in four phases: prophase, metaphase, anaphase, and telophase.

And here's a mnemonic for the phases of mitosis
"Meet And Talk!" (Prophase, Metaphase, Anaphase,
Telophase).



Cells are not always in the cell cycle. Many cells are nei
preparing to divide; they are simply carrying out their r
These cells are said to be in gap 0 (G_0). Some cells are i
and will eventually reenter the cell cycle. Other cells, st
neurons, are in permanent G_0 and will never divide aga

Check Yourself

Interactive

Question

Check Answer

Question

During which stages of the cell cycle does the cell have twice the amount of genetic material it normally has?

Check Answer


During which stages of the cell cycle does the cell have twice the amount of genetic material it normally has?

Answer: The cell has twice the normal amount of genetic material during the S and M stages—that is, after S stage and continuing up until cytokinesis. The cell has double the amount of genetic material after S because DNA replication occurs during S. During M, all that genetic material is packaged into chromosomes, but the amount of genetic material does not change.

Science and Society

Henrietta Lacks and Immortal Cells

A lot of medical research relies on studying human cells in a laboratory. But for many years, scientists could not even grow human cells outside the body. The cells would live for a while, but not long, and reproducing, but then they would die. A huge breakthrough occurred when scientists discovered that cells from Henrietta Lacks could live and grow in the lab indefinitely. Her cells, called HeLa cells, are still used in research today.



originally obtained from a woman named Henrietta Lacks, who died of cervical cancer in 1951, when she was only 31 years old. Since then, HeLa cells have contributed to scientific research in countless ways. They have helped scientists develop treatments, the polio vaccine, in vitro fertilization, and HeLa cells have also contributed to studies of leukemia and even the effects of zero gravity in space.

However, Henrietta Lacks's cells were removed without her knowledge or consent while she was a patient at Johns Hopkins Hospital. For many decades, her family did not know that her cells had been collected and saved, and they were being used widely in research.

The story of Henrietta Lacks and HeLa cells raises important ethical issues, including informed consent, privacy, and profit. It has led to stricter policies about informed consent and the ownership of patient biological samples. These issues continue to be important today, especially since personal information is being collected and used in ways that HeLa cells could infringe on the privacy of Lacks's descendants. Profit and compensation are also issues, as pharmaceutical companies have made huge profits on products that have been made using research on HeLa cells. Some family members have also

considered seeking compensation from companies that profited from the use of Lacks' cells.



Henrietta Lacks's cancer cells have contributed to medical and scientific research, but they were taken without her knowledge or consent. Her family did not know for

15.8 How Cells Use Energy

Learning Objective

Describe the role of enzymes in cells.

At any moment, countless chemical reactions are occurring. These reactions sustain life by allowing cells to carry out such functions as building macromolecules, transporting molecules across membranes, and dividing. But what determines exactly which reactions occur?

In order for a chemical reaction to occur, two conditions must be met. First, the reaction must obey the law of conservation of mass. The reacting molecules must collide with enough energy for the reaction to go—they must have the *activation energy* needed for the initial breaking of bonds.

Let's look at conservation of energy first. *Exothermic* reactions release energy, and *endothermic* reactions absorb energy. Because of the law of conservation of energy, exothermic reactions tend to happen all by themselves. On the other hand, endothermic reactions can occur only if energy is supplied to the system.

external source is provided. In cells, this external source is found in molecules of adenosine triphosphate, or **ATP**.

Unifying Concept

The Law of Conservation of Energy [Section 4.10](#)

Integrated Science 15C: Chemistry

ATP and Chemical Reactions

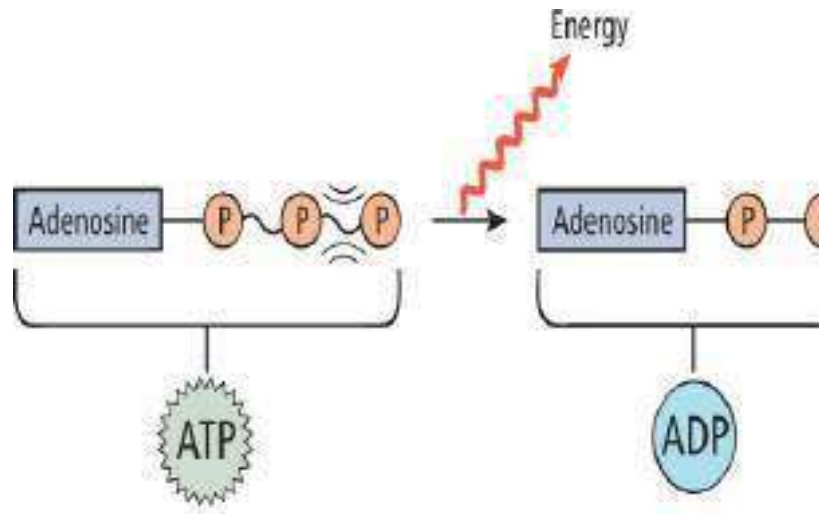
Learning Objective

Explain how ATP provides cells with the energy needed to run chemical reactions.

ATP provides energy for cellular processes. It consists of an adenosine molecule and three phosphate groups. Cells release energy from ATP when one of its phosphate groups is removed, leaving adenosine diphosphate, or ADP ([Figure 15.1](#)). Cells eventually turn ADP back into ATP by adding a phosphate group during cellular respiration, a process you will learn about later in this chapter. As you can see in [Figure 15.1](#), ATP acts like a rechargeable battery that can be repeatedly used.

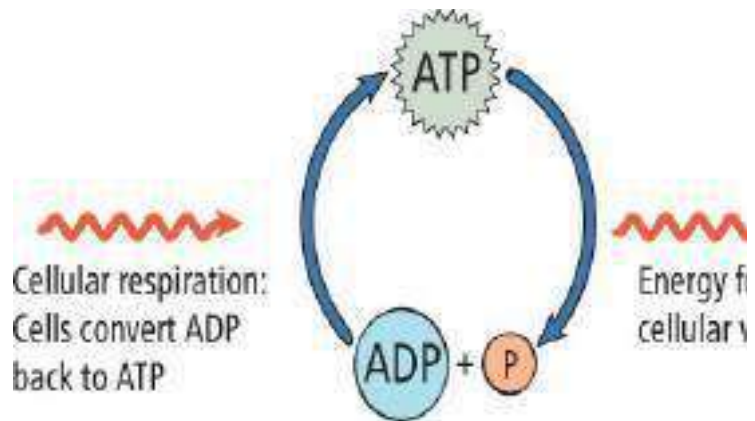
recharged. Of course, the second law of thermodynamics tells us that it will take more energy to make ATP than we eventually get out of it. This means that not all the energy we take in through food gets turned into growth, reproduction, or activity; a large proportion of it is lost to the environment as heat.

Figure 15.31



Energy is obtained from ATP when one of its phosphate groups is removed, leaving ADP.

Figure 15.32



Cells obtain energy from ATP when one of its phosphate groups is removed, leaving ADP. ADP is eventually turned back into ATP through the addition of a phosphate group during cellular respiration.

Unifying Concept

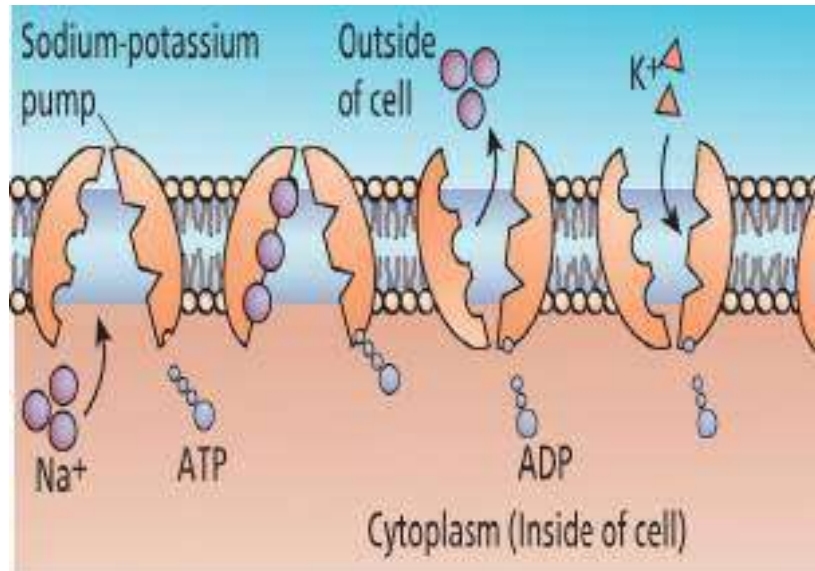
The Second Law of Thermodynamics **Section 3.1**

An example of a biological process that requires the hydrolysis of a molecule of ATP to run is the sodium-potassium pump. The sodium-potassium pump uses active transport to move sodium ions from a low concentration of sodium ions (Na^+) and a high concentration of potassium ions (K^+) inside animal cells to a high concentration of sodium ions outside and a low concentration of potassium ions inside. Maintaining appropriate ion concentrations helps to regulate water flow into and out of the cell.

critical for such processes as the firing of neuron contraction of muscles.

How does the pump work? The sodium-potassium transport protein in the cell membrane (Figure 15.33) behaves like a swinging door, shuffling ions into and out of the cell. In its default state, the protein is open to the outside of the cell. There, it binds three sodium ions. An ATP reaction, in which a molecule of ATP transfers a phosphate group to the protein, causes the protein to shift and open to the inside of the cell. The sodium ions are released, and two potassium ions are bound, causing the phosphate group to be released. The loss of the phosphate group causes the transport protein to shift back to its original position and release the potassium ions inside the cell. Amazingly, more than 50% of all the ATP consumed by animals is used to run the sodium-potassium pump.

Figure 15.33



The sodium-potassium pump moves sodium ions and potassium ions into cells. One molecule of A^r movement of three sodium ions out and two pota

Check Yourself

Interactive

Question 1

Check Answer

Question 2

Check Answer

Question 1

Each “pump” of the sodium-potassium pump moves three sodium ions out and three potassium ions in. If you have five molecules of ATP, how many potassium ions can be transferred from one side of the cell membrane to the other?

Check Answer


Each “pump” of the sodium-potassium pump moves three sodium ions out and three potassium ions in. If you have five molecules of ATP, how many potassium ions can be transferred from one side of the cell membrane to the other?

Answer: Fifteen sodium ions can be moved out of the cell, and fifteen potassium ions can be moved into the cell.

Question 2

If ATP were temporarily unavailable, what would happen to a cell?

We now see how cells use energy from ATP to power c
But a second condition must be met before a chemical r
The reacting molecules must collide with enough energ
reaction going—this activation energy is needed for the
bonds. Unfortunately for living organisms, the activatio
essential chemical reactions is very high. Some importa
take 100 years to happen on their own. Because of this,
catalysts, which lower the activation energy of reactions
to happen more quickly. The catalysts in cells are large,

called enzymes . Enzymes help specific chemical reactions occur more quickly by lowering the activation energy. With the help of enzymes, important chemical reactions can happen in minutes instead of taking 100 years.


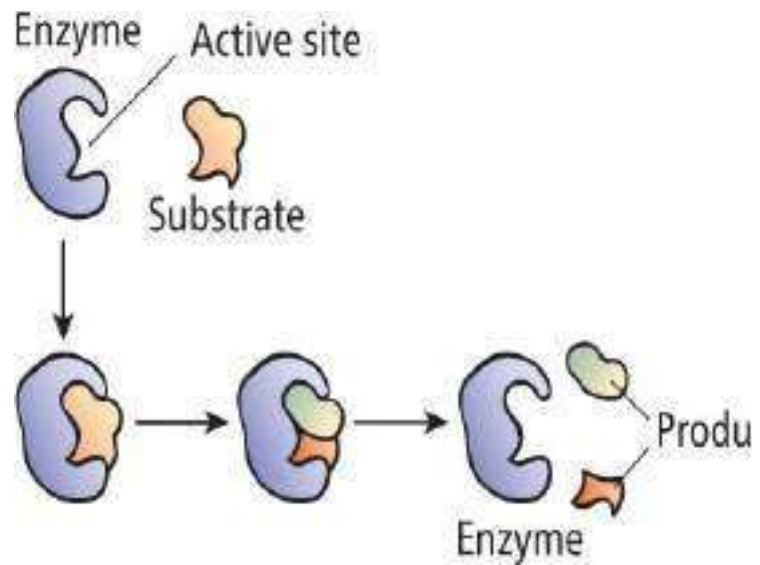
How does an enzyme work? An enzyme binds the reactant—the enzyme's *substrate*—at its active site and then releases the product (Figure 15.34 ). Enzymes, like other catalysts, are not destroyed in the reactions they catalyze. This means that enzymes can catalyze the same reaction over and over again. Enzymes catalyze nearly all of the chemical reactions in cells; in fact, several thousand unique enzymes have been identified in living organisms. Each enzyme is highly specific for a certain reaction—that is, it is very picky about the substrate to which it binds and the reaction it catalyzes.

Figure 15.34

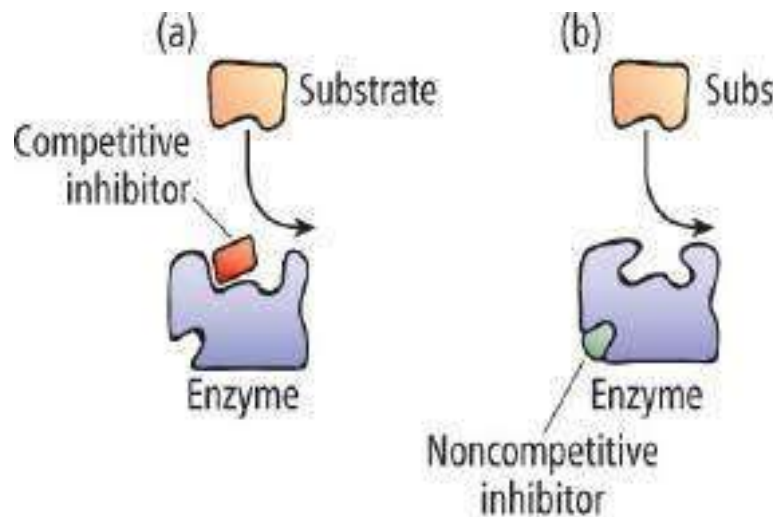


Enzymes are large proteins that function as catalysts. They are highly specific, binding to only specific molecules and catalyzing specific reactions. Note that the enzyme is not used up in the reaction and so it is available to catalyze the same reaction again.

Cells regulate enzymes carefully in order to control the rate of metabolic reactions. Regulation takes place in different ways. First, cells control the synthesis and degradation of enzymes. (Enzymes are not used up when they catalyze a reaction, so they must be actively degraded when they are no longer needed.) Second, how well an enzyme works depends on the chemical features of its environment—the temperature, pH, and other factors. For example, if the temperature is too high or too low, the enzyme's shape may change and the reactants may not be able to bind to the active site. Enzymes can be blocked by inhibitors. In competitive inhibition (Figure 15.35a), an inhibitor binds to the active site of an enzyme,

from binding to its substrate. (If a substrate fits into an enzyme like a key in a lock, the inhibitor is like bubblegum stuck in the keyhole. This type of inhibition is called competitive inhibition because the substrate and inhibitor compete for the active site. Cyanides are toxic because they competitively inhibit enzymes that are critical for cellular respiration. In noncompetitive inhibition (Figure 15.35b), an inhibitor binds to an enzyme somewhere other than at the active site, changing the shape of the active site so that the enzyme can no longer bind to its substrate. Lead is toxic because it binds to a number of enzymes in the body and disrupts their structure.)

Figure 15.35



(a) In competitive inhibition, the inhibitor binds to the active site and blocks the substrate from binding. (b) In noncompetitive inhibition, the inhibitor binds to the enzyme somewhere other than the active site. This changes the shape of the active site so that the enzyme is no longer able to bind to the substrate.

Many medications work by inhibiting enzymes. The antibiotic penicillin kills bacteria by inhibiting an enzyme that bacteria need to make cell walls. Aspirin (Figure 15.36) works as a painkiller because it inhibits an enzyme needed to make prostaglandins, molecules that make you sensitive to pain.

Figure 15.36



Aspirin is an effective painkiller because it inhibits an enzyme needed to make prostaglandins. Prostaglandins make you sensitive to pain.

Integrated Science 15D: Physics and Chemistry

Photosynthesis

Learning Objective

Explain how plant cells use light energy from the Sun, carbon dioxide, and water to make sugars.

Along the highways of California's Central Valley, farmers celebrate the work of farmers. Some of them say *TURNING WATER AND SUNLIGHT INTO FOOD*. This is what all plants do. They take sunlight and carbon dioxide and turn them into organic molecules, some of which are turned into living plant matter. (It turns out that plants also take up carbon dioxide from the air, too, as we will see.)

Plants are constantly removing carbon dioxide from the air as they photosynthesize. You may have heard that the increasing amount of carbon dioxide in the atmosphere is causing global warming. This is because plants are removing carbon dioxide from the air.

conserving forests is an important part of the battle against global warming.

Plants and certain other organisms use photosynthesis to convert light energy from the Sun into chemical energy in organic molecules. Almost all life on Earth depends on photosynthesis for organic molecules and energy because plants and other photosynthesizers (such as algae and certain bacteria) are food for herbivores, and they are also food for carnivores. So, photosynthesizers are the source of all food.

The chemical reaction for photosynthesis is:

Unifying Concept

Waves Section 8.1



Carbon dioxide, water, and sunlight go in; glucose and oxygen come out. (Keep in mind, though, that this is a summary of the overall process of photosynthesis. In fact, a large number of chemical reactions are needed before the reactants of photosynthesis are converted into the products.) The oxygen released during photosynthesis is the source of the

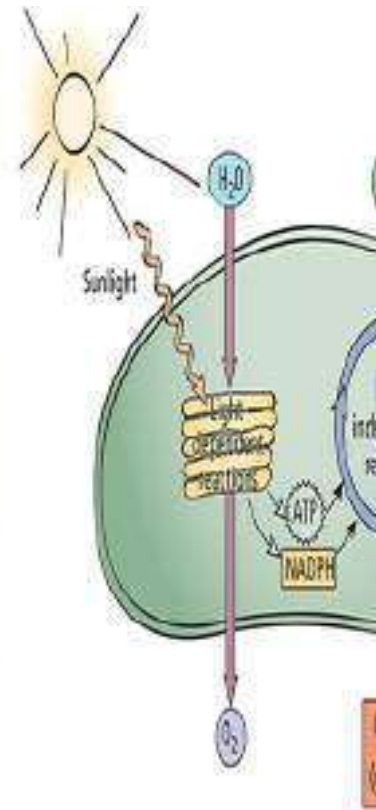
breathe—yet another way photosynthesis is found as we know it.

Photosynthesis takes place in the chloroplasts of (Figure 15.37a). It occurs in two steps: *light-dependent reactions* and *light-independent reactions* (Figure). During the light-dependent reactions, energy is captured from sunlight. During the light-independent reactions, carbon dioxide is fixed—that is, carbon atoms are moved from atmospheric carbon dioxide to the organic molecule glucose.

Figure 15.37



(a) Chloroplast



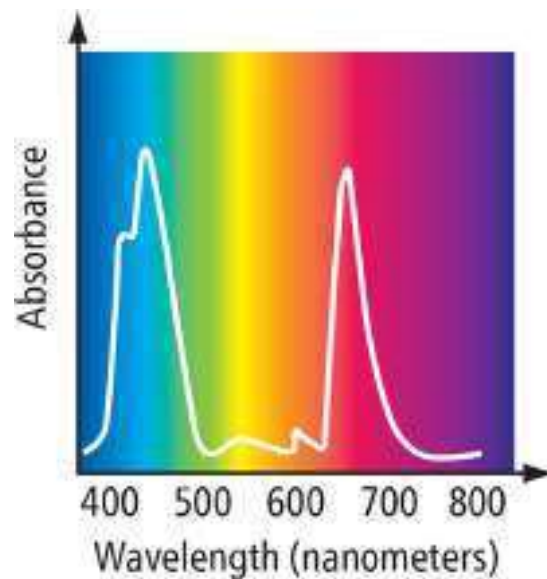
(b) Photosynthesis

(a) Photosynthesis takes place in plant organelles chloroplasts, found primarily in stems and leaves. shows a chloroplast in a lilac leaf. (b) Photosynthesis consists of two steps: the light-dependent and light-independent

The light-dependent reactions begin when sunlight strikes a chlorophyll molecule inside a chloroplast. Chlorophyll is a green pigment, meaning it is a molecule that absorbs light. Light is just one part of the electromagnetic spectrum (which also includes radio waves, ultraviolet light, X-rays, and gamma rays.) Chlorophyll absorbs blue-violet light and re

best, as you can see in [Figure 15.38](#). The light that does not absorb—green light—is reflected by plants, which is why plants are green.

Figure 15.38

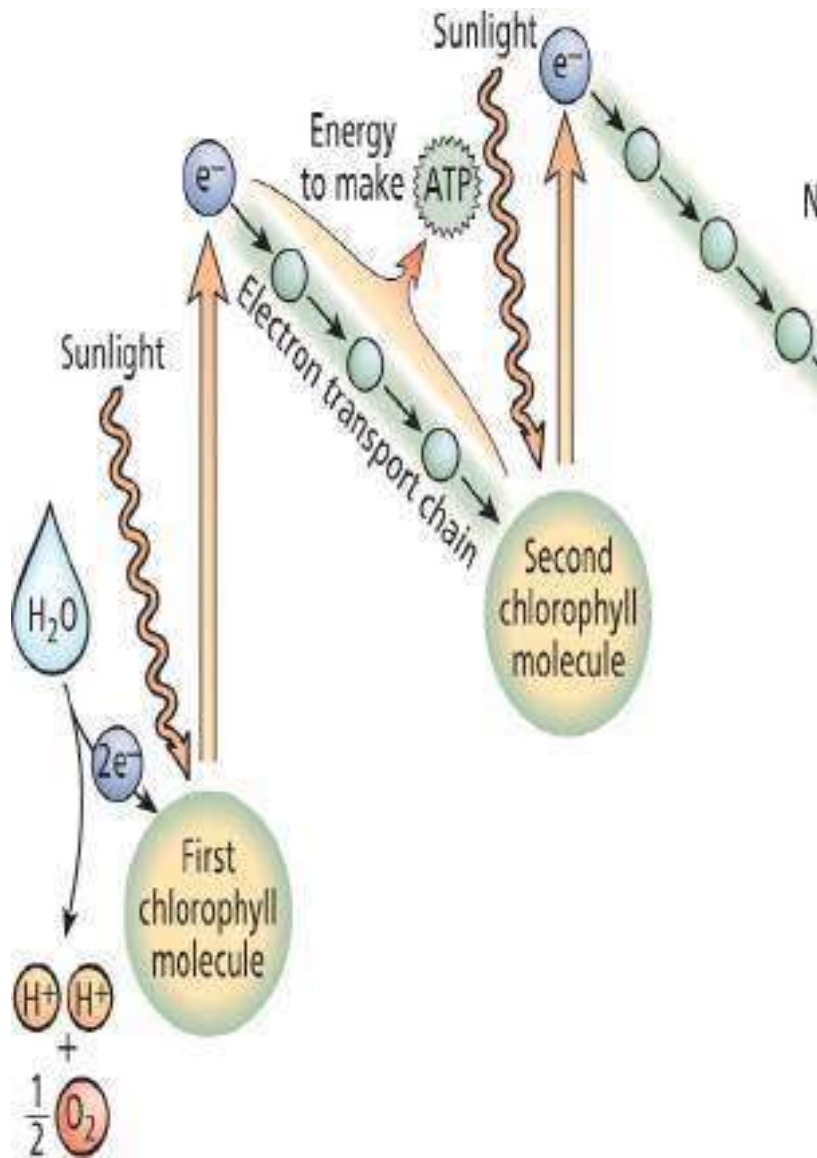


Light is a type of electromagnetic radiation. Like all electromagnetic radiation, it takes the form of waves. The colors of visible light have different wavelengths, about 400 nanometers for blue-violet light to 800 nanometers for red light. This graph shows that chlorophyll a absorbs light best in the violet and red-orange regions. It does not absorb green light well.

When sunlight strikes a chlorophyll molecule, the energy of the sunlight excites an electron in the chlorophyll molecule.

knocks it out (Figure 15.39). The chlorophyll molecule is now missing an electron, extracts an electron from water (H_2O), which causes oxygen (O_2) to be produced. The high-energy electron that was knocked out of the chlorophyll molecule passes down an electron transport chain. An *electron transport chain* consists of a series of carrier molecules, each of which receives the electron and then passes it on to the next carrier. You can imagine an electron transport chain as a cartoon fire brigade, in which a bucket of water is passed from one person to the next until the last person tosses it over the flames (Figure 15.40). As the bucket of water, passed from one carrier to the next, the electron passes down the transport chain, it loses energy. This energy is used to convert ADP into ATP. At the end of the electron transport chain, a second, different chlorophyll molecule receives the electron. This chlorophyll molecule is excited by sunlight, and the electron is knocked out again and passes down a second electron transport chain. This time the energy lost by the electron as it passes down the transport chain is used to convert a molecule called $NADP^+$ into $NADPH$.

Figure 15.39



In the light-dependent reactions of photosynthesis transport chains capture energy from sunlight and produce ATP and NADPH. Oxygen is released.

Figure 15.40



In an electron transport chain, the electron is passed from one carrier to the next the way a bucket of water is passed from one person to the next in a cartoon fire brigade. The energy is released as it is passed down the chain.

Did you know that some plants do not photosynthesize? These plants live as parasites that absorb nutrients from their hosts—other plants. Parasitic plants often lack chlorophyll, which also means they may not look green.

To summarize, two important things happen during photosynthesis. First, energy from sunlight is converted into chemical energy in the form of ATP and NADPH. Second, oxygen is released.

In the light-independent reactions, also known as *cycle*, the cell uses the energy stored in ATP and carbon (see [Figure 15.37b](#)). During the Calvin cycle, molecules of carbon dioxide (CO₂) are taken in and used to make a molecule of glucose (C₆H₁₂O₆). Cells use glucose as a starting point for making other carbohydrates, lipids, and proteins. In the addition of nitrogen, amino acids and nucleic acids, in short, all the macromolecules of life.

Check Yourself

Interactive

Question 1

Check Answer

Question 2

Check Answer

Question 1

What three things does a plant need to photosynthesize? What is made during photosynthesis?

Check Answer

What three things does a plant need to photosynthesize? What is made during photosynthesis?

Answer: Plants need sunlight, water, and carbon dioxide for photosynthesis. Two products are glucose and oxygen.

Question 2

Is oxygen released during the light-dependent or the light-independent photosynthesis?

Technology

Artificial Leaves

Plants turn sunlight, water, and carbon dioxide into molecules that store energy. Can people develop leaves that do the same thing? How would people develop artificial leaves?

Artificial leaves use water, carbon dioxide, and energy from the Sun to create a fuel that stores energy for later use. This “artificial fuel” essentially saves energy from the Sun in a form that can be easily stored, transported, and used. Solar fuels are expected to take the place of fossil fuels such as oil and coal. Fossil fuels currently provide most of the energy that humans use. Unlike fossil fuels, solar fuels are carbon neutral—they do not create a net addition of carbon dioxide to the atmosphere because they take carbon dioxide from the atmosphere to create the fuels in the first place. This is important because rising carbon dioxide levels in the atmosphere have led to climate change and global warming.

What does an artificial leaf look like, and how does it work? The current model is a coated chip of silicon in a glass container. When sunlight strikes the chip, a solar cell (like the cells in solar panels) converts light energy from the Sun into electricity. This allows molecules in the cobalt-phosphate catalyst to split water into hydrogen and oxygen. The oxygen is released, and so far, this accomplishes the same thing as the light reactions of photosynthesis. Then, special “hydrogen-producing” bacteria use the hydrogen, along with carbon dioxide from the atmosphere, to build the fuels. The bacteria basically

accomplish the same thing as the light-independent of photosynthesis.

The results so far are promising—a group at Harvard has created an artificial leaf that is even more efficient than natural plants at using sunlight energy. Where natural plants convert only about 1% of the energy in sunlight to make glucose, the artificial leaf uses 3% to 4% of the energy in sunlight to produce glucose. Will artificial leaves be part of the solution to climate change? Scientists are currently working toward bringing the technology to market.



Artificial leaves build solar fuels using sunlight, water, and carbon dioxide.

Integrated Science 15E: Ch

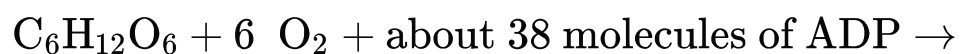
Cellular Respiration and Ferm

Learning Objective

Explain how cells break down glucose to obtain energy in the form of ATP.

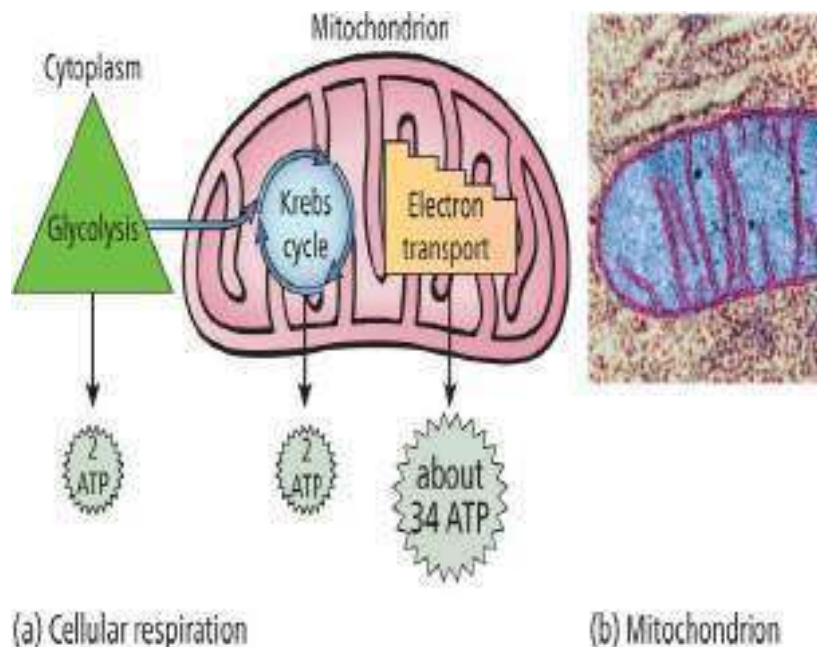
What do the following things have in common: heart rate during exercise, bread dough rising, and alcohol fermentation? They are all related to how cells obtain energy.

All cells need ATP, which provides the energy required for essential cellular processes. In order to obtain ATP, cells break down glucose and other organic molecules. The oxygen-using, breakdown of glucose is known as **respiration**. The equation for cellular respiration is:



Glucose, oxygen, and ADP go in; carbon dioxide, ATP come out. This equation summarizes the pro cellular respiration. The many chemical reactions from the beginning to the end of cellular respiration are divided into three steps: glycolysis, the Krebs cycle, and electron transport (Figure 15.41).

Figure 15.41



(a) Cellular respiration takes place in three steps: glycolysis, the Krebs cycle, and electron transport. Glycolysis occurs in the cytoplasm. The Krebs cycle and electron transport occur in the mitochondria. (b) This is an electron micrograph of a mitochondrion.

Glycolysis

The first step in breaking down glucose is *glycolysis* (literally means “sugar splitting”). Glycolysis takes place in the cell cytoplasm. During glycolysis, the six-carbon glucose molecule is split into two molecules of pyruvic acid, each of which contains three carbon atoms. Two molecules of ATP are produced in the process.

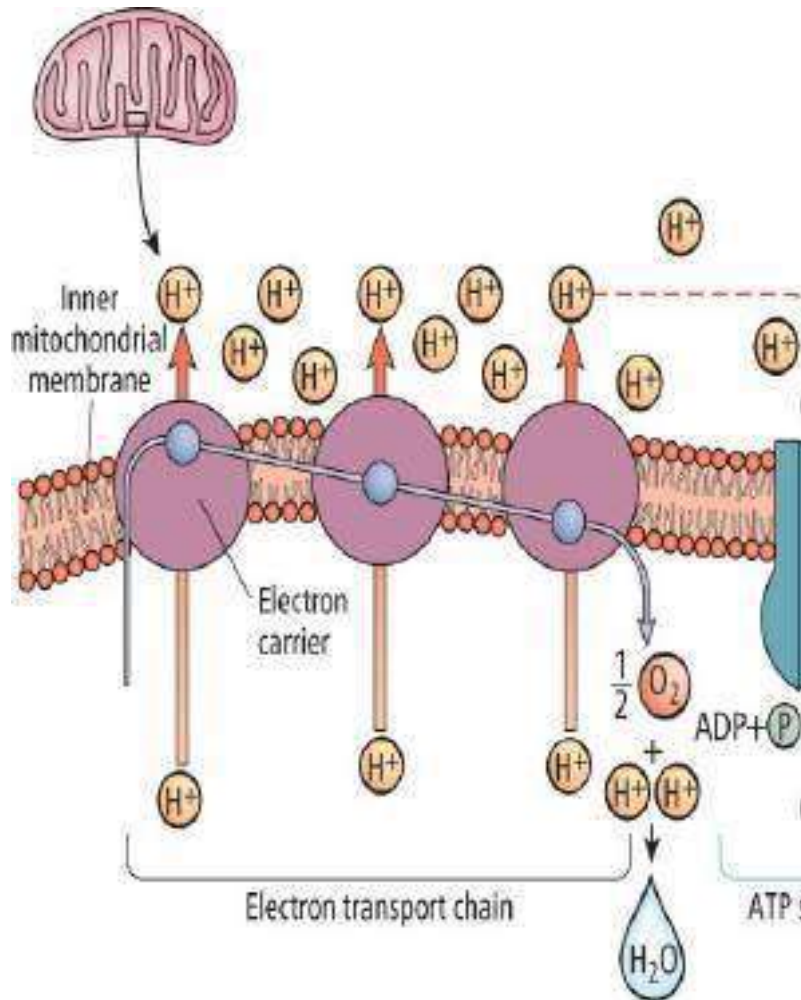
The Krebs Cycle and Electron Transport

The Krebs cycle and electron transport occur in the mitochondria. Before entering the Krebs cycle, the pyruvic acid that is produced during glycolysis is converted into acetyl-CoA and bound to a molecule of coenzyme A. This entity is called acetyl-CoA. During the Krebs cycle, acetyl-CoA is broken down into carbon dioxide. Two molecules of ATP and additional energy is stored in two other molecules, NADH and FADH₂.

During electron transport, electrons carried by NADH and FADH₂ are sent down electron transport chains (ETC). As electrons are passed from one carrier in the tr

to the next, they lose energy. This energy is used to pump hydrogen ions (H^+) across a membrane inside the mitochondrion. At the end of the electron transport chain, electrons combine with an oxygen molecule to form water (This is what all the oxygen we breathe is for—it is to catch those electrons at the end of electron transport). The concentration gradient of hydrogen ions across the mitochondrial membrane is then used to make ATP. As hydrogen ions move back across the inner mitochondrial membrane (down their concentration gradient), they pass through a protein complex called ATP synthase, which converts ADP into ATP. This process generates most of the ATP during cellular respiration.

Figure 15.42



As electrons move down electron transport chain ions are pumped across the membrane inside mit When the hydrogen ions move back across the m generate ATP.

Fermentation

In certain cells, glycolysis is sometimes followed *anaerobic* (non-oxygen-using) process known as **fermentation** [ⓘ] instead of the aerobic process ju

Fermentation yields no ATP, but it does regenerate molecules necessary to keep glycolysis going. It can continue to obtain ATP through glycolysis.

Alcoholic fermentation is an anaerobic process that takes place in the cytoplasm of yeast cells. In alcoholic fermentation, the pyruvic acid from glycolysis is broken into ethanol and carbon dioxide. Alcoholic fermentation is essential both to making wine and to baking bread. Yeast cells ferment the sugar in grape juice to turn it into wine. The same process makes bread rise—yeast cells ferment the sugar in bread dough, releasing tiny bubbles of carbon dioxide. (And, yes, fermentation also produces ethanol in bread, but it evaporates during baking. This is why you can't be 21 to purchase dinner rolls.)

As yeasts ferment the sugars in bread dough, they release tiny bubbles of carbon dioxide gas, which makes the dough rise.



Lactic acid fermentation is an anaerobic process that occurs in some animal cells as well as in certain species of fungi. It takes place in the cytoplasm of these cells. In lactic acid fermentation, the pyruvic acid from glycolysis is converted down to lactic acid. In animal muscle cells, lactic acid fermentation occurs during strenuous exercise, when the oxygen supply—despite heavy breathing—can't meet the demand. By regenerating the molecules required for glycolysis, lactic acid fermentation allows muscle cells to continue to make ATP without oxygen. The lactic acid produced during strenuous exercise causes a burning sensation in the muscles. Red blood cells, which lack mitochondria, rely on lactic acid fermentation for all their ATP. Finally, lactic acid fermentation by certain species of bacteria and fungi is used to produce cheese and yogurt.

Why do you continue to breathe hard even strenuous activity ends? The liver needs to convert lactic acid back into pyruvic acid, which can then be converted back into glucose again.

Your body relies on cellular respiration for endurance activities such as long-distance or cycling, but on lactic acid fermentation for activities that require a burst of energy, such as sprinting or hitting a baseball.

Table 15.2 compares cellular respiration and fermentation.

Table 15.2 Comparing Cellular Respiration and Fermentation

Cellular Respiration

Aerobic (uses oxygen)

Steps: glycolysis, Krebs cycle, electron transport

Takes place in cytoplasm (glycolysis) and mitochondria (Krebs cycle and electron transport)

Makes 38 molecules of ATP

Fermentation

Anaerobic (does not use oxygen)

Steps: glycolysis, fermentation

Takes place in cytoplasm only

Makes 2 molecules of ATP (from glycolysis)

Check Yourself

Interactive

Question 1

Check Answer

Question 2

Check Answer

Question 1

About 38 molecules of ATP are obtained from 1 glucose molecule. How many come from glycolysis, the Krebs cycle, and electron transport?

Check Answer

About 38 molecules of ATP are obtained from 1 glucose molecule. How many come from glycolysis, the Krebs cycle, and electron transport?

Answer: Of the approximately 38 ATP molecules, 2 come from the Krebs cycle, and about 34 from electron transport.

Question 2

How are the chemical reactions for photosynthesis and cellular respiration different? How are they similar?

Summary of Terms (Knowledge)

For instructor-assigned homework, go to
www.masteringphysics.com

Active transport □

Transport across the cell membrane that requires energy.

ATP □

Adenosine triphosphate, the molecule that provides the energy for cellular processes.

Biology □

The study of life and living organisms.

Carbohydrates □

Organic molecules that consist of a single simple sugar molecule.

Cell membrane □

The structure that separates the inside of the cell from the outside of the cell.

Cells □

The basic units of life that make up all living organisms.

Cellular respiration □

The aerobic breakdown of glucose to produce ATP.

Chloroplasts □

The organelles within plant cells in which photosynthesis occurs.

Chromosomes □

The DNA-containing structures within cells.

Cytoplasm □

The part of a cell that is inside the cell membrane but outside the nucleus.

Diffusion □

The passive movement of molecules from an area of high concentration to an area of low concentration.

Enzymes □

Complex proteins that catalyze chemical reactions in living organisms.

Eukaryotes □

Organisms whose cells have a true nucleus, such as protozoa, plants, and fungi.

Fermentation □

The anaerobic breakdown of glucose that results in the production of ethanol and carbon dioxide (alcoholic fermentation) or lactic acid (acid fermentation).

Lipids □

Hydrophobic organic molecules, many of which include long hydrocarbon chains, are the primary component of cell membranes.

Mitochondria □

Eukaryotic organelles that break down organic molecules to produce ATP.

Mitosis □

A form of cell division in which one cell divides into two, each of which contains the same genetic information as the parent cell.

Nucleic acids □

Organic molecules that are composed of chains of nucleotides and carry genetic information.

Nucleus □

A structure within eukaryotic cells that is surrounded by a nuclear membrane and that contains the cell's DNA.

Organelles □

Structures within the cytoplasm of eukaryotic cells that perform specific functions in the cell.

Passive transport □

Transport across the cell membrane that does not require energy from the cell.

Photosynthesis □

The process in plants and some other organisms in which light energy from the Sun is converted into chemical energy in organic molecules.

Prokaryotes □

Single-celled organisms, such as bacteria and archaea, that lack a nucleus.

Proteins □

Organic molecules composed of folded chains of amino acids.

Reading Check Questions (Comprehension)

15.1 Characteristics of Life

1. What are some of the characteristics of living organisms?
2. Describe what it means to say that living things exist in populations that evolve.

15.2 The Two Types of Cells: Prokaryotic and Eukaryotic

3. What are some examples of prokaryotes? What are some examples of eukaryotes?
4. Describe three or more differences between prokaryotic and eukaryotic cells.
5. How is the DNA of prokaryotes packaged differently from the DNA of eukaryotes?

15.3 Tour of a Eukaryotic Cell

6. What is the nucleus of a cell?
7. Describe the functions of the following organelles: ribosomes, lysosomes, chloroplasts.

15.4 The Cell Membrane

8. What are three components of the cell membrane?
9. How are phospholipids arranged in the cell membrane?
10. What are some of the functions of membrane proteins?

15.5 Transport Into and Out of Cells

11. What is diffusion?
12. What is the difference between diffusion and facilitated diffusion?
13. What distinguishes passive transport from active transport?
14. How do endocytosis and exocytosis move materials into and out of cells?

15.6 Cell Communication

15. What are gap junctions? What function do they
16. Describe what happens when a message molecule binds to a receptor on the cell membrane.
17. Why do only certain cells receive and respond to a message molecule?

15.7 How Cells Reproduce

18. What are the stages of the cell cycle? What happens during the S phase (synthesis (S))?
19. Describe the phases of mitosis.
20. What are the end products of mitosis?

15.8 How Cells Use Energy

21. Why do cells need catalysts? What are the catalysts?
22. Describe two ways that cells can regulate enzyme activity.
23. How does penicillin kill bacteria?

Think Integrated Science

15A—The Big Molecules that Life

24. What are some of the different functions of pro
25. Give an example of (a) a carbohydrate that func
storage and (b) a carbohydrate that has a struct
26. Describe the structure of DNA.
27. Explain this statement: Proteins, carbohydrates
nucleic acids are called macromolecules becaus
composed of smaller units joined together.

15B—The Microscope

28. Why are light microscopes of limited use to cell
29. Why are electron microscopes particularly usef
biologists?

15C—ATP and Chemical Reactions in Cells

30. How does ATP provide energy for cells?
31. Is the amount of energy it takes to make ATP the same amount of energy that cells eventually get out of it?
32. Describe how the sodium-potassium pump works. What is the active transport of sodium and potassium ions?

15D—Photosynthesis

33. Why is almost all life on Earth dependent either directly or indirectly on photosynthesis?
34. What happens during the light-dependent reactions of photosynthesis? What happens during the light-independent reactions?
35. In the chemical reaction for photosynthesis, what are the reactants and what are the products?

15E—Cellular Respiration and

Fermentation

36. Describe the process of glycolysis. How much ΔG during glycolysis?
37. About how many ATP molecules does a cell obtain from one molecule of glucose through cellular respiration? What products result from cellular respiration?
38. What are the products of alcoholic fermentation?
39. Give two examples of cells in the human body that use fermentation. Why does each of these cells use fermentation?

Think and Do (Hands-On Application)

40. Does a pound of lipid (such as fat or oil) really weigh more than a pound of carbohydrate? Examine the number of calories in a bag of sugar and a stick of butter or a bottle of cooking oil. How many calories are in a pound of sugar? What about a pound of butter or cooking oil?
41. Carefully place a teabag in a mug of very still hot water. Observe what happens. Why is the water darker near the teabag than farther away from it? If you remove the teabag and wait, will your tea eventually become uniformly dark? Explain why. Which cellular transport mechanism is involved? Explore and explain.
42. Find a recipe and mix up some bread dough. List the ingredients. (You may also be able to buy some pre-made dough at a supermarket; some supermarkets sell dough for pizza or bread crusts.) Place a ball of dough in a bowl or other container. Note how big the ball is. Let the dough sit for an hour.

dough risen? Pull it apart. Do you see any evidence
work?

Think and Compare (Analysis)

43. Rank these three living things from largest to smallest: (a) a tuberculosis bacterium, a prokaryote; (b) a baker's yeast cell, a single-celled eukaryote; (c) a human, a multicellular eukaryote.
44. Rank the molecules in order of the amount of energy they contain, from most to least: (a) ATP, (b) starch, (c) glucose.
45. Rank the processes in order of how much ATP they produce, from most to least: (a) glycolysis, (b) electron transport, (c) fermentation.

Think and Solve (Mathematical Application)

46. As energy-storage substances, carbohydrates provide 4 kilocalories of energy per gram, whereas fats provide 9 kilocalories of energy per gram. The American black bear hibernates for as long as seven months in the winter in which it does not eat. Before hibernating, black bears lose 12.5% of weight, often spending 20 hours a day eating and gaining much as 50 kilograms of fat. Show that the bear would gain 112.5 kilograms if it stored this energy as carbohydrates instead of as fat.
47. A typical cell in the body makes about 10 millimoles of ATP per second. Show that the cell breaks down 10 millimoles of glucose per second.
48. Two different bacteria have radii of 1 micrometer and 2 micrometers. What is the surface area of each cell? How does the surface area compare with the volume for each? What is the surface-area-to-volume ratio? Why is the ratio important? How do you obtain more molecules through diffusion? Why is the ratio important?

more challenging for the larger cell to meet its needs for diffusion? Recall that the surface area of a sphere is $4\pi r^2$ and the volume of a sphere is $\frac{4}{3}\pi r^3$.

- 49.** Proteins are folded chains of amino acids. All the living organisms are made up of only 20 different amino acids. Show that there are 400 different ways to make a dipeptide, 8000 different ways to make a tripeptide, and 64000 different ways to make a tetrapeptide. How many different ways are there to make a polypeptide of 10 amino acids? Do you see why the number of living organisms that can be made is practically countless?

Think and Explain (Syntheses)

15.1 Characteristics of Life

50. How can you tell a plant is alive even though it is not moving around?
51. What are some features of living organisms? Do all human beings show each of these features.
52. Bacteria reproduce by dividing in two. Is this an example of asexual reproduction or sexual reproduction? Explain your answer.

15A—The Big Molecules that Make Up Life

53. Are you made up of the same macromolecules as a plant? Explain your answer.
54. When birds migrate south for the winter, they may travel hundreds or even thousands of kilometers in a relatively short period of time.

time. Why do birds put on a layer of fat before migration? What would happen if they stored the form of carbohydrate?

55. Swimming mammals such as sea otters and beaver are described as having “waterproof” fur that keeps them dry as they swim. A close look at their fur coats shows they have very dense fur. In addition, the fur is covered with a layer of oil that helps repel water. Which macromolecules are involved and are involved in keeping swimming mammals dry?



56. DNA uses only four different kinds of nucleotides. How do these four nucleotides code for all the different kinds of proteins found in different living things?

15.2 The Two Types of Cells: Prokaryotic and Eukaryotic

57. Are your cells more like those of yeast or those of a prokaryotic cell? Defend your answer.
58. You look at a cell under a microscope and discover it has mitochondria and chloroplasts. Is the cell a prokaryotic cell? Is the cell from a plant or from an animal? Defend your answers.

15B—The Microscope

59. You hike near a pond, where you find strands of cress. Each of the eggs is about 1 to 2 mm in diameter. If you want to study the eggs as they develop into plants, what kind of microscope could you use?



60. What kind of microscope could you use to look at the seeds?
61. What kind of microscope could you use to look at the developing plants?

15.3 Tour of a Eukaryotic Cell

62. How are a cell's cytoskeleton and organelles like skeleton and organs?
63. What organelle is found only in plants? What do they do? Does this explain why animals have to eat?
64. Some cells in the body have more mitochondria than others. For example, nerve cells, muscle cells, and liver cells have many mitochondria. Bone cells and fat cells have very few mitochondria. What do you think explains this difference?
65. How is the function of a cell wall different from a cell membrane? Do you have cell walls, cell membranes, or neither?

15.4 The Cell Membrane

66. Explain why phospholipids form a double layer membrane. Be sure to use the words *hydrophilic* and *hydrophobic* in your answer.
67. Why is the cell membrane called a fluid mosaic model?

15.5 Transport Into and Out of

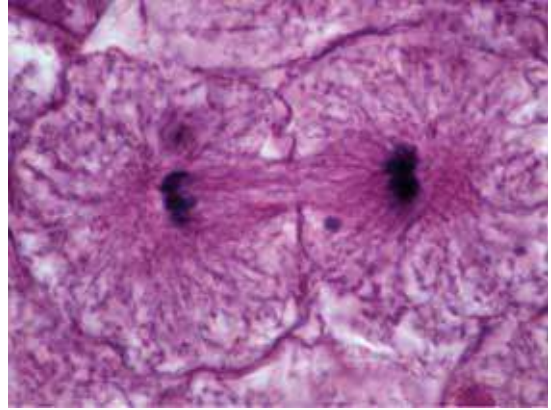
68. Transport proteins and the molecules they transport are often described as fitting together like a lock and key. Why is it so important that they have such a specific fit?
69. You learned that all cells face the challenge of controlling water flow. You also learned that water is able to cross the cell membrane directly or through aquaporins. Are cells that live in freshwater habitats likely to have the problem of too much water entering their cells or too little water entering? Why?
70. Glucose moves into many cells through facilitated diffusion. Why does this work because there is usually a higher concentration of glucose molecules outside the cell than inside the cell. In what case? (Hint: Do cells use up the glucose inside the cell?)
71. Why does oxygen diffuse into cells rather than out of cells? Why does carbon dioxide diffuse out of cells rather than into cells?
72. In plants, roots absorb water (among other functions). Why are the roots of many plants highly branched?
73. What is the difference between endocytosis and exocytosis? How do they allow a protein to cross the cell membrane?

15.6 Cell Communication

74. How are gap junctions and plasmodesmata similar and how do they differ?
75. Message molecules and their receptors are described together like a lock and key. Why is it important that there is such a specific fit?
76. If growth hormone is found in the bloodstream over the body, why do only certain parts of the body grow?

15.7 How Cells Reproduce

77. Imagine that a cell goes through all the stages of mitosis except that cytokinesis doesn't happen. How would the resulting cells be different from normal cells?
78. The figure below shows a cell in the process of mitosis. Which stage of the cell cycle is it?



15.8 How Cells Use Energy

- 79.** The deadly nerve gas sarin binds to an enzyme acetylcholinesterase, which breaks down acetylcholine. If acetylcholine is not broken down, muscles relax after contracting. Without prompt treatment, collapse and death follow. Sarin works by binding to acetylcholinesterase at the site where acetylcholine binds. What form of enzyme regulation does this represent?
- 80.** Enzymes and their substrates are described as having a lock and key fit. Why is it important that they have such a specific fit?
- 81.** What is an enzyme? What role do enzymes play in cells?
- 82.** Describe at least two different ways cells can regulate the activity of enzymes.

15C—ATP and Chemical Reaction Cells

83. If ATP is like a rechargeable battery, how is it used and how is it recharged?
84. Explain why it takes more energy to make ATP than is eventually get out of ATP.

15D—Photosynthesis

85. What happens to a plant that is kept in the dark?
86. You collect some pondweed from a local pond and put it in an aquarium. One day, you notice that bubbles are being produced by your plant, as in the photo here. Why is the plant producing bubbles? What kind of gas is in the bubbles?



87. Global warming has resulted from the large amount of carbon dioxide released when fossil fuels such as oil are burned for energy. Carbon dioxide traps heat. Why might deforestation and forests also contribute to global warming?
88. Write a letter to Grandma telling her about how photosynthesis works. Explain the three things plants need in order for photosynthesis to occur. Why would human life be impossible without photosynthesis?

15E—Cellular Respiration and Fermentation

89. Why can't you live without oxygen?
90. What are some differences between fermentation and cellular respiration? Which process produces more ATP? Which cells in the human body use fermentation?
91. You visit a friend who is a winemaker. Some of the grapes are fermenting in a vat. When you take a look, you see the wine is covered with a layer of bubbles. Why are there bubbles? What kind of gas is inside the bubbles?



92. Why is champagne bubbly? (Hint: In nonbubbly wine fermentation happens with the grape juice exposed to air. In champagne, there is an extra round of fermentation in the bottles are capped tight.)

93. Some animals that live in desert environments, kangaroo rat, never drink water. Kangaroo rats eat the starches and lipids in the dry seeds they eat. All living organisms need water, and, in fact, the kangaroo rats have about the same water content as other animals. How do kangaroo rats get their water?



Think and Discuss (Evaluation)

94. A friend in your study group claims that a change in an amino acid in an important protein can cause a change in function. Another friend says this doesn't make sense because a protein with a slight change should still be able to function. What do you say?
95. A friend in your class is reading about cells that have membranes around the droplets in the form of tiny lipid droplets. He says, "It says that the membranes around the droplets are just a single layer, instead of a double layer like everywhere else. Does it make sense, does it?" What is your reply?
96. You and a friend are eating lunch in the cafeteria. Both of you smell very strong perfume. "Wow," your friend says, "I wish they would turn the fan off. It's blowing that perfume all over the place." You say, "Even if they turn the fan off, there would still be perfume diffusion. You would still smell the perfume." Your friend says, "You're correct." What do you say?
97. You and a friend go to a garden shop to buy ferns. Your friend says, "Didn't we just leave the ferns in the garden?" What do you say?

make their own organic molecules through photosynthesis. Plants shouldn't need fertilizer." Another customer asks you for your discussion and looks at the bag of fertilizer. "Well," she says, "it looks like the main ingredients are nitrogen and phosphorus. I don't know if plants can make their own stuff or not." What do you say? Do you buy the

98. You are talking with a winemaker about yeast. The winemaker says that yeast can survive under both aerobic and anaerobic conditions. The winemaker says, "but what I don't understand is why they need so much more sugar under anaerobic conditions. I've heard that they need a hundred times as much sugar." Can you explain why yeast might need more sugar under anaerobic conditions than under aerobic conditions? Is his estimation of a hundred times as much sugar reasonable?

Readiness Assurance Test (1)

Readiness Assurance Test

Interactive

If you have a good handle on this chapter, if you really do, then to score 7 out of 10 on this RAT. If you score less than 7, you need to review before moving on.

Choose the BEST answer to each of the following:
10 questions

1. 1.

Which of the following is *NOT* a characteristic of living things?

use energy

Incorrect.

Press enter after select an option to check the answer

maintain themselves

Incorrect.

Press enter after select an option to check the answer

have the capacity to reproduce

Incorrect.

Press enter after select an option to check the answer

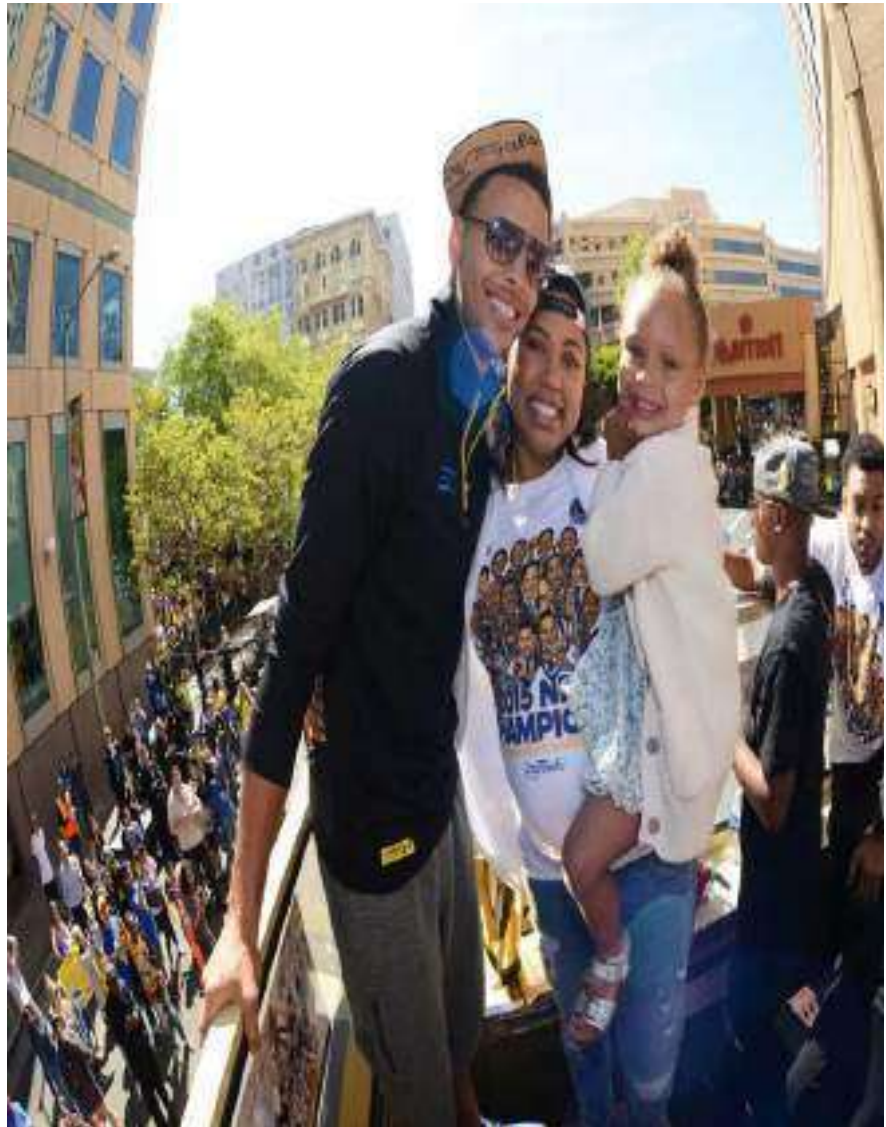
are part of populations that remain constant from one generation to the next

Correct.

Press enter after select an option to check the answer

Chapter 16

Genetics



16.1 What Is a Gene?

16.2 Chromosomes: Packages of Genetic Information

INTEGRATED SCIENCE 16A: CHEMISTRY: *The Structure of DNA* □

HISTORY OF SCIENCE: *Discovery of the Double Helix* □

INTEGRATED SCIENCE 16B: CHEMISTRY AND BIOLOGY: *DNA in Hot Environments* □

16.3 DNA Replication □

16.4 How Proteins Are Built □

16.5 Genetic Mutations □

INTEGRATED SCIENCE 16C: PHYSICS: *How Radiation Causes Genetic Mutations* □

16.6 Meiosis and Genetic Diversity □

16.7 Mendelian Inheritance □

16.8 More Wrinkles: Beyond Mendelian Inheritance

SCIENCE AND SOCIETY: *Genetic Counseling* □

16.9 The Human Genome □

SCIENCE AND SOCIETY: *Don't Spit Just Anywhere* □

16.10 Cancer: Genes Gone Awry

INTEGRATED SCIENCE 16D: EARTH SCIENCE

Causes of Cancer

16.11 Genetic Engineering

TECHNOLOGY: *Genetically Engineered Mosquito*

TECHNOLOGY: *Genome Editing with CRISPR-Cas9*

16.12 DNA Technology—What Could Possibly Go Wrong?

SHE HAS her mother's eyes and her father's nose—but not her *father's* eyes and her *mother's* nose? Why do living organisms resemble their parents? Why does a chicken egg always hatch a chick, a flamingo, or a bullfrog, or—just once!—a *Tyrannosaurus*? Why do offspring of living organisms are like their parents because they inherit their parents' genes. But what are genes? What do genes do? How do genes determine what organisms are like? How are changes in genes responsible for the remarkable diversity of life on Earth? How do genes cause devastating diseases as cancer? How can genetics research help us understand everything from what we eat to how long we live? We'll answer these questions in this chapter.

16.1 What Is a Gene?

Learning Objective

Define a gene, and explain why an organism's genes determine many of its characteristics.

Genes determine many traits in living organisms—the color of an orchid's flowers, the length of a cat's tail, the substance of a crab's shell or a bacterium's cell wall. In humans, genes determine eye color, whether we are tall or short, and whether our hair is straight or curly. Genes even influence our personalities. But what exactly does a gene do? How does a gene determine a trait?

A **gene** is a section of DNA that contains the instructions for making a protein. An organism's genes, found in its DNA, make up its **genotype**. The traits of an organism make up its **phenotype**. For example, you might have two genes for eye color, one brown gene and one blue gene. If so, you will have brown eyes. Your genotype is one brown gene and one blue gene, but your phenotype is brown eye color. How a genotype becomes phenotype—how genes become traits—is one of the topics covered in this chapter.

But, if genes contain instructions for building proteins, we wonder: Why are proteins so important? Why do so many things depend on proteins? The answer is that proteins do many things in living organisms. Proteins provide structure, transport molecules, function in cell communication, and protect organisms from disease. In addition, enzymes are proteins that are needed for practically every chemical reaction that occurs in living things.

16.2 Chromosomes: Packaging Genetic Information

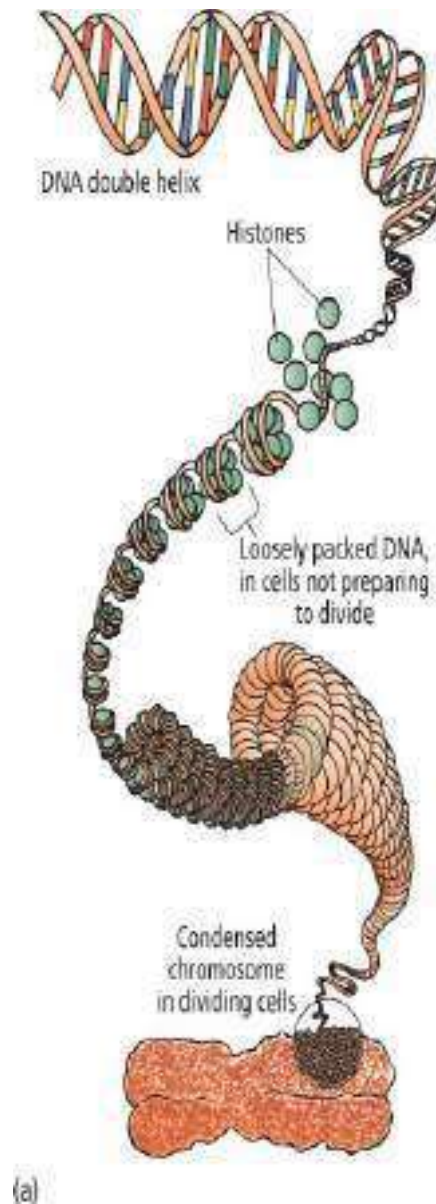
Learning Objective

Describe how DNA is packed into chromosomes.

A single human cell contains about 7 feet of DNA

Where are our genes? In eukaryotes, DNA is found in the nucleus where it is packaged in structures called *chromosomes* (Figure 16.1). Each chromosome consists of a long DNA molecule wrapped around small proteins called histones. The histones keep DNA tightly tangled when it is not being used. DNA is unwound from the histones when the cell needs to use it. Chromosomes are loosely packed most of the time, but they become condensed during cell division.

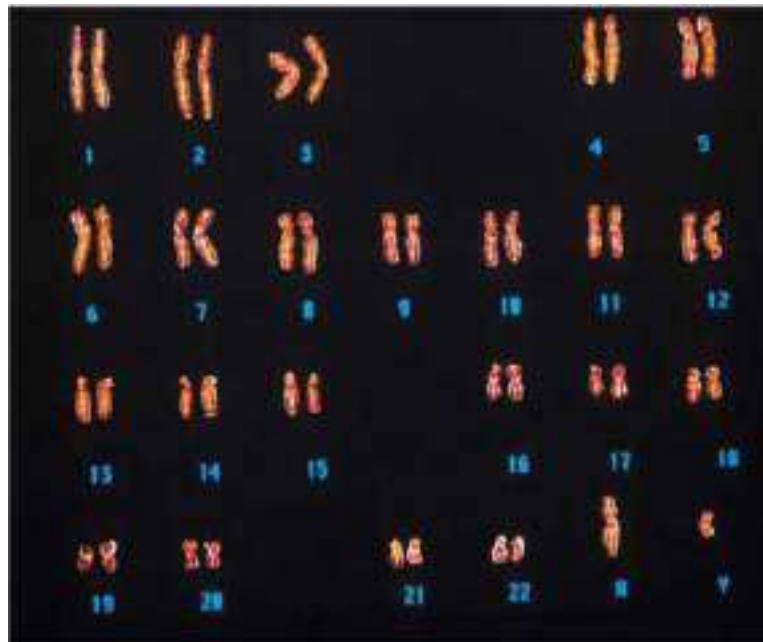
Figure 16.1



(a) Chromosomes consist of DNA wrapped around histones. Chromosomes are loosely packed most of the time but condensed during cell division. (b) This photo shows chromosomes that are condensed in preparation for cell division.

Most cells have two of each kind of chromosome, like a pair of shoes. These cells are **diploid**, and their matched chromosomes are called *homologous chromosomes*. Some cells—such as sperm and egg cells—have only one of each kind of chromosome. These cells are called *haploid*. Different organisms have different numbers of chromosomes. For example, humans have 78 (39 pairs), mosquitoes have 6 (3 pairs), and yeast has 16 (8 pairs). In humans, there are 46 chromosomes, or 23 pairs. The last pair are called *sex chromosomes* because they determine the sex of the individual. Females have two X chromosomes, whereas males have one X and one Y chromosome. The rest of the chromosomes are known as autosomes.

Figure 16.2



Humans have 23 pairs of chromosomes. The last pair, the sex chromosomes, determine whether a person is male or female.

Red blood cells do not have any chromosomes. They also do not even have a nucleus. This makes red blood cells unique because they can move through blood vessels more easily. However, this means that red blood cells can't make the proteins they need to repair and maintain themselves. Because of this, red blood cells do not live very long and must be replaced frequently.

Most of our cells (except our haploid sperm and eggs) have 46 chromosomes, with the same DNA and the same genes. So you wonder: If all our cells have the same genes, what makes different kinds of cells so different? For example, what makes a brain cell different from a muscle cell? The answer is that different genes are *expressed* in the two cells. The proteins a brain cell makes are very different from the proteins a muscle cell makes. Since proteins are made from DNA, let's start at the beginning by looking at the structure of DNA?

Check Yourself



Question 1

Check Answer

Question 2

Check Answer

Question 1

If a cell contains the chromosomes shown in Figure 16.2, is the cell diploid?

Check Answer

If a cell contains the chromosomes shown in Figure 16.2, is the cell diploid?

Answer: The cell is diploid because it contains two of each kind of chromosome.

Question 2

Integrated Science 16A: Chemistry

The Structure of DNA

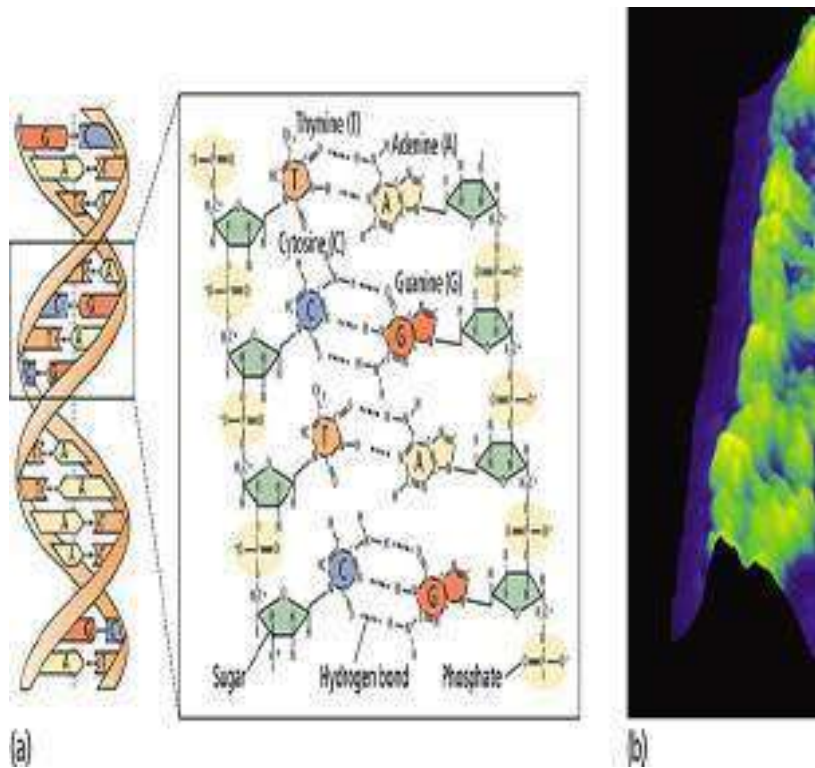
Learning Objective

Describe the structure of DNA.

Now that we know where genes are, let's look more closely at what genes are made of, at DNA itself. A molecule of deoxyribonucleic acid, or **DNA**, consists of two

Together, the two strands make a spiral ladder with a series of “rungs” (Figure 16.3). Because DNA is made of two strands twisted into a spiral or helix, it is called a *double helix*.

Figure 16.3



(a) DNA is shaped like a spiral ladder with two sugar-phosphate strands as the “sides” of the ladder and nitrogenous bases as the “rungs.” Hydrogen bonds hold the paired nitrogenous bases together. (b) This photograph of DNA shows the shape of a double helix.

Let's look at a single strand of DNA, and then how DNA's two strands fit together. A DNA strand is a chain of nucleotides, each of which includes a nitrogenous sugar molecule, and a phosphate group. The sugar in nucleotides is deoxyribose. So, a DNA strand has a backbone (or "side" of the ladder) made up of alternating molecules of deoxyribose sugar and phosphate. Sticking out from the backbone is a series of nitrogenous bases. Each base is half of a "rung" of the DNA ladder. The four bases found in DNA are adenine (A), guanine (G), cytosine (C), and thymine (T).

Now let's put two strands of DNA together. Each base on one strand binds with a base on the other strand using bonds called hydrogen bonds. Because each nitrogenous base can best form hydrogen bonds with another specific nitrogenous base, the binding of bases always happens in a specific way. Adenine always pairs with thymine (A-T) and guanine always pairs with cytosine (G-C).

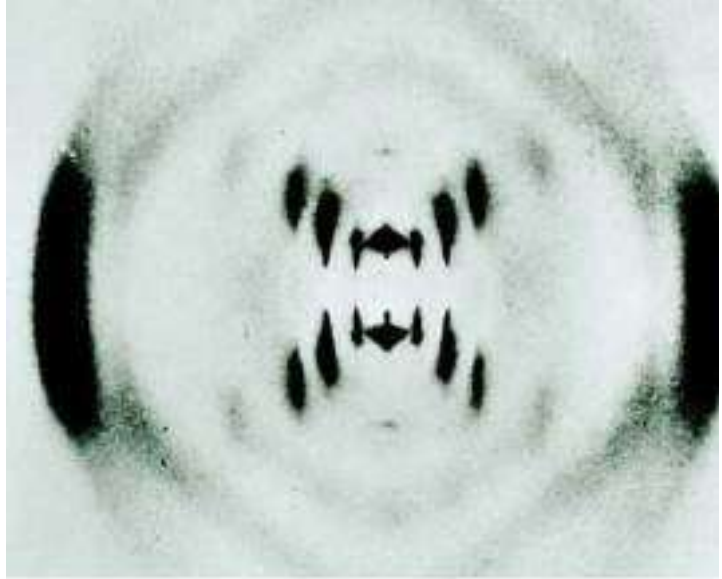
Unifying Concept

The Scientific Method [Section 1.3](#) 

History of Science

Discovery of the Double Helix

By the early 1950s, scientists knew that the genetic material of eukaryotic organisms was contained in their chromosomes. Scientists also knew that, of the two types of molecules in chromosomes—proteins and DNA—the genetic material was DNA. The structure of DNA was still a mystery, though it represented the biggest unsolved problem in biology. Francis Crick and James D. Watson began to tackle the problem. Their hope was to build a model of DNA that was consistent with available experimental evidence. At the time, both Rosalind Franklin and Maurice Wilkins were working on X-ray diffraction photos of DNA.



Rosalind Franklin's X-ray photo may look like a blurry mess to you, but to Watson and Crick it showed that DNA was a double helix.

The breakthrough came in January 1953, when Watson and Crick saw Rosalind Franklin's photograph of DNA. A report of Franklin's experimental findings also made its way to Watson and Crick. Watson and Crick began to build their model of DNA, testing it against Franklin's photographs and data. A few weeks later, they had it—DNA was a double helix. The two strands were held together by hydrogen bonds between adenine and thymine, and guanine and cytosine, the nitrogenous bases. The Watson-Crick model of DNA was published in April 1953, along with two papers of supporting evidence, one by Wilkins and his colleagues.

one by Franklin and her assistant. Acceptance of Crick model was immediate and widespread.



(a)



(b)

(a) James D. Watson and Francis Crick figured out the structure of DNA in 1953. (b) Rosalind Franklin took the famous photo that led Watson and Crick to the structure of DNA.

For their discovery of the double helix, Watson, Crick, and Maurice Wilkins were awarded the 1962 Nobel Prize in Physiology or Medicine. Franklin had died by then—of ovarian cancer, which probably resulted from radiation exposure related to her work. She never knew how important her results had been to Watson and Crick to develop their model. In fact,

importance to the discovery of DNA structure was appreciated until Watson wrote his memoir, *The L*

Check Yourself

Interactive

Question
Check Answer
Question

If one strand of DNA contains the nucleotides ACCTGA, what on the opposite strand?

Check Answer

If one strand of DNA contains the nucleotides ACCTGA, what on the opposite strand?

Answer: Because of the way the nitrogenous bases pair, the op

Integrated Science 16B: Chemistry and Earth Science

DNA in Hot Environments

Learning Objective

Describe the DNA of organisms that live in hot environments.

Some microorganisms live in habitats that are so extreme that scientists once thought they could not possibly survive. Hydrothermal vents are found on the ocean floor at the boundary between tectonic plates, where magma rising from the seafloor heats the water to very high temperatures. Similar vents are found on land in areas where magma sits close to Earth's surface. Yellowstone National Park is particularly famous for its many hot springs (Figure 16.4). Both hydrothermal vents and hot springs turn out to be home to many species of bacteria and archaea that find these high temperatures—as high as 100°C (212°F)—perfectly

Figure 16.4



Grand Prismatic Spring in Yellowstone National Park features large mats of microorganisms (rust colored) that live in the extremely hot water. The DNA of these organisms is twisted into a "supercoil" that prevents it from separating into separate strands.

Organisms that live in these super-hot environments possess a number of features that help them survive there.

consider their DNA. DNA's two strands will separate at high temperatures, causing the molecule to fall apart. How do bacteria and archaea deal with this problem? One hypothesis was that they might have many G–C pairs in their DNA, as well as fewer A–T pairs. In DNA, the bond between G and C nucleotides consists of three hydrogen bonds, while the bond between A and T consists of only two hydrogen bonds. So, having many G–C pairs would result in stronger bonds between the two strands of DNA. However, not all species in super-hot environments have an unusually high proportion of G–C pairs, others do not. A better hypothesis appears to be that organisms in super-hot environments have their DNA twisted into a particular kind of tight “supercoil” that allows DNA to remain double-stranded at the high temperatures of hydrothermal vents and hot springs. In fact, it is telling that all known species from super-hot habitats have supercoiled DNA and that the trait is not found in other microorganisms.

Unifying Concept

The Scientific Method [Section 1.3](#) 

Check Yourself

Interactive

Question

Check Answer

Question

DNA will separate into two strands at high temperatures. How do organisms that live in hydrothermal vents and hot springs keep their DNA from separating?

Check Answer

DNA will separate into two strands at high temperatures. How do organisms that live in hydrothermal vents and hot springs keep their DNA from separating?

Answer: They keep their DNA in a tight supercoil.

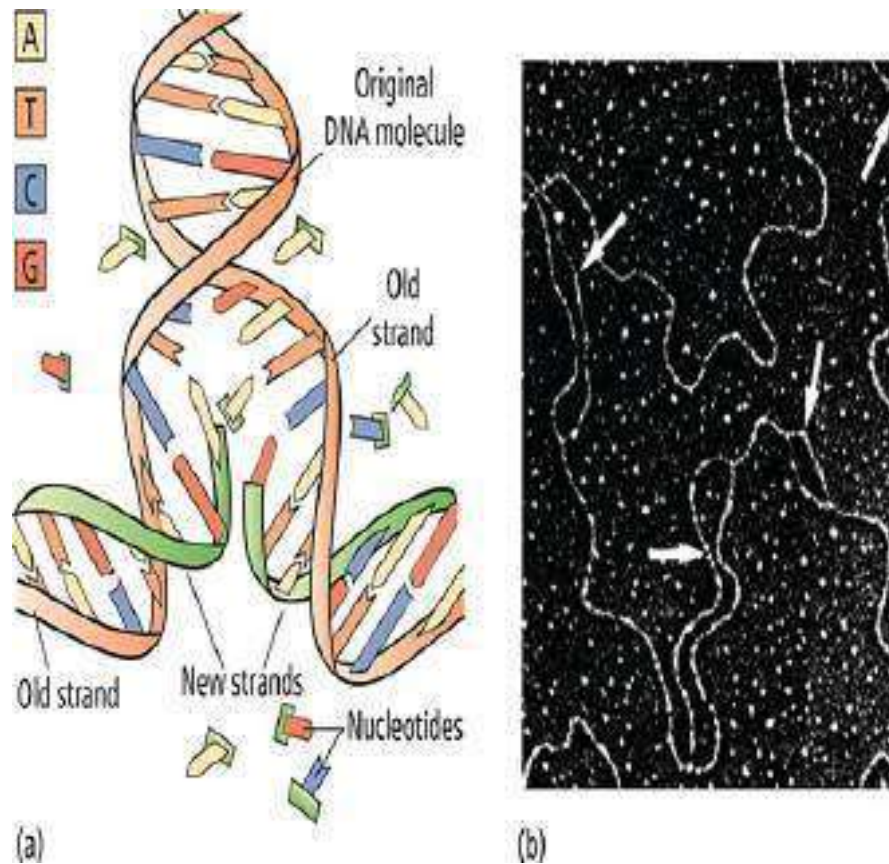
16.3 DNA Replication

Learning Objective

Explain how DNA is copied.

DNA must be copied in order for cells to divide and reproduce. This process is called **DNA replication**. During DNA replication, the two DNA strands are separated as if the spiral ladder were unzipped in the middle. Each strand then serves as a template for building a new strand. This is possible because of the way the nitrogenous bases pair: A always pairs with T, and G always pairs with C. As free nucleotides pair up with nucleotides on the template strand, they are attached to form a new DNA strand. Each new DNA molecule includes one old strand and one new strand, and the new DNA molecules are identical to the original DNA molecule (Figure 16.5).

Figure 16.5



(a) When DNA is copied, the two strands are separated (orange backbone) serves as a template for building a new backbone). (b) This photo shows DNA replication in the cell. Arrows show where the DNA strands have been separated and are being replicated.

During DNA replication, 50 nucleotides are added every second. This sounds fast—and it is—but we have billions of pairs of nucleotides in each cell! It's a good thing that replication occurs simultaneously at many different points in the cell.

chromosome. As a result, a human cell can copy DNA in only a few hours.

DNA replication always begins at fixed spots within chromosomes. In prokaryotes, replication begins simultaneously at many origins on a chromosome, allowing the job to be completed efficiently.

16.4 How Proteins Are Built

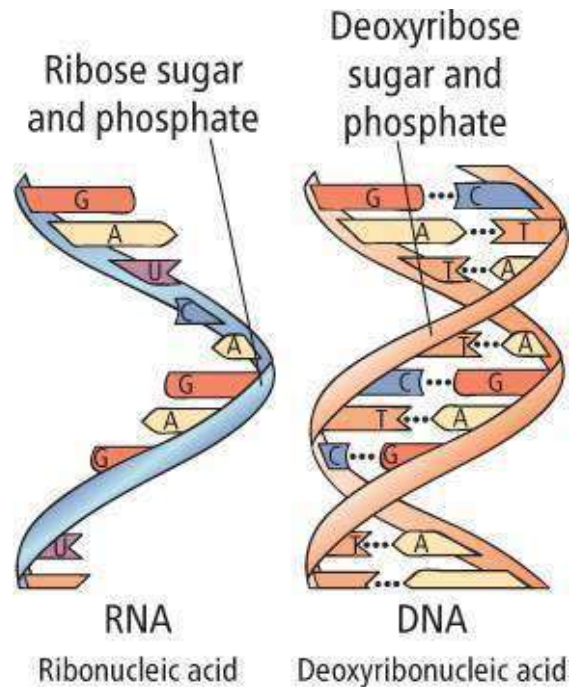
Learning Objective

Explain how information contained in DNA is used to build protein.

We now know the structure of DNA and how DNA is copied. We are almost ready to look at how DNA provides cells with the instructions for building proteins. Before we do that, though, we have to look at another molecule—RNA.

Like DNA, ribonucleic acid ⁱ, or **RNA**, consists of a sugar-phosphate backbone attached to nitrogenous bases (**Figure 16.6** [□]). RNA differs from DNA in three ways: (1) RNA has only one strand; (2) RNA uses the sugar ribose instead of deoxyribose; and (3) RNA uses the nitrogenous base uracil (U) instead of thymine (T).

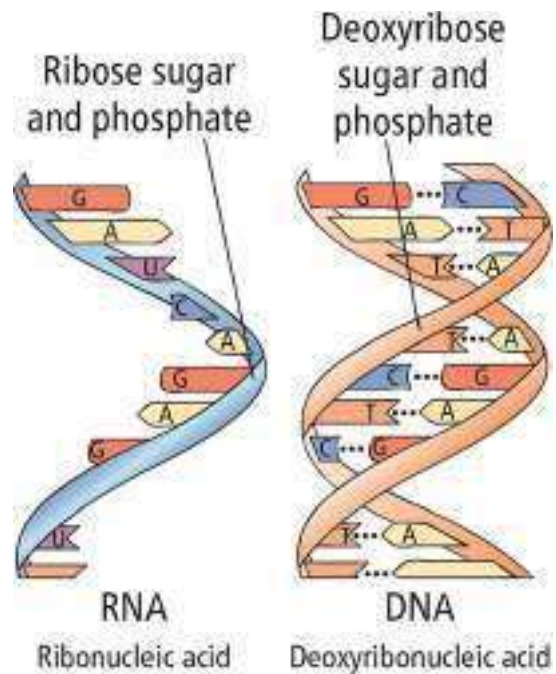
Figure 16.6



RNA is a single-stranded nucleic acid. RNA uses the sugar ribose, and it uses the nitrogenous base uracil instead of thymine.

During **transcription** ⓘ, DNA is used as a template for the synthesis of a single molecule of RNA. During **translation** ⓘ, this RNA molecule is used to assemble a protein (Figure 16.7 □).

Figure 16.7



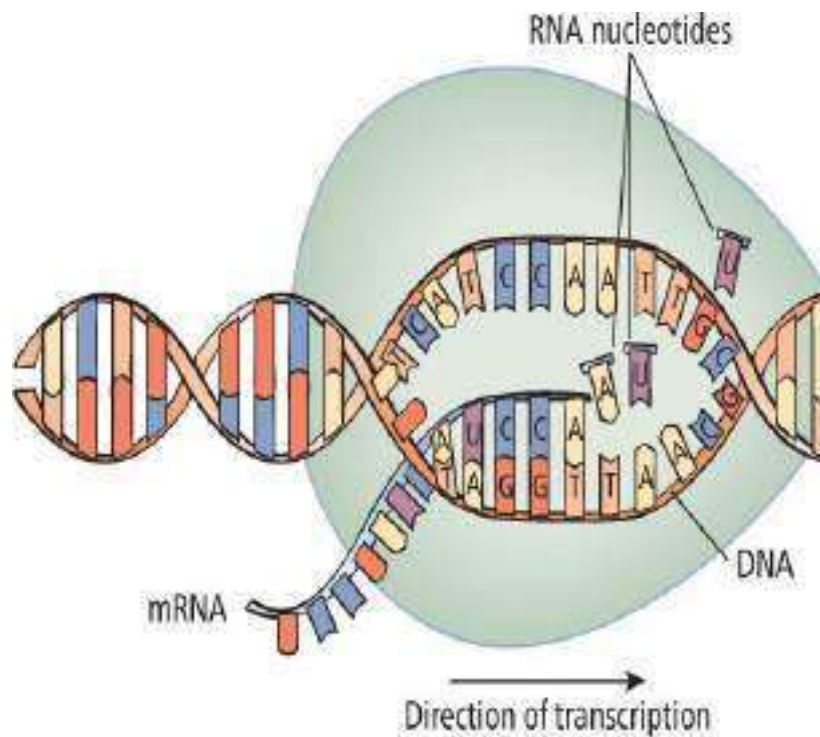
DNA is used to build a protein through transcription ar

Transcription

In eukaryotes, transcription occurs in the cell nucleus. DNA are separated, and one strand serves as a template RNA transcript. Special nucleotide sequences in the DNA transcription should begin and end, marking the beginning gene. The construction of the RNA transcript follows the pairing rules that exist for DNA, except that RNA uses uracil (U) instead of thymine (T). So, where DNA has the nucleotides A, C, G, and T, the RNA transcript will have the nucleotides U, G, C, and A.

(Figure 16.8). As free RNA nucleotides pair up with complementary nucleotides on the DNA strand, they are added to the growing mRNA molecule. Once transcription is complete, the DNA zips back together and the RNA transcript begins a processing phase.

Figure 16.8



During transcription, information in DNA is stored in a

Check Yourself

Int

Question

Check Answer

Question

If a stretch of DNA has the nucleotide sequence ACCTGAT, w
the RNA transcript have?

Check Answer

If a stretch of DNA has the nucleotide sequence ACCTGAT, w
the RNA transcript have?

Answer: The RNA transcript will have the nucleotide sequence

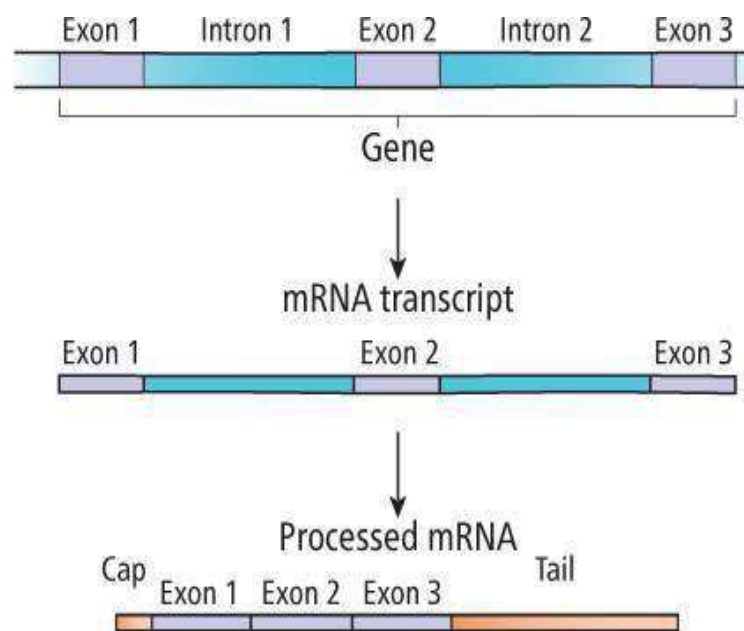
If you have trouble remembering which are exons
are introns, just think: “EXons EXpressed, INtrons
trash.”



During the processing phase, the RNA transcript becom
messenger RNA ⁱ molecule, or **mRNA** molecule. First,
nucleotides that are not used to build the protein, calle

removed (Figure 16.9). The stretches of nucleotides that build the protein, called *exons*, remain. It is as if a starting Shakespeare's *Hamlet* contained the line "aggfr uidosa to rewerwe not to be," and the irrelevant parts had to be removed to leave the coherent "to be or not to be." Scientists are not surprised to exist. However, a single RNA transcript can sometimes be processed in multiple ways, resulting in different mRNA molecules. A 5' cap and "tail" are added to the beginning and end of the RNA. After processing is complete, the mRNA molecule moves from the nucleus to the cytoplasm, where it will be translated to a protein.

Figure 16.9



The RNA transcript goes through a processing phase in which introns are removed and a cap and tail are added. The result is an mRNA molecule that is ready for translation.

Check Yourself

Interactive

Question

Check Answer

Question

Suppose you have the following RNA transcript. The exons and introns are indicated. What will the mRNA molecule look like after processing?

UAGCCUGUAUGGACUUGUCAACGGGUCAUACCGAUUCGAUCAG

The diagram shows the RNA sequence UAGCCUGUAUGGACUUGUCAACGGGUCAUACCGAUUCGAUCAG. A horizontal line below the sequence has four vertical tick marks. Below these tick marks are the labels 'intron', 'exon', 'intron', and 'exon' from left to right. The first 'intron' label is under the first two nucleotides (UAG), the first 'exon' label is under the next three (CCUG), the second 'intron' label is under the next five (UAUGGACU), and the second 'exon' label is under the last four (UCAUC).

The RNA transcript displayed is as follows: UAGCCUGU (intron) UCAACGGGUCAUACCGA (intron) UUCGAUCA (exon).

Check Answer

Suppose you have the following RNA transcript. The exons and introns are indicated.

Translation

During translation, mRNA is used to build a protein. This process takes place in the cell cytoplasm at organelles called ribosomes, which are composed of proteins and a type of RNA called *ribosomal RNA*.

How does translation work? Remember that a protein is made of amino acids. In translation, three nucleotides along the mRNA form a three-letter “word” called a **codon**. During translation, these are “read” from the mRNA molecule one at a time. Most codons tell the ribosome to add a specific amino acid to the growing polypeptide chain. A few codons tell the ribosome that there are no more amino acids to add to the protein and that translation is complete. The *genetic code* is the set of rules that tells each codon stands for (Table 16.1). For example, the codon UCU translates to the amino acid serine, and the codon GUC translates to the amino acid valine. Certain codons, such as UAA, are called stop codons because they tell the ribosome that there are no more amino acids to add to the protein. The first codon to be translated from mRNA is methionine. So, you read the codons in mRNA, string together the amino acids in the right order, and presto! You have a protein.

Table 16.1 The Genetic Code

		Second base			
		U	C	A	G
U	UUU } Phenylalanine	UCU } Serine	UAU } Tyrosine	UGU } Cysteine	
	UUC } (Phe)	UCC } (Ser)	UAC } (Tyr)	UGC } (Cys)	
	UUA } Leucine	UCA } (Ser)	UAA } Stop	UGA } Stop	
	UUG } (Leu)	UCG }	UAG } Stop	UGG } Tryptophan	
C	CUU } Leucine	CCU } Proline	CAU } Histidine	CGU } Arginine	
	CUC } (Leu)	CCC } (Pro)	CAC } (His)	CGC } (Arg)	
	CUA }	CCA }	CAA } Glutamine	CGA }	
	CUG }	CCG }	CAG } (Gln)	CGG }	
A	AUU } Isoleucine	ACU } Threonine	AAU } Asparagine	AGU } Serine	
	AUC } (Ile)	ACC } (Thr)	AAC } (Asn)	AGC } (Ser)	
	AUA }	ACA }	AAA } Lysine	AGA } Arginine	
	AUG } Methionine or start	ACG }	AAG } (Lys)	AGG } (Arg)	
G	GUU } Valine	GCU } Alanine	GAU } Aspartic acid (Asp)	GGU } Glycine	
	GUC } (Val)	GCC } (Ala)	GAC }	GGC } (Gly)	
	GUA }	GCA }	GAA } Glutamic acid (Glu)	GGA }	
	GUG }	GCG }	GAG }	GGG }	

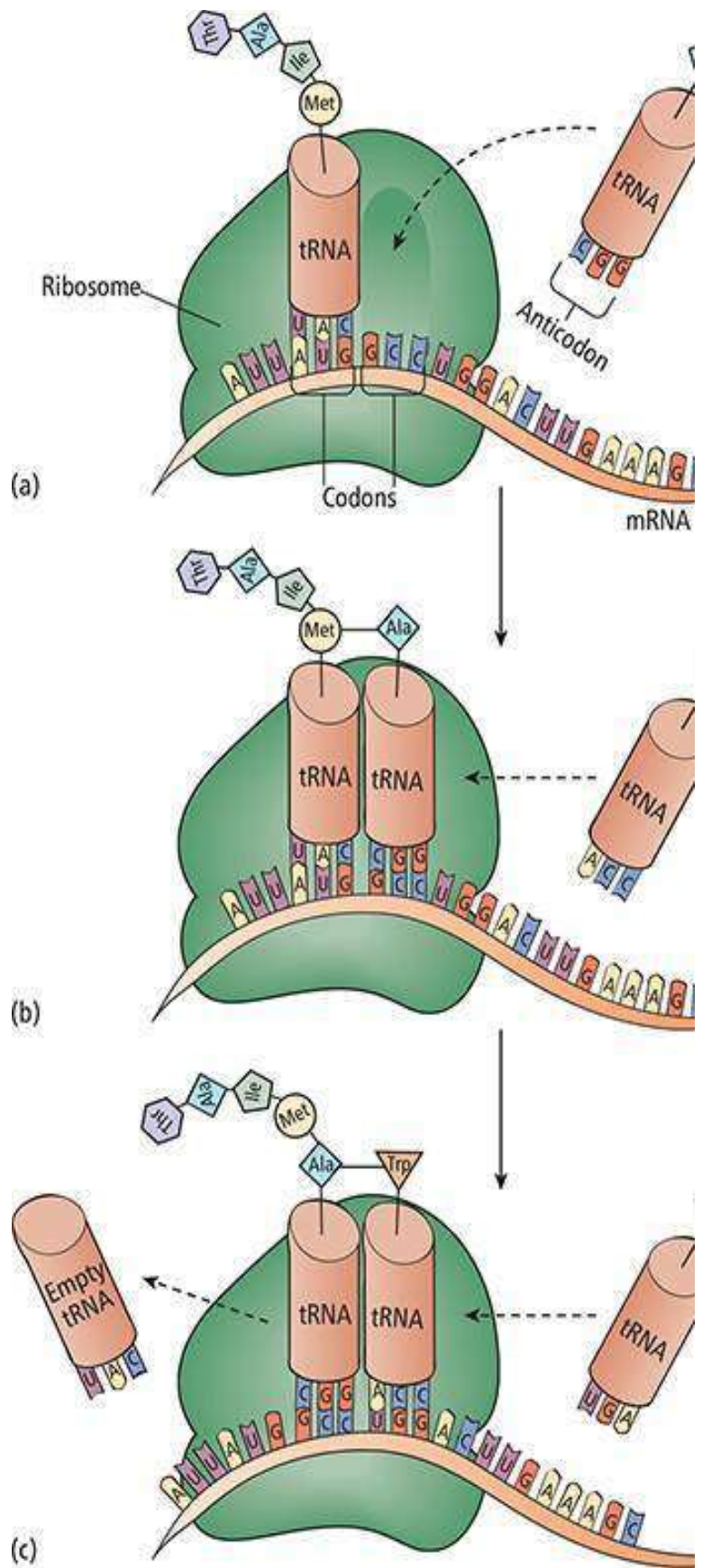
With very few exceptions, the genetic code is the same in all living organisms. Animals, fungi, plants, bacteria, and viruses use the same genetic code! This suggests the genetic code originated very early in the evolution of life and was then passed on to all living species.

Now, how is all this accomplished? Translation requires messenger RNA, **transfer RNA** (tRNA), or tRNA. A tRNA molecule includes

three nucleotides called an *anticodon* and carries a single amino acid.

During translation, the mRNA molecule binds to a ribosome. The tRNA being translated is positioned at a specific site. A tRNA with an appropriate anticodon binds to the codon (Figure 16.10a). The pairing of anticodon to codon follows the usual rules—A binds with U, G binds with C. The amino acid carried by the tRNA is then transferred to the growing protein (Figure 16.10b). After this, the ribosome translocates along the mRNA so that a new codon can be translated (Figure 16.10c). The process is repeated until a stop codon is reached. As translation ends, the growing protein folds up into its appropriate three-dimensional shape.

Figure 16.10



During translation, an mRNA molecule is translated to
The anticodon of a tRNA molecule binds to a codon in
molecule. (b) The amino acid carried by the anticodon
growing protein. (c) The mRNA molecule is shifted so t
can be translated.

A ribosome builds a typical protein in less than o

Check Yourself

Interactive

Question 1

Check Answer

Question 2

Check Answer

Question 1

A molecule of mRNA has the codon GUC. What is the anticodon
binds to it during translation? What amino acid does the tRNA

Check Answer

A molecule of mRNA has the codon GUC. What is the anticodon
binds to it during translation? What amino acid does the tRNA

Answer: The tRNA has the anticodon CAG. Looking at the gen
see that this tRNA molecule carries the amino acid valine. (Wh
genetic code table, remember that you need to look up the cod
valine.)

Question 2

Consider the mRNA sequence AUGAGCCUGUAC. What strir

16.5 Genetic Mutations

Learning Objective

Define a genetic mutation, and describe the potential consequences of genetic mutations.

A genetic mutation occurs when the sequence of nucleotides in an organism's DNA is changed. Genetic mutations have two main sources: errors that are made during DNA replication and exposure to agents that damage DNA, such as ultraviolet light, X-rays, and chemicals.

A genetic mutation can have no effect at all, or it can have a significant effect. A mutation in a gene is likely to have a bigger effect than a mutation in DNA that is not part of a gene. A mutation in an exon is likely to have a bigger effect than one in an intron. A mutation in an egg or sperm is likely to have a bigger effect than one that strikes a skin cell on the body because a mutation in an egg or sperm can be passed on to offspring and then appear in every cell in the offspring's body.

The majority of genetic mutations have no effect on prokaryotic organisms. A small number of mutations interfere with

function, and so are disadvantageous for organisms. In mutation will produce something new and advantageous. They are the original source of all genetic diversity, and they provide the raw materials for evolution. For this reason, mutations are crucially responsible for the diversity of life on Earth.

Mutations can interfere with how our proteins function. It is definitely wise to avoid exposure to chemicals and other things that cause mutations.

Point Mutations

A *point mutation* occurs when one nucleotide is substituted for another, such as when a C becomes a G. A point mutation may change a single amino acid in a sequence of amino acids in a protein. For example, a point mutation that changes AAC to AAG changes the amino acid asparagine to the genetic code in [Table 16.1](#).) Not all point mutations change amino acids, however. A point mutation that changes C to C has no effect because both codons stand for the same amino acid. You might wonder: Does changing one amino acid in a protein matter? The answer is sometimes. Some amino acid changes have no effect on protein function. Others have a significant effect—a single


change is responsible for several serious human diseases, such as sickle cell anemia, which we will discuss later in this chapter.

Frameshift Mutations

Nucleotides can also be inserted into or removed from a DNA sequence. If this happens in a gene, the codons that are “read” during translation are shifted, producing a *frameshift mutation*. Frameshift mutations change a protein’s amino acid sequence and usually result in nonfunctional proteins.

Nonsense Mutations

A nonsense mutation is a mutation that creates a stop codon in the middle of a gene. Nonsense mutations cause translation to stop before the amino acids in a protein have been added. Nonsense mutations result in short, often nonfunctional, proteins. Both point mutations and frameshift mutations can result in a nonsense mutation.

Figure 16.11  shows examples of different mutations. It compares mutations to changes in English sentences—t

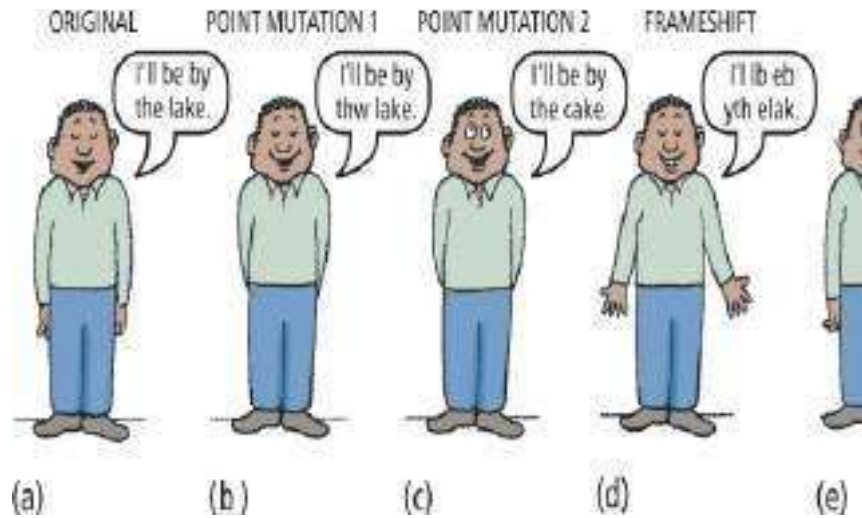
understand how different mutations affect proteins.

Figure 16.11

(a) Original sequence:	AGC	CUG	UAC	UGG	ACA	UUK
	serine	leucine	tyrosine	tryptophan	threonine	leucine
(b) Point mutation 1:	AGC	CUG	UAC	UGG	ACU	UUK
	serine	leucine	tyrosine	tryptophan	threonine	leucine
(c) Point mutation 2:	AGG	CUG	UAC	UGG	ACA	UUK
	arginine	leucine	tyrosine	tryptophan	threonine	leucine
(d) Frameshift mutation:	AGC	UCU	GUA	CUG	GAC	AUU
	serine	serine	valine	leucine	aspartic acid	isoleucine
(e) Nonsense mutation:	AGC	CUG	UAG	UGG	ACA	UUK
	serine	leucine	STOP			

Mutations can affect proteins in many different ways. (a) original nucleotide sequence. (b) This point mutation does not change the amino acid sequence of the protein. (c) This point mutation changes one amino acid into another. (d) The insertion of a nucleotide causes a frameshift mutation that completely changes the sequence of amino acids in a protein. (e) This nonsense mutation produces a stop codon, which results in the production of a shorter protein.

Figure 16.12



If a DNA nucleotide sequence were a sentence, different mutations have different effects on the meaning of the sentence. (a) original sentence (DNA nucleotide sequence). (b) This has only a minimal effect on the meaning (protein). (c) mutation affects the meaning (protein) significantly. (d) frameshift mutation that causes the meaning to be lost (nonfunctional). (e) This is a nonsense mutation that can be lost (the protein is nonfunctional).

Check Yourself

Two point mutations are shown below. What effect does each mutation have on the protein that is produced? (Use the genetic code in Table 16.1.) (Original sequence: AGC CUG UAC UGG ACA UUG CCA.)

Question 1

Check Answer

Question 2

Check Answer

Question 1

AGC CUG UAC UGG ACC UUG CCA

Check Answer

AGC CUG UAC UGG ACC UUG CCA

Answer: ACC and ACA code for the same amino acid (threonine), so the mutation has no effect on the protein.

Question 2

Integrated Science 16C: Part 1

How Radioactivity Causes Genetic Mutations

Learning Objective

Explain the effect of ionizing radiation on DNA.

In 1986, a terrible nuclear accident occurred at the Chernobyl Nuclear Power Plant in the Ukraine. Two workers

first few days, and an additional 28 people died over the next few months. But some of the effects of the accident became apparent years later. Since the Chernobyl accident, over 7000 people who were exposed at the time have developed thyroid cancer. This is attributed to genetic mutations caused by radioactivity. Radioactivity also caused mutations in living things in the Chernobyl area, as shown in Figure 16.13. How does radioactivity cause mutations?

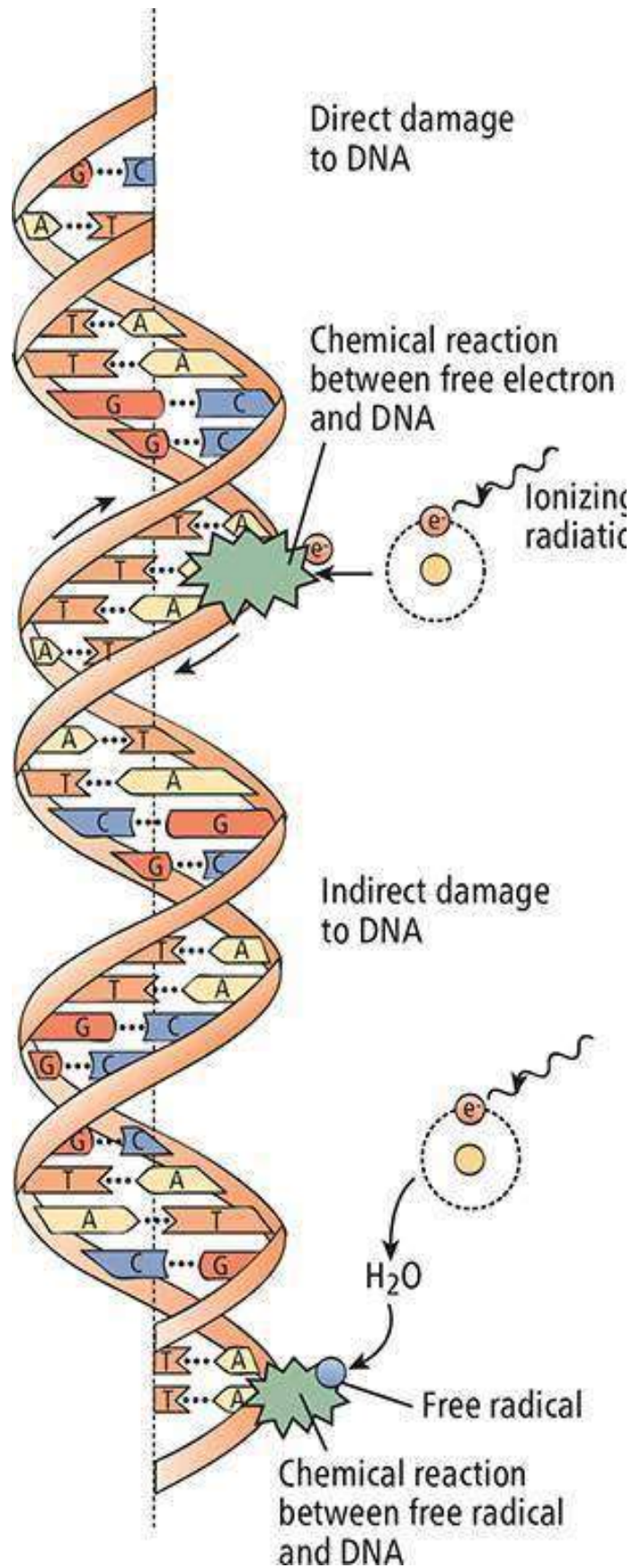
Figure 16.13



Several years after the nuclear accident at the Chernobyl Nuclear Power Plant, living things were found which were believed to be related to the accident. (a) This figure shows a severely deformed trunk and branches, as well as unusually large and sharp needles. (b) This fruit from a quince tree near Chernobyl is much larger than normal quince fruit (left).

Radioactive materials release ionizing radiation—beta particles, and alpha particles. When these forms of radiation strike electrons in the body with enough energy to free the electrons from the atoms they were orbiting, they become free electrons. Sometimes, the free electrons damage DNA directly. More frequently, the damage occurs indirectly when the free electrons strike water molecules in a cell and produce free radicals. A *free radical* is a group of atoms that has an unpaired electron and is consequently highly reactive. Free radicals react with many molecules in the body, including DNA. These interactions damage DNA, causing genetic mutations (see Figure 16.14).

Figure 16.14



Radioactivity causes genetic mutations by releasing radiation. Ionizing radiation strikes and frees electrons from the body. These free electrons can strike and damage DNA or produce free radicals that interact with and damage DNA.

Cells can repair DNA damage, but they vary in their ability to do so. Cells in the body that divide frequently often repair DNA and pass on mutations before they have time to repair DNA damage. As a result, frequently dividing cells are especially vulnerable to radiation damage. Frequently dividing cells include cells in the bone marrow (where blood cells are made), in the lining of the digestive tract, in the testis, and in the developing fetus. Cancer cells also divide frequently, which is why radiation is used to treat some tumors.

Check Yourself

Question 1

Check Answer

Question 2

Check Answer

Question 1

When radiation is used to treat cancer, why does it kill many tu
many normal cells survive?

Check Answer

When radiation is used to treat cancer, why does it kill many tu
many normal cells survive?

Answer: Tumor cells divide frequently, so they are less able to
damage caused by radiation. Excessive DNA damage is often f

Question 2

~~Why does radiation therapy for cancer cause such side effects a~~

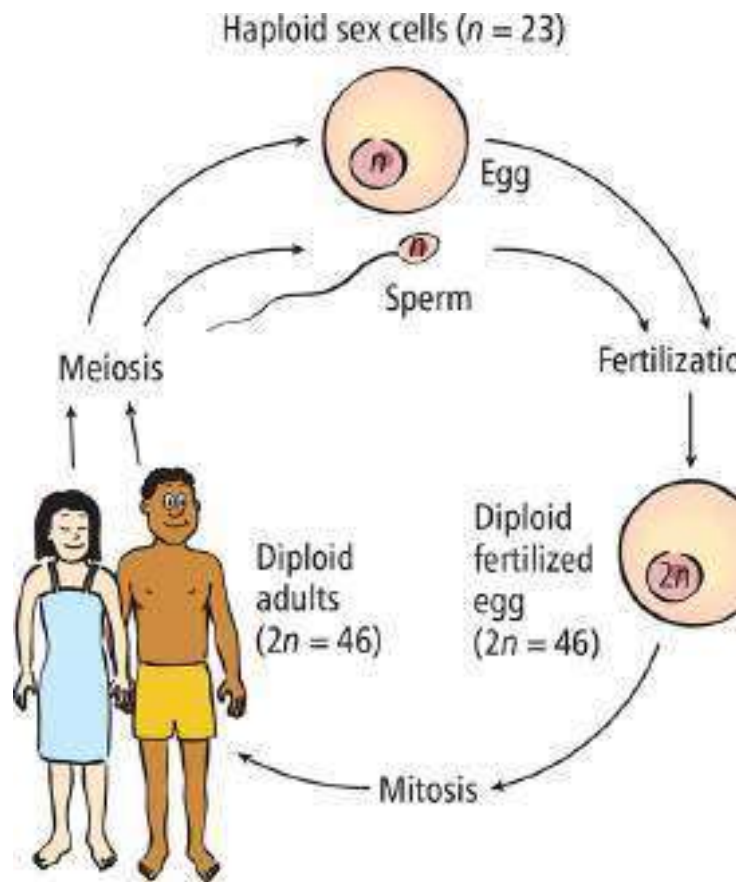
16.6 Meiosis and Genetic D

Learning Objective

Describe meiosis, and explain how it contributes diversity.

You have learned that some cells reproduce through a 1 division called mitosis. In mitosis, one cell divides into each of which contains the same genetic information as **Meiosis** is another type of cell division. Meiosis is use cells, such as eggs and sperm. Only the cells that produ go through meiosis. In meiosis, one diploid cell, with tv chromosome, divides into four haploid cells, each with kind of chromosome. The normal diploid chromosome restored during sexual reproduction when sperm and e fertilization (**Figure 16.15**).

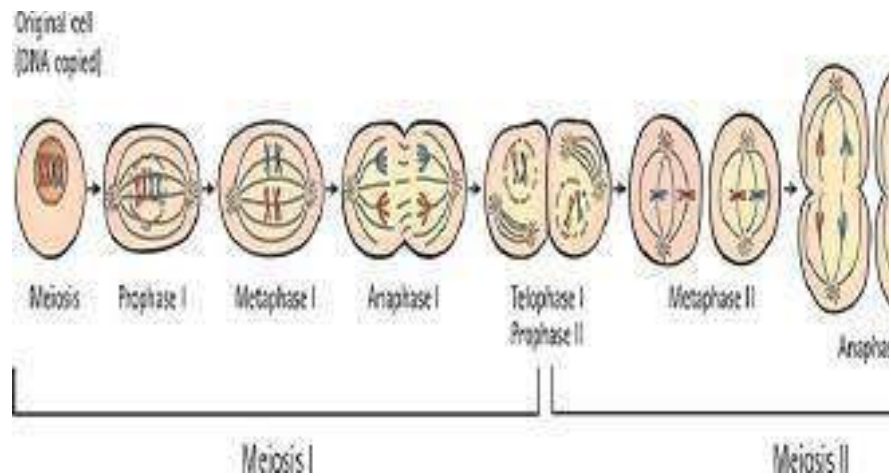
Figure 16.15



Sperm and eggs are haploid cells produced during meiosis. After fertilization, sperm and egg fuse to make a diploid cell, which then develops into a diploid individual.

When meiosis begins, the diploid cell has already copied its DNA. Meiosis takes place in two steps: *meiosis I* and *meiosis II*. During meiosis I, the original cell divides into two cells. These two cells divide again to produce four haploid cells.

Figure 16.16

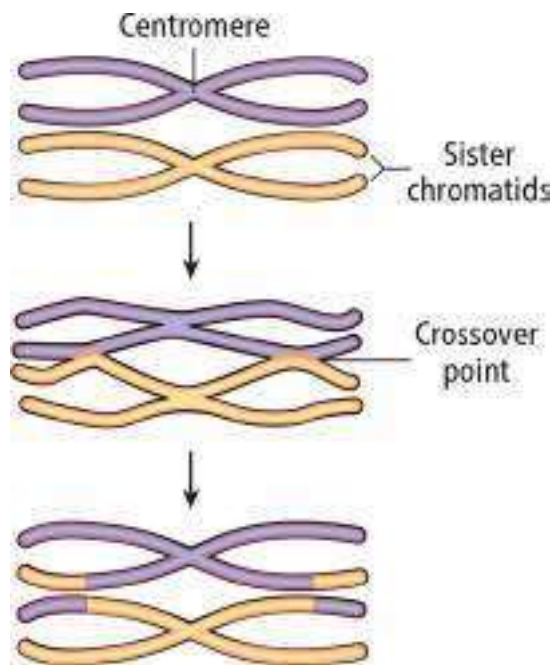


Meiosis produces four haploid cells.

Meiosis I begins with prophase I. During *prophase I*, the chromosomes condense and the membranes of the nucleus break down. Each chromosome includes two identical sister chromatids. Homologous chromosomes then line up with each other, and a process called *crossing over* occurs. In crossing over, a chromosome exchanges segments with its homologous chromosome (Figure 16.17). As a result, the chromosomes in the dividing cell are no longer identical to the original cell. Instead, many chromosomes now include segments from both of the two original homologous chromosomes. On a gene level, crossing over results in **recombination**, the production of new genes different from those found in the original chromosomes. This is why this is important when we consider how meiosis produces genetic diversity. In *metaphase I*, homologous chromosomes line up at the metaphase plate.

of the cell. In *anaphase I*, the homologous chromosomes move to opposite ends of the cell. In *telophase I*, the chromosomes move to opposite ends of the cell. Cytokinesis occurs, producing two cells.

Figure 16.17



During meiosis, homologous chromosomes exchange genetic material in a process called crossing over. The result of crossing over is that the chromosomes end up with parts of each of the two original chromosomes—you can see that after crossing over, the chromosomes are part purple and part yellow.

Meiosis II is similar to meiosis I, except for a few key differences. In *metaphase II*, the single, unpaired chromosomes (as opposed to the paired chromosomes in *metaphase I*) align at the equator of the cell.

homologous chromosome pairs) move to the center of the cell. In *anaphase II*, the sister chromatids separate. In *telophase II*, the chromatids move to opposite ends of the cell. Cytokinesis then occurs, producing four haploid cells.

How Meiosis and Sexual Reproduction Produce Genetic Diversity

Siblings resemble each other, but they're not exactly alike because the eggs and sperm of their parents are all different, and each child receives different genes.

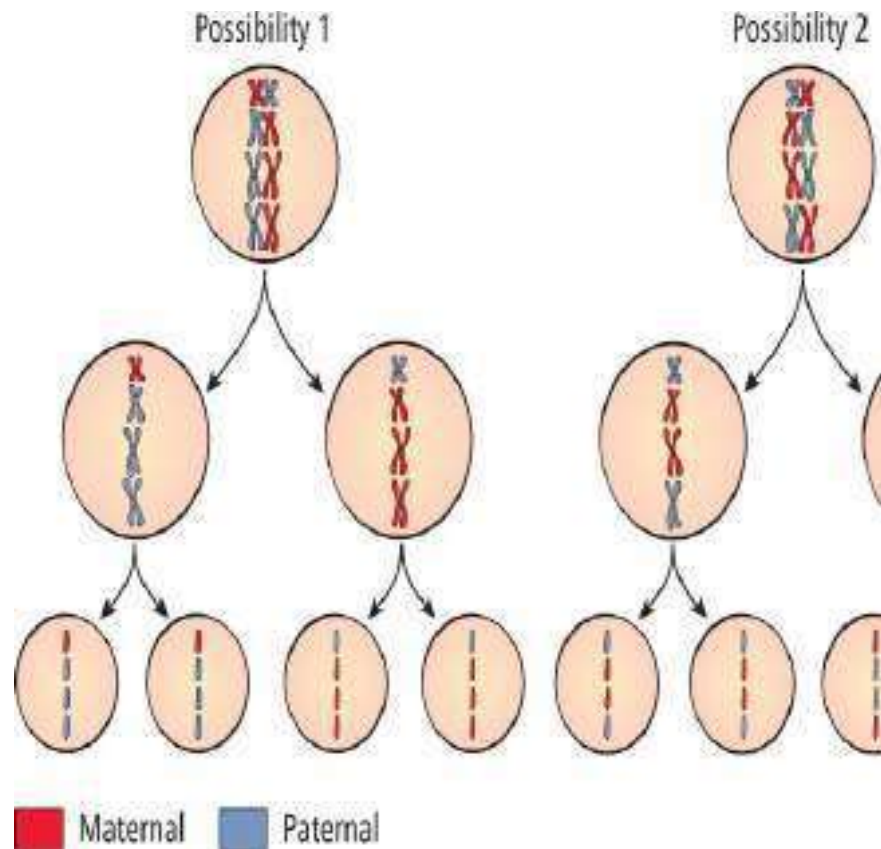
In humans, meiosis in males produces four sperm cells, while meiosis in females produces only one egg. This is because one of the four haploid cells—the future egg—receives almost all of the cytoplasm. This ensures that the egg will have the resources it needs to develop. The other three cells receive almost no cytoplasm and quickly degenerate.

Meiosis produces this genetic diversity in two ways. First, crossing over. At the start of meiosis, our cells have two of each chromosome—a maternal chromosome from our mother and a paternal chromosome from our father.

chromosome from our father. Every time meiosis occurs, crossing over takes place. But the key is that crossing over takes place at a different point along the chromosome every time. This means that the chromosome in our eggs and sperm is a unique mix of maternal and paternal chromosomes.

Even without crossing over, though, all our sex cells would be genetically different. This is because homologous chromosomes separate independently during meiosis I. One egg might get maternal chromosomes 1, 3, 5, 6, and so on and paternal chromosomes 2, 4, 7, 8, and so on. A second egg is certain to get different chromosomes, perhaps maternal chromosomes 2, 3, 5, 6, and so on and paternal chromosomes 1, 4, 7, 8, and so on (Figure 16.18). There are a huge number of possibilities!

Figure 16.18



Each time meiosis occurs, the resulting cells receive different combinations of maternal and paternal chromosomes. There are just two possibilities when meiosis occurs in an organism with 23 pairs of chromosomes. With the 23 pairs found in humans, there are 8,388,608 possibilities.

A mistake during meiosis can cause a sperm or egg cell to end up with the wrong number of chromosomes. In humans, the embryos produced by these sex cells usually do not survive, but there are exceptions. One of the most common chromosomal abnormalities is having three copies of a chromosome.

chromosome 21, which is called trisomy 21. Trisomy 21 causes Down syndrome, a condition characterized by mental retardation and defects of the heart and respiratory system.

Finally, during fertilization, when an egg and sperm join, the genetic material is brought together in different ways. Each of the many possible eggs can join with each of many different possible sperm.

Comparing Mitosis and Meiosis

There are three key differences between mitosis and meiosis. (1) Mitosis produces two cells; meiosis produces four cells. (2) Mitosis produces diploid cells; meiosis produces haploid cells. (3) The cells produced by mitosis are identical to one another and to the original cell, while the cells produced by meiosis are all different.

16.7 Mendelian Inheritance

Learning Objective

Describe Mendel's laws, and explain how they account for his breeding results.

We look like our parents because we inherit our parent's traits. Do we resemble our parents in certain ways but not others? Why do we have our mom's dimples but not her curly hair? Why do brown-eyed parents sometimes have a blue-eyed child? In all, why do traits sometimes skip generations? For example, Grandpa's nose might not show up in any of his children, but it suddenly appears in his granddaughter. How can we explain this?

Gregor Mendel ([Figure 16.19](#)) discovered the answers to these questions. Mendel did not make his discoveries by studying humans, though. He studied peas.

Figure 16.19









Gregor Mendel was the founder of modern genetics. He was examining a plant.

Mendel's First Law

Mendel bred pea plants, which vary in a number of traits: round or wrinkled peas, yellow or green peas, purple or white flowers, and other variations. Mendel started by finding plants that were true-breeding, meaning these plants always produced offspring that looked like them. He then bred two plants that differed in a single trait—a round-pea plant and a wrinkled-pea plant.

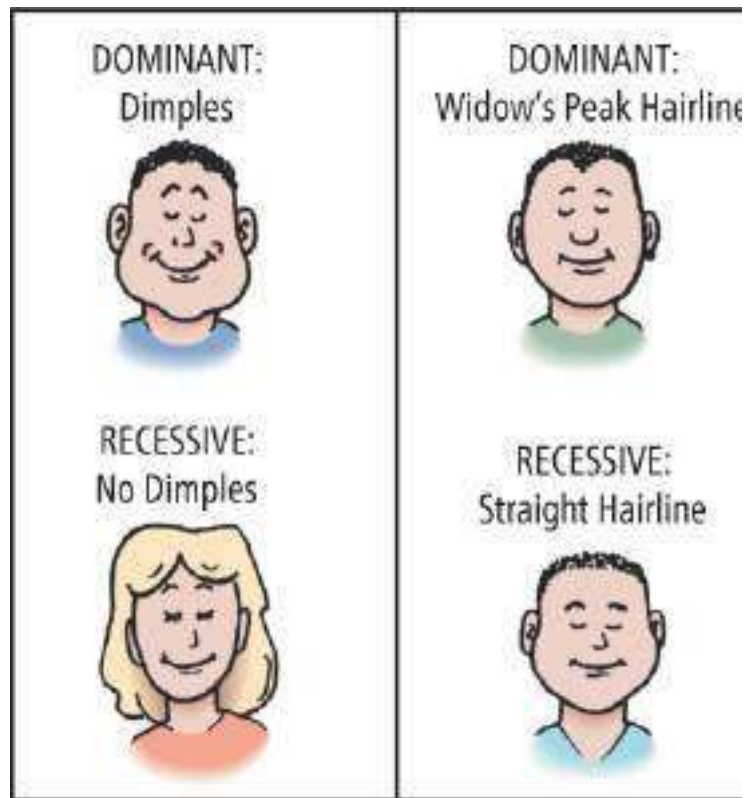
What did Mendel find? Mendel found that when he bred pea plants that differed in a single trait, all of the offspring resembled one of the parents. For example, when a round-pea plant was bred with a wrinkled-pea plant, all the offspring had round peas. Traits that were expressed in the offspring (such as round peas) Mendel called *dominant*. Traits that were not expressed in the offspring (such as wrinkled peas) Mendel called *recessive*. In every pair of traits Mendel looked at, one trait was dominant and the other was recessive (Figure 16.20). Mendel also looked at dominant and recessive traits too (Figure 16.21).

Figure 16.20

	Seed shape	Seed color	Flower color
Dominant trait	Round 	Yellow 	Purple 
Recessive trait	Wrinkled 	Green 	White 

Mendel bred pea plants that varied in a number of traits. In each pair of traits he looked at, one trait was dominant and the other was recessive.

Figure 16.21



Dimples are a dominant human trait. So is a hairline that peaks in the middle—a widow's peak hairline.

Check Yourself

Interactive

Question

Check Answer

Question

When Mendel bred green-pea plants and yellow-pea plants, all yellow peas. Which trait is dominant? Which trait is recessive?

Check Answer

When Mendel bred green-pea plants and yellow-pea plants, all yellow peas. Which trait is dominant? Which trait is recessive?

Answer: Yellow peas are dominant. Green peas are recessive.

After breeding two plants that differed in a single trait, offspring with themselves. (Many plants can breed with something humans can't do.) For example, after Mendel plants and wrinkled-pea plants together, he took their offspring (which were round-pea) and bred them with themselves. Mendel surprised to find that the recessive trait, which had disappeared in the first generation, reappeared in the second generation. In the second generation, the ratio of plants expressing the dominant trait to plants expressing the recessive trait was 3:1—that is, three times as many plants expressing the dominant trait as those expressing the recessive trait.


What happened with Mendel's peas is a lot like the crook about the crook in Grandpa's nose at the beginning

section. The crook disappears in Grandpa's child, reappears in Grandpa's granddaughter, just the way wrinkled peas disappeared in the first generation and reappeared in the next generation.

How did Mendel explain this result? Mendel postulated that traits are made up of two separate alleles in the gene. One allele is inherited from each parent. This is with his first law: the principle of segregation. The *principle* says that when an individual makes sex cells (sperm or egg cells) each cell carries one allele and the other half carry the other allele.

Unifying Concept

The Scientific Method [Section 1.3](#) 

Let's see how the principle of segregation explains Mendel's results. Mendel looked at plants that differed in a single trait: round peas or wrinkled peas. The round-pea plant had two round alleles, or genotype RR . The wrinkled-pea plant had two wrinkled alleles, or genotype rr . (A capital letter is used for a dominant trait and a lowercase letter for a recessive trait.) The RR and rr plants are homozygotes for this trait—a homozygote  has two identical alleles for a given trait.

When Mendel bred the RR (round-pea) and rr (wrinkle) together, the first-generation offspring inherited an R allele from the round parent and an r allele from the wrinkled parent. The first-generation offspring had the genotype Rr . An Rr plant is heterozygous for this trait because it has two different alleles. Which trait do Rr plants have? An Rr plant has round peas because the R allele is dominant. The **dominant** allele is expressed in the heterozygote; the recessive allele is not expressed in the heterozygote; it is hidden.

Check Yourself

Interactive

Question 1

Check Answer

Question 2

Check Answer

Question 3

Check Answer

Question 1

In humans, “dimples” is dominant and “no dimples” is recessive. Use D and d to represent the two alleles. Which allele represents “dimples” and which represents “no dimples”?

Check Answer

In humans, “dimples” is dominant and “no dimples” is recessive. Use D and d to represent the two alleles. Which allele represents “dimples” and which represents “no dimples”?

Answer: We use capital letters for dominant traits and lowercase letters for recessive traits. So D represents “dimples” and d represents “no dimples”.

Question 2

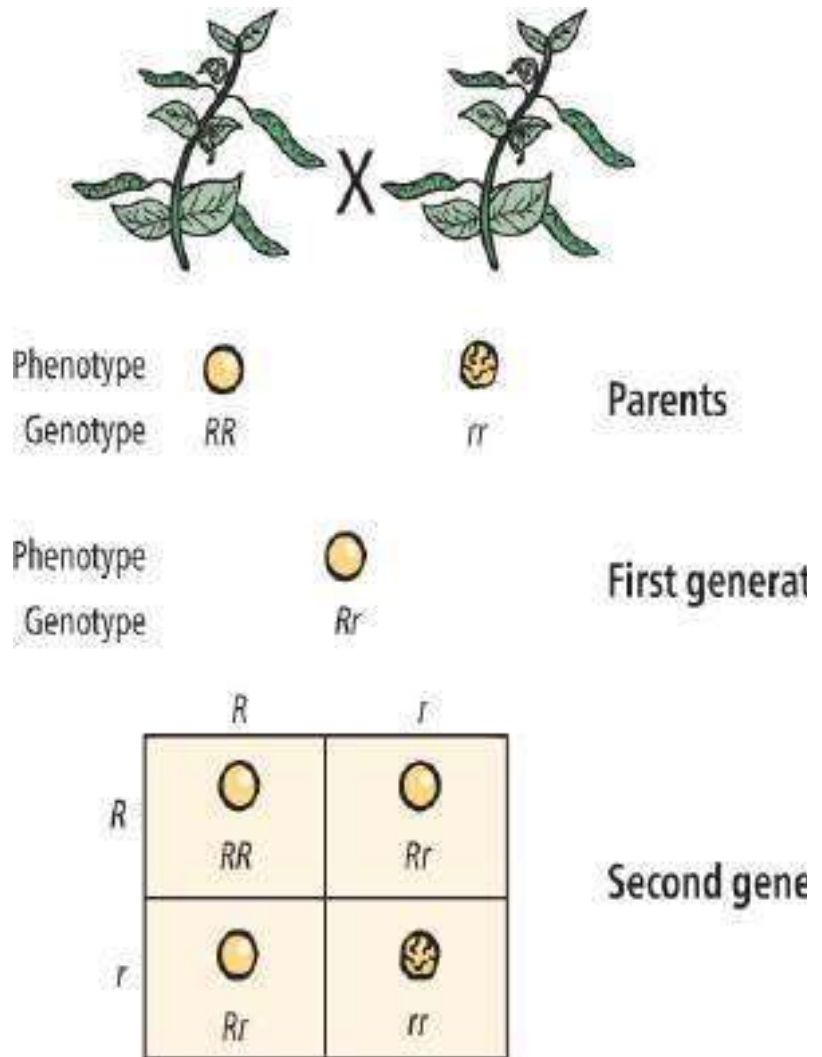
What is the genotype of a person who is a heterozygote for dimples? What is the phenotype of a person whose genotype is Rr —that is, does she have dimples?

Check Answer

Then Mendel bred the Rr plants with themselves. According to the principle of segregation, Rr plants make equal numbers of R and r gametes. What alleles will the offspring inherit? It is equal to the number of offspring will get (1) R egg and R sperm, (2) R egg and r sperm, (3) r egg and R sperm, or (4) r egg and r sperm. This means that one-quarter of the offspring are RR , half are Rr , and a quarter are rr (Figure 15.10). Rr plants have round peas; rr plants have wrinkled peas.

quarters of the offspring have round peas, and one-quarter wrinkled peas—the ratio of round-pea plants to wrinkled-pea plants

Figure 16.22



Mendel bred a round-pea plant with a wrinkled-pea plant. In the first generation, all the offspring had round peas. Then Mendel bred the offspring with themselves. The result was round-pea plants and wrinkled-pea plants in a ratio of 3:1.

Check Yourself

Interactive

Question 1

Check Answer

Question 2

Check Answer

Question 1

You breed a tall pea plant (TT) with a short pea plant (tt). What the sex cells of each plant? What alleles do the offspring inherit tall or short?

Check Answer

You breed a tall pea plant (TT) with a short pea plant (tt). What the sex cells of each plant? What alleles do the offspring inherit tall or short?

Answer: The tall plant produces sex cells that carry the T allele produces sex cells that carry the t allele. The offspring are Tt . T

Question 2

Mendel's Second Law

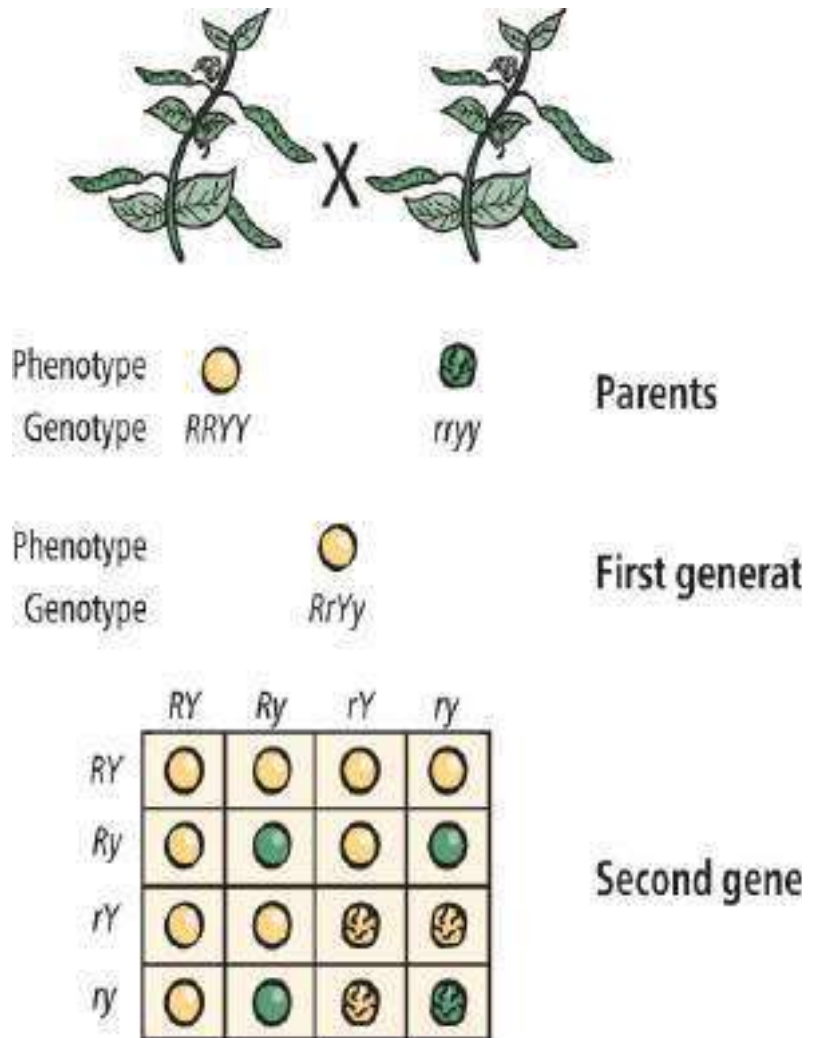
Mendel's next experiment was to breed plants that differ in two traits. He bred plants with round yellow peas ($RRYY$) to plant green peas ($rryy$). In the first generation, all the offspring had round yellow peas. They had the Y alleles from the first parent and r and y alleles from the second parent. The offspring were $RrYy$. They had round yellow peas.

Next, Mendel bred the $RrYy$ plants with themselves. He considered two possibilities. The first possibility is that alleles for the two traits travel together when the offspring make sex cells. If this is the case, the plants should make only two kinds of sex cells: RY and ry (because R and Y were inherited together from one parent, and r and y were inherited from the other parent). The second possibility is that all genes behave independently when sex cells are made. In this case, the plants should make sex cells with all combinations of alleles: RY , Ry , rY , and ry .

When the $RrYy$ plants were bred with themselves, the offspring showed four types of pea: round yellow, round green, wrinkled yellow, and wrinkled green. This couldn't happen if all the sex cells had been RY and ry because then all the offspring would have either round yellow or wrinkled green peas. You could never get wrinkled yellow or round green peas. Also, the ratio of round yellow:round green:wrinkled yellow:wrinkled green peas was 9:3:3:1, exactly what you would expect if sex cells carry all combinations of alleles (Figure 16.23). This is Mendel's second law: the *principle of independent assortment*.

Unifying Concept

Figure 16.23



When Mendel bred plants that differed in two traits, the traits were inherited independently. Breeding plants with round yellow seeds and plants with wrinkled green seeds produced plants with round yellow seeds in the first generation. In the second generation, Mendel observed four different combinations of traits in a ratio of 9:3:3:1.

Mendel knew nothing about meiosis when he developed his ideas on inheritance. However, we now know that Mendel's laws are true because of the way sex cells are produced during meiosis.

Check Yourself

Interactive

Your father gave you an allele for no dimples (d) and an allele for a straight hairline (W). Your mother gave you a dimples allele (D) and a straight hairline allele (w).

Question 1

Check Answer

Question 2

Check Answer

Question 3

Check Answer

Question 1

What is your genotype? Are you a homozygote or a heterozygote for dimples and hairline traits?

Check Answer

What is your genotype? Are you a homozygote or a heterozygote for dimples and hairline traits?

Answer: Your genotype is $DdWw$. You are a heterozygote for both traits.

Question 2

What is your phenotype? That is, do you have dimples? Do you have a straight hairline?

Check Answer

16.8 More Wrinkles: Beyond Mendelian Inheritance

Learning Objective

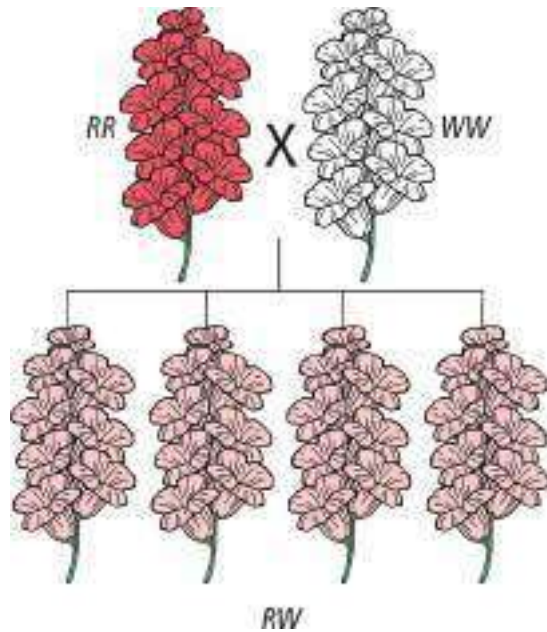
Explain how traits can be inherited in ways that are different from Mendelian genetics.

Mendel's work provided the vital first steps in our understanding of inheritance. But inheritance can also be more complicated than Mendel described. Let's consider some additional wrinkles.

Incomplete Dominance

In *incomplete dominance*, there are two alleles for a trait, and neither is dominant. The heterozygote has an intermediate trait. If you breed a red snapdragon with a white snapdragon, you get pink snapdragons (Figure 16.24).

Figure 16.24




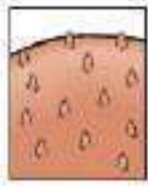
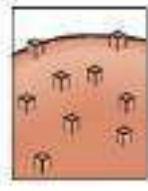

Flower color in snapdragons shows incomplete dominance. A snapdragon with red flowers (RR) is bred with a snapdragon with white flowers (WW), the offspring (RW) have pink flowers.

Codominance

In *codominance*, a heterozygote with two different alleles expresses traits of *both* alleles. An example can be found in human blood type. Blood type describes molecules on the surface of your red blood cells. You can have the A molecule (blood type A), the B molecule (blood type B), neither (blood type O), or both (blood type AB). The alleles are: A, B, and O. A person with genotype AA or Aa has A molecules (blood type A). A person with genotype BB or Bb has B molecules (blood type B). A person with genotype AB has both A and B molecules (blood type AB). A person with genotype OO has no A or B molecules (blood type O).

molecules (blood type B). A person with genotype OO has no surface molecules (blood type O). A person with genotype AB has both A and B surface molecules (blood type AB)—both the A trait and the B trait are expressed. The A and B alleles are codominant (Figure 16.25).

Figure 16.25

Blood type (Phenotype)	O	A	B	AB
				
Genotype	OO	AA or AO	BB or BO	AB

Human blood type offers an example of codominance. Blood type is determined by combinations of the A, B, and O alleles. The O allele is recessive to A and B, but A and B are codominant.

Knowing your blood type can be a matter of life and death. If you ever receive blood cells with a surface molecule that your body doesn't normally have, your body attacks them. This causes the blood cells to clump together, which can be fatal.

Polygenic Traits

Polygenic traits are determined by more than one gene. (“many,” so *polygenic* refers to “many genes.”) Human height and skin color are both polygenic. Polygenic traits show more of a range of variation than traits determined by a single gene. To see why, consider

Suppose the three genes A, B, and C determine height. (The number of genes are actually involved.) Each gene has a tall allele which we will indicate with *T* and a short allele which we will indicate with *S*. The shortest people have three short alleles—genotype $A_S A_S B_S B_S C_S C_S$. People with genotype $A_T A_S B_S B_S C_S C_S$ (two short alleles and one tall allele) are somewhat taller, then $A_T A_T B_S B_S C_S C_S$ (one short allele and two tall alleles) are even taller, and so on. In total, the three genes produce a gradation of heights (Figure 16.26).

Figure 16.26

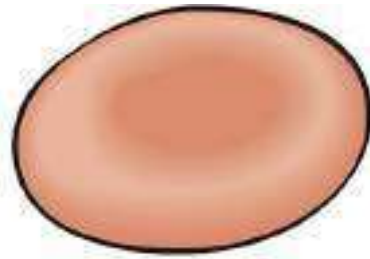


Human height is a polygenic trait. Taller people have more alleles for height-related genes. (Height is also affected by nongenetic factors such as diet and exercise.)

Pleiotropy

In *pleiotropy*, a single gene affects more than one trait. Sickle cell anemia provides an example of pleiotropy in humans. A single allele for hemoglobin makes red blood cells turn sickle under certain conditions, causing tissue damage and pain (Figure 16.27). Homozygotes (people who have two sickle-cell alleles) are severely affected. Heterozygotes (people who have one sickle-cell allele and one normal allele) have only mild symptoms. Given the sickle-cell's harmful effects, scientists were puzzled by how common it is among people of African descent. Why hadn't natural selection caused the sickle-cell allele to disappear from African populations?

Figure 16.27



Normal red blood cell



Sickled red blood cell

The sickle-cell allele offers an example of pleiotropy in which one allele can cause normally round red blood cells to assume a sickle shape, resulting in pain and tissue damage. However, the allele also provides protection from malaria.

Pleiotropy provides the answer. It turns out that the sickle-cell allele protects people from malaria. This is an example of pleiotropy: the sickle-cell allele affects more than one trait—it affects the shape of red blood cells *and* resistance to malaria. The fact that the sickle-cell allele protects against malaria—along with the allele's mild symptoms—

heterozygotes—explains why the allele is common in populations. The fact that malaria has been a danger in the past.

Linked Genes

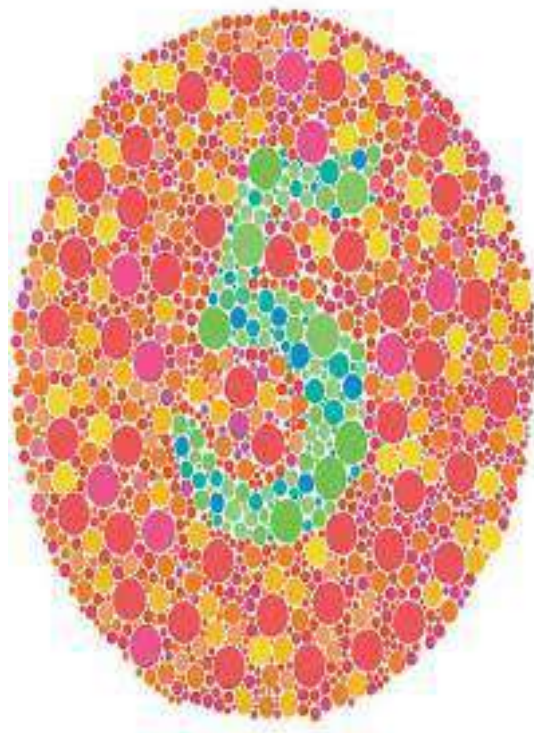
Linked genes are frequently inherited together, in apparent violation of Mendel's principle of independent assortment. How are they linked? Independent assortment occurs when alleles for different chromosomes separate independently at meiosis. But, if two genes are on the *same* chromosome, they are often inherited together—though not quite all the time, because sometimes crossing over breaks them up. In fact, the closer two alleles are to each other on the same chromosome, the more likely they are to be inherited together. The genes for Mendel's pea traits happened to be on different chromosomes, that's why he concluded that genes sort independently. The genes for wing size in fruit flies are linked genes.

Sex-Linked Traits

Sex-linked traits are determined by genes found on the sex chromosomes. Because males have only one X chromosome, they have only one copy of the genes on that chromosome.

for these traits. This means that males need only one re
express a recessive sex-linked trait, whereas females ne
alleles. Because of this, recessive sex-linked traits are se
males than in females. In humans, two recessive sex-lir
green color-blindness (Figure 16.28) and the blood di
Both conditions affect far more males than females.

Figure 16.28



(a)



(b)

Red-green color-blindness is a sex-linked trait that affects males more than females. (a) This image is used to test for red-green color-blindness. Do you see the number? (b) A plate of fruits seen by a person with red-green color-blindness.

Science and Society

Genetic Counseling

What is your risk of someday having a child with a genetic disease? Are there tests that show whether a developing fetus has a genetic disease? What is it like to raise a child with a genetic disease? These are some of the questions that genetic counselors help people answer.

Genetic counseling is especially relevant for couples with a family history of genetic disease. Genetic counseling begins by creating a family tree that shows which family members are affected by genetic disease. They then use information about the inheritance pattern of the disease in question to determine whether the disease allele is dominant or recessive and to assess a couple's risk of having an affected child.

For some diseases, medical tests can provide additional information. Those with a family history of Tay–Sachs (a fatal disease of the central nervous system) or cystic fibrosis (a serious disease characterized by mucus buildup in the respiratory system, digestive system, and other organs) can undergo genetic testing to determine whether they are *carriers* of the disease. For recessive diseases, whether they possess a disease allele in addition to a normal allele. Because these diseases affect only people who have two recessive alleles, a couple is at risk of having an affected child only if both parents are carriers. If both parents are carriers, procedures such as *chorionic villus sampling* and *amniocentesis*, in which fetal cells are collected and analyzed during pregnancy, can be used to determine whether the fetus is affected. Couples may also have the option of using *in vitro* fertilization, testing the embryos, and implanting only unaffected ones.

Genetic testing is also useful for families without a history of genetic disease. For Down syndrome, a condition characterized by mental retardation and other health issues, the risk is primarily on the age of the mother. Older women have a higher risk of having children with Down syndrome. Down syndrome is caused by trisomy 21, the presence of three copies of chromosome 21.

chromosome 21 instead of two. Tests during pregnancy look at the chromosomes in a fetus's cells to determine whether they show trisomy 21.



Down syndrome occurs in about one out of every 700 babies born. It is caused by trisomy 21.

Check Yourself

Question 1

Check Answer

Question 2

Check Answer

Question 1

You breed a plant with two blue-flower alleles to a plant with two white-flower alleles. If the blue allele is incompletely dominant to the white allele, what color flowers will the offspring have?

Check Answer

You breed a plant with two blue-flower alleles to a plant with two white-flower alleles. If the blue allele is incompletely dominant to the white allele, what color flowers will the offspring have?

Answer: They will have pale blue flowers.

Question 2

You breed a plant with two blue-flower alleles to a plant with two white-flower alleles. If the blue allele is incompletely dominant to the white allele, what color flowers will the offspring have?

16.9 The Human Genome

Learning Objective

Describe the key features of the human genome.

As soon as Crick and Watson discovered the structure of DNA, scientists began to develop tools for studying—as well as manipulating—genetic material. Advances in DNA technology now allow scientists to determine the total genetic material of a living organism—the organism's genome. One of the first genomes scientists chose to study was that of the human genome.

Science and Society

Don't Spit Just Anywhere!

What can your saliva tell people about you? Saliva contains DNA, and your DNA can reveal a lot about you. Not only does it hold information about things like your hair and eye color, but it also contains information that you might consider

such as your likelihood of developing certain diseases. As more research is done on the human genome, people's genetic data reveal even more about them. How can we protect our genetic privacy in the age of DNA?

DNA privacy issues have gotten more attention recently because it has become cheaper and easier to store and analyze an individual's DNA. DNA testing kits from companies like 23andMe and AncestryDNA are now extremely popular. For an exchange for a saliva sample, these companies give you interesting information about your genetic background. This information can include your health risks as well as information about your ethnic background and ancestry. Over the 2017 holiday season alone, AncestryDNA sold 1.5 million DNA test kits.

But using these services comes with a price. Often, the terms include fine print that gives them the right to keep your DNA information—and to sell it. The pharmaceutical company Genentech recently paid \$60 million to 23andMe for access to the millions of human genomes in its collection. Although DNA information is supposedly anonymous, some researchers have found it easy to link genetic information back to specific individuals.

Currently, the Genetic Information Nondiscrimination Act (GINA) prevents people's DNA information from being used for employment purposes. Employers cannot use DNA information to decide whether to hire people or fire people, and they cannot use this information to decide how much to pay people. GINA also cannot be used to deny people health insurance or to determine the costs of that insurance. However, there are no protections when it comes to life insurance or disability insurance. Some people and politicians could one day decide to weaken GINA. So, perhaps you should think twice before you spend



DNA test kits allow people to learn about their health and ancestry, but companies may use or sell people's

information.

The Human Genome Project, which was completed in 2003, determined the DNA sequence of the entire human genome. We now know there are about 3.2 billion nucleotide pairs in the human genome, and more than 99.9% of these are identical in all humans.

We also know that the human genome is not made up of only genes. In fact, less than 2% of the genome carries instructions for proteins. Most of the genome—at least 50%—consists of non-coding DNA that appear over and over. Although repeat sequences do not have a direct function, they may occasionally rearrange the human genome, creating new genes or reshuffling existing ones.

Humans have a total of about 19,000 genes. Genes are organized into clusters at random spots along our chromosomes, with large amounts of non-protein-coding DNA between them. Some genes have alternative transcripts that are processed in different ways. The rest

gene can provide the instructions for building multiple function of more than half of our genes is still complete

Scientists also estimate that there are over 10 million loci in the human genome where the nucleotide sequence differs among individuals. These differences are called *single-nucleotide polymorphisms* (SNPs). SNPs make every person unique, of course, but they make it possible for scientists to identify genes related to human diseases.

Check Yourself

Interactive

Question

Check Answer

Question

Scientists believe that most mutations have little effect on genes. Do you use what you learned about the human genome to support this?

Check Answer

Scientists believe that most mutations have little effect on genes. Do you use what you learned about the human genome to support this?

Answer: Genes make up less than 2% of the human genome. T

16.10 Cancer: Genes Gone

Learning Objective

Explain how genetic mutations that occur during lifetimes give rise to cancer.

Cell division is normally a carefully orchestrated process that involves a large number of genes. Cancer occurs when mutations cause cells to divide out of control. A mutation in a single gene is not enough to produce cancer—mutations in many important genes are required.

Cancer tends to strike older people more often than younger people because mutations have had more time to accumulate in their cells. People who have been exposed to mutation-causing agents, such as radiation, acquire mutations more rapidly, making cancer more likely to develop. In addition, some people are prone to developing certain types of cancer because they have inherited mutations in cancer-related genes. For example, mutations in the *BRCA* genes (named for *BR*east *C*ancer) are associated with aggressive breast and ovarian cancers.

In a deadly cancer, tumor cells do more than divide out. Cancers are said to have *metastasized* if tumor cells have the ability to spread around the body and give rise to secondary tumors. Metastasis is a crucial point in disease progression because cancer is much harder to treat once they have metastasized.

Integrated Science 16D: Earth and Space Science

Environmental Causes of Cancer

Learning Objective

List and describe some important environmental causes of cancer.

When people migrate from one place to another, the risk of developing cancer is determined largely by the place they move to, rather than the place they have moved from. This suggests that cancer is primarily an environmental, rather than an inherited, disease. In fact, a person's environment is responsible for about 80%–90% of the mutations

cancer, with inherited genetic factors accounting 10%–20%.

Environmental factors that increase the risk for cancer include smoking, diet, radiation, ultraviolet light, chemical exposure, and infection by certain viruses and bacteria. The roles of factors such as smoking and radiation are well understood, and we know how and why these things increase genetic damage. The roles of other factors are still being studied. In general, scientists know that diet is important in the development of many cancers. However, people's diets are such a complex mix of nutrients that it can be hard to connect any particular foods to cancer. Yet, most of the research shows that a diet rich in fruits and vegetables can help protect against cancer.

A well-known environmental risk factor for skin cancer is ultraviolet (UV) light from the Sun. The ozone in Earth's atmosphere protects life by absorbing most of the harmful UV light. In the 1980s, a large hole in the atmospheric ozone layer was discovered. Ozone loss was blamed on the use of so-called chlorofluorocarbons (CFCs) in refrigerants and aerosol sprays. The chlorine in CFCs speeds up the break

ozone, causing it to become depleted. An international agreement to phase out the use of CFCs has succeeded in shrinking the ozone hole. This is considered one of the major environmental successes. Staying out of the sun and using sunscreen also help reduce exposure to UV radiation (Figure 16.29).

Figure 16.29



Reducing exposure to UV light will help you avoid skin cancer. Here, Io and Pico demonstrate the use of hats and sunglasses. Also in use, though not visible, is lots of sunscreen.

Check Yourself

Question

Check Answer

Question

If cancer is usually caused by environmental factors, why is it a genetic disease?

Check Answer

If cancer is usually caused by environmental factors, why is it a genetic disease?

Answer: Cancer is a genetic disease because it is the result of genetic mutations. But, unlike other genetic diseases, cancer is not usually an *inherited* disease. The mutations that cause cancer are not usually inherited from parents. Instead, they are caused mainly by environmental factors.

16.11 Genetic Engineering

Learning Objective

Use examples to describe some practical uses of genetically modified organisms and cloning.

Advances in DNA technology have led to many practical applications as well as some serious concerns. Genetic engineering is a process of changing the traits of organisms by directly manipulating their DNA. In this section, we will look at two applications of genetic engineering: genetically modified organisms and cloning.

Genetically Modified Organisms

A genetically modified organism, or GMO, is an organism whose genetic material has been changed through genetic engineering. GMOs are often engineered for some practical purpose.

Scientists produced one of the first useful GMOs when they inserted a gene for human insulin into the bacterium *Escherichia coli*.

inhabitant of the human digestive tract. At the time, insulin to treat some forms of diabetes, had to be collected from pigs and cows. When genetically modified *E. coli* began producing human insulin, the advantages were clear—human insulin produced easily and in large amounts. In 1982, insulin became the first genetically engineered pharmaceutical product (Figure 16.30). Genetically engineered bacteria now produce many other pharmaceuticals, including many different human molecules and medicines. Scientists continue to work to expand this list.

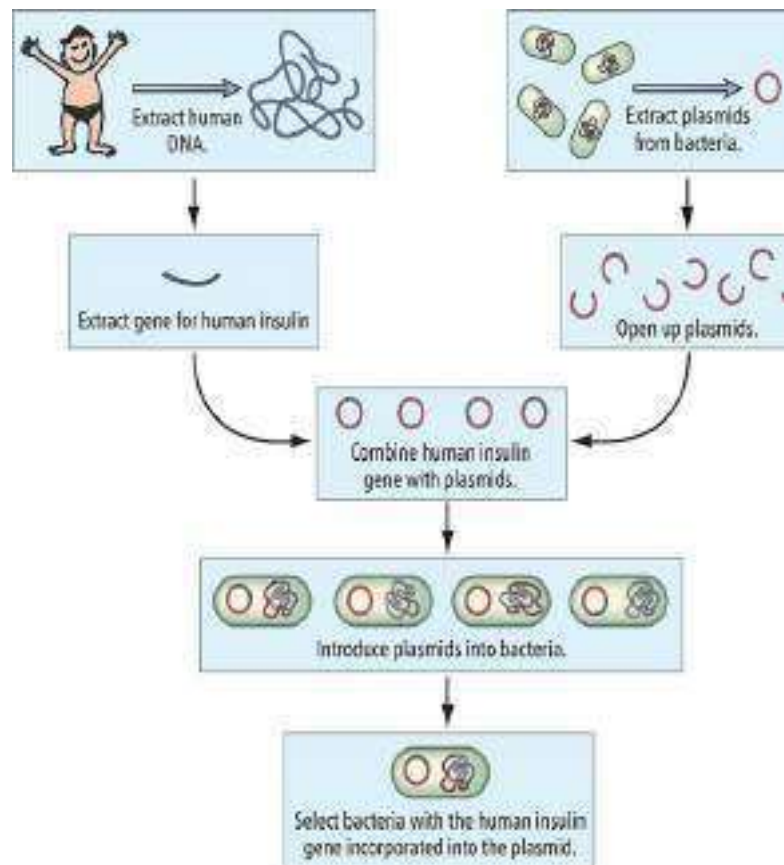
Figure 16.30



Genetically engineered bacteria (and other microorganism) produce a wide variety of important pharmaceutical products. This is a production facility.

Figure 16.31 shows a typical process for developing genetically engineered bacteria. In this example, a human gene is extracted from a human and combined with bacterial DNA. The bacterial DNA, which contains the human gene, is then re-introduced into bacteria.

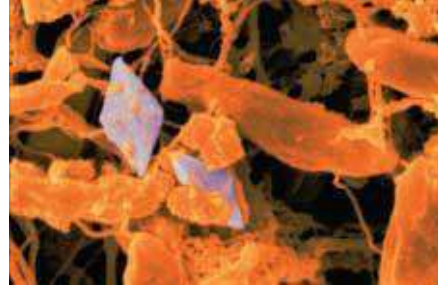
Figure 16.31



This figure shows how bacteria can be genetically modified to produce human insulin. Genetically modified bacteria often carry genes in plasmids, small circles of DNA separate from the bacterial chromosome.

Many genetically modified plants and animals have also been created by scientists. Genetically engineered plants have been created for a variety of purposes. Some produce useful products—for example, tobacco plants are used to make medicines for certain autoimmune diseases. Other GM plants have genes that offer resistance to disease, or herbicides. Genetically engineered varieties of plants, including corn, soybeans, and cotton, have been created from the soil bacterium *Bacillus thuringiensis*, shown in Figure 16.32. This gene codes for a toxic protein that kills certain insects. Some crops resistant to these pests. Many other GM plants carry genes that makes them resistant to the herbicide Roundup. Farmers use these “Roundup Ready” crops can use Roundup to kill weeds without damaging their crops.

Figure 16.32



The soil bacterium *Bacillus thuringiensis* (orange) makes toxins, shown in purple, that are toxic to many insects. Genetic crops with this gene also make the toxic crystals, making them resistant to many pests.


Technology

Genetically Engineered Mosquitoes

Could genetically engineered mosquitoes finally help defeat one of their tiniest, deadliest enemies? Mosquitoes spread diseases such as malaria, dengue fever, and the recent Zika. All of these have severe impacts on humans. For example, malaria kills nearly half a million people each year and Zika can cause severe birth defects when it is passed to pregnant women.

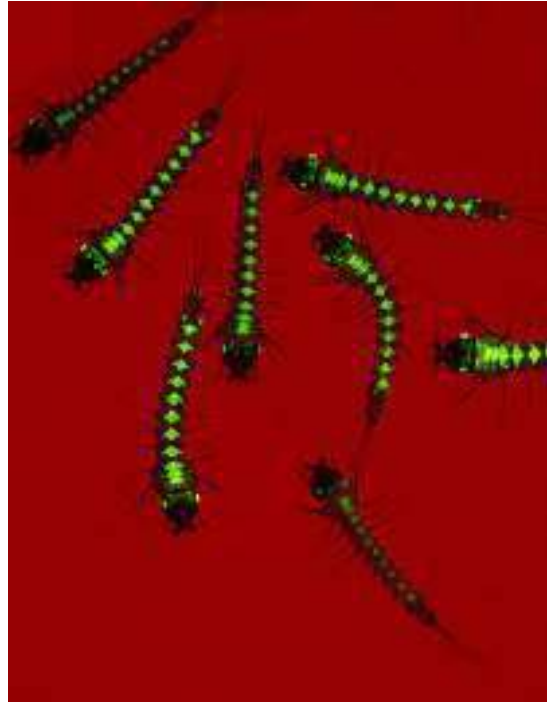
How can genetically engineered mosquitoes help spread of human diseases? Scientists are working on different approaches. The British company Oxitec has developed genetically engineered “friendly” male mosquitoes. These males mate normally with females, but they have a gene that causes their offspring to die as larvae and never become biting adults. Over time, the release of enough “friendly” males causes mosquito populations to decline. Studies show that Oxitec’s “friendly” males can reduce mosquito populations by as much as 95%. Another team at Imperial College London, has developed a “gene drive” that spreads female infertility in mosquitoes. Gene drives cause certain alleles to be inherited more often than expected by Mendelian inheritance, with the result that the gene spreads very quickly. The Imperial College team’s gene drive uses three genes that prevent females from laying eggs. The release of mosquitoes with the gene drive can cause mosquito populations to decline quickly.

But what are the potential consequences of wiping out an entire insect population? How would it affect other insects that interact with mosquitoes? And could mosquitoes be replaced by an even worse insect?



Another genetic engineering approach aims to develop mosquitoes that are themselves resistant to disease. If the mosquitoes will be unable to spread disease, the advantages of this approach are that wiping out target populations is not necessary and unintended consequences are less likely. Groups at the University of California at San Diego and the University of California, San Diego, are developing genetically engineered mosquitoes with high activity of the immune system that fights the malaria parasite. These mosquitoes are resistant to malaria and will not transmit disease to humans.

Whether any of these strategies will defeat mosquitoes will be determined. But it seems clear that genetic engineering could provide powerful tools in the battle against this enemy.



These mosquito larvae are glowing because they are genetically engineered organisms. Scientists are working on developing genetically engineered mosquitoes that may help reduce the spread of diseases such as malaria, dengue fever,

Still other GM plants have been engineered to grow in saline environments. Some GM varieties of tomato, canola, and cotton can grow in salty soils with the help of a special ion transporter gene from a naturally salt-tolerant plant. (Salty soils are a common problem in intensive agriculture.) Considerable effort is now being put into developing plants that are resistant to drought and high temperatures.

have worsened with global warming. Drought-tolerant wild barley and the resurrection fern (Figure 16.33) have genes that can be transferred to crops such as wheat. GM wheat with drought-related wild barley genes needs only one-eighth as much water as regular wheat. Other research is focusing on the development of genetically engineered plants for biofuels and for use in cleaning up pollutants.

Figure 16.33



Naturally drought-resistant plants such as the resurrection fern have genes that can be transferred to crop plants, enabling them to survive high temperatures and severe droughts that accompany climate change. These ferns appear dead, but they will revive as soon as water is available.

Genetically engineered animals make proteins for human consumption, agricultural products, and aid in the study of human disease. Sheep and goats make foreign proteins in their milk, and

working on a GM chicken that can produce foreign proteins. In agriculture, researchers increased wool production in sheep by inserting special DNA sequences from mice. Other scientists are using a roundworm gene to engineer healthier pork—GM pigs produce higher amounts of healthy omega-3 fatty acids.

Technology

Genome Editing With CRISPR-

It's been called the biotechnology discovery of the century. But what exactly is CRISPR-Cas9? CRISPR-Cas9 is a powerful tool for genome editing. It allows scientists to add, remove, or change DNA at specific locations in the genome. The CRISPR-Cas9 system was developed by Jennifer Doudna and Emmanuelle Charpentier at the University of California, Berkeley, in 2012.


CRISPR-Cas9 is based on a system used by some bacteria to defend themselves from viruses. When viruses attack bacteria, the bacteria save some of the virus's DNA in special "arrays." If the viruses ever return, DNA from the arrays is used to make RNA. This RNA locates matching

sequences in the attacking viruses. Then, the Cas9 enzyme cuts the DNA apart, destroying the virus.

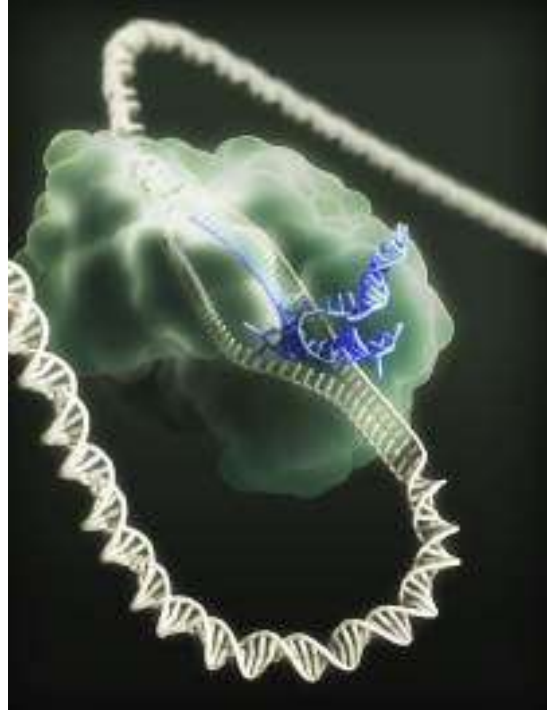
The CRISPR-Cas9 genome editing tool works in a similar way. Scientists create “guide RNA” with the desired target sequence and attach it to the Cas9 enzyme. The RNA locates the matching DNA, and the Cas9 enzyme cuts it. Specific genes can then be added or removed from that location in the genome.

The CRISPR-Cas9 system is exciting to biologists because of its many potential uses. For example, many serious inherited diseases, including hemophilia and cystic fibrosis, are the result of a small number of faulty genes. CRISPR-Cas9 allow scientists to cut out the faulty genes and replace them with normal, working versions. Genome editing could lead to treatments for more genetically complex diseases like cancer. Although CRISPR-Cas9 has yet to be used to treat human diseases, it has already been used to slow tumor growth in mice, to spread infertility in female mosquitoes, and to remove HIV, the virus that causes AIDS, from living organisms.

This powerful technology raises some ethical concerns.



however. First, there are issues of safety. More research is needed to determine what could go wrong if CRISPR-Cas9 is to be used to treat human diseases. For example, in a recent experiment, the Cas9 enzyme cut the human genome at unintended locations in addition to the target location. A second question is, what limits, if any, should be placed on editing the human genome? Although most people support using a technology such as CRISPR-Cas9 to treat genetic diseases, reasonable people disagree about whether other uses are ethical. For example, is it ethical to use genetic editing to “enhance” human traits? Many people also favor using genetic technologies in human eggs and sperm, but they would produce genetic changes that would be passed from one generation to the next.



The CRISPR-Cas9 genome editing system include (blue) that helps to locate a target in the DNA ger
The Cas9 enzyme (green) linked to the RNA cuts the appropriate spot.



Jennifer Doudna, a professor at the University of California, Berkeley, invented the CRISPR-Cas9 genome editing technology.

The first GM animal to arrive at supermarkets was an Atlantic salmon called "AquAdvantage". It grows twice as fast as regular salmon and requires less space. "AquAdvantage" salmon has DNA from two other species: a growth hormone gene from a different salmon species and a growth hormone gene from a fish called ocean pout. With this DNA, the AquAdvantage salmon can grow year-round rather than seasonally, and it can reach market weight in half the time of regular Atlantic salmon. It took 25 years for

Drug Administration (FDA) to approve the salmon for sale, which occurred in 2015. The first sales occurred in Canada.

Finally, GM animals, particularly GM mice, are used to study human diseases. Genes introduced into GM mice can make them susceptible to human diseases that they don't otherwise have.

According to the United Nations, about 815 million people were hungry in 2016. This is 11 percent of the global population. Many people believe that genetically modified plants will be a necessary part of agriculture's future to feed the world—particularly given the challenges that global warming is bringing.

Cloning

Cloning is the creation of an organism that is genetically identical to one that already exists. Plant cloning is a routine part of agriculture, but cloning is much harder in animals—particularly mammals. There are a number of potential uses. In agriculture, cloning could be used to create genetically identical animals that have desirable traits. In

even extinct animals could be cloned to increase their numbers. In addition, some people have expressed interest in cloning deceased loved ones.

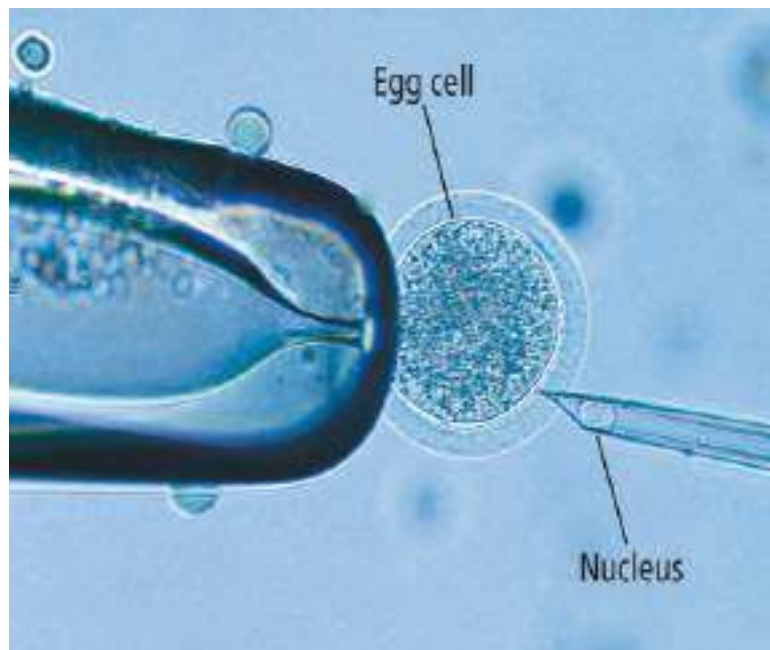
In 1997, Dolly the sheep became the first cloned mammal (Figure 16.34). Cloning was done through a process called nuclear transplantation. In *nuclear transplantation*, the nucleus of an animal being cloned is placed into an egg cell that has had its nucleus removed (Figure 16.35). The resulting embryo is then implanted into a surrogate mother. Since Dolly, other mammals have been cloned, including dogs, cats, mice, and horses, as well as species such as the European mouflon (a small wild sheep) and the banteng (a type of wild cattle). In January 2018, a pair of Chinese rhesus macaques—became the first cloned primates. Unfortunately, cloned animals often suffer from developmental abnormalities and health problems. Today, there is only limited use of animal cloning to replicate a few particularly desirable animals. Human cloning has never been performed and would certainly run into serious ethical and legal obstacles. More than 30 countries have formally banned human cloning. Although there is no such ban in the United States, law prohibits the use of federal funds from being used to work on human cloning.

Figure 16.34



Dolly the sheep was the first cloned mammal.

Figure 16.35



This photo shows a key step in the process of animal cloning: a somatic cell nucleus from the animal being cloned (in this case, a cow) is being inserted into an egg cell that has had its own nucleus removed.

A group of Japanese, Russian, and American scientists are trying to use tissue from a frozen mammoth to clone a woolly mammoth. The plan is to insert the nucleus of a mammoth cell into an elephant egg cell that has its nucleus removed. If an embryo results, it could then be implanted into a female elephant.

Check Yourself

Interactive

Question

Check Answer

Question

Is an animal produced through nuclear transplantation genetically identical to the animal that provides the nucleus, the animal that provides the egg, or the animal that provides the egg and the mother? Explain.

Check Answer

Is an animal produced through nuclear transplantation genetically identical to the animal that provides the nucleus, the animal that provides the egg, or the animal that provides the egg and the mother? Explain.

16.12 DNA Technology—What Could Possibly Go Wrong?

Learning Objective

Explain some of the safety, social, and ethical concerns associated with DNA technology.

Although DNA technology has been the source of great benefit, it has also given rise to serious concerns. Could scientists accidentally create deadly bacteria or virus? Are GM plants and animals safe? Are GM crops damaging the environment and giving rise to dangerous "superweeds"? Also, which DNA technologies could be used on humans, and what impact will this have on our society? Finally, who will have access to DNA technologies?

Some genetically engineered bacteria and viruses are dangerous to human health or natural habitats. To help keep these organisms from leaving the lab, scientists give them genetic mutations that prevent them from performing important natural functions. This makes it difficult for them to survive in the wild. (In the lab, scientists keep them in a controlled environment.)

providing conditions that make up for the genetic deficit. Without these precautions, accidental releases remain a legitimate concern.



Genetically modified crops are probably the most controversial application of recombinant DNA technology today. In the United States, GM crops are widely used. In 2014, more than 90% of the soybeans, cotton, and corn crops were genetically modified varieties. In many European countries, GM crops are banned or strictly controlled. One basic question is: Are GM plants safe to eat? In 2010, the European Commission released the results of research and concluded that GM plants are not riskier to human health than plants produced through conventional breeding. However, scientists and consumer groups worry that safety testing is not sufficient.

adequately tested. In 2009, a group of two dozen scientific research institutions in 17 states warned the U.S. Environmental Protection Agency that the companies that develop GM crops act to “inhibit public scientists from pursuing their research in the name of the public good” and that these companies have made independent analyses of GM crops impossible.

A related issue is the labeling of GM foods (Figure 16.36). Labeling is not currently required in the United States, although a majority of consumers favor it. Labeling is opposed by industry, which argues that consumers may avoid products that are labeled.

Figure 16.36



Are genetically modified foods safe? Should they be lab people, including these protestors in San Diego, California, additional regulation is needed.

Another concern about GM crops is their effect on the environment. For example, crops that contain *Bacillus thuringiensis* genes, which kill pest species, can also kill nontarget species. "Roundup Ready" crops encourage farmers to use more chemical herbicides, which can harm the environment. Some weeds can also evolve resistance, becoming "superweeds."

A further worry is contamination by genetically engineered genes. In a 2007 test of "Roundup Ready" creeping bentgrass for use on golf courses, some plants escaped from a field and ended up in irrigation canals miles away in Oregon. Hundreds of plants were found, including many that had already produced seeds. GM crops could also breed with wild plants and transfer herbicide-resistance genes to the wild varieties, creating "superweeds." One such plant, a resistant mustard weed, was discovered in 2005 in a field used for trials of GM oilseed rape (a produce canola oil). Before the discovery, such transfer was nearly impossible.

Genes from GM crops can also contaminate traditional crops. A 2008 study by the Union of Concerned Scientists studied corn, canola, and soybeans and found that the traditional seed supplies for all three were contaminated with DNA from genetically modified varieties. Contamination is a particular worry for organic farmers because organic products are prohibited from including GM varieties. In 2011, an organic farmer in Australia lost his organic neighbor after GM canola blew onto his fields, resulting in the loss of his organic license.

Scientists have been trying to figure out why so many honeybee populations are in decline. One factor is the use of Roundup. A 2018 study found that the herbicide glyphosate makes honeybees vulnerable to deadly infections and damages beneficial bacteria in the honeybees' gut.

A final concern about GM crops is cost. GM seeds are typically more expensive than traditional seeds, and farmers in many parts of the world are encouraged to take out large loans to buy "insect-proof" GM seeds. In India, many farmers who had taken out such loans found that the crops failed due to drought (some GM crops require irrigation), and many of the farmers went bankrupt.

Finally, what about DNA technology and human society? What happens when we apply DNA technologies to ourselves?

disease is one thing, but what about enhancing our abilities? What constraints be placed on DNA technology? In addition, as new technologies are developed, who will control access to them? Will important technologies be available only to the wealthy? On the other hand, could the ability to manipulate DNA become readily available—in easy, do-it-yourself kits? Will we have to think through the social and ethical implications of a new technology and legislate effective controls? And what if something unexpected happens (see [Figure 16.37](#))? We will be facing questions like these as they come.

Figure 16.37



In the 1993 movie *Jurassic Park*, things don't go according to plan at a theme park filled with cloned dinosaurs.

When a private company began to clone cats for people who missed their deceased pets, the price tag was \$5,000.

Summary of Terms (Knowledge)

For instructor-assigned homework, go to
www.masteringphysics.com

Alleles □

Versions of a gene.

Codon □

A sequence of three nucleotides in an mRNA molecule for an amino acid or ends translation.

Deoxyribonucleic acid (DNA) □

The cell's genetic material: a double-stranded molecule with sugar-phosphate backbones attached by pairs of matching bases, in the form of a double helix.

Diploid □

Describes a cell that has two of each kind of chromosome

DNA replication □

The process through which a DNA molecule is copied in order to divide and reproduce.

Dominant □

Describes an allele that is expressed in a heterozygote.

Gene □

A section of DNA that contains the instructions for building a protein

Genetic engineering □

The process of changing the traits of organisms by directly manipulating their DNA.

Genetic mutation □

A change in the nucleotide sequence of an organism's DNA

Genetically modified organism □

An organism whose DNA has been changed through genetic engineering

Genome □

The total genetic content of an organism.

Genotype □

The genetic makeup of an organism.

Haploid □

Describes a cell that has one of each kind of chromosome.

Heterozygote □

An organism that has two different alleles for a given gene.

Homozygote □

An organism that has two identical alleles for a given gene.

Meiosis □

A form of cell division in which one diploid cell divides into four haploid cells.

Messenger RNA (mRNA) □

An RNA molecule made during transcription that carries information from DNA to the ribosomes.

Phenotype □

The traits of an organism.

Recessive □

Describes an allele that is not expressed in a heterozygote.

Recombination □

The production of new combinations of genes that differ from the combinations found in the parental chromosomes results from crossing over during meiosis.

Ribonucleic acid (RNA) □

A single-stranded molecule consisting of a sugar-phosphate backbone attached to a series of nitrogenous bases.

Transcription □

The first step in building a protein, in which a messenger RNA molecule is assembled from information contained in DNA.

Transfer RNA (tRNA) □

An RNA molecule that transfers an amino acid to a growing polypeptide chain during translation.

Translation

The assembly of a protein based on information contained in an mRNA molecule.

Reading Check Questions (Comprehension)

16.1 What Is a Gene?

1. What is a gene?
2. Why do proteins determine many of an organism's traits?

16.2 Chromosomes: Packages of Genetic Information

3. How is DNA packaged into chromosomes?
4. What is the difference between a diploid cell and a haploid cell? What types of cells are haploid?

16.3 DNA Replication

5. How is DNA copied?

6. Is a new molecule of DNA put together using two strands?

16.4 How Proteins Are Built

7. How does RNA differ from DNA?
8. What base-pairing rules are followed in making a transcript from a DNA template?
9. What is a codon?
10. Describe the role of tRNA in translation.

16.5 Genetic Mutations

11. What are the two main causes of genetic mutations?
12. What is a point mutation?
13. What is a frameshift mutation, and what is its effect?

16.6 Meiosis and Genetic Diversity

14. What is crossing over? Why is crossing over important for genetic diversity?

15. What are the products of meiosis?

16.7 Mendelian Inheritance

16. What is the difference between a dominant trait and a recessive trait?

17. When Mendel bred pea plants that differed in a single trait, what did he see in the offspring? When Mendel allowed the offspring to self-fertilize, what did he see?

16.8 More Wrinkles: Beyond Mendelian Inheritance

18. What is codominance? Provide an example of codominance.

19. What is a polygenic trait? Provide at least one example of a polygenic trait.

20. What is pleiotropy?

16.9 The Human Genome

21. How many genes does a human have?

22. What is an SNP?

16.10 Cancer: Genes Gone Awry

23. Is cancer usually the result of a single genetic mutation?

24. What does it mean for a cancer to have metastasized?

16.11 Genetic Engineering

25. What is a genetically modified organism?

26. Use examples to describe how genetically modified organisms are useful to humans.

27. Explain how a mammal is cloned.

16.12 DNA Technology—What Possibly Go Wrong?

28. Describe some of the safety, social, and ethical issues that relate to genetically modified crops.

Think Integrated Science

16A—The Structure of DNA

29. Why is DNA described as a double helix?
30. How is DNA like a ladder? What are the “sides” what are the “rungs”?
31. What are the four nucleotides found in DNA? F

16B—DNA in Hot Environmer

32. Why are temperatures very high in hydrotherm springs?
33. Why can very high temperatures be a problem
34. What is unusual about the DNA of organisms tl environments?

16C—How Radioactivity Caus

Genetic Mutations


35. Explain how DNA is damaged by exposure to r materials.
36. Which cells are most vulnerable to ionizing rad
37. Why is radiation used to treat some forms of ca

16D—Environmental Causes c

38. What are some of the most important cancer-re environmental risk factors?
39. How is the loss of ozone from Earth's atmosphere cancer?

Think and Do (Hands-On Application)

40. Trace the inheritance of blood type in your immediate family. What is your blood type? What blood-type alleles do you have? (Note: You may be able to say for sure what alleles you may have to list multiple possibilities.) What are your parents' blood types? What alleles might they have? What alleles may or may not be able to say for sure. What are the possibilities?) If you are a heterozygote, can you determine which allele you received from your mother and which allele from your father?
41. Answer the questions in **Exercise 40** for the presence of dimples and for straight hairline versus wavy hairline.
42. How different is mouse growth hormone from human growth hormone? Nucleotide sequences for the two genes are available at the National Center for Biotechnology Information Web site at <http://www.ncbi.nlm.nih.gov>. Perform a search for accession numbers NM_008117 and NM_008118.

down to look at the mRNA sequences. You may
a limited portion of the gene—say, the first 30 n
there differences between the mouse mRNA an
mRNA? How many differences are there? Now
code (Table 16.1 ) to translate the mRNA sequ
acids. Do the differences in mRNA sequences r
amino acid sequences?

Think and Compare (Analysis)

43. Rank these types of human cells in order of the chromosomes they have, from most to least: (a) a brain cell, (c) a red blood cell
44. Let's assume that human height is a polygenic trait controlled by three genes: A, B, and C. For each gene, there is a tall allele and a short allele. We'll use *T* and *S* to indicate these. You and your friend have the following genotypes: $A_S A_S B_S B_S C_S C_S$, $A_S A_T B_S B_S C_S C_S$, $A_T A_T B_T B_T C_T C_T$, $A_S A_T B_T B_T C_T C_S$. Rank them from tallest to shortest.
45. The human genome includes all the DNA found on all 22 pairs of autosomes and the X and Y chromosomes. Rank these parts of the human genome from highest percentage of our total DNA to lowest percentage of our total DNA: (a) DNA that is identical in all humans, (b) DNA that is not identical in all humans, (c) DNA that codes for making proteins, (d) repeat sequences.

Think and Solve (Mathematical Application)

46. If an organism's diploid cells have 64 chromosomes, how many chromosomes will its haploid cells have?
47. One strand of DNA has the nucleotide sequence CTGAGGTCAGGA. What are the nucleotides of the complementary strand?
48. A section of DNA with the nucleotide sequence CTGAGGTCAGGA is transcribed. What will the sequence of the RNA transcript be?
49. Suppose an mRNA molecule with the nucleotide sequence AGUCGUUGGCAGGAAGUA is translated. What amino acids will be produced?
50. Suppose an mRNA molecule has the nucleotide sequence AGUCGUUGGCAGGAAGUA. What point mutation in the sequence will produce a nonsense mutation?
51. Suppose an mRNA molecule has the nucleotide sequence AGUCGUUGGCAGGAAGUA. Give two examples of point mutations that would not change the amino acid sequence.

mutations in this sequence that will not affect the sequence codes for.

52. You have a pea plant with round seeds. Can you determine what pea-shape alleles the plant carries? What are the possibilities? You want to distinguish between the two possibilities, so you decide to let the plant self-fertilize. What do you expect in each case?
53. A woman carries an allele for red-green color-blindness on her X chromosomes. Her husband is not red-green color-blind. Show that her daughters are not at risk for red-green blindness but her sons are at risk.

Think and Explain (Synthesis)

16.1 What Is a Gene?

54. What is the difference between genotype and phenotype? Which part of your genotype or phenotype is determined by a single gene?
55. How do your genes determine what kinds of proteins occur in your cells?

16.2 Chromosomes: Packages of Genetic Information

56. Is your finger made of diploid cells or haploid cells?
57. Why do some of your cells have only 23 chromosomes instead of 46?
58. What kind of sex chromosomes do you have? Where are sex chromosomes found?
59. Do different types of cells in your body have different chromosomes? If not, what makes them so different from one another?

16A—The Structure of DNA

60. If you know the nucleotides on one strand of DNA, you can tell what nucleotides are on the other strand.
61. A DNA nucleotide is made up of a nitrogenous base, a sugar, and a phosphate group. Explain how these molecules form the DNA “ladder.”
62. If DNA is made up of nitrogenous bases, sugar, and phosphate groups, why is all the genetic information contained in the nitrogenous bases rather than in the sugar molecules or phosphate groups?

16B—DNA in Hot Environments

63. Explain why scientists initially thought that organisms in hot environments might have more G–C nucleotide pairs than A–T nucleotide pairs. Then explain why the scientific evidence supports this hypothesis.
64. Explain why the scientific evidence supports the hypothesis: Supercoiled DNA is the key feature that allows DNA of microorganisms to remain double-stranded in hot environments.

16.3 DNA Replication

65. When DNA is copied, why isn't there an "old" and a "new" molecule?
66. Can RNA replicate the way DNA replicates? Why or why not?

16.4 How Proteins Are Built

67. How is transcription similar to DNA replication? How is it different?
68. We compared mRNA processing to editing "agggdfjkl sdf or rewerwe not to be" to obtain "to be cdfjkl sdf". In this comparison, is "aggfr" an exon or an intron? Why?
69. What is the genetic code?
70. Do all codons code for amino acids? If not, what do they code for?

16.5 Genetic Mutations

71. Are point mutations in the first, second, and third codon equally likely to cause a change in the amino acid sequence of a protein? What type of point mutation is most likely to change the amino acid sequence? Use the genetic code (Table 16.1) to answer these questions.
72. Why is a frameshift mutation more likely to disrupt protein function than a point mutation?
73. You are studying two different mutations in a gene that codes for a protein. In the first, a nonsense mutation occurs near the beginning of the gene. In the second, a nonsense mutation occurs near the end of the gene. Which mutation is more likely to disrupt protein function?
74. You are studying two different mutations in a gene that codes for a protein. In one mutation, a single nucleotide is substituted near the beginning of the gene. In the other mutation, three nucleotides are inserted near the beginning of the gene. Which mutation is more likely to disrupt protein function? Why?

16C—How Radioactivity Causes Genetic Mutations

75. Explain what a free radical is and why free radicals cause genetic mutations.
76. Survivors of the atomic bombs in Hiroshima and Nagasaki developed leukemia and other forms of cancer at higher rates. Explain why.

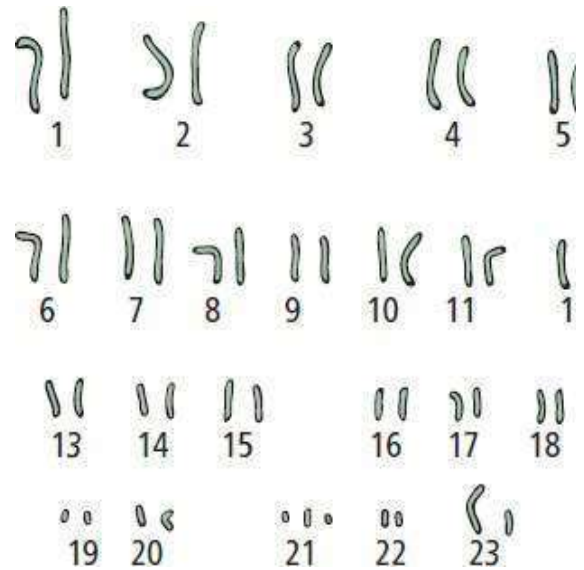
16.6 Meiosis and Genetic Diversity

77. How can the same two parents produce children that are genetically different?



78. Describe three differences between mitosis and meiosis.

79. The figure below shows a set of human chromosomes. What is unusual about this person's genetic makeup? How might a problem during meiosis relate to this condition? What issues might this person suffer from?



16.7 Mendelian Inheritance

80. Explain how a trait can skip generations.
81. If you have dimples, will all your children have dimples? (Remember that "dimples" is a dominant trait.)



82. Is it possible for two parents with widow's peak who has a straight hairline? Is it possible for two straight hairlines to have a child with a widow's peak? (Remember that a widow's peak hairline is dominant and a straight hairline is recessive.)

16.8 More Wrinkles: Beyond Mendelian Inheritance

83. Can you tell what alleles a pea plant with round seeds has? Can you tell what alleles a red snapdragon has? Why?

different?

84. You are in an accident and you need a blood transfusion. You have forgotten your blood type. Which type of blood should be given? Does this explain why people with type O blood are called universal donors?
85. Universal receivers are people who can safely receive any blood type during a blood transfusion. Which blood types are universal receivers? Explain your answer.
86. Why are there more color-blind men than color-blind women?

16.9 The Human Genome

87. Does all your DNA code for proteins?
88. Explain how studying SNPs could help scientists identify genetic mutations that are related to specific human diseases.

16.10 Cancer: Genes Gone Awry

89. Cancer is caused by “genes gone awry”—yet can also be inherited as a genetic condition. Explain why.

90. Are older people or younger people more likely to get cancer? Defend your answer.
91. What are some factors that could make certain people more likely to develop cancer than others?

16D—Environmental Causes of Cancer

92. Explain how the chlorofluorocarbons (CFCs) in aerosol sprays affect Earth's ozone layer. Have international agreements to phase out the use of CFCs helped protect the ozone layer?
93. Australia has one of the highest skin cancer rates in the world. Scientists believe that two factors behind this are the high levels of ultraviolet radiation present there and the popularity of tanning. Explain how these factors could lead to unusually high skin cancer rates.

16.11 Genetic Engineering

94. How can genetic engineering help humans adapt to global warming and climate change?

95. How might genetic engineering affect the human future?

16.12 DNA Technology—What Possibly Go Wrong?

96. What is a “superweed”? Explain the benefits and risks of genetically engineered crops that are resistant to herbicides.

97. Write a letter to Grandpa telling him about genetic engineering. Tell him why the development of this technology could result in many practical applications. Also discuss the potential dangers of this technology. Are you more worried about the possible consequences of genetic engineering technology?

Think and Discuss (Evaluati

98. What are the three types of RNA, and what is the function of each type?
99. Your friend Stacie says, "I understand how a point mutation can result in a nonsense mutation, but I don't get how a frameshift mutation can result in a nonsense mutation. Can you explain? Can you come up with an example of a frameshift mutation that results in a nonsense mutation?"
100. "Listen to this," your friend says, reading from a newspaper article. "Scientists believe that most genetic mutations have a neutral effect on organisms, a small number have a disadvantageous effect, and an even smaller number have an advantageous effect." She looks at you. "Do you agree, and if so, why?"
101. Does the process of meiosis explain Mendel's first law (principle of segregation) and the principle of independent assortment?
102. In the case of linked genes, explain why two genes are more likely to be inherited together the closer together they are on the same chromosome.

- 103.** You learned that when red snapdragons are bred with white snapdragons, the offspring are pink snapdragons, illustrating incomplete dominance. What happens when you cross a red snapdragon with another pink snapdragon?
- 104.** Artemisinin is a powerful antimalaria drug. Unfortunately, it is expensive and in short supply because it must be extracted from the leaves of the sweet wormwood tree, a rare plant with a limited distribution. As a result, many of the people who suffer most from malaria cannot afford artemisinin. How can genetic technology be used to address this problem?
- 105.** If you were a lawmaker, what constraints would you place on DNA technology? Should there be different rules for applying DNA technology to humans and other animal species?

Readiness Assurance Test (1)

Readiness Assurance Test

Interactive

If you have a good handle on this chapter, if you really do, then to score 7 out of 10 on this RAT. If you score less than 7, you need to review before moving on.

Choose the BEST answer to each of the following:
10 questions

1. 1.

If an organism's haploid cells have 10 chromosomes, then have

5 chromosomes.

Incorrect.

Press enter after select an option to check the answer

10 chromosomes.

Incorrect.

Press enter after select an option to check the answer

20 chromosomes.

Correct.

Press enter after select an option to check the answer

none of these

Incorrect.

Press enter after select an option to check the answer

Chapter 17

The Evolution of Life



INTEGRATED SCIENCE 17A: CHEMISTRY, EARTH AND ASTRONOMY: *The Origin of Life* □

INTEGRATED SCIENCE 17B: ASTRONOMY AND
SCIENCE: *Is There Life on Mars?* □

17.1 Charles Darwin and *The Origin of Species* □

17.2 How Natural Selection Works □

HISTORY OF SCIENCE: *The Peppered Moth* □

17.3 Adaptation □

SCIENCE AND SOCIETY: *Antibiotic-Resistant Bacteria* □

INTEGRATED SCIENCE 17C: PHYSICS: *Staying
Keeping Cool* □

17.4 Evolution and Genetics □

TECHNOLOGY: *Evolutionary Algorithms* □

17.5 How Species Form □

17.6 Evidence Of Evolution □

TECHNOLOGY: *More Mutants, Please!* □

INTEGRATED SCIENCE 17D: EARTH SCIENCE
Tangible Evidence of Evolution □

17.7 The Evolution of Humans □

BASILISKS RUN on top of water to catch prey and escape predators. Komodo dragons taste food with the hairs on their feet. Bats catch insects with their wings. Cactuses grow sharp spines that protect them from animals. These are all adaptations, and the countless other ways in which organisms are structured to survive and reproduce, make up the incredible diversity of life on Earth. How do living things change over time in response to their environments? After all, a giraffe can't grow a long neck because it *wants* to. So, how do traits that make living things well suited to surviving and reproducing in their environments actually come about? The same process explains how new types of living things—organisms—originate? Also, if all organisms today evolved from early life forms, then how did life get started in the first place? Read on to discover the secrets of life.

Integrated Science 17A: Chemistry, Earth Science, and Space Science Astronomy

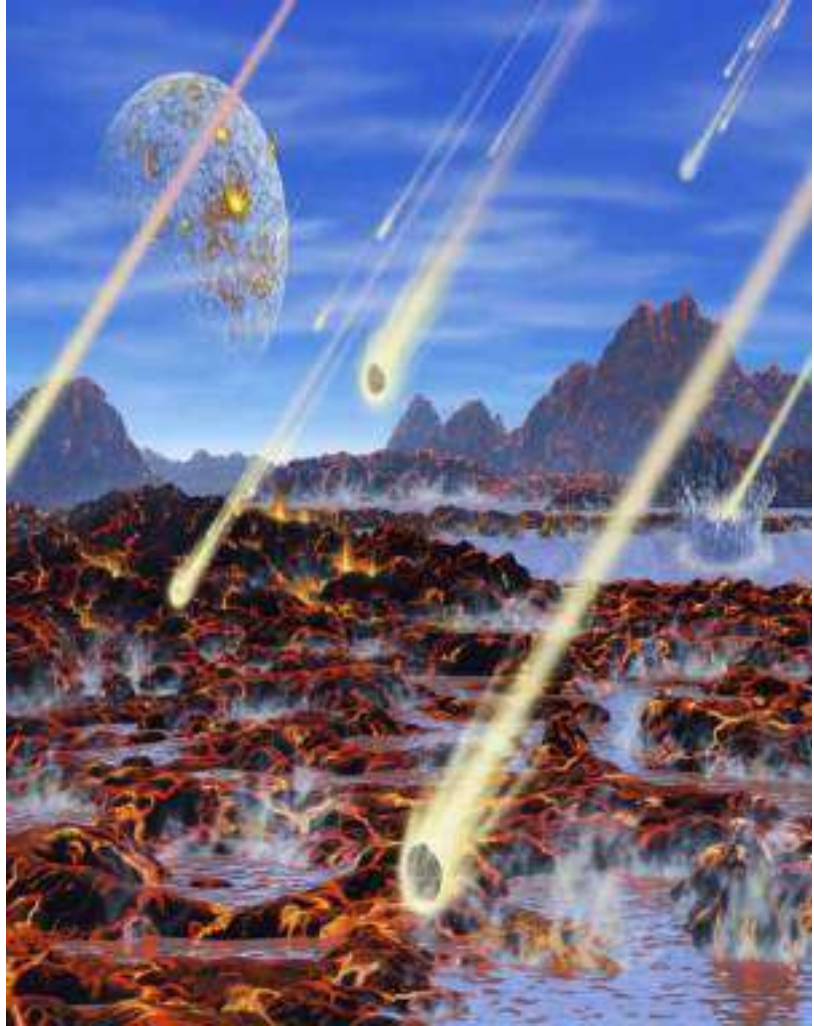
The Origin of Life

Learning Objective

Explain what scientists know about the origin of life and describe the evidence that supports their ideas.

How did life originate? We know from fossils that life existed on Earth for at least 3.5 billion years. This is the Earth on which life evolved was very different from the Earth of today. It contained vast, lifeless oceans, volcanoes, and a turbulent atmosphere filled with storms and incoming meteors (Figure 17.1). The environment of the early Earth included no oxygen, which was produced by the activity of living things. Although this environment seems a hostile place for life today, it has been appropriate for producing the first life. Why was that the early Earth environment could produce life from nonliving materials? A famous experiment suggests the answer to this.

Figure 17.1




Early Earth was very different from the Earth of today. Volcanoes spewed hot fumes into the atmosphere, and the surface was bombarded by Earth's surface.

Unifying Concept

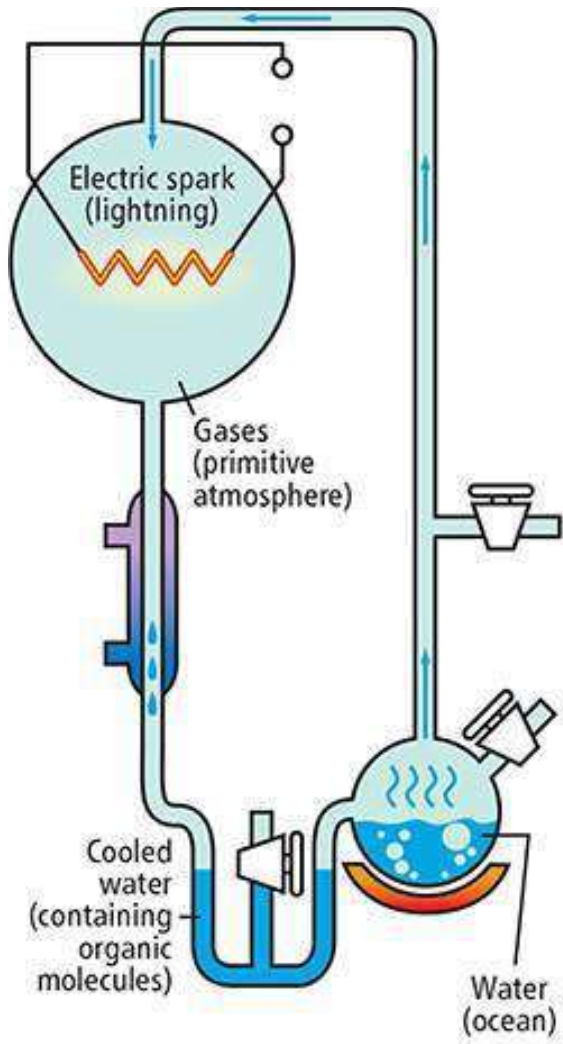
The Scientific Method [Section 1.3](#)

In 1953, Stanley Miller and Harold Urey built a model of early Earth in a chemistry lab ([Figure 17.2](#)). A flask containing



mixture of simple compounds—including water v ammonia, methane, and hydrogen gas—simulate atmosphere. Liquid water was added to represen oceans. Electric sparks sent through the gases s lightning. When this model of early Earth was ass amazing thing happened. Many complex organic were formed, including amino acids, the building proteins. Not only had these molecules formed q they also formed in huge numbers. Further exper showed that all the important organic molecules life—not just amino acids but also sugars, lipids, nitrogenous bases found in RNA and DNA—can b a similar way.

Figure 17.2



(a)



(b)

Stanley Miller and Harold Urey built a model of the early Earth and showed that complex organic molecules could be synthesized during lightning storms. (a) Miller and Urey built a model of Earth's early atmosphere and oceans. (b) A diagram of Miller and Urey's experiment.

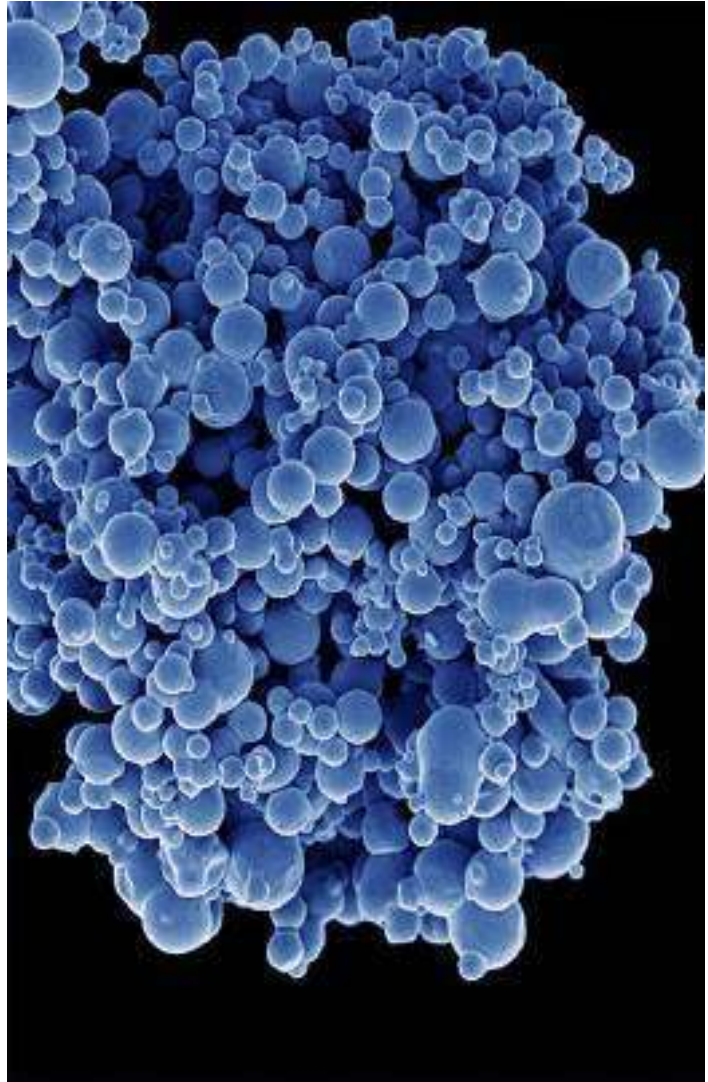
However, some scientists today question the importance of the Miller–Urey experiment. They think that Earth's early atmosphere was actually quite different from the atmosphere Miller and Urey used and that organic molecules may not have been so easy to generate. They have two other hypotheses for how Earth got its first organic building blocks. One hypothesis is that organic molecules were brought to Earth by meteorites. Earth was steadily bombarded by meteorites during its early history, and some of the meteorites recovered here do in fact contain a wide variety of complex organic molecules, presumably formed on the meteorite. For example, a meteorite found in Australia in 1969 contained nearly one hundred different amino acids. A second hypothesis is that large numbers of organic molecules were synthesized in deep-sea environments on Earth, similar to the hydrothermal vent habitats of today.

Unifying Concept

The Scientific Method [Section 1.3](#) 

The next question is how these many separate or molecules advance to become living cells. Scientists know the entire story, but they have discovered some. For example, when certain lipids are added to water, they spontaneously form tiny hollow spheres called liposomes. Liposomes have double membranes similar to cell membranes. Although they are not alive, liposomes sometimes behave like living cells—they grow, shrink, and divide ([Figure 17.3](#)). Liposomes also run chemical reactions inside the vesicle and control what molecules move into and out of the vesicle, some of the features of living cells.

Figure 17.3



Liposomes show some cell-like behaviors. Some liposomes are growing and dividing.

Some liposomes may have eventually captured nucleic acids, that is, primitive genes. These early genes were probably composed of RNA, not DNA. This is because, even in the absence of ribosomes and enzymes, short strands of RNA can spontaneously

assemble from individual nucleotides and even re themselves. With a few more changes, RNA-cont liposomes may have become the very first cells— organisms on Earth. However it occurred, the tra living cells was complete by 3.5 billion years ago, the earliest known fossil organisms. **Figure 17.4** bacteria fossils from early in the history of life.

Figure 17.4



Ancient fossils of bacteria show that life has existed for a long time. This fossil stromatolite, left by mats of photosynthetic bacteria, is 2.72 billion years old.

A lipid sphere with captured nucleic acids—ultimate ancestor of all life today?

Check Yourself

Interactive

Question

Check Answer

Question

Miller and Urey found that organic molecules are easily formed from nonorganic materials. But why do some scientists question their experiment?

Check Answer

Miller and Urey found that organic molecules are easily formed from nonorganic materials. But why do some scientists question their experiment?

Integrated Science 17B:
Astronomy and Earth Science

Is There Life on Mars?

Learning Objective

Explain why scientists consider Mars a good place to look for evidence of life.

People have wondered for a very long time whether there is life elsewhere in the Universe. One obvious place to look is in our own Solar System. Scientists quickly gravitated toward Mars. Being closest to Earth, they seemed like the most Earthlike conditions. But early exploration revealed that Venus would be hostile to life as we know it. Venus has almost no water, a crushingly dense carbon dioxide atmosphere, clouds of sulfuric acid, and a surface temperature of 462°C (864°F)! As a result, attention focused on Mars. Mars is not obviously hospitable to life either. The planet is dry, and its average temperature is only about -6°C, though some parts can warm to a comfortable 20°C. Mars's thin atmosphere also lets through ultraviolet radiation from the Sun that would kill most living things on Earth. However, many of Mars's geological features were clearly carved by water, and the evidence suggests that Mars once had liquid water as well as warmer temperatures and a thicker atmosphere.

this was millions or billions of years ago. Could there be life on Mars today?

Searching for life on Mars has meant searching for water since life as we know it cannot exist without water. NASA orbiters around Mars and rovers on the Martian surface have looked for places on the planet where pockets of liquid water might still exist (Figure 17.5). And they have found evidence of water. Specifically, they have seen seasonal streaks of water ice in certain craters. This has encouraged scientists to look for larger water reservoirs that might still exist under the surface. In 2020, NASA plans to send new rovers to Mars that not only will look for water but also will use ultraviolet light and X-rays to search for carbon molecules and other organic compounds.

Figure 17.5

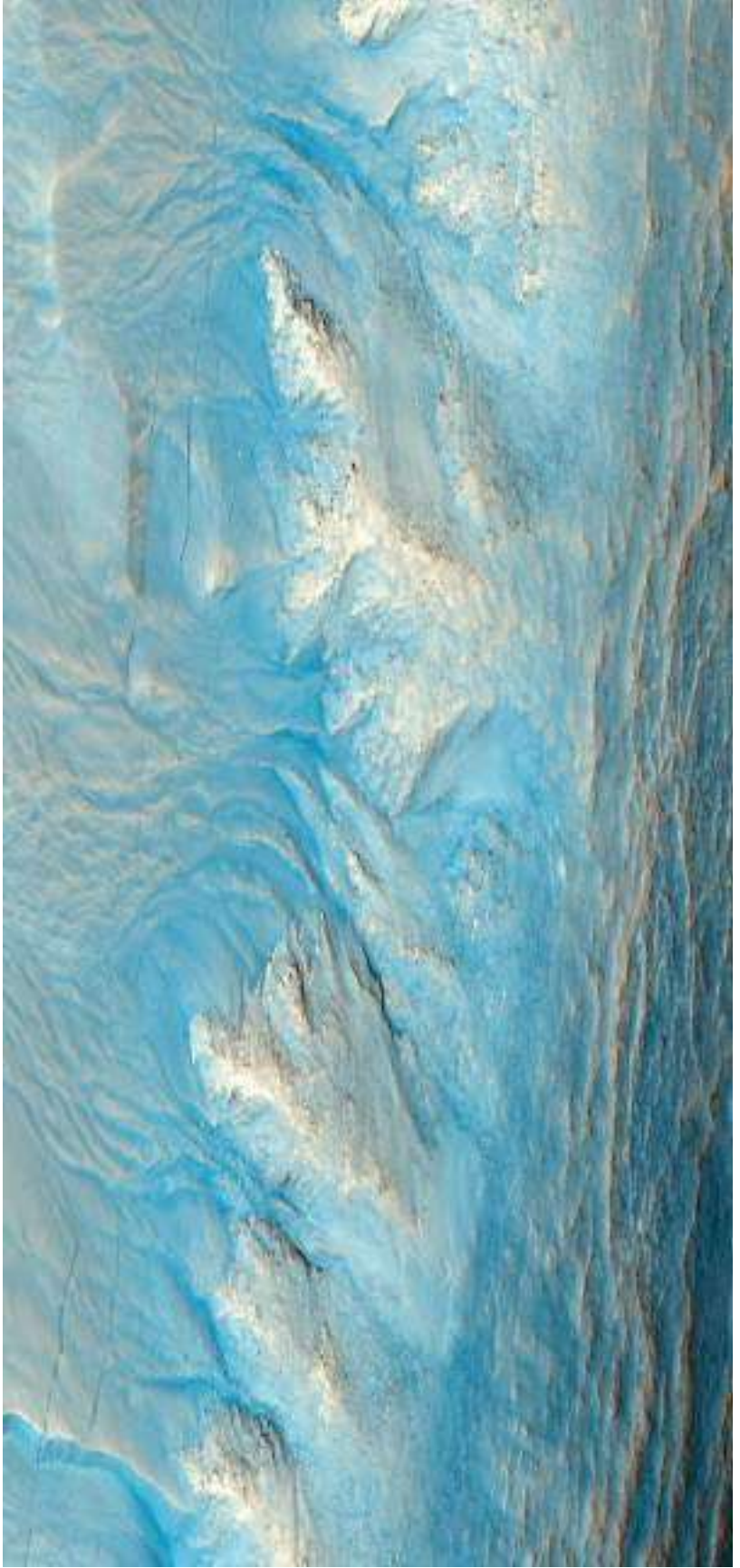


Since it landed in 2012, the Mars rover *Curiosity*, the size of a small car, has been exploring the Mars. Its mission is to search for evidence of current or past life.

Even if there is no Martian life today, there could have been life on Mars. This life may have thrived in the oceans and then gone extinct as the planet dried and its atmosphere thinned (Figure 17.6). If so, the living

have left fossils behind. Scientists plan to search Mars's sedimentary rocks, the same types of rock often rich in fossils on Earth.

Figure 17.6



Many features of Mars's surface provide evidence once was a large amount of water on the planet. The image of a crater shows that it once held a large lake. The sediments that remain could be a good place to search for Martian fossils.

Of course, Martian life could be very different from life on Earth, in which case scientists will have to completely re-evaluate what to look for. Interestingly, according to NASA scientists, there is one way in which we do know whether there is life on Mars, and we know that because we have found it there. A small number of microbes from Earth have hitchhiked to Mars along with NASA's Martian rovers. These microbes have survived NASA's best efforts to decontaminate spacecraft before they took off, as well as the harsh conditions of the journey itself. What this means is that the microbes have already survived high temperatures, radiation, and harsh environments with little or no food. They also have the ability to hibernate for long periods until conditions are favorable. Having hitched a ride to Mars, the microbes are now on the Red Planet and could well survive there for many years.

Check Yourself

Interactive

Question

Check Answer

Question

Why is Mars currently considered a more likely place to find li

Check Answer

Why is Mars currently considered a more likely place to find li

Answer: Venus has almost no water and is extremely hot. Mars once had plenty of liquid water. Although Mars is now much drier, there is evidence that some amount of water still exists on the planet.

The Content

17.1 Charles Darwin and *The Origin of Species*

Learning Objective

Describe some of the experiences and influences that brought Darwin to his theory of evolution through natural selection.

How has life on Earth changed over time? For example, from tiny, primitive cells to humans, hippos, redwoods, and the amazing diversity of life on Earth today?

For thousands of years, people believed that life on Earth had always been the same. They believed that Earth had always had the same species. They thought that the world would be the same forever. Then fossils were discovered in Earth's rocks, and people began to wonder. Fossils suggested that the kinds of species living on Earth had changed over time—old species disappeared, and new species appeared. Also interesting was that fossil organisms sometimes showed a close resemblance to modern species, as you can see in the fossils of horses.

Figure 17.7 □. Could some fossils actually be the ancestor species?

Figure 17.7



Could fossils be the ancestors of modern species? This fossil, found in Germany, is about 50 million years old. It has a clear resemblance to a horse, yet is only the size of a fox.

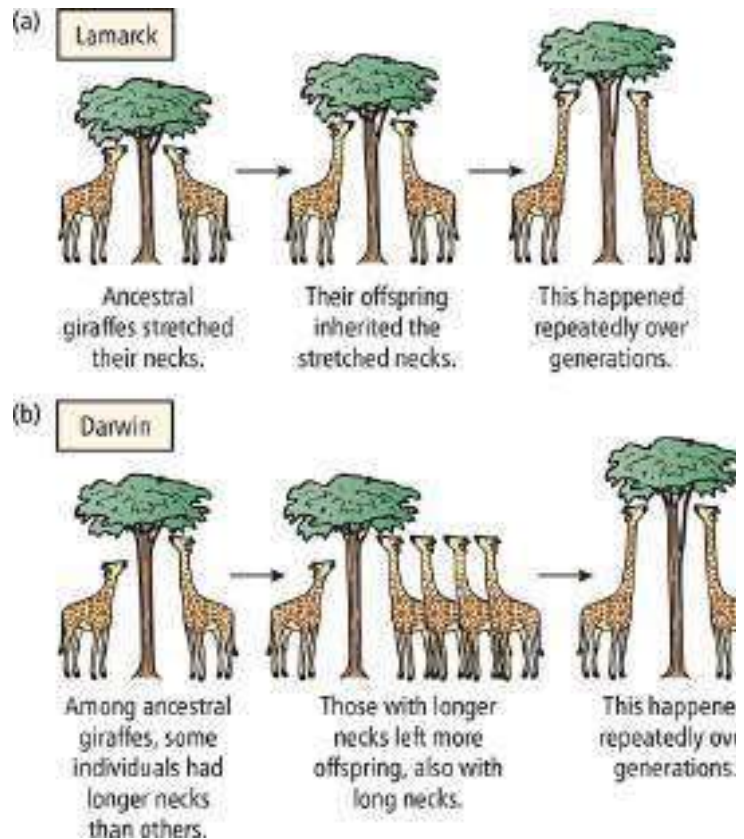
French naturalist Jean-Baptiste Lamarck (1744–1829) was the first to argue that this was the case. Lamarck believed that new species were descended from ancestors that had evolved—characteristics that became better adapted to the environments they lived in. According to Lamarck, organisms acquired new characteristics during their lifetime and then passed these characteristics to their offspring.

ancestral giraffes stretched their necks to grab the high and their necks became longer. These giraffes then passed their necks to their offspring. The offspring reached for even higher leaves, stretching their necks even further, and so on (Figure 17.8). The theory for how change occurs, called the *inheritance of acquired characteristics*, proved to be incorrect: Organisms cannot pass on characteristics acquired during their lifetimes to their offspring. These acquired characteristics are not genetic. However, the evidence in support of Darwin's theory set the stage for the modern synthesis.

Unifying Concept

The Scientific Method [Section 1.3](#) 

Figure 17.8



(a) Lamarck believed that organisms acquired new characteristics during their lifetimes and passed these characteristics to their offspring. In his theory of evolution by natural selection, Darwin argued that organisms with advantageous traits left more offspring than organisms without those traits. As a result, advantageous traits became more common in the population.

English naturalist Charles Darwin (1809–1882), shown here, set forth the theory of evolution in his book *The Origin of Species by Means of Natural Selection*, published in 1859. Darwin proposed that evolution is the result of inherited changes in populations of organisms over time. This theory applies to all the living forms on Earth.

Figure 17.9



Charles Darwin developed the theory of evolution by n

Darwin's theory of evolution grew out of the observatic
aboard the H.M.S. *Beagle*, which sailed around South A
to 1836. As the ship's official naturalist, Darwin studied
species, collecting large numbers of plants, animals, and
became increasingly intrigued by the question of how s
the way they were. He was particularly struck by the liv
encountered on the Galápagos Islands, 950 kilometers 1

American continent. Darwin took particular note of the species of Galápagos finches—now known as Darwin’s finches showed remarkable variation in the size and shape with each beak being suited to, and used for, a different (17.10). How had the beaks of these finches come to Darwin wrote, “Seeing this gradation and diversity of small, intimately related group of birds, one might really an original paucity of birds in this archipelago, one species taken and modified for different ends.”*

Figure 17.10



The finches Darwin saw on the Galápagos Islands—now finches—show remarkable variation in the size and shape. Each is suited to a different diet. (a) The cactus finch has that it uses to eat cactus pulp and flowers. (b) The large a blunt, powerful beak that it uses to crack seeds. (c) Th

finch has a woodpecker-like beak that it uses to drill holes, and then uses a cactus spine to pry out insects.

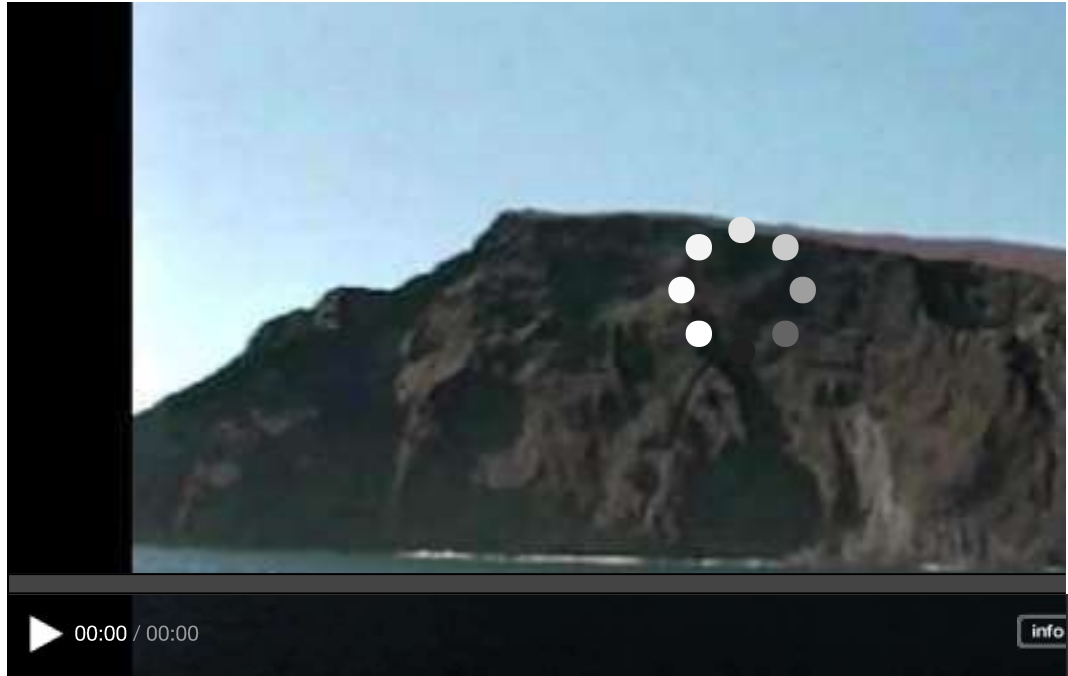
There's an expression: Genius is 1% inspiration and 99% perspiration. Darwin's genius reflects a lot of perspiration. While on the *Beagle*, Darwin collected 1529 alcohol-preserved specimens and 3907 skins, bones, and other specimens. He also recorded 2000 pages of notes on animals, and geology. It's no wonder that when he put down his theory, he was able to support it with a wealth of well-considered examples.

Darwin was also inspired by the work of two of his contemporaries: Charles Lyell and Thomas Malthus. Lyell, a geologist, argued that geological features were created not by major catastrophes, as the favored theory of the time—but by gradual processes that had their effects over long time periods. For example, the formation of a canyon did not require a cataclysmic flood but could result from the slow erosion of rock over millennia. Darwin realized that the same gradual change over long periods could produce all the diversity of living organisms as well as all their remarkable features.

The economist Thomas Malthus was a second important influence on Darwin, and the one who led Darwin to his great idea of natural selection. Malthus observed that human populations grow much faster than available food supply could support. He concluded, with despair, that famine was an inevitable part of human existence. Darwin applied Malthus's idea to the natural world, arguing that, because there are not enough resources for all organisms to survive and to reproduce as much as they can, living organisms must undergo an intense "struggle for existence." As a result, organisms with traits that leave more offspring than organisms with other traits will pass those traits on to the next generation, causing the population to change over time. To go back to the giraffe example, Darwin argued that ancestral giraffes with longer necks were able to reach the high leaves on trees, getting more food, and therefore surviving and leaving more offspring than ancestral giraffes with shorter necks. This happened repeatedly over many generations. Over time, there were more longer-necked giraffes in the giraffe population (Figure 17.8b). This process, which is called natural selection, is the major driving force behind evolution.

Watch [Galápagos Islands Overview](#)





Watch Galápagos Marine Iguana



Check Yourself

Interactive

Question 1

Check Answer

Question 2

Check Answer

Question 1

If Lamarck had been correct and evolutionary change occurred inheritance of acquired characteristics, what trait might a bodybuilder's offspring have?

Check Answer

If Lamarck had been correct and evolutionary change occurred inheritance of acquired characteristics, what trait might a bodybuilder's offspring have?

Answer: If Lamarck were correct, the bodybuilder's children would have increased muscle mass that the bodybuilder had acquired over a lifetime of weightlifting. Because Lamarck's theory turned out to be incorrect, children will have to do their own bodybuilding.

* Charles Darwin, *The Voyage of the Beagle*, 1909.

17.2 How Natural Selection

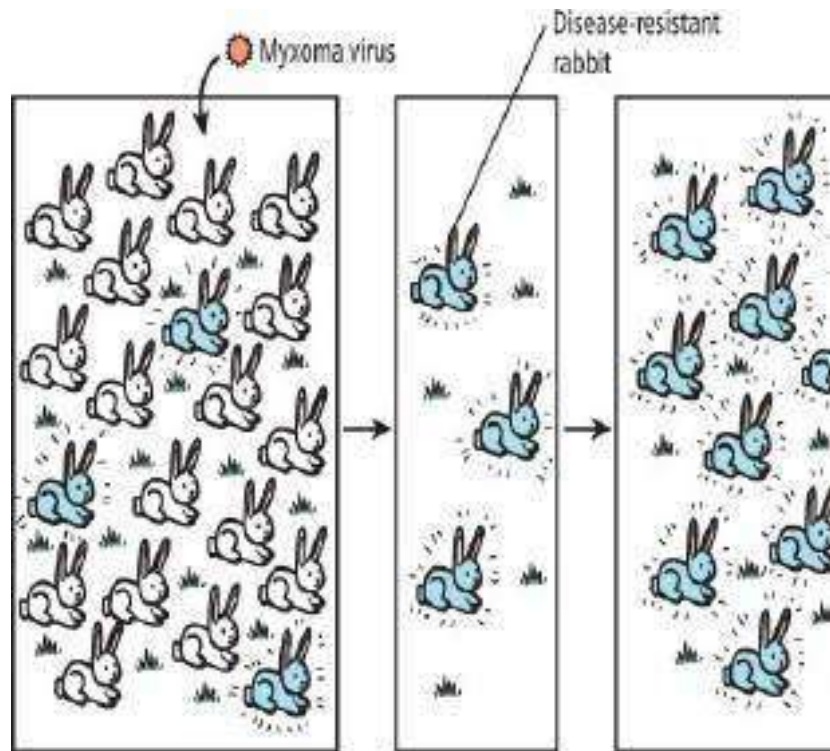
Learning Objective

Explain how natural selection results in populations becoming adapted to their environments.

Rabbits were introduced into Australia in 1859, when Thomas Austin released 24 individuals onto his property in the southeast of the continent. The rabbits quickly became pests, devastating natural habitats. Breeding “like rabbits,” they spread across the continent in such large numbers that they were described as a “grasshopper” that covered the land. Many attempts were made to control the rabbit population, including the construction of an 1822-kilometer-long “rabbit-proof” fence—still the longest fence in the world. Unfortunately, by the time the fence was completed in 1907, the rabbits had already gotten through. (The fence wouldn’t have worked anyway—even if it were completed, rabbits would pile up so thickly behind it that they would eventually be able to hop right over their companions’ backs.)

In the early 1950s, the government decided to try to control the rabbit population by releasing myxoma virus, a virus deadly to rabbits. The virus was a wonder, killing more than 99.9% of infected rabbits. Within a few years, however, fewer rabbits were dying. What happened? Within the original rabbit population, a small number of individuals happened to be resistant to the myxoma virus. These individuals survived the disease and reproduced, producing disease-resistant offspring (Figure 17.11). Over time, the number of disease-resistant rabbits increased, and the virus became less effective. The rabbit population had evolved resistance to the virus through natural selection.

Figure 17.11



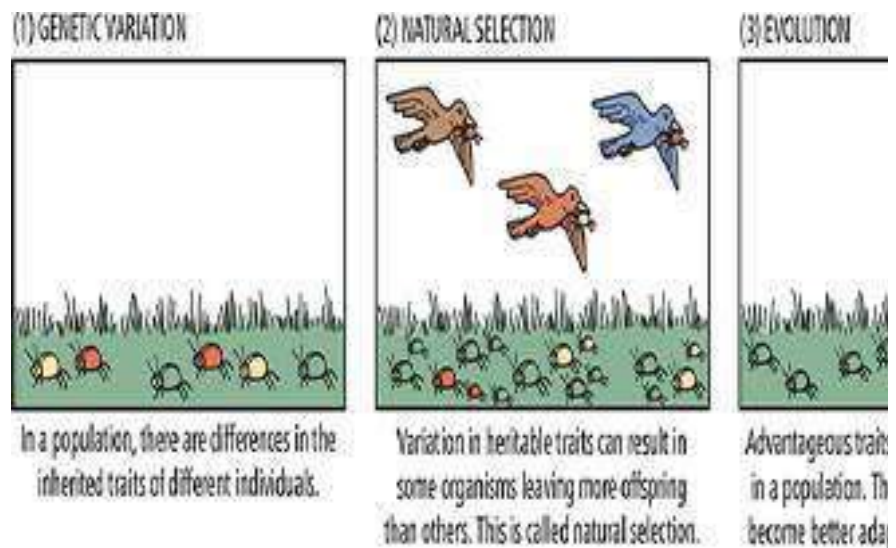
Deadly myxoma virus initially killed 99.9% of infected rabbits, leaving only a small number of naturally disease-resistant rabbits (blue). These rabbits reproduced, passing their trait of myxoma resistance to their offspring. The population became more resistant, and the virus became less effective.

Natural selection occurs when organisms with advantageous traits produce more offspring than organisms with other traits, causing the population to change over time. Let's look more carefully at the process of natural selection.

1. *Genetic variation.* In any population of organisms, individuals have many traits that show variation—that is, they differ from individual to individual. Some of these traits are determined at least partly by genes and so are inherited traits—traits passed from parents to offspring. Differences in the traits of different individuals is known as genetic variation. In humans, for example, there is genetic variation in hair color, eye color, foot size, blood type, and many other traits.
2. *Natural selection.* Some inherited traits are advantageous. Organisms with inherited, advantageous traits tend to produce more offspring than organisms with other traits. This process is called natural selection. The fitness of an organism is the number of offspring it leaves over its lifetime compared to other individuals in the population. An organism that produces more offspring than other individuals in the population has a greater fitness.
3. *Evolution.* Because organisms with advantageous traits produce more offspring, advantageous traits are “selected” and become more common in a population. Over time, the population changes—evolves—to become better suited to its environment.

Figure 17.12 summarizes the process of natural selection although natural selection acts on individuals within a population, allowing some individuals to leave more offspring than others, the population as a whole that evolves and becomes adapted to its environment.

Figure 17.12



How natural selection works.

Check Yourself

Question 1

Check Answer

Question 2

Check Answer

Question 1

Which of these traits show genetic variation in cats: fur color, tail length, and number of eyes?

Check Answer

Which of these traits show genetic variation in cats: fur color, tail length, and number of eyes?

Answer: Fur color and tail length show genetic variation in cats. Tail length and fur color are traits that differ among cats. The number of eyes does not show genetic variation in cats—all cats have two eyes.

Question 2

The cheetah is the fastest land animal on Earth. It can run 112 kilometers/hour (70 miles/hour)! Cheetahs prey on Thomson's gazelles that can run 50 kilometers/hour (31 miles/hour). How might natural selection have shaped the cheetah's fast running speed?



History of Science

The Peppered Moth


During the Industrial Revolution, coal was the primary energy source in England. Burning coal slathered dark soot on trees and the ground. And then a startling thing happened to the peppered moths in England. They had always been light-colored, but the scattering of dark peppery flecks that gave them their name. Their coloration made them hard to see in lichen-covered trees and rocks. (Lichens are a combination of fungi and photosynthetic algae or bacteria growing together; they form crustlike growths on rocks, trees, and other surfaces.) It was believed that this camouflage protected the moths from birds, their main predators.

As the Industrial Revolution progressed, pollution killed the lichens, leaving the trees first bare and then dark with soot. In 1848, the first dark peppered moth was found in the industrial center of Manchester, England. Dark moths probably always existed in the population, but they were extremely rare. Over the next decades, as more coal was burned and the environment became increasingly sooty, more dark moths were seen. By 1895, 98% of peppered moths in industrialized areas were dark. Then, in the second half of the 20th century, antipollution laws were passed

disappeared. Light moths increased in number, and dark moths have all but disappeared.

Did natural selection cause the coloration shifts in the peppered moth? Biologists hypothesized that in light habitats, natural selection favored light moths because they were better camouflaged. In sooty habitats, natural selection favored dark moths. A series of experiments by Bernard Kettlewell tested this hypothesis. Kettlewell released equal numbers of marked dark and light moths in both polluted and unpolluted areas. After a while, he tried to recapture them. In polluted areas, Kettlewell recaptured more dark moths than light moths, which suggested that dark moths had a survival advantage. The opposite was true in unpolluted habitats: Kettlewell recaptured more light moths. Kettlewell also placed tree trunks and filmed birds eating the moths. He discovered that birds ate what they could see: Birds ate more light moths in unpolluted habitats and more dark moths in polluted habitats.

Kettlewell's work became a classic example of natural selection. Eventually, however, certain aspects of his experiments were challenged. For example, moth biologists pointed out that peppered moths don't usually sit on tree trunks.



trunks, where Kettlewell had placed them. Instead, they rest on the undersides of branches. In addition, Kettlewell released the normally nocturnal moths during the day, which may have affected the moths' ability to find resting places. Finally, Kettlewell used a mix of lab-raised and wild moths, which could differ in their behavior. These findings were confirmed by Michael Majerus of Cambridge University to conduct a series of experiments between 2001 and 2007. Majerus' work confirmed that bird predation was the key factor in the change in relative numbers of light and dark peppered moths. It is interesting that a shift from light to dark forms in peppered moths (and back again, as pollution is cleaned up) has been observed in more than 70 other moth species in England and the United States alone.



Can you find the moths? Light peppered moths are camouflaged on lichen-covered trees.

17.3 Adaptation

Learning Objective

Use examples to describe different kinds of adaptations found in living organisms.

Natural selection leads to the evolution of adaptations—organisms well suited to living and reproducing in their environment. The Check Yourself question in the preceding section gave an example of an adaptation—the cheetah's speed. The cheetah's speed is an adaptation that helps it acquire the food it needs to survive and reproduce.

Adaptations can relate to various aspects of an organism's life. Some adaptations help organisms survive. Survival is important because it is usually an important first step toward successful reproduction. Survival requires that organisms be able to acquire food and other resources. It also requires that organisms avoid becoming prey for someone else (Figure 17.13). Anti-predator adaptations include camouflage, toxicity, or just the ability to hide or run away.

Figure 17.13



(a)



(b)

Almost every organism has adaptations that help prevent becoming food for someone else. (a) The spines of this cactus prevent most animals from eating it. (b) When threatened, this squid releases a cloud of dark ink that may confuse a predator long enough for the squid to escape.

Other adaptations have evolved to help organisms acquire mates. These include the beautiful feathers of male peacocks and birds (Figure 17.14a), the sexy “rib-bits” of male frogs, and the songs of many male birds. Males have evolved these “sexual

females of the species find them attractive. In other species, females choose their mates based on attractive traits. Instead, many other males to obtain mates. The adaptations of these males include large size, great strength, or fighting structures such as antlers (Figure 17.14b). Natural selection that favors individuals best able to acquire mates is also called *sexual selection*.

Figure 17.14



(a)



(b)

Some adaptations for acquiring mates. (a) The beautiful male bird of paradise help attract female mates. (b) The fighting for control of territory as well as mates.

The peacock may be the organism with the most adaptation for attracting mates. The male peacock fan of colorful tail feathers not only is admired by more important, impresses peahens.

Finally, some adaptations relate to bearing and raising young. Figure 17.15 shows one such adaptation—parental care. Parental care occurs because natural selection favored organisms that were able to ensure that their offspring survive and thrive. Parental care is found in many species, including humans.

Figure 17.15



Parental care occurs in many species. This male poison frog is carrying his tadpoles on his back.


Natural selection has produced remarkable adaptations does not plan ahead—it does not plan to make a falcon. Instead, adaptations are built step by step, through the selection of the most successful forms.

Science and Society

Antibiotic-Resistant Bacteria

A patient is ill with pneumonia and gets a prescription for penicillin. After three days, he feels better and stops taking the pills. A few days later, his symptoms return. He gets another prescription for penicillin and starts taking them again, but this time they have no effect. What happened? This frightening phenomenon is called *antibiotic resistance*. Antibiotic resistance is caused by natural selection: Penicillin killed most of the pneumonia-causing bacteria, but a few penicillin-resistant bacteria survived. These bacteria multiplied, and the patient's infection came back. Over time, the bacteria are resistant to penicillin.

Antibiotics are wonder drugs. When penicillin, the first antibiotic, appeared, it dramatically cut the number of deaths from pneumonia.




and deaths resulting from bacterial infections. After a decade of use, however, the first penicillin-resistant strains appeared. Since then, antibiotic resistance has spread to more and more bacterial populations, leading to the need for more and more different antibiotics. Diseases that were once easily treated—tuberculosis, pneumonia, even common childhood ailments such as ear infections—are now often resistant to multiple antibiotics. In 2016, the World Health Organization reported that about 600,000 new cases of multi-drug resistant tuberculosis appear each year, resulting in about 200,000 deaths.

Some of the most dangerous antibiotic-resistant bacteria are found in hospitals, where the use of many different antibiotics allows widely resistant strains to evolve. One such strain is methicillin-resistant *Staphylococcus aureus* (MRSA), a bacterium that is resistant to most of the antibiotics currently available. MRSA is responsible for more than 90,000 life-threatening infections and 20,000 deaths in the United States each year. Another concerning strain is vancomycin-resistant enterococci (VRE), which are beginning to show resistance to the antibiotic vancomycin, often considered “the drug of last resort.” A particularly worrisome development is the emergence of MRSA in the community. The Centers for Disease Control (CDC)

that 1 in 3 people carry *S. aureus* in their nose, and some people carry MRSA. Sometimes, these can turn into serious infections. Community-based MRSA infections usually start as skin infections and spread through skin-to-skin contact. In severe cases, these can turn into “flesh-eating” disease, and are often halted only by drastic measures such as amputation. Environments with a higher risk for community-based MRSA infections include athletic facilities, dorms, prisons, and long-term care centers. Compared to people whose infections are treated with antibiotics, people who have antibiotic-resistant MRSA require longer hospital stays and are more likely to die from their infections.

All antibiotic use has the potential of contributing to antibiotic resistance. However, resistance has been greatly accelerated by the overuse of antibiotics. Under pressure from patients and other factors, physicians may prescribe antibiotics for illnesses caused by bacteria. (Many common illnesses, such as the common cold, flu, and most sore throats, are caused by viruses.) The overuse of antibiotics selects for resistance in the normal (non-disease-causing) bacterial populations in our bodies, making it easier for resistance genes to be transferred to disease-causing bacteria that later invade the body. The fact that



sometimes stop taking their medications too soon to the problem; this selects for antibiotic-resistant bacteria without providing the sustained dose that would kill the bacteria. Antibiotics have also been seen in heavy use in the livestock industry, where animals have long been treated with antibiotics regularly—even when they are healthy to promote growth. Unfortunately, this practice greatly promotes the evolution of antibiotic resistance. The Centers for Disease Control report that, each year in the U.S., about 6 million antibiotic-resistant salmonella infections are reported. For example, in August 2011, an outbreak of antibiotic-resistant salmonella in ground turkey caused at least 79 illnesses and one death. In 2017, an antibiotic-resistant salmonella outbreak was linked to contact with infected dairy calves, which were used in 4-H youth agricultural programs across the country. This outbreak resulted in 56 illnesses and 10 hospitalizations.

What can be done about antibiotic resistance? First, we must learn to use antibiotics wisely, taking them only when they are needed—that is, for bacterial infections—and taking the entire course of treatment. Second, public health and veterinarians can promote a socially responsible

antibiotics by educating patients and agricultural proper use of these drugs. Third, the use of antibiotics in livestock should be controlled. In early 2017, the Drug Administration finally banned the use of antibiotics in livestock gain weight. Farmers now have to obtain prescriptions for antibiotics from veterinarians, rather than being able to buy it at feed stores or online. However, scientists are concerned that loopholes in the law that heavy use of antibiotics in livestock could occur since many antibiotics are less effective now because of resistance, scientists must search for new antibiotics to take the place of those that no longer do the job.

Check Yourself

Interactive

Mating is very dangerous for a male praying mantis. Quite often she will eat him as he mates with her.

Question 1

Check Answer

Question 2

Check Answer

Question 1

What advantage does the female gain from eating the male?

Check Answer

What advantage does the female gain from eating the male?

Answer: The female gets nutrients when she eats the male.

Question 2

Would it be more advantageous (“adaptive”) for the male not to



When a male praying mantis (the smaller insect on top) mates with a female, he is in danger of having his head bitten off.

Integrated Science 17C: Physics and Chemistry Staying Warm and Keeping Cool

Learning Objective

Explain how the need to thermoregulate affects the size and shape of animals that live in very cold or very hot habitats.

In this section, we will see how being the right size and shape can be an adaptation. Most mammals maintain a constant body temperature. We humans, for example, have a body temperature that always stays around 37°C (98.6°F). Animals that live in extremely hot or extremely cold habitats have adaptations to be able to maintain appropriate body temperatures in those environments—to *thermoregulate*. In deserts, animals are able to lose heat to avoid overheating. In cold environments, animals have to be able to retain heat.

A key factor in thermoregulation is an animal's surface area to volume ratio. The heat an animal produces depends on its volume. The heat it loses to its environment depends on its surface area because heat is lost through the body surface. As a result, animals are better able to *lose* heat if they have a high surface-area-to-volume ratio, and they are better able to *retain* heat if they have a low surface-area-to-volume ratio. This has consequences for both the size and shape of animals that live in extreme habitats.

A large animal tends to have a *lower* surface-area-to-volume ratio because volume increases more quickly than surface area as organisms get bigger (see [Figure 17.16](#) for an example with apples). For this reason, animals that live in cold climates are often larger than related species that live in warm climates. For example, the smallest bear in the world is the sun bear, which lives in the tropical forests of Southeast Asia ([Figure 17.17a](#)). Sun bears weigh between 27 and 65 kilograms (60 and 143 pounds). The largest bear in the world is the polar bear, which ranges throughout the Arctic ([Figure 17.17b](#)). Polar bears weigh between 200 and 800 kilograms (440 and 1764 pounds).

Figure 17.16



The amount of *caramel* on this caramel-covered apple is determined by its surface area. The amount of *apple* in this caramel-covered apple is determined by its volume. The surface-area-to-volume ratio is the amount of caramel per unit volume of apple. A small caramel-covered apple has a high surface-area-to-volume ratio. A big caramel-covered apple has a low surface-area-to-volume ratio.

Figure 17.17



(a)



(b)

(a) The small sun bear is found in tropical forests Asia. A small animal is better able to lose heat because of its high surface-area-to-volume ratio. (b) The polar bear, the largest terrestrial carnivore in the world, is found in the Arctic. A large animal is better able to retain heat because of its low surface-area-to-volume ratio.

Good cooks know that there are a lot more peelings from several small potatoes than from one large potato of the same volume. This is because little things have more skin per volume than big things!

Animals adapted to hot versus cold climates also have different body shapes. Desert species often have long legs and large ears.

increase the surface area available for heat dissipation. In warm climates, long ears and legs are also covered with extensive blood vessels that carry heat from the core of the body to the surface. In cold climates, convection, the transfer of heat by moving air, is a major mode of heat loss. Arctic species often have short appendages and thick fur that help conserve heat. An example is the rabbit shown in Figure 17.18.

Unifying Concept

Convection Section 6.9

Figure 17.18



(a)



(b)

(a) This black-tailed jackrabbit lives in a California desert. Extensive blood vessels in its ears help it dissipate heat. It has long legs. (b) This arctic hare is a relative of the black-tailed jackrabbit. Its ears are much smaller.

Unifying Concept

Convection [Section 6.9](#) 

Check Yourself

Interactive

Question

Check Answer

Question

On cold days, people often bundle up babies and small children. Are babies more likely to need the extra bundling than adults? Why?

Check Answer

On cold days, people often bundle up babies and small children. Are babies more likely to need the extra bundling than adults? Why?

Answer: Babies have higher surface-area-to-volume ratios than adults.

17.4 Evolution and Genetics

Learning Objective

Explain how an understanding of genetics produces insights about the mechanisms of evolution and the origin of genetic variation.

So far, we've seen how natural selection acts on organisms: giraffe neck length, cheetah speed, peppered moth color, and so on. This is only part of the story, though, because what gets passed on to offspring are not traits—they are genes. The incorporation of genetics into Darwin's theory of evolution took place in the twentieth century and produced many new insights about how populations evolve.

The focus on genes led to a description of evolution as changes in the *frequencies of genes over time*. *Allele frequencies* describe how many of the different alleles are in a population. For example, the peppered moths discussed earlier have a light allele (a) and a dark allele (A). A population with many light moths and few dark moths has allele frequencies of 92% a and 8% A . As the habitat becomes


dark moths become more common, and the dark allele frequency. In a polluted area, the allele frequencies might be 95% *A*.

Technology

Evolutionary Algorithms


Genetic variation, natural selection, and evolution are very effective in producing living things that are well adapted to living in their environments. Can a similar process be used by engineers to solve other problems?

Computer scientists use “evolutionary algorithms” to solve a wide variety of problems. Evolutionary algorithms are computer programs that mimic biological processes in order to solve complex problems. For example, suppose you were designing a race car and need to determine what materials to use and what body shape the car should have. An evolutionary algorithm that works on this problem would begin with a “population” of possible solutions: car designs using different materials and different shapes. None of these starting designs




anywhere close to a good race car. Then, a way to measure the “fitness” of each design is needed. The fitness determines how well each possible design performs based on the criteria that the designers are interested in. In the case of a race car, fitness is determined based on criteria such as speed, safety, and fuel efficiency. An evolutionary algorithm then determines the fitness of each of the different possible designs in the population and allows them to “reproduce” based on their fitness.

In an evolutionary algorithm, reproduction only slightly differs from what resembles reproduction in living things. For example, the best designs from the parent generation—such as the design with the highest fitness so far—may survive unchanged into the next generation. Other “offspring” in the next generation are created by representing combinations of multiple “parents.” An evolutionary algorithm introduces random changes into the parents before they reproduce. An evolutionary algorithm is run for many generations, across repeated rounds of mutation and reproduction, before it eventually yields the best solution that it can find. These solutions have the highest fitness that the program was able to generate.



Evolutionary algorithms are used in a wide variety of applications today. In addition to race cars, evolutionary algorithms have been used to design airplanes and ships. Evolutionary algorithms have also been successful in finding out the best ways to route shipments or traffic, and in code breaking, at modeling Earth's climate, and in creative pursuits such as writing poetry!





Evolutionary algorithms use a strategy similar to natural selection to find solutions to problems such as circuit design, global climate modeling, traffic routing, and even writing poetry.

We can describe natural selection in terms of allele frequency.

1. *Genetic variation.* Genetic variation exists when there are multiple alleles for a gene within a population. For example, in pea plants, there are two alleles for color, A and a .
2. *Natural selection.* A specific allele may give an organism a survival advantage that allows it to reproduce more than others in the population. In a polluted habitat, for example, a dark-colored allele is advantageous.
3. *Evolution.* As a result, more copies of the advantageous allele are passed to the next generation, and the frequency of the advantageous allele increases in the population. In a clean habitat, the frequency of the A allele increases.

Notice that, although natural selection *affects* genes and frequencies, natural selection does not act *directly* on genes. Another way to say this: Natural selection acts on an organism's phenotype (traits), not on its genotype (genes). To see this, consider the peppered moth. In peppered moths, the dark allele (A) is dominant and the light allele (a) is recessive. This means that both AA and Aa moths have dark wings (Figure 17.19). Whether a moth is eaten by a bird depends on the moth's phenotype (whether it is dark or light), not its genotype. A bird is equally likely to eat a dark moth with genotype AA or Aa .

Figure 17.19




Natural selection acts on phenotype, not genotype. In the case of the two dark moths, it's the phenotype (dark color) that matters, not the genotype (AA versus Aa).

Mechanisms of Evolution

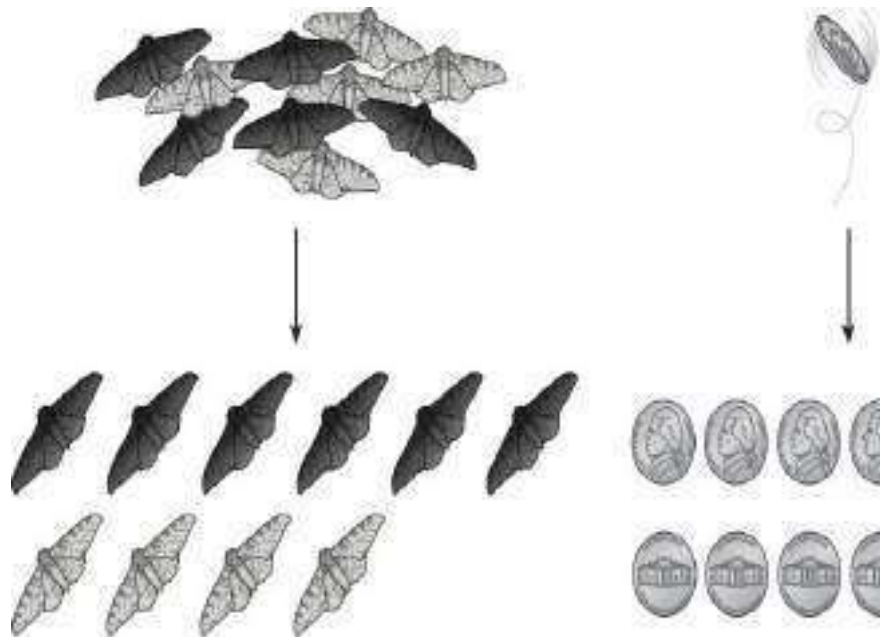
Natural selection is the driving force behind evolution, populations to become adapted to their environments. selection is not the only mechanism that causes popula Populations also change over time because of mutation drift, and gene flow. In order to understand these proce the example of peppered moths again.

Mutation pressure exists if the alleles responsible for pe are more likely to mutate in one direction than the othe genetic mutation may be more likely to turn a dark alle than vice versa. If so, then over time the frequency of th increase.

Genetic drift  is the evolution of populations due to cl half-polluted town where light moths and dark moths a successful—neither allele is advantageous. Now suppos wiped out part of the town's peppered moth populatio *happen*—just by chance—that more dark moths survive. frequency of the dark allele will increase. Notice that ge produces evolution (inherited changes in a population) this evolution is not the result of natural selection—the advantageous. Genetic drift can also occur when, just b

alleles of one type are transmitted to the next generation the other type. For example, even if light and dark moths have equal fitness, light moths might just happen to leave more offspring (therefore more light alleles) one year. Genetic drift works like a coin flip (Figure 17.20). In our imaginary town, light and dark moths are equally likely to survive and reproduce the same way you are equally likely to get heads or tails when you flip a coin. But, if you flip a coin many times, you won't always get *exactly* 50 heads and 50 tails. Similarly, if you have many moths born in the next generation, there won't necessarily be 50 light ones and 50 dark ones.

Figure 17.20



If light and dark moths have equal fitness, we would expect the same number of offspring. However, just by chance one might leave more offspring than the other, resulting in genetic drift. For the same reason that, even though you expect the same number of heads and tails when you flip a coin 10 times, you might get 6 or more tails.

Genetic drift is particularly important in small populations. In a small population, chance is more likely to change allele frequencies significantly. To see why, consider flipping a coin 10 times (a small population) versus 1000 times (a large population). With 10 flips, it's not at all unlikely that you'll get heads 60% of the time—that is, 6 heads and 4 tails. On the other hand, a similar result with 1000 flips (600 heads and 400 tails)—is practically impossible.

Gene flow describes changes in allele frequencies that result from the movement of alleles into or out of a population. For example, a polluted town may be next to a woodland that is home to many light-colored moths. If a few of these light-colored moths migrate from the woodland to the town, the frequency of the light allele in the town will increase.

Where Genetic Variation Comes From

Natural selection cannot happen without genetic variation. Populations with more variation have a better chance of surviving in a changing environment. This is because in a population with more genetic variation, it is more likely that there are alleles that will allow individuals to survive under the new conditions. For example, during the Industrial Revolution, dark-colored moths would have had a better chance of surviving in polluted areas than light-colored moths. If all the moths had been light and none were dark, populations with only light moths might have been wiped out.

But where does genetic variation come from? An understanding of genetics enabled biologists to answer this question. Genes constantly create new variations within populations. For example, a genetic mutation changes the amino acids in a protein, creating a new allele for a given gene. Sexual reproduction also creates genetic variation by bringing together alleles for different traits from two parents. Then, any of the mechanisms of evolution—natural selection, mutation pressure, genetic drift, or gene flow—can act on that variation to determine whether that new allele becomes more or less common in the population.

Check Yourself

Question 1

Check Answer

Question 2

Check Answer

Question 1

In a peppered moth population, genetic drift causes the frequency to increase one year. Will genetic drift have the same effect the

Check Answer

In a peppered moth population, genetic drift causes the frequency to increase one year. Will genetic drift have the same effect the

Answer: Genetic drift is evolution due to chance, and there is no chance will have the same effect the following year. The situation is like flipping coins—when you flip a coin 100 times and then do it a second time, you may get more heads the first time and more tails the second time.

17.5 How Species Form

Learning Objective

Explain how new species arise.

We have seen how evolution through natural selection mechanisms causes populations to change over time. Can you explain how different kinds of living things came to live? How does evolution produce new species?

A **species** is a group of organisms whose members can mate with one another but not with members of other species. (Notice that this definition works only for organisms that reproduce sexually. For asexual reproducing organisms, species are usually recognized by distinct morphological characteristics and ways of life.) This means that the key to the formation of new species—is the evolution of *reproductive isolation*—is the evolution of *reproductive isolation* that prevent two groups of organisms from interbreeding.

Humans may vary in significant ways from one part of the world to another, but we all belong to the same species because all humans are able to interbreed!

There are two kinds of reproductive barriers: ones that work before fertilization and ones that work after fertilization. These are prezygotic and postzygotic reproductive barriers. (A zygote is a fertilized egg, so *prezygotic* means “before fertilization” and *postzygotic* means “after fertilization.”) *Prezygotic reproductive barriers* prevent individuals of different species from mating in the first place or prevent mating from occurring if they do mate. There are many types of prezygotic barriers—organisms may differ in when they breed, where they breed, or in the details of their courtship rituals. Their sex organs may not fit together properly, preventing successful sperm transfer. Behavioral differences may prevent fertilization if sperm is transferred. **Figure 17.21** shows an example of a prezygotic reproductive barrier. *Postzygotic reproductive barriers* act after fertilization has taken place. Postzygotic barriers occur when mating produces hybrids that either don’t survive or are unable to breed themselves. The mule, the offspring of a horse and a donkey, is sterile and cannot reproduce. Likewise, a liger, the product of the mating of a lion and a tiger, is sterile.

Figure 17.21



During courtship in red-crowned cranes, the birds dance to each other, bob their heads, stretch their necks, extend their wings straight into the air, singing in unison. Unless you can perform the behaviors just right, you have little hope of convincing a female crane to mate with you.

Watch [Albatross Courtship](#)





Watch Blue-footed Booby Courtship

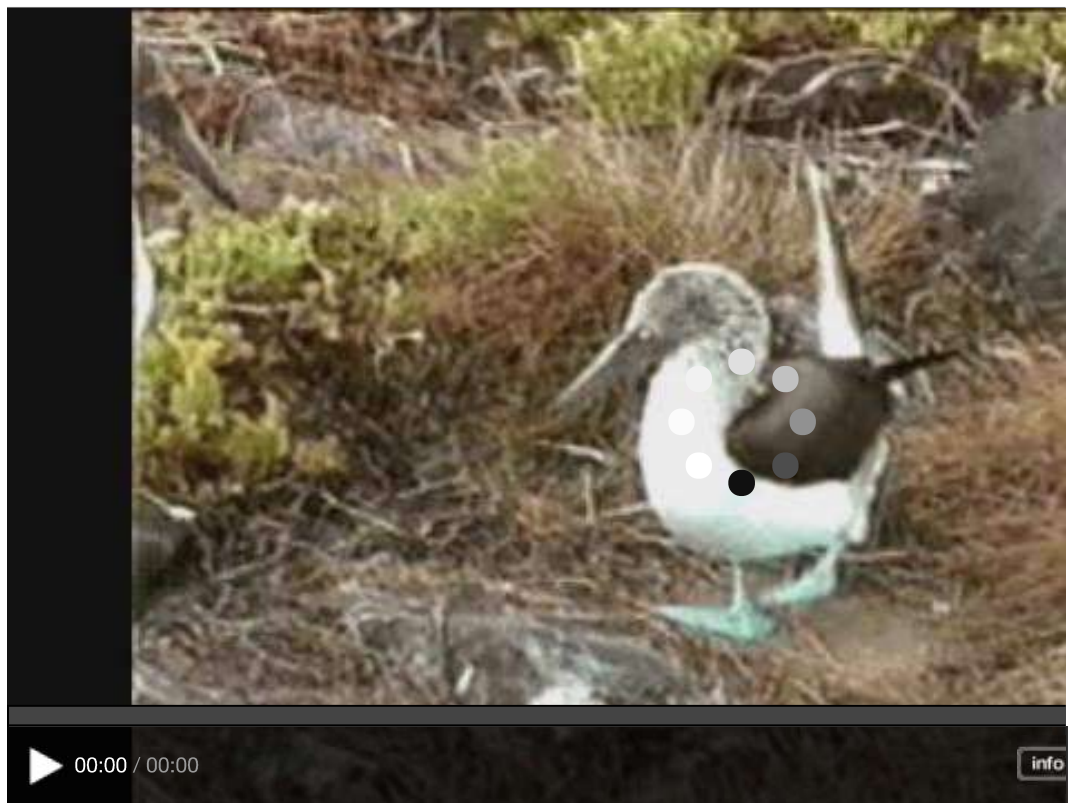


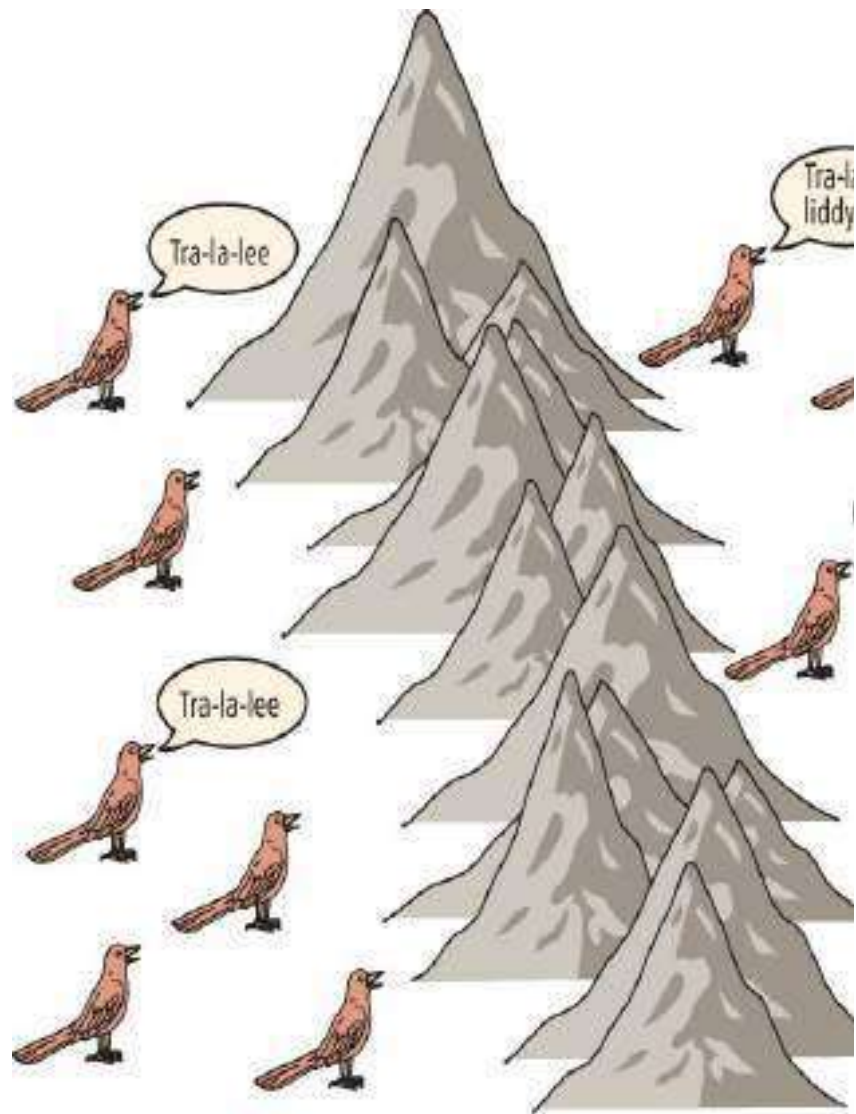
Figure 17.22



A postzygotic reproductive barrier—the liger, a lion–tiger sterile.

Now let's consider how reproductive barriers—and their evolution—evolve. In *allopatric speciation*, new species are formed when a geographic barrier divides a single population into two populations (Figure 17.23). A geographic barrier could be a range, a river, an ocean, a canyon, or—for aquatic organisms, a landmass. Once two populations are geographically isolated, they evolve independently. Over time, natural selection may contribute to the evolution of key differences that prevent interbreeding. If a reproductive barrier evolves, the populations become separate species.

Figure 17.23



Geographic barriers isolate populations and allow them to evolve independently. Sometimes, a reproductive barrier will evolve, leading to allopatric speciation. In this example, the courtship song diverges by a mountain range, resulting in a prezygotic barrier.

Numerous instances of allopatric speciation have been documented since the Isthmus of Panama, 3 million years ago, divided the Americas from the Pacific Ocean, splitting hundreds of types of marine life into separate Caribbean and Pacific populations. Most of these populations subsequently speciated by evolving reproductive isolation, including the wrasses in [Figure 17.24](#). Adaptive radiations are spectacular examples of allopatric speciation where many species, each adapted to a distinct way of life, evolve from a single ancestor. Adaptive radiations have occurred on island archipelagos where there are abundant opportunities for geographic isolation. Examples of adaptive radiations include Darwin's finches and the Hawaiian honeycreepers, which include more than 30 species that differ in plumage, behavior, and size, and diet ([Figure 17.25](#)).

Figure 17.24



The formation of the Isthmus of Panama 3 million years ago separated Pacific and Caribbean marine populations, producing new species through allopatric speciation. The blue-headed wrasse (Caribbean) and the Cortez rainbow wrasse (Pacific) are descended from a single species that formerly spanned Pacific and Caribbean waters.

Figure 17.25



The Hawaiian honeycreepers represent an adaptive radiation of more than 30 bird species. The honeycreepers differ in beak shape and size, and diet. Unfortunately, many species are

endangered because of habitat destruction and the introduction of nonnative species such as rats, pigs, mongooses, cats, and dogs.

Sympatric speciation occurs without geographic isolation. Sympatric speciation is less common than allopatric speciation and can occur from a sudden chromosomal change. One such chromosomal change is *polyploidy*, which occurs when organisms inherit more than two sets of chromosomes, usually as a result of errors during meiosis. Sympatric speciation can also result from hybridization. Sympatric speciation occurs when two species interbreed and produce fertile offspring. Polyploidy and hybridization, chromosomal differences between species and the parent species prevent interbreeding. These types of speciation are more common in plants than in animals.

Check Yourself

Interactive

Question 1

Check Answer

Question 2

Check Answer

Question 3

Check Answer

Question 1

A small river forms, dividing a group of moles into two isolated many years, a biologist puts together moles from opposite sides finds that they will not mate. Has speciation occurred? If so, what speciation was it?

Check Answer

A small river forms, dividing a group of moles into two isolated many years, a biologist puts together moles from opposite sides finds that they will not mate. Has speciation occurred? If so, what speciation was it?

Answer: The moles on the two sides of the river now represent

17.6 Evidence of Evolution

Learning Objective

List and provide examples of the main kinds of evidence that support the theory of evolution.

All scientific theories make predictions about what we should observe in nature. If these predictions are confirmed, the theory is supported. The theory of evolution has been tested repeatedly against the natural world, and the evidence for evolution is overwhelming. The main kinds of evidence support the idea that evolution explains the diversity of life on Earth: (1) observations of natural selection, (2) artificial selection, (3) similarities in body structures and organs, (4) DNA and molecular evidence, (5) patterns of distribution, (6) hierarchical organization of living things, (7) biogeography, and (8) fossils. We will look at the first eight topics here, and then continue in Integrated Science 17D.

Unifying Concept

The Scientific Method [Section 1.3](#) 

1. *Observations of natural selection in action.* In many cases, scientists have seen natural selection produce evolutionary changes in populations; they have observed and measured changes in populations. These include some of the most famous examples that have been looked at: Australian rabbits evolved resistance to the myxoma virus, so that over time a smaller and smaller number of individuals died from the disease. Peppered moths became better camouflaged in their environment as the environment became more and more common as habitats became more polluted, and then they became less and less common as the environment was cleaned up. Bacteria evolved resistance to certain antibiotics, so that these antibiotics no longer controlled infections. Scientists have also studied how the beaks of Darwin's finches changed during a drought, how insects evolve resistance to pesticides, and natural selection in a wide variety of other populations.
2. *Artificial selection.* **Artificial selection** is the selection of organisms with desirable traits in order to obtain offspring with similar traits. Humans artificially select for desirable traits in domesticated animals and crops all the time: We select for faster racehorses to try to get faster racehorses; different breeds of dogs to produce superior hunters, herders, or sled pullers (see [17.26](#)); and varieties of strawberries to grow to

sweetest fruit. In artificial selection, humans control the reproductive success of different organisms and produce distinct evolutionary changes in populations over time. These changes can be dramatic—think how much a Chihuahua differs from the animal it is descended from, the wolf. [17.27](#) to see the difference between the corn cob and teosinte, the plant from which corn was bred. Humans have produced countless forms of domestic animals with traits valued by humans.

Figure 17.26



Artificial selection has produced great diversity in dogs.

Figure 17.27




Corn (*below*), one of the most important agricultural crops, was laboriously bred through artificial selection from teosinte. Teosinte has tiny cobs, only a few rows of kernels, and a hard covering on its seeds.

Technology

More Mutants, Please!

People use artificial selection to obtain plants and animals with desirable traits. But artificial selection is limited by the variation that exists in populations. For example, you can't breed green cats because there simply aren't any cats with greenish fur. But is there a way to try to generate variation in populations?



Scientists use a technology called mutation breeding to generate genetic variation in organisms, mainly through mutation breeding, scientists use highly radioactive isotopes to produce mutations in plants. After exposing seeds, seedlings, or mature plants to the radiation, they screen the results and search for useful new plant varieties.

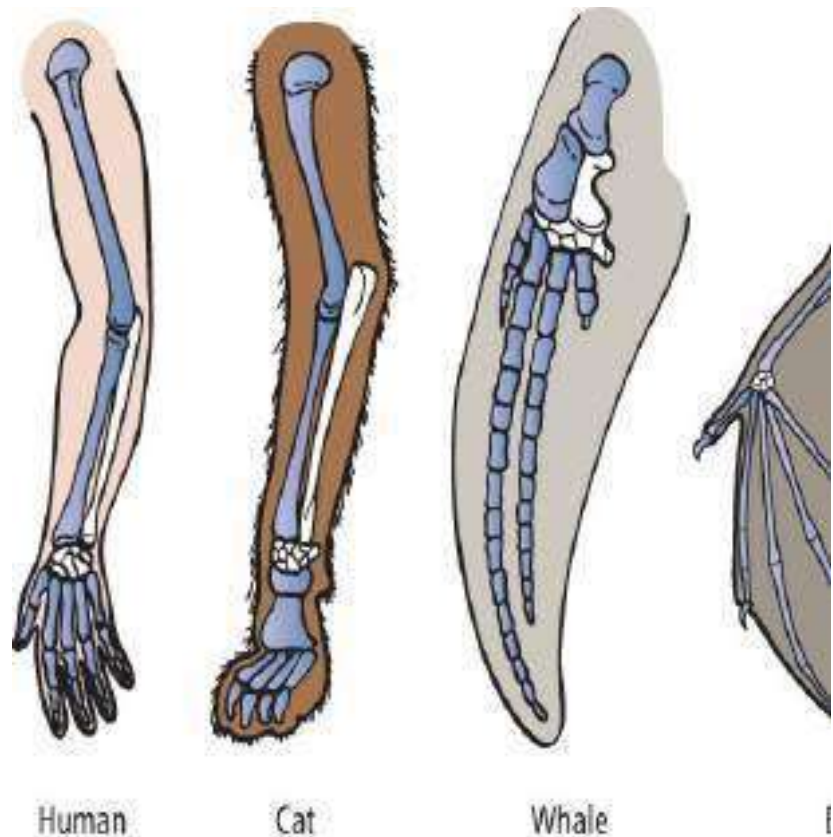
Mutation breeding has provided many useful crop varieties. About half the rice now grown in California is derived from a mutant dwarf variety that produces more grain. Mutation breeding also produced Japanese pears that are resistant to fungus, cocoa that is resistant to viruses, barley used in making high-end Scotch whiskeys, and peanuts with resistant shells. Perhaps the most familiar product of mutation breeding is the ruby red grapefruit. A natural red grapefruit was discovered in Texas in 1929, and attempts were made to breed it. Unfortunately, the bright color of the fruit faded over time. Mutation breeding successfully produced a stable variety of red grapefruit, and most of the grapefruit grown today is of this ruby red variety.



The popular ruby red grapefruit was produced through mutation breeding.

3. *Similarities in body structures.* We see evidence of common evolutionary histories of species in the structures of their bodies. The forelimbs of different mammals. Different mammal forelimbs for different purposes: Humans use their forelimbs as hands for manipulating tools, cats use theirs to climb, dogs use theirs as flippers, and bats use theirs as wings. If all these animals had originated independently, we would expect their forelimbs to look completely different. Each limb would have been designed from scratch to best perform its function. Despite the different functions of human hands, cat legs, dog paws, and bat wings, all these limbs show the same arrangement of bones (Figure 17.28). This suggests that the forelimb was inherited from a common ancestor and then modified by natural selection for different functions.

Figure 17.28



Although these mammalian limbs are used for different purposes, they are all composed of the same set of bones, evidence that they all evolved from a common ancestor.

A mouse and a whale are about as different as two animals can be. Yet just about every bone in a mouse corresponds to a specific bone in a whale. These similarities suggest that mice and whales had a common ancestor and their skeletons were modified over time by natural selection in different environments and ways of life.

4. *Vestigial organs*. An organism's evolutionary history leaves traces in its body. Some organisms have vestigial organs that are not functional—they are just the remains found in the organism's ancestor. For example, snakes are legless. But did you know that certain snakes have tiny, partial hind legs? The tiny stubs have no purpose, just the remains of what once were bigger limbs. Vestigial hind legs provide evidence that snakes evolved from animals with legs. In the same way, many blind cavefish have non-functional eyes in their lightless habitats but retain the remains of eyes (Figure 17.29). These vestigial organs suggest that cavefish evolved from animals with eyes.

Figure 17.29



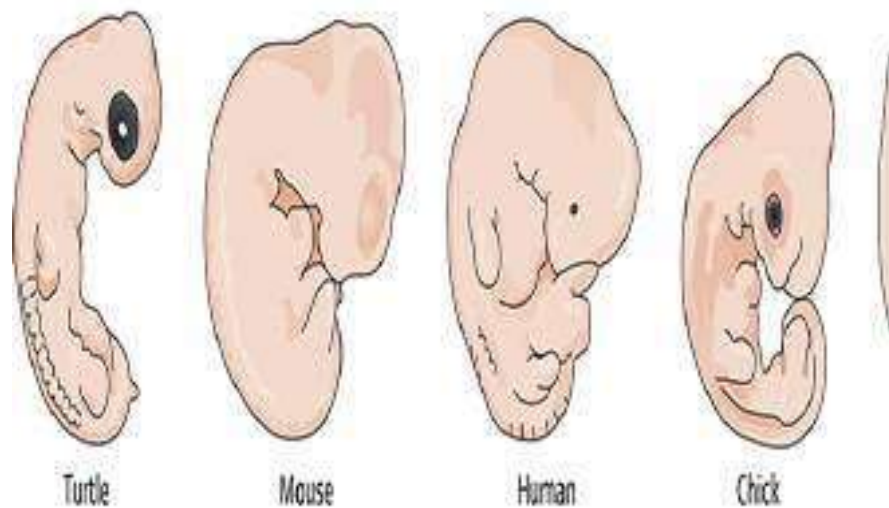
The Texas blind salamander lives in lightless caves. It has small eyes (dark dots in the photo) that are covered by skin.

5. *DNA and molecular evidence.* The DNA of related species tends to have very similar nucleotide (ACGT) sequences. In fact, the more closely related two species are, the more similar their DNA sequences tend to be. This is true not only for DNA sequences that code for proteins, but even for sequences that have no known function. If each species on Earth had originated independently, we would not expect to see similar noncoding DNA in related species. The high degree of similarity suggests that DNA did not originate independently.

each species but was inherited from a common ancestor and modified during evolution.

6. *Patterns of development.* Related species develop similar patterns of development. Each species on Earth had originated independently, but we expect these similarities in development. For example, even though humans have no tails, we go through a tailed stage like other vertebrates (Figure 17.30).

Figure 17.30



Related species go through similar stages in their development. Even though a human embryo goes through a tailed stage just like the mouse embryo, even though humans don't have tails.

7. *Hierarchical organization of living things.* Darwin's evolution explains Earth's diversity of species as a result of numerous speciation events. If this is true, we expect living things to be organized into hierarchical "nested groups"—that is, "groups within groups." Species should have fewer traits in common with distant relatives, and more traits in common with species that are more closely related. This is in fact how living things are organized. Humans, for example, share a backbone with vertebrates such as fishes, amphibians, reptiles, and mammals; they share four limbs with terrestrial vertebrates such as amphibians, reptiles, and mammals but not with more distantly related groups; they share a waterproof skin with amphibians and mammals but not with amphibians, which are more distantly related; and they share the trait of nursing their young with other mammals but not with the more distantly related reptiles. Living things fit into a hierarchical organization as predicted by evolution. We do not see traits scattered randomly among living things. For example, we do not see a backbone shared by vertebrates plus some worms and some insects. The characteristics that organisms have make sense in light of their evolutionary history and relationships.

8. *Biogeography*. *Biogeography* is the study of how species are distributed on Earth. Biogeography consistently supports the idea that organisms evolved in a particular region and then left descendants in the places where they spread. Biogeography does not support the idea that organisms were specially designed to fit into a specific type of habitat and then distributed where these habitats occur on Earth. For example, even though the Arctic and Antarctic environments, they are occupied by entirely different species (Figure 17.31).

Figure 17.31



The Arctic and Antarctic, which have similar habitats, are occupied by very different species. Polar bears are found in the Arctic but not in the Antarctic. Penguins are found in the Antarctic but not in the Arctic.

What biogeography does show is that the ranges of many organisms are bounded by geographic barriers such as oceans or mountains. For example, many organisms are restricted to a single continent. Closely related species tend to be found close together, suggesting they evolved in one place and then spread. For example, Darwin's finches are found in or near the Galápagos, and all the Hawaiian finches are found in Hawaii. Similarly, island species are usually more closely related to species found on the closest mainland. Islands also tend to have more species than an area of equal size on the mainland, and many species are *endemic*, meaning they are found nowhere else. Finally, islands tend to be occupied by many flying animals, including terrestrial ones (Figure 17.32). All these points suggest that organisms were not dispersed purposefully around Earth but, instead, evolved in one place and then left descendants where they were.

Figure 17.32



Why are terrestrial vertebrates rare or absent from islands? Why are island species common? This is the Hawaiian hoary bat, the last native mammal found on Hawaii prior to human colonization of the island.

Check Yourself

Interactive

Question
Check Answer
Question

Many species found on islands resemble species found on the mainland.
How does this provide evidence for evolution?

Check Answer

Many species found on islands resemble species found on the mainland.
How does this provide evidence for evolution?

Answer: This pattern suggests that island species evolved when individuals colonized the island and then evolved in isolation, rather than species were distributed purposefully around Earth.

Integrated Science 17D: Earth and Space Science

Fossils: Earth's Tangible Evidence of Evolution

Learning Objective

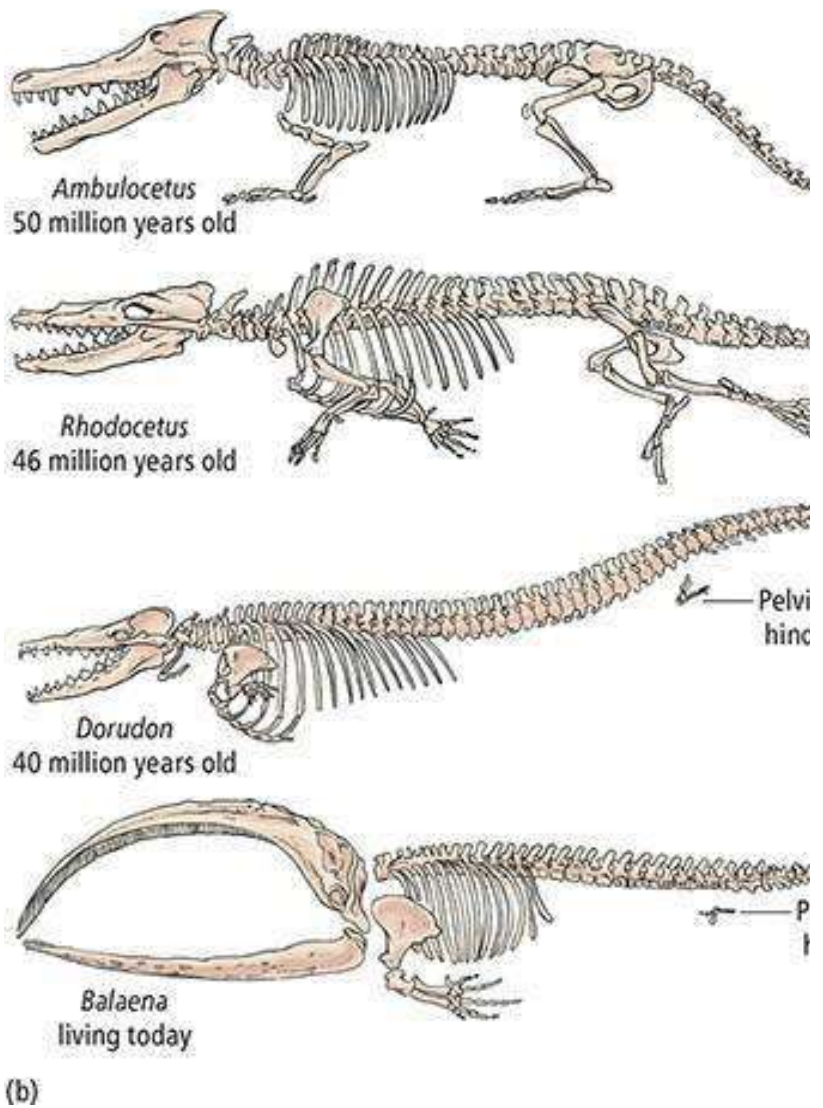
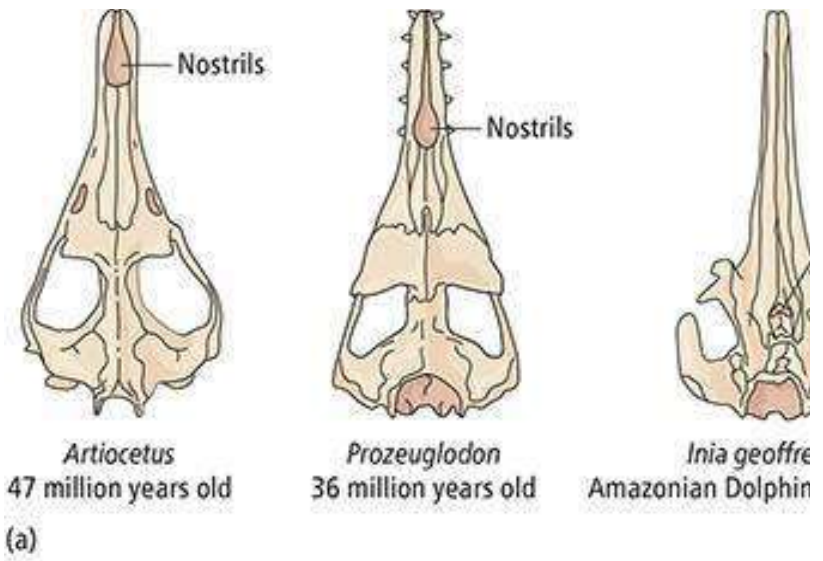
Explain how fossils provide evidence of evolution.

Evolution has left a record in Earth's rocks in the form of fossils. Scientists can date fossils from the age of the rock formations they belong to and follow the evolutionary path of the species.

organisms over time. For example, fossil whales show that whales are descended from hoofed mammals. Fossils also tell us how many key whale traits evolved. In [Figure 17.33a](#), we can see how, over time, whale nostrils moved from the front of the skull to the top of the skull, forming a blowhole. Fossil whales also show how whales lost their hind limbs and became more and more adapted to an aquatic environment. The oldest whale fossils, such as the 50-million-year-old *Ambulocetus*, have large hind legs that were used for walking and for swimming ([Figure 17.33b](#)). *Ambulocetus* has small hooves on its front legs, providing clear evidence that whales are descended from hoofed mammals. *Rhodyocetus*, a 46-million-year-old fossil whale, shows reduced hind limbs; these are not attached to the backbone and so could not have supported much weight. *Rhodyocetus* also shows reduced muscles that would have been effective for swimming. In the 40-million-year-old *Dorudon*, hind limbs are present but are tiny: *Dorudon* was clearly a fully aquatic species. In modern whales, there is no evidence of hind limbs on the body, although tiny remnants of the pelvis and some vertebrae and femurs remain inside the body.

Figure 17.33

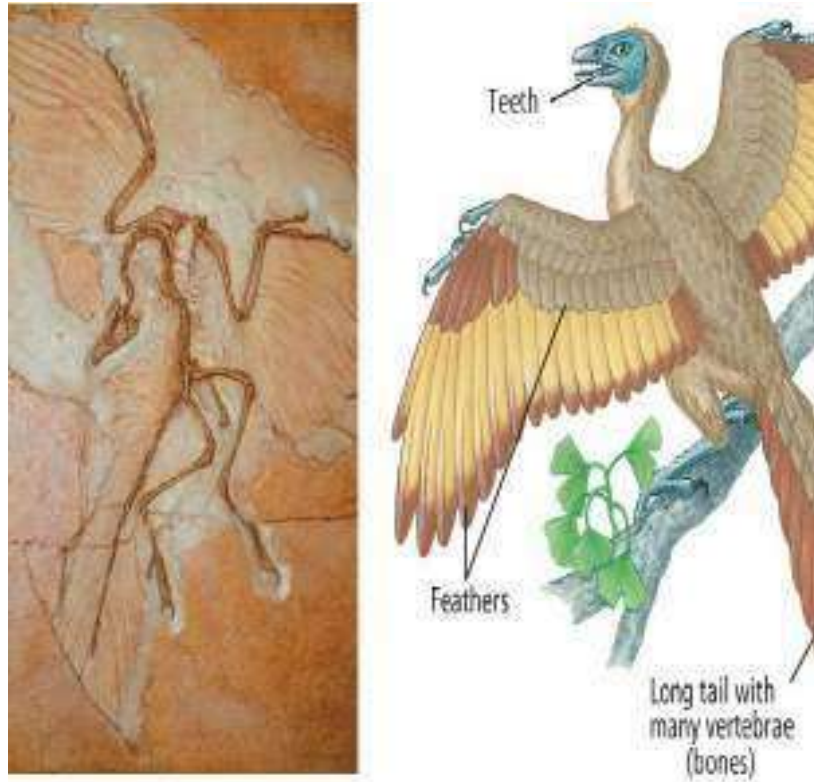




Fossil whales show how key features of these mammals evolved over time. (a) These fossil skulls show that the position of the nostrils shifted over time, from a position in the side of the skull to a position on top of the skull—the “blowhole” of modern species. (b) Fossil whales also show the reduction and loss of hind legs over time.

Archaeopteryx, the famous 150-million-year-old fossil (Figure 17.34), also shows intermediate traits in the evolution of birds from their dinosaur ancestors. *Archaeopteryx* has many birdlike features, such as feathers, wings, and a wishbone. However, it also has dinosaur-like features, including claws on its wings, bone structure, and teeth.

Figure 17.34



Archaeopteryx, an early bird, has features of both the dinosaur it evolved from and modern birds.

You just learned that *Archaeopteryx*, the earliest bird, had clawed wings. Most birds today do not have claws on their wings, but there are a few exceptions—the most famous may be the hoatzin, which lives in tropical forests in the Amazon. Hoatzin chicks use their claws to move along branches. In addition, when threatened, the

drop from one tree, swim or move to another trunk, and then climb back up using their c

Check Yourself

Interactive

Question

Check Answer

Question

How do fossil whales provide evidence for evolution?

Check Answer

How do fossil whales provide evidence for evolution?

Answer: Fossils show how key traits evolved in whales. For example, fossils that have been found show traits that are intermediate between the ancestors (nostrils in front of the skull and large function.

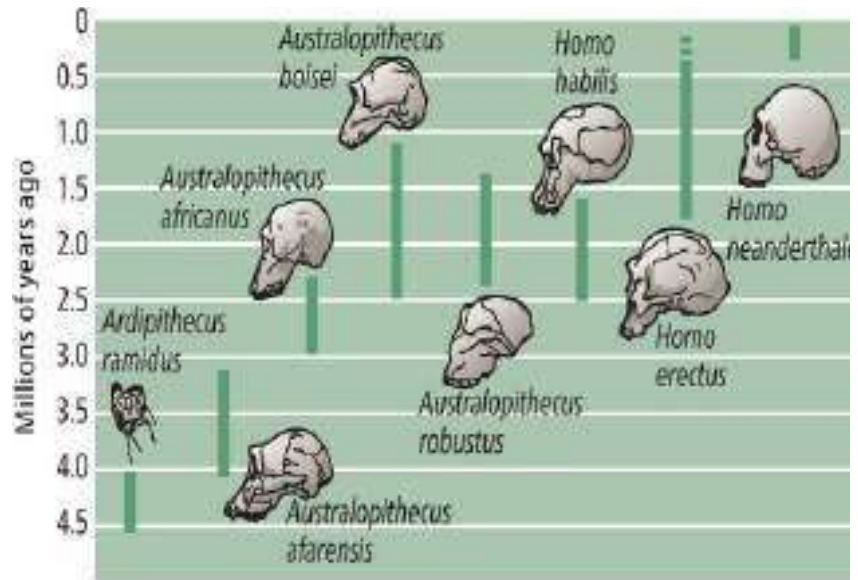
17.7 The Evolution of Humans

Learning Objective

Describe some fossil hominids and what they reveal about the evolution of humans.

Humans are *primates*, a group of mammals that also includes monkeys and apes. This does not mean we are descended from modern species of monkey or ape, just that we share a common ancestor with these species more recently than we do with a dog or a plant. Humans are also *hominids*, the group within the primate order that includes modern *Homo sapiens* (our species) as well as several extinct relatives. Although humans are the only hominids in existence today, fossil hominids provide clues as to how humans evolved. Human evolution is shown in [Figure 17.35](#).

Figure 17.35



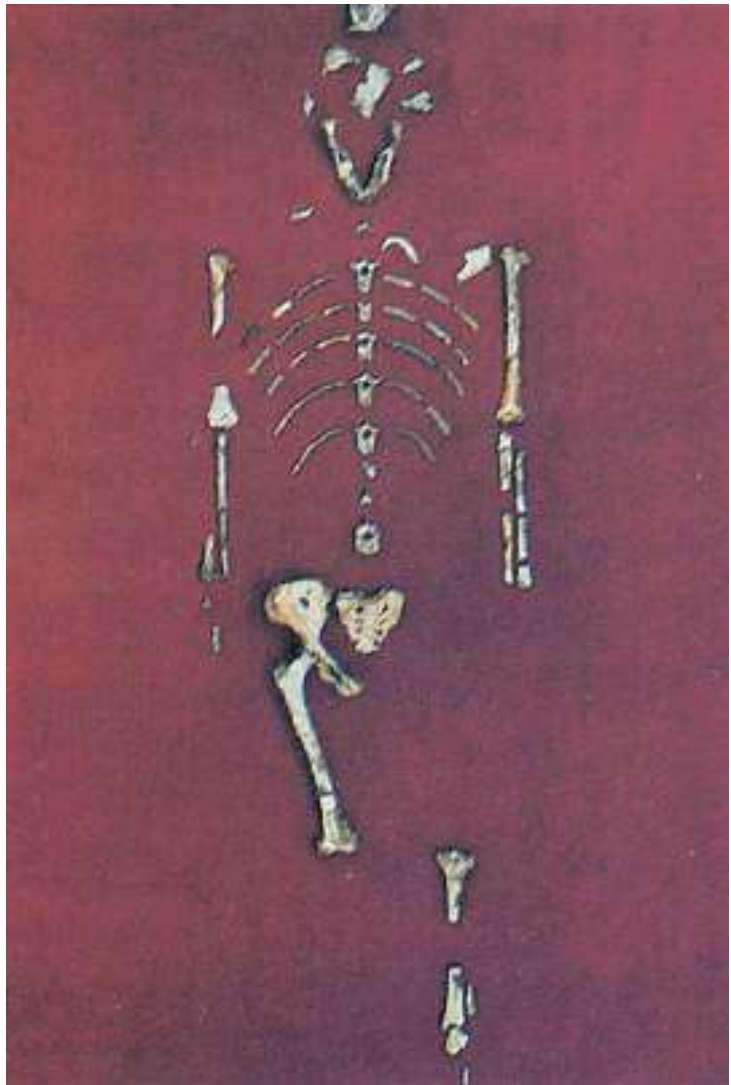
This timeline shows when certain hominid species exist. The skulls (or skull fragments) are all drawn to the same scale to show relative brain sizes.

Humans are not descended from any species of ape that is living today. However, we are more closely related to monkeys and apes than we are to other animals. *Descended from* and *related to* are entirely different concepts.

Every creature alive now is equally evolved. Every creature alive today is the product of at least 3.5 billion years of evolution. Humans are not “more evolved” than any other species.

Some of the earliest hominids known belong to the group *Australopithecus*. Fossil *Australopithecus* have been found in Africa, where hominids originated. "Lucy," the famous *afarensis* fossil shown in **Figure 17.36**, dates from about 3 million years ago. When she was alive, Lucy stood 3 feet 8 inches tall, about the size of a chimpanzee's. However, the bones clearly make it clear that she walked upright on two legs. In fact, *Australopithecus* fossils show that an upright posture developed about 3 million years ago and therefore evolved long before modern man and intelligence.

Figure 17.36



"Lucy," a fossil *Australopithecus afarensis*, stood upright two feet.

Homo habilis is the earliest known species in the group . includes the species most closely related to modern hu
habilis fossils are 2.2 million years old. *Homo habilis* hac
than *Australopithecus*. *Homo habilis* also made stone too

scientific name means “handy man.” Male *Homo habilis* than females. This is interesting because in other primates, gorillas and baboons, a big size difference between males and females is a sign that males fight each other for female mates.

Homo erectus lived from about 2 million years ago to about 300,000 years ago. *Homo erectus* had an even larger brain than *Homo habilis*. The brain of *Homo erectus* was only a little smaller than that of modern humans. *Homo erectus* was a skilled toolmaker as well as a species to migrate out of Africa and spread into what is now Asia. Like *Homo habilis*, older *Homo erectus* fossils show a much larger size difference between males and females. However, later fossils of the species show a male–female size difference closer to that present in modern humans, suggesting the development of a more humanlike social structure.

The Neanderthals—*Homo neanderthalensis*—are closely related to modern humans (Figure 17.37). They lived from about 400,000 years ago to about 30,000 years ago. Neanderthals had very thick, curved brow ridges, and their brains were as large as those of modern humans. Recent findings show that Neanderthals were effective hunters, had complex social rituals, and made use of medicinal plants. One question that remains unanswered is whether the Neanderthals had language.

years, modern humans coexisted with Neanderthals. However, Neanderthal populations disappeared as modern humans emerged. Scientists are not sure why, although it seems likely that modern humans outcompeted the Neanderthals and drove them to extinction. The development of modern genetic techniques has allowed scientists to collect information about the Neanderthals from a new perspective (Figure 17.38). Using fossil remains, scientists were able to sequence the Neanderthal genome. This resulted in a huge surprise—modern humans have some Neanderthal DNA! Neanderthal DNA makes up about 1 to 4 percent of the genome of most humans. These findings indicate that Neanderthals and modern humans interbred in the past.

Figure 17.37



Neanderthals coexisted with modern humans and interbred. These reconstructions appear at the Neanderthal Museum in Germany.

Figure 17.38



A scientist drills a sample of bone from a Neanderthal fossil and extract and study its DNA.

The earliest fossils of modern humans, *Homo sapiens*, were found in Ethiopia and are 195,000 years old. Although anatomically modern humans are quite old, the cultural traits we associate with modern humans—things like art, music, and religion—are more recent, appearing about 50,000 years ago. The reason for this gap between anatomically modern humans and modern behavior is the subject of continued debate.

Check Yourself

Interactive

Question 1

Check Answer

Question 2

Check Answer

Question 3

Check Answer

Question 1

Have multiple species of hominids ever coexisted on Earth? Do
than humans survive to this day?

Check Answer

Have multiple species of hominids ever coexisted on Earth? Do
than humans survive to this day?

Answer: The timeline of hominid evolution shows that multiple
hominids coexisted during much of hominid history. Today, ho
the only species of hominids in existence. The others have all d

Summary of Terms (Knowledge)

For instructor-assigned homework, go to
www.masteringphysics.com

Adaptations □

Evolved traits that make organisms well suited to living in their environments.

Artificial selection □

The selective breeding of organisms with desirable traits produce offspring with similar desirable traits.

Evolution □

Inherited changes in populations of organisms over time

Fitness □

The number of offspring an organism produces in its life relative to other organisms in the population.

Gene flow □

The evolution of a population due to the movement of alleles into or out of the population.

Genetic drift □

The evolution of a population due to chance.

Genetic variation □

Differences in the inherited traits of different individuals in a population.

Natural selection □

The process in which organisms with inherited, advantageous traits produce more offspring than organisms with other traits, causing advantageous traits to become more common in a population.

Speciation □

The formation of new species.

Species □

A group of organisms whose members can breed with each other but not with members of other species.

Reading Check Questions (Comprehension)

17.1 Charles Darwin and *The Origin of Species*

1. What was Lamarck's theory about how evolution occurred?
2. What impressed Darwin about the finches on the Galapagos Islands?
3. How did the work of Thomas Malthus influence Darwin?
4. How did Charles Lyell's work influence Darwin?

17.2 How Natural Selection Works

5. What is an inherited trait?
6. What is genetic variation?
7. Describe how natural selection occurs.

17.3 Adaptation

8. From the point of view of natural selection, why is it important for an organism to survive?
9. Define sexual selection and provide some examples of adaptations that evolved as a result of sexual selection.
10. Why is parental care adaptive in certain species?

17.4 Evolution and Genetics

11. Does natural selection act on genotype or phenotype?
12. Define genetic drift and provide an example of how it can cause a population to evolve.
13. What is gene flow? Use an example to explain how it can cause a population to evolve.
14. Why are genetic mutations and sexual reproduction important in creating and maintaining genetic variation in populations?

17.5 How Species Form

15. What is a species?

16. What is the difference between a prezygotic reproductive barrier and a postzygotic reproductive barrier? Give an example of each.
17. Explain the difference between allopatric speciation and sympatric speciation. Which is more common?
18. What is an adaptive radiation?

17.6 Evidence of Evolution

19. What is artificial selection? Why does artificial selection provide evidence for evolution?
20. Why does the similarity of the mammalian limb bones in different species of mammals provide evidence for evolution?
21. How does biogeography provide evidence for evolution?

17.7 The Evolution of Humans

22. What important feature of modern humans can be traced to 4-million-year-old *Australopithecus* fossils?
23. What was the first species of hominid to leave Africa and move into Europe and Asia?

24. How old is our species, the modern humans known as *sapiens*?

Think Integrated Science

17A—The Origin of Life

25. What experiment did Miller and Urey perform? results?
26. What are three hypotheses for how Earth's orga originated?
27. What are liposomes? What characteristics of lip scientists think that liposomes may have been t real cells?
28. Why is RNA, rather than DNA, believed to be t material?

17B—Is There Life on Mars?

29. Why do scientists think life on Mars is more lik Venus?
30. Why are scientists interested in searching for w

31. Is there evidence that Mars once had water?
32. Is there evidence that Mars currently has water?
33. Do scientists know whether there is life on Mars?

17C—Staying Warm and Keeping Cool

34. Why is the surface-area-to-volume ratio important for thermoregulation?
35. Recall that the amount of caramel on a caramel apple is determined by the apple's surface area, and the amount of apple is determined by the apple's volume. If you like caramel more than apple, should you choose one large caramel apple or two smaller caramel apples with the same total volume? Defend your answer.
36. You are studying a species of tropical goat and a related Arctic species. Based on your knowledge of thermoregulation in mammals and its effect on the behavior of organisms, predict some of the differences you would expect between the tropical and Arctic species.

17D—Fossils: Earth's Tangible Past

of Evolution

37. How do fossils provide evidence for evolution?
38. Explain how the fossil whales that have been discovered support Darwin's theory of evolution.
39. What does the fossil *Archaeopteryx* tell us about evolution?

Think and Do (Hands-On Application)

40. Look at these photos, which are from Kettlewell's 1958 publication on peppered moths. If *you* were the predator of peppered moths, would there be natural selection? Why or why not? (How many moths do you see? Which one did you see first?)



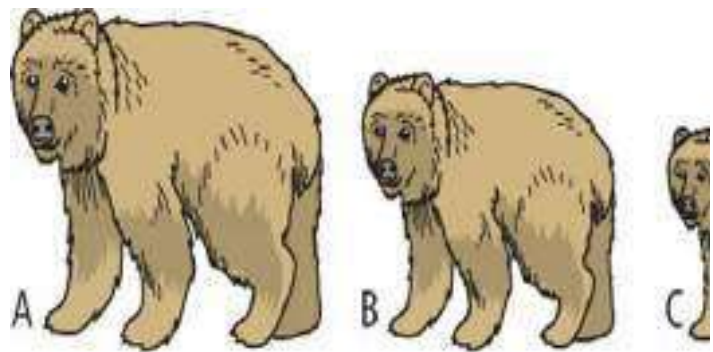
41. Take a hike or a walk in your neighborhood and observe the plants, insects, birds, and other organisms that you encounter. For each organism, note one or two traits that are adapted to its environment. Did you notice any organisms that keep other organisms from being eaten by potential predators?

types of adaptations were these—ones that allow them to find mates or ones that allow them to remain camouflaged? What are any adaptations related to finding mates? What are any adaptations related to raising offspring?

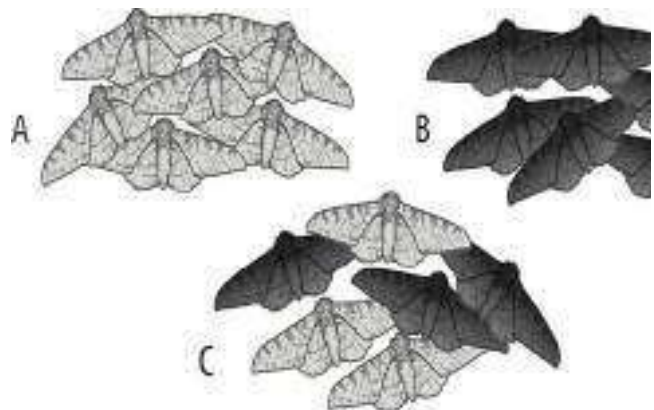
- 42.** Here's one more thing to think about during your observations: many species you see (whether they are pigeons, squirrels, house flies, sow bugs, or others) all share the ability to coexist in a human-created environment. What adaptations allow these species to thrive in human communities?

Think and Compare (Analysis)

43. Three bears are shown. Rank the bears according to how well suited they are to living (and thermoregulating) in a cold climate, from best suited to least suited.



44. Peppered moths collected from three different habitats are shown. Rank the habitats the moths live in, from most polluted to least polluted (most sooty to least sooty).



Think and Solve (Mathematical Application)

45. Let's look at how natural selection causes advantages to become more common in populations. Suppose you have a population of bugs in which some individuals are green and some individuals are brown. Suppose that, because brown bugs are better camouflaged against predators, each brown bug produces 1.5 brown offspring per generation (on average) and each green bug leaves one green offspring per generation (on average). (a) Why is this natural selection? Why? (b) You start with two brown and two green bugs in generation 1. How many brown and green bugs are there in generation 2? Calculate the number of brown and green bugs there are in generations 1 to 10. Show that 94% of the bugs in generation 5 are brown, and more than 99% in generation 10 are brown. Why?
46. Let's consider a very small population of snapdragons with only two individuals. One snapdragon has two alleles for flower color—it is RR . The other snapdragon has one red allele and one white allele for flower color—it is RW . Show that

the red allele R in the population is 0.75 and the white allele W is 0.25.

47. Now let's assume that the two snapdragons in c mate and produce a single offspring with genot have a snapdragon population with only one in the allele frequencies of the red and white allele population. Is this an example of genetic drift?

Think and Explain (Syntheses)

17A—The Origin of Life

48. Why do scientists consider Miller and Urey's experiment important? Why do some scientists question the experiment Miller and Urey made when they designed their experiment?
49. What role might environments similar to hydrothermal vents have played in the origin of life?
50. How are liposomes similar to cells? How are they different from real cells?
51. Explain why the earliest life on Earth may have been based on liposomes containing RNA.

17B—Is There Life on Mars?

52. Of the planets in the Solar System other than Earth, why do scientists initially focus on Mars and Venus as the most likely to harbor life?

53. What features of Venus would make it difficult it to live there?
54. What features of Mars would make it difficult for things to survive there?
55. How much evidence is there that Mars currently that it once supported life? What kind of evidence is being searched for to determine whether there is life

17.1 Charles Darwin and *The Origin of Species*

56. What role did fossils play in the development of —and later Darwin's ideas—about evolution?
57. How did Darwin's experience on the *Beagle* influence his later work?
58. Horned lizards defend themselves with spiky horns on their heads and bodies. Some individuals will even jab at predators with their horns. How might the evolution of these horns have occurred?



17.2 How Natural Selection Works

59. What are some human traits that do not show genetic variation?
What are some that do show genetic variation?
60. How would you determine whether a trait you are studying is an inherited trait?
61. How is the story of the myxoma virus and Australia similar to the story of antibiotic resistance in bacteria?
62. Nancy Burley of the University of California, Irvine conducted the following experiment: She placed red color bands on some male birds and green color bands on the females.

birds. Females preferred to mate with males that had the most colorful tail feathers. Is this an example of natural selection? Why or why not?

63. What does it mean to say that one rabbit has gray fur and another has white fur? Is this an example of natural selection? Why or why not?
64. In recent decades, average human height has increased in many parts of the world. Do you think this is an example of natural selection? Why or why not?
65. On islands, many large animals—such as elephants—become miniaturized. On the other hand, many small animals, including some rodents—evolve to be exceptionally large. How might natural selection produce these results?
66. A single sunflower can have hundreds or even thousands of seeds. Will each of these seeds grow into a sunflower plant? Why or why not? What would happen if every one of these seeds grew into a sunflower plant?



17.3 Adaptation

67. Male birds of many species have brighter feathers. Bright colors on males are often adaptations for sexual selection, as in the cardinal. Is being less colorful adaptive? Defend your answer.



- 68.** John Endler studied guppies that lived in ponds and noticed that the males in different populations had different coloration patterns. Males that lived in ponds with predators tended to have bright colors and large tails, while males that lived in ponds without predators tended to have dull colors and small tails. He knew that female guppies preferred to mate with brightly colored males. Explain the role of natural selection in these guppy populations.
- 69.** Not all brightly colored animals are trying to attract mates. Some animals use bright colors as a warning. For example, a bright yellow and black striped pattern is a warning to predators that an animal is poisonous.

bees and wasps (yellow and black), coral snake (black and red), and poison dart frogs (many different bright colors). Explain how bright colors are adaptations in the natural world.

70. Write a letter to Grandma telling her about drug resistance in living organisms. Explain to her why drug resistance is a common phenomenon, including why insects become resistant to pesticides over time as well as why tuberculosis and malaria have become harder to treat in recent years.



17C—Staying Warm and Keeping Cool

71. You are at the supermarket, shopping for dinner. You need 5 pounds of peeled, chopped potatoes for a recipe. Should you buy 5 pounds of small potatoes or large potatoes? Why?
72. Explain why mammals that live near the poles are generally larger than related mammals that live near the equator.
73. Two species of foxes are shown here. One is a blue fox. The other is an Arctic fox. Which is which? How do they differ? Describe at least two traits that make each animal adapted to its environment.



17.4 Evolution and Genetics

74. Can chance cause a population to evolve?
75. You are studying a population of beetles that in some individuals and some yellow individuals. You know that the yellow color is recessive.

an inherited trait in the population. By counting red and yellow beetles over a period of 5 years, the proportion of red individuals is increasing and the proportion of yellow individuals is decreasing. Could you determine whether this is a result of natural selection? Are there other potential explanations?

76. In a population of mice that you are studying, tail length is found to be increasing over time. However, you find no evidence that natural selection is acting on tail length. What are the possible explanations for your observation?

17.5 How Species Form

77. Why is speciation often associated with the presence of a geographic barrier?
78. Individuals of two different fish species sometimes hybridize, but their offspring die soon after hatching. Is this an example of a prezygotic or postzygotic reproductive barrier?
79. Finches on two closely situated islands look different. On one island, they have brown tail feathers, and on the other island they have black tail feathers. Can you conclude that the two islands are separated by a geographic barrier?

different species? How could you determine whether they are in fact distinct species?

80. At your field site, there are butterflies with yellow wings and butterflies with orange wings. After observing them for a while, you notice that the yellow butterflies always mate in open meadows under trees, whereas the orange butterflies always mate in meadows. Can you conclude that they are different species?

17.6 Evidence of Evolution

81. What are some examples of artificial selection? How is artificial selection and natural selection similar? How are they different?
82. Many dogs have a dewclaw, a toenail located on the inner side of the front leg. Although some dogs can use their dewclaw to grip objects, in many it serves no purpose. In fact, if not regularly trimmed, it can become overgrown and cause discomfort. Is the dewclaw a vestigial organ? How does the presence of a dewclaw provide evidence for evolution?
83. How do the bones of the human hand provide evidence for evolution?
84. Islands tend to have fewer species than the nearest mainland. Furthermore, island species often include many

and few terrestrial ones. Do these biogeographic patterns support evolution? Why?

85. Many of the living organisms in Hawaii are found nowhere else on Earth. Hawaii has numerous unique species of plants, insects, mammals, mushrooms, and other living organisms. What is the best explanation for this?



17D—Fossils: Earth's Tangible of Evolution

86. Why do fossil whales have legs?

87. This photo shows the leg bone of a fossil horse leg bone of a modern horse (right). What do th about horse evolution?



88. Scientists have found a number of fossil turtles. turtle did not have a “shell” but did have wide, along its back (“top”) side and expanded belly c belly (“bottom”) side. A second, more recent tu full bottom shell. Although this second fossil tu full top shell, it did have a partial shell extendir backbone as well as wide, expanded ribs. What

fossils tell us about turtle evolution? Does it support the hypothesis that turtles evolved in water rather than on land? (Hint: If the bottom shell evolved first, what kind of protection did it help defend turtles from?) Explain your answer.

17.7 The Evolution of Humans

89. Laura says she doesn't believe that humans were descended from chimpanzees or gorillas. Jeff says he doesn't believe that humans were descended from chimps or gorillas. Explain why biologists also don't believe that humans were descended from chimps or gorillas.
90. In one of the most spectacular archaeological finds, the skeletons of a tiny human relative were discovered on an Indonesian island in 2004. Nicknamed "hobbits," these adults had skulls the size of grapefruits and were about the size of 3-year-old modern children. *Homo floresiensis* lived on an island with pygmy elephants, giant rodents, and Komodo dragons. How might *Homo floresiensis* have evolved to have very small brains in this environment?

Think and Discuss (Evaluation)

91. If there is life on Mars (and this life had evolved adaptations might the organisms have? How might they differ from life on Earth?
92. If life evolved on Venus, what adaptations might it have?
93. During a drought, the supply of seeds available to a population decreases. The smaller, softer seeds are quickly eaten up. Finches with larger beaks are better able to crack the larger seeds that remain. What evolutionary changes do you expect to see in the population?
94. Caterpillars of the Monarch butterfly eat plants that contain toxic chemicals. As a result, their tissues become toxic. Other animals that try to eat Monarchs vomit and then avoid the stomach contents. The viceroy butterfly has a red and-black pattern in the future. The viceroy is a different butterfly. Viceroys resemble monarchs, but they are not. How is the appearance of the viceroy adaptive? How could this be tested? Hypothesis?



Can you tell which is the monarch and which is a viceroy? Viceroy butterflies have a black stripe in the hind wing that monarchs do not.

95. You are eating a salad when you almost bite down on an insect hidden among the lettuce leaves. The friend with you says, "That would have been gross, but it would have poisoned you." Do you agree?
96. Bird eggs vary tremendously in color. Do you think the color of a bird's eggs is adaptive? What factors may have influenced the evolution of egg color in different species?



97. A population of beetles that includes both sand individuals is introduced into a grassy environment. What do you expect the population to evolve due to natural selection? Suppose that another beetle population lives in a sandbank. Most of the individuals in this population are light-colored. If beetles regularly migrate from one population to the other, what will be the effect on each population? Will it make it easier or harder for these beetle populations to survive in their environments?
98. Islands tend to have fewer species than an area of the same size on the mainland. Is this consistent with the idea that species spread around Earth purposefully? Is it consistent with the idea that species spread randomly?

99. Scientific theories must be falsifiable. Is evolution an example, can you imagine some biogeographic pattern that would not be consistent with evolution? Has any such pattern been found?
100. Scientists who are searching for new fossils of dinosaurs usually look in Africa. Does this make sense, or should they expand their search?
101. Broad-spectrum antibiotics are effective against many types of bacteria. Narrow-spectrum antibiotics are effective against certain types of bacteria. Public health officials recommend that one way to combat antibiotic resistance is to use narrow-spectrum antibiotics whenever possible. Do you think the use of narrow-spectrum antibiotics instead of broad-spectrum antibiotics could slow the evolution of antibiotic-resistant bacteria.

Readiness Assurance Test (1)

Readiness Assurance Test

Interactive

If you have a good handle on this chapter, if you really do, then to score 7 out of 10 on this RAT. If you score less than 7, you need to review before moving on.

Choose the BEST answer to each of the following:
10 questions

1. 1.

When Stanley Miller and Harold Urey built their model of which of the following formed spontaneously?

complex organic molecules

Correct.

Press enter after select an option to check the answer

oxygen

Incorrect.

Press enter after select an option to check the answer

living cells

Incorrect.

Press enter after select an option to check the answer

viruses

Incorrect.

Press enter after select an option to check the answer

Chapter 18

Diversity of Life on Earth



18.1 Classifying Life 

18.2 The Three Domains of Life 

18.3 Bacteria □

TECHNOLOGY: *Bacterial Clean-Up Crews* □

18.4 Archaea □

18.5 Protists □

18.6 Plants □

SCIENCE AND SOCIETY: *Ethnobotany* □

INTEGRATED SCIENCE 18A: PHYSICS AND CHEMISTRY

Moving Water Up a Tree □

18.7 Fungi □

18.8 Animals □

INTEGRATED SCIENCE 18B: EARTH SCIENCE

CHEMISTRY: *Coral Bleaching and Ocean Acidification*

SCIENCE AND SOCIETY: *Disappearing Insects* □

HISTORY OF SCIENCE: *Classifying the Platypus*

INTEGRATED SCIENCE 18C: EARTH SCIENCE

the Male Turtles? □

INTEGRATED SCIENCE 18D: PHYSICS: *How Big*

18.9 Viruses and Prions

THE SLENDER loris is one of about 1.5 million species named and described on Earth. But scientists estimate that there are home to as many as 2 billion species in all. Earth's living organisms show remarkable diversity in their adaptations and ways of life. What are the major groups of living things? Is it true that life on Earth could exist without that tiniest of life forms—bacteria? Why do some flowers smell sweet, while others smell like, well . . . a dead horse? Can insects ever produce a 10-foot mosquito? And are there really thousands of species of dinosaurs flying around on Earth today? Read on to explore the diversity of life.

18.1 Classifying Life

Learning Objective

Describe how biological classification relies on relationships among species.

Imagine having 1.5 million books, or 1.5 million socks. You need some way to organize them! In biology, the 1.5 million species are also organized using a classification system.

Linnaean Classification

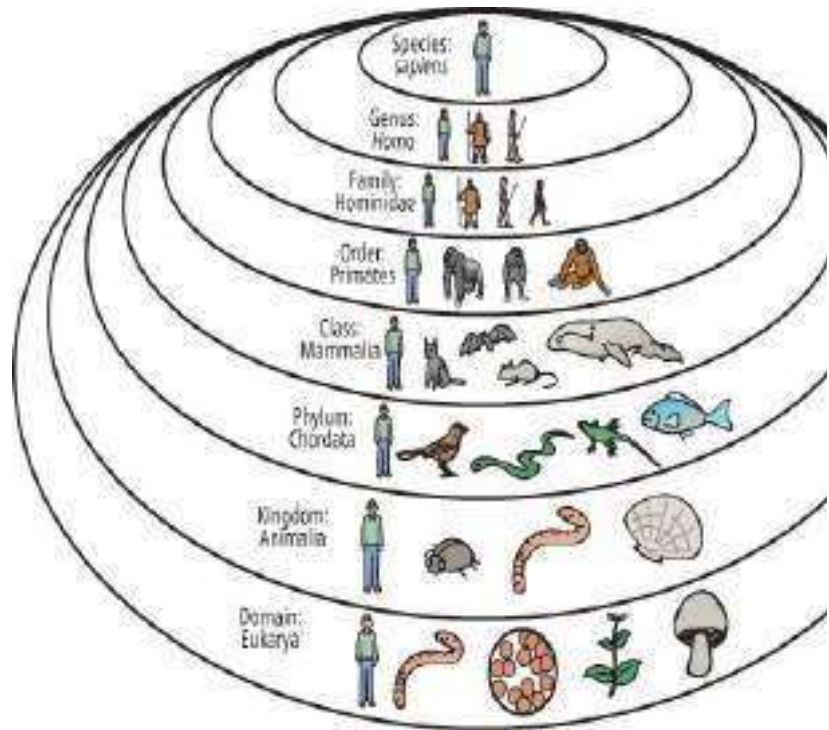
The biological classification system used today was developed by Swedish naturalist Carolus Linnaeus in the 18th century. His system divides species into groups based on their similarities.

Under the Linnaean system, all living things are divided into three domains. Each domain is divided into different kingdoms. Each kingdom is divided into different phyla. Each phylum is divided into different classes. Each class is divided into different orders. Each order is divided into different families. Each family is divided into different genera. Each genus is divided into different species.

into different families. Each family is divided into different genera, and each genus includes one or more different species.

Figure 18.1 shows the classification of humans. Humans belong to the domain Eukarya, which includes all eukaryotes. This domain includes animals, plants, fungi, and many other living things. Humans belong to the kingdom Animalia, which includes all animals. We are in the phylum Chordata, which includes the vertebrates and a few other groups. We are in the class Mammalia, which includes all mammals. We are in the order Primates, along with monkeys, apes, lemurs, and tarsiers. We are in the family Hominidae, which includes humans and extinct human relatives. We are in the genus *Homo*, which includes humans and our closest fossil relatives. Finally, our species is *Homo sapiens*.

Figure 18.1



In the Linnaean classification system, humans belong to Eukarya (eukaryotes), kingdom Animalia (animals), phylum Chordata (chordates), class Mammalia (mammals), order Primates (primates/apes), family Hominidae (humans and some of our extinct relatives), genus *Homo*, and species *sapiens*.

Mnemonics are little sayings that help people remember things. You can use this mnemonic to remember classification in the Linnaean system: In his domain, Phillip called the class to order—the family genus speak.

In addition to his system of classification, Linnaeus also has rules about how species are named. All species have a two-part name made up of their genus name and species name. For example, humans are *Homo sapiens* (“wise human”) and dogs are *Canis familiaris* (“intimate dog”). Genus and species names are Latin; both names are in italics with the genus name capitalized. Sometimes the genus name is abbreviated as a single letter, as in *H. sapiens*.

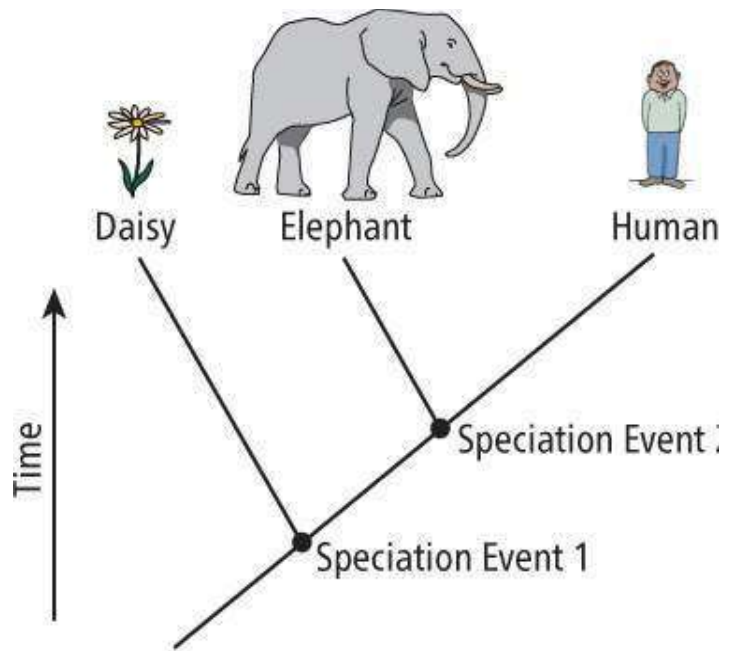
Evolution and Classification

Since Linnaeus’s time, science has expanded our understanding of the history of life on Earth. Darwin’s theory of evolution shows that the great wealth of species on Earth is the result of numerous instances of speciation followed by the independent evolution of new species. While maintaining the framework of the Linnaean classification system, biologists now classify living things based on this evolutionary history. Specifically, they group species together based on how they are related to one another, rather than on how “similar” they are. How does this work?

Biologists use diagrams called evolutionary trees ⁱ to show evolutionary relationships among a group of species.

A simple evolutionary tree is shown in **Figure 18.2** [□]. The tree shows three species—daisies, elephants, and humans. Notice the first Speciation Event 1. Up until the time specified by this event, daisies, elephants, and humans had a shared history. Then a speciation event occurred, producing two separate lineages. (A *lineage* is a line of descendants from an ancestor.) One of the lineages eventually gave rise to daisies (and many other species, which are not shown). The other lineage eventually gave rise to humans and elephants (and many other species not shown). At a later point in time, a second Speciation Event 2 occurred, splitting the lineage that led to elephants from the lineage that led to humans. This evolutionary tree tells us that, because humans and elephants split from each other more recently than they split from daisies, humans and elephants are more closely related to each other than to daisies. Therefore, humans and elephants should be classified together, and daisies should be classified separately. This is exactly what we do when we classify organisms. Humans and elephants are *animals* but daisies are *plants*.

Figure 18.2



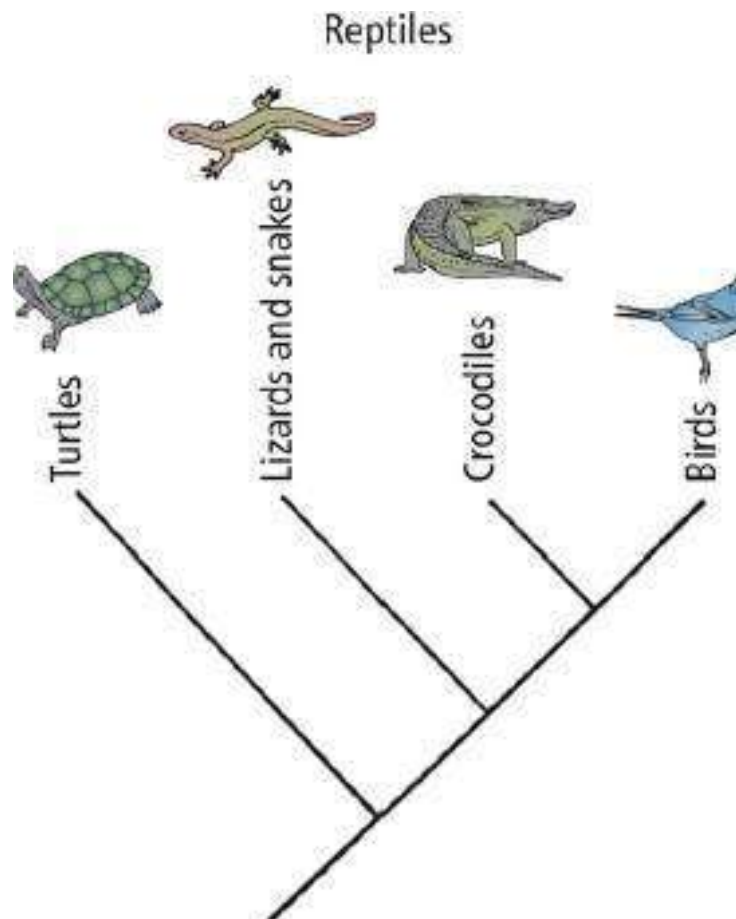
An evolutionary tree shows how species or other biological groups are related. This evolutionary tree for humans, elephants, and daisies shows that humans and elephants are more closely related to each other than either is related to daisies.

Many traditional biological groups already satisfy these criteria. These groups already divide up living things in a way that is consistent with their evolutionary relationships. Familiar groups such as animals, birds, mammals, and amphibians remained the same when classification systems changed to incorporate evolutionary relationships.

However, other traditional biological groups have required rethinking. One such group is the reptiles. The reptiles

included turtles, lizards, snakes, and crocodiles. Birds were a separate group. Turtles, lizards, snakes, and crocodiles were grouped together based on shared features such as “cold-blooded” and possession of scales. Birds were placed in a different group because they are “warm-blooded” and have feathers. However, the evidence from the reptiles in **Figure 18.3** shows that birds actually rebranch within the reptiles. This means that birds must be considered reptiles too.

Figure 18.3



This evolutionary tree shows that birds are nested with reptiles. This means that they must be considered reptiles also.

But how do scientists construct the evolutionary trees based on? Biologists use fossils as well as information on behavior, and genetics of existing species to reconstruct relationships. DNA sequences have proved to be a part source of information.*

It is also important to remember that biological classification work in progress. As biologists learn more about the evolution they sometimes need to draw new evolutionary trees. Changes to reflect this new understanding of species relationships

Unifying Concept

The Scientific Method [Section 1.3](#) 

Check Yourself

Interactive

Question 1

Check Answer

Question 2

Check Answer

Question 3

Check Answer

Question 1

The scientific name of the endangered orangutan of Sumatra is is its genus name? Its species name?

Check Answer

The scientific name of the endangered orangutan of Sumatra is is its genus name? Its species name?

Answer: The genus name is *Pongo*; the species name is *abelii*.

Question 2

Birds aren't just reptiles—they're dinosaurs! This birds are nested within the dinosaurs also, which them dinosaurs too. So, dinosaurs didn't *all* go e survived, and they are certainly alive and well toc nearly 10,000 known species.

* DNA can also provide information about how long it has been since par organisms split off from one another. This is possible because certain gen *clocks*, evolving (accumulating changes in their DNA sequence) at a fairly By looking at how much the DNA sequence of a gene differs between twc can estimate how long ago the organisms diverged. Multiple genes, as we the fossil record, can be used to help estimate divergence times.

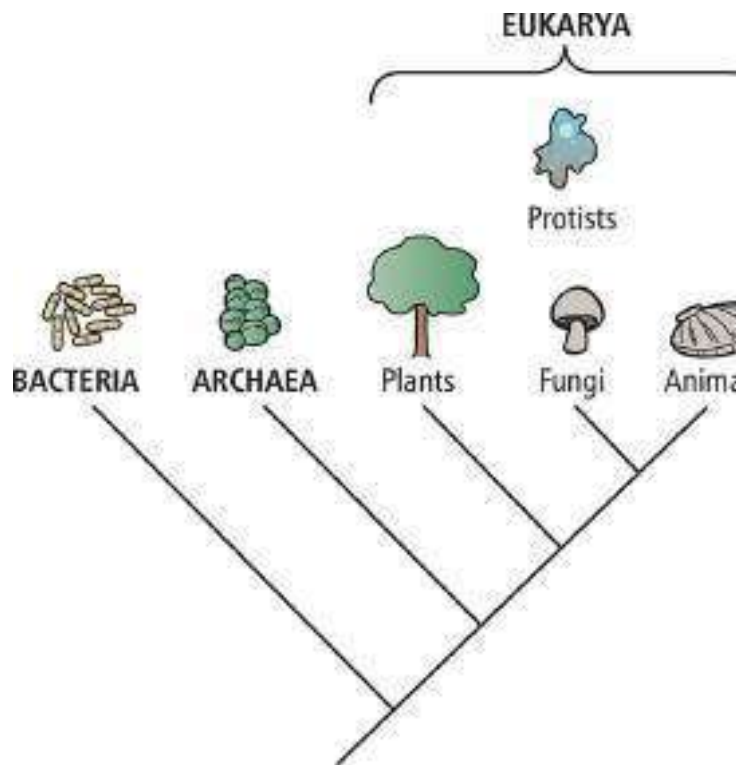
18.2 The Three Domains of

Learning Objective

Describe the key features of each domain of life.

Life is classified into three domains: Bacteria, Archaea, and Eukarya. In the history of life—probably 2.5 to 3.5 billion years ago—organisms split into two separate lineages: one that produced Bacteria and one that produced Archaea and Eukarya (Figure 18.4).

Figure 18.4



The three domains of life are Bacteria, Archaea, and Eukarya. Eukarya includes Plants, Fungi, Animals, and Protists. Protists are on the tree because the group includes many separate lineages that do not have a clear place to go. (Protists would have to be drawn “twigs” in various spots within Eukarya.)

Bacteria and Archaea consist of prokaryotic organisms, whose cells do not have a nucleus. Eukarya includes all eukaryotic living things whose cells have a nucleus. The domain Eukarya is divided into four kingdoms: Protists, Plants, Fungi, and Animals.

Table 18.1 shows some key characteristics of each group, whether species are prokaryotic or eukaryotic, whether single-celled or multicellular, and how species obtain nutrition. Some species obtain energy and organic molecules from other living organisms, while others, like plants, obtain energy from sunlight. Some species, like plants and other animals do today. **Autotrophs** convert inorganic carbon into food and organic molecules. Plants are autotrophs.

Table 18.1 Key Characteristics of the Major Groups

Group	Type of Cells	Single-Celled or Multicellular	Way of Nutrition
Bacteria	Prokaryotic	Mostly single-celled	Heterotrophic or autotrophic
Archaea	Prokaryotic	Single-celled	Heterotrophic or autotrophic
Eukarya			
Protists	Eukaryotic	Single-celled or multicellular	Heterotrophic or autotrophic
Plants	Eukaryotic	Multicellular	Autotrophic
Fungi	Eukaryotic	Single-celled or multicellular	Heterotrophic
Animals	Eukaryotic	Multicellular	Heterotrophic

The Protist kingdom is problematic because it includes aren't plants, animals, or fungi—that is, it's a hodgepodge that represent many separate lineages. Amoebas, kelp, and protists, although they have little in common besides that they are eukaryotes. Until a more accurate classification emerges, we are stuck with the group *Protists*.

Check Yourself

Interactive

Question

Check Answer

Question

Are humans more closely related to bread mold or to cherries?

Check Answer

Are humans more closely related to bread mold or to cherries?

Answer: Humans are animals, bread mold is a fungus, and cherries are plants.

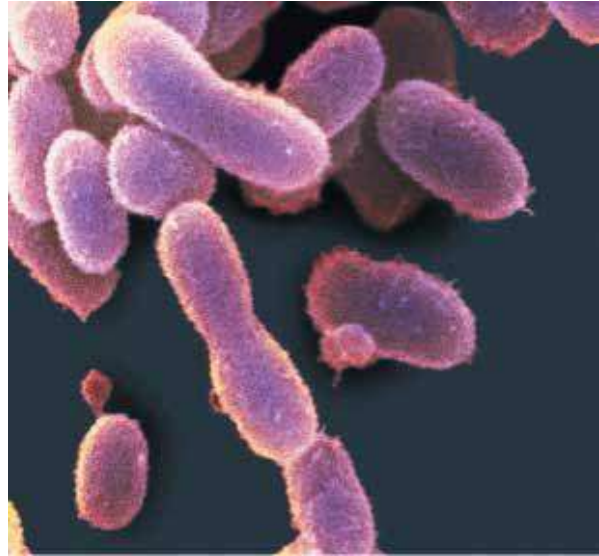
18.3 Bacteria

Learning Objective

Describe the key features and ecological significance of bacteria.

They live on your body by the trillions, occupy habitats where few other organisms can survive (Figure 18.5), and devastate humans with diseases such as plague and tuberculosis. Yet life could not quickly end without them. *They* are bacteria, one of the most ancient lineages on Earth. Earth's oldest fossils, 3.5 billion years old, are bacteria.

Figure 18.5



Bacteria can live in habitats where no other organisms could. Tiny bacteria were found in a 120,000-year-old ice core beneath a glacier in Greenland. They live in a habitat with low temperatures, high pressure, and little oxygen or nutrients.


Bacteria are prokaryotes so diverse that it is hard to make generalizations about them. Some bacteria are autotrophs like plants, make their own food through photosynthesis. Others are chemoautotrophs that make food using chemical energy instead of energy from sunlight. Still others are heterotrophs that eat organic matter. Heterotrophic bacteria are so diverse in their diets that just about any type of organic molecule is food for some bacteria. Most bacteria are single-celled, but others form large clusters. Bacteria come in varied shapes, including spheres, rods, and spirals. Many can move by using whiplike structures called flagella.

Bacteria typically reproduce asexually by dividing. However, they can also exchange genetic material at least occasionally—when they take up small pieces of naked DNA from the environment, when bacteria take up DNA from dead cells, or when bacteria inadvertently transfer DNA between organisms, or when they form biofilms and join together and one passes DNA to the other. Under ideal conditions, bacteria can divide very quickly, as often as every 20 minutes. This allows bacterial populations to grow rapidly when conditions are good. In poor conditions, many bacteria form spores, tough, thick-walled structures that stay dormant until conditions improve.

Technology

Bacterial Clean-Up Crews

In 2010, the Deepwater Horizon offshore oil-drilling rig collapsed in the Gulf of Mexico. The result was the worst marine oil spill in history—more than 5 million barrels of oil escaped the well. The response workers and volunteers tried to contain the spill, but it was too late. They tried to burn it away, but they also tried to use living organisms that would ultimately deal with the spill. Bacteria. All oceans have natural communities of bacteria that can consume oil. Dozens of species feed off the hydrocarbons in oil.



oil, consuming oxygen and releasing carbon dioxide as a byproduct of the process. After the Deepwater Horizon spill, scientists observed a 30% decrease in oxygen levels in Gulf waters, and many types of bacteria were hard at work.

The use of living organisms to clean up polluted soil and water is called *bioremediation*. Bioremediation has been around for a long time—for example, bacteria have been used for many years to decompose human wastes in sewage treatment plants. But scientists are realizing that with proper management, bacteria can be remarkably effective at cleaning away a variety of messes, everything from oil spills to hazardous waste.


In the case of oil spills, the application of chemical dispersants may aid bacteria in their work. Dispersants break up oil slicks into smaller droplets so that it is easier for bacteria to reach the oil. However, the use of dispersants is controversial because they are toxic to humans and other species. Some dispersants may also harm the bacteria they are trying to help. Scientists have also tried to develop genetically engineered bacteria that can consume oil more efficiently. So far, though, no g

engineered strain can match the capabilities of naturally occurring species.



Chemical dispersants are spread over an oil slick following the Deepwater Horizon explosion. The dispersants break the slick into smaller droplets, making it easier for bacteria to consume the oil.

What about nuclear waste? Can bacteria help us clean it up? A remarkable answer is yes. Some unusual bacteria called *Geobacter* attach to the radioactive uranium in nuclear waste. *Geobacter* bacteria use long extensions called pili to pull energy from the waste, which simultaneously prevents the waste from escaping into groundwater. Some researchers



hoping to genetically engineer *Geobacter* strains which could make them even better at cleaning up

Life on Earth would be impossible without bacteria because of their important role in *decomposition*, the breaking down of complex organic matter. Without bacterial decomposition, carbon would stay trapped in organic matter, all the carbon dioxide in the atmosphere would eventually be used up, and photosynthesis would stop. Bacteria also cycle other nutrients on Earth; some bacteria fix nitrogen from its inorganic atmospheric form to varieties that can be used by other organisms.

Countless bacteria live in and on our bodies, particularly in the mouth, respiratory tract, and intestines. A few are potentially harmful, but others benefit us by producing antibiotics, keeping more dangerous bacteria from invading our bodies, and used to make foods such as cheese and yogurt, and some genetically engineered strains produce human insulin and other important molecules. Of course, other bacteria cause diseases, including

tuberculosis, syphilis, and Lyme disease. The development of substances that kill bacteria, was a huge step forward in

Most bacteria are very small. However, a few are large enough to see with the naked eye! The largest bacteria known are *Thiomargarita namibiensis*, whose name means “sulfur pearls of Namibia.” (Discovered in Namibia in long strands like strings of pearls.) These giant bacteria are about the size of the period at the end of this

Check Yourself

Interactive

Question

Check Answer

Question

Some people get yeast (fungal) infections after taking antibiotic

Check Answer

Some people get yeast (fungal) infections after taking antibiotic

Answer: Antibiotics kill “bad” bacteria as well as the normal “

18.4 Archaea

Learning Objective

Describe the key features and ecological significance of archaea.

Once considered a group of funny-looking bacteria, **archaea** (pronounced “arc-kee-uh”) are now recognized as a distinct domain of prokaryotic organisms more closely related to eukaryotes than to bacteria. Key features of archaean genetics in particular link archaea to eukaryotes: their ribosomes are like those of eukaryotes, their genes are organized like those of eukaryotes, and their DNA is associated with histone proteins, like that of eukaryotes.

Many archaea are adapted to extreme environments, such as deep-sea hydrothermal vents or the scalding waters of hot springs and hydrothermal vents (Figure 18.6). These archaea are called “extremophiles” because they live in extreme conditions. Biologists are interested in extremophiles because they provide clues about what the earliest life forms were like. For example, certain archaea thrive in hydrothermal

habitats deep in the oceans, where life may have first evolved. Some archaea obtain energy from a chemical that is abundant in hydrothermal vents: hydrogen sulfide, and form the basis of remarkable vent communities that are entirely independent of sunlight.

Figure 18.6



Large colonies of extremophile archaea—the orange and red structures—live in the scalding waters of this Nevada geyser.

Not all archaea are extremophiles, though—many live in more moderate places. Some are found in the open ocean, and others live in

tracts of termites, cows, and other herbivores. These animals have digestive systems that hosts digest plant material, and they release methane as a byproduct. In fact, because methane is a powerful greenhouse gas, the billions of cows, sheep, and other livestock contribute significantly to global warming.

18.5 Protists

Learning Objective

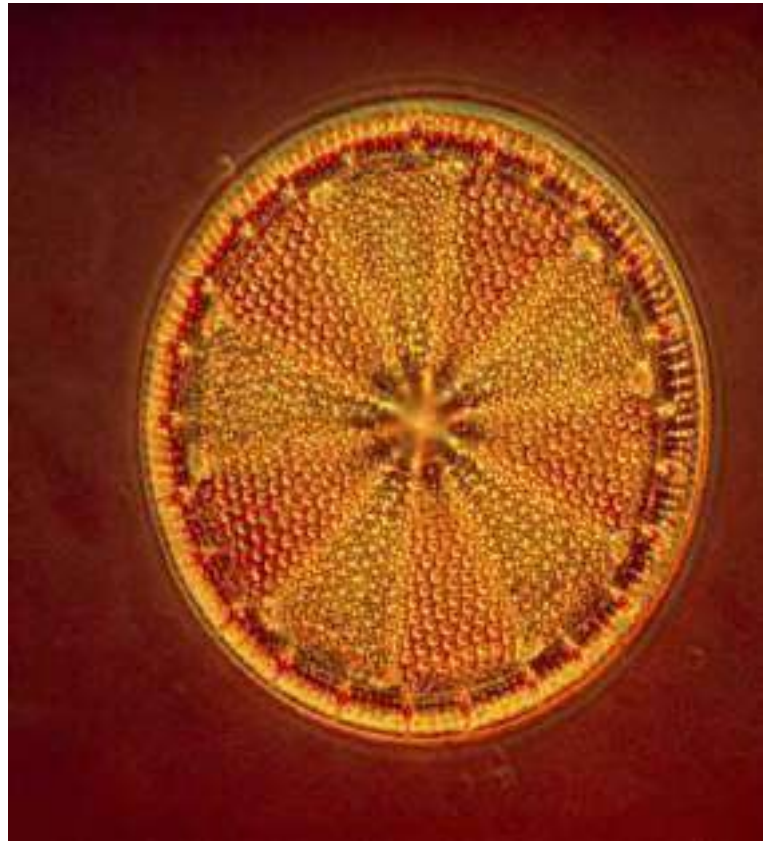
Describe the key features and ecological significance of protists.

Eukaryotes that are not plants, animals, or fungi are in a group called **Protists**. This group includes autotrophs and heterotrophs, even species that use both strategies to obtain nutrition. Protists can be single-celled or multicellular. Certain protists, like slime molds, are actually somewhere between single-celled and multicellular. Some protists can change from one condition to the other during the course of their life cycle. Protists reproduce asexually, but others use sexual reproduction. Protists currently includes many separate lineages, so the process of splitting it into separate groups.

Many protists are autotrophs that get their food from photosynthesis. *Diatoms* are single-celled protists that float in the open ocean and perform most oceanic photosynthesis and are a critical part of marine food chains. Diatoms have elaborate shells made of silica.

18.7). These shells are sometimes used in human-made products. For example, they provide the gritty texture of some toothpaste.

Figure 18.7



This microscopic view of a diatom shows its silica shell.

Dinoflagellates are another group of single-celled marine organisms. Some dinoflagellates are autotrophs, and others are heterotrophs. When sunlight and nutrients are plentiful, dinoflagellate populations can explode, producing "red tides." Believe it or not, the disc

gives red tides their name is caused by the huge number of dinoflagellates in the water! Red tides aren't always red, though. They can be purple, green, orange, brown, or blue, depending on the species of dinoflagellate that is responsible. Some red tides are toxic; shellfish that eat the contaminated dinoflagellates become contaminated and poisonous to humans.

Some photosynthetic protists are multicellular and can form large, complex structures. For example, all the different kinds of seaweeds are produced by multicellular algae. They form huge oceanic forests that are home to many unique species (Figure 18.8). Red algae are the source of some of the seaweeds, including Japanese nori. Green algae are a group of multicellular protists that likely gave rise to terrestrial plants.

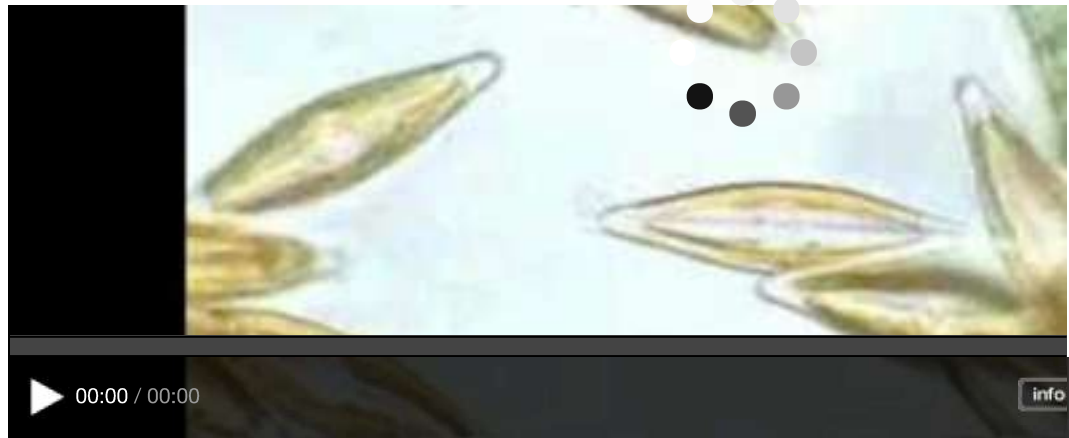
Figure 18.8



Kelp forms marine “forests” that are home to diverse species. This forest is off the West Coast of the United States.

Watch Diatoms Moving





Watch Dinoflagellates



Heterotrophic protists are typically active, single-celled organisms that lack a cell wall and special cell vacuoles for digesting prey. *Amoebas* move by

of their body forward and then pulling the rest of the body forward (Figure 18.9). The extensions are called pseudopodia (“false feet”) and they surround and engulf their prey. *Ciliates* move by beating hairlike projections called cilia. *Flagellates* move by whipping their flagellum. Both ciliates and flagellates have openings that serve as “mouths.” One group of flagellates, called the choanoflagellates, gave rise to animals.

Figure 18.9



This freshwater amoeba feeds on bacteria and smaller protists. It uses its pseudopodia to move as well as engulf food.

Watch *Paramecium* Cilia





Watch *Paramecium* Vacuole

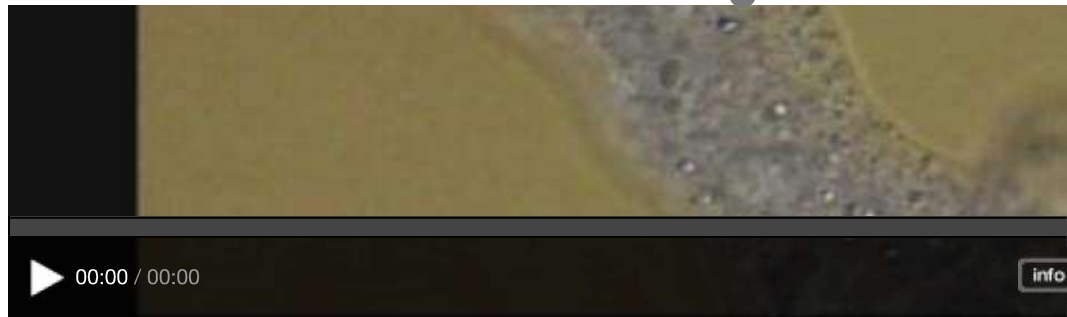


Watch Amoeba



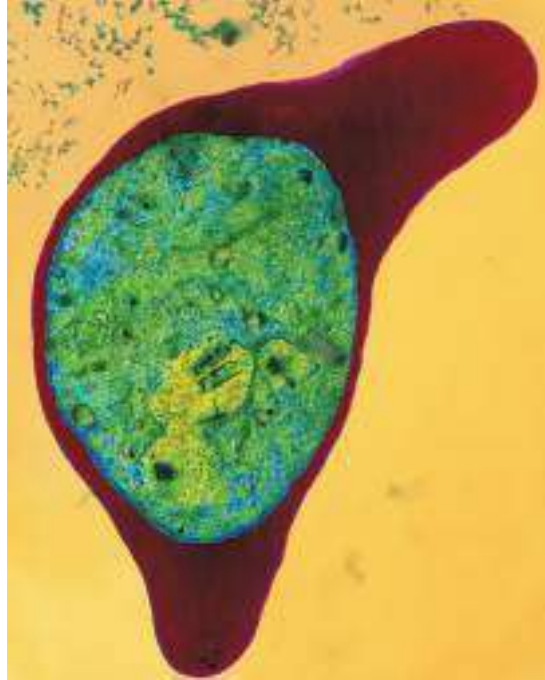
Watch Amoeba Pseudopodia





Protists cause a number of serious human diseases, including African sleeping sickness, and amoebic dysentery. Malaria is caused by *Plasmodium* protists that divide their life cycle between humans and mosquitoes. Humans contract the disease when infected mosquitoes bite them. The protists then move into our red blood cells (RBCs) and reproduce in huge numbers. The synchronized emergence of the protists from host red blood cells causes chills, fever, and vomiting.

Figure 18.10



This misshapen red blood cell has been infected by the protist *Plasmodium* (shown in green).

18.6 Plants

Learning Objective

Describe the key features and ecological significance of the major groups of plants.

Photos of Earth from space show large green patches stretching across wide areas of the continents. Much of Earth's land surface is green because it is covered with plants. **Plants** are terrestrial autotrophic eukaryotes that obtain energy through photosynthesis. They are green because they contain chlorophyll, a pigment used in photosynthesis.

Plants have a variety of adaptations for living in terrestrial environments. Roots anchor them to the ground and absorb water and nutrients from the soil. Shoots, the stems and leaves of a plant, conduct photosynthesis. The leaves of plants have a large surface area for catching light energy. The powers photosynthesis. Carbon dioxide, which is also used in photosynthesis, diffuses from the air into leaves through small openings called *stomata* (Figure 18.11).

Unifying Concept

The Second Law of Thermodynamics [Section 6.5](#)

Figure 18.11



Stomata are tiny pores in plant leaves that allow carbon dioxide to enter and oxygen to exit. You can see several stomata in this magnified image of

Most plants also have a *vascular system*, a sort of plant “system” that distributes water and other resources. The

system consists of two types of tissue: xylem and phloem. The xylem is made up of dead, tube-shaped cells through which water and minerals move up from the roots. The phloem consists of living cells that transport sugars produced during photosynthesis down from the leaves. The fluid that flows in a plant's vascular system is known as *sap*. You may be familiar with maple syrup, which is made by boiling the sap collected from the vascular systems of maple trees.

Plant reproduction occurs through an *alternation of generations*. The life cycle alternates between a haploid stage called a *gametophyte* and a diploid stage called a *sporophyte*. You may remember that haploid cells contain a single set of chromosomes, whereas diploid cells contain two sets of chromosomes. The details of this life cycle vary among the three major groups of plants—mosses, ferns, and seed plants.

Mosses

Mosses are small plants with simple leaves and no vascular tissue. They often grow in dense clumps in bogs, forests, and other moist habitats (Figure 18.12). Mosses are restricted to moist habitats for several reasons. First, because mosses do not have a vascular system, every part of a moss plant must obtain water directly from the environment.

environment through diffusion. Second, male and female usually separate, and during reproduction, sperm must reach the female plant through a film of water in the environment.

Figure 18.12



Mosses growing in the forest understory in Great Smoky Mountains National Park, Tennessee.

Mosses are unique among plants in that the gametophyte is larger than the sporophyte. When you see a moss in the forest

at a haploid gametophyte.

Ferns

Ferns are seedless plants with distinctive feathery leaves found in the forest understory, where they thrive in the trees (Figure 18.13). Unlike mosses, ferns have a vascular system for transporting water and nutrients. However, ferns are still dependent on water for reproduction because their sperm swim through the environment to fertilize the egg. Because of this, ferns can live only in moist habitats. In ferns, the sporophyte is much larger than the haploid gametophyte. When you see a fern in the forest, you are looking at a diploid sporophyte.

Figure 18.13



Ferns grow in Muir Woods National Monument in California.

Seed Plants

Seed plants are the largest group of plants by far. Two key plant reproduction have made these plants successful in land habitats: pollen and seeds. **Pollen** consists of many grains, each of which is a male gametophyte wrapped in a protective coat. The male gametophyte produces the sperm used in reproduction. Sperm can be transported to female gametophytes, which produce eggs, or (as we will see) by animals. Because the sperm of seed plants do not have to swim through the environment to fertilize eggs, they are not restricted to moist environments.

Seed plants also make seeds. The fertilized eggs of seed plants are small embryos that are encased in a tough outer coating that provides a nutrient supply—this entire structure is a seed. Seeds can survive in a dormant state until environmental conditions are appropriate for germination. This is why many seeds do not sprout until you plant them in soil. All the seed plants you see are diploid sporophytes.

The two main groups of seed plants are conifers and flowering plants. *Conifers* include plants such as redwoods, pines, cedars, and firs. They have waxy, needlelike leaves and reproductive structures called cones (Figure 18.14). Male cones release pollen, and then wind carries the pollen to female cones. Because wind blows pollen all over the place, conifers make large amounts of pollen—this makes it more likely that some of the pollen will reach female cones. Fertilization occurs in the female cones, which eventually drop the mature seeds.

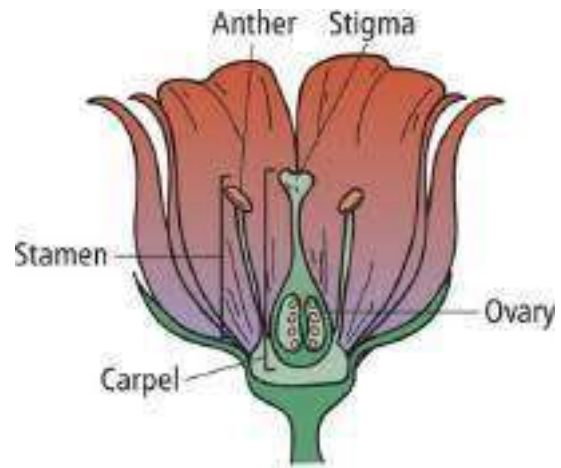
Figure 18.14



Conifers are seed plants with reproductive structures called cones and seeds from a Sequoia redwood.

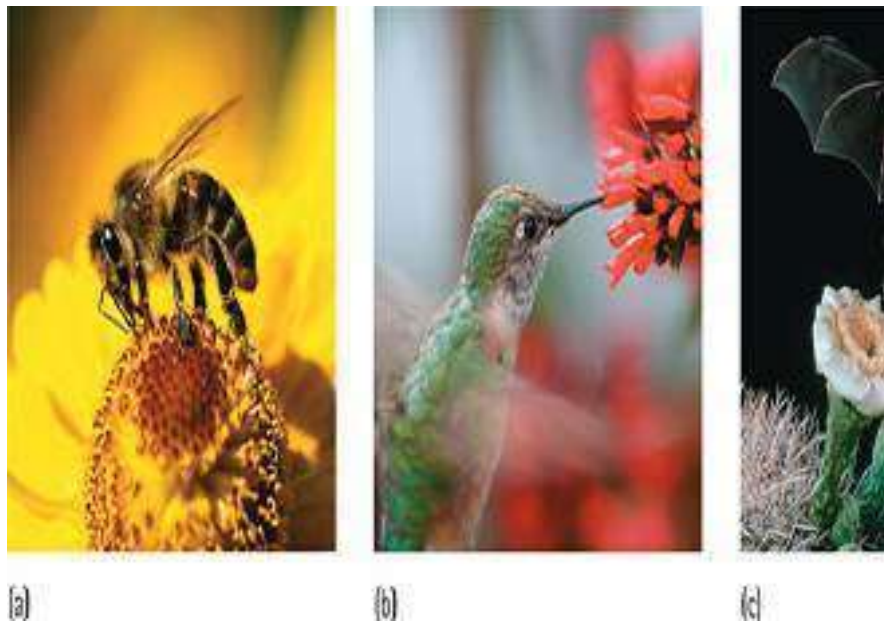
Flowering plants are the largest and most successful group of plants. Flowering plants have two important features absent in nonflowering plants: a **flower** and fruit. A **flower** functions in reproduction—it contains the male and female reproductive structures that produce pollen and the female structure that produces eggs (Figure 18.15). The *stamen* is the male reproductive structure. It consists of a stalk capped with an *anther* where pollen is produced. The *carpel* is the female reproductive structure. It includes an ovary where eggs develop and a stalk capped by the *stigma*, a sticky surface that traps pollen. In many flowering plants, insects or other animals transfer pollen from one flower to another. The petals, scent, and color of flowers have evolved to attract specific animal pollinators, and their pollinators can be so perfectly suited to each other that they often look at one and predict features of the other. For example, Charles Darwin studied a night-blooming orchid in Madagascar and predicted that there should exist a nocturnal moth with a proboscis 30 centimeters long. Forty years later, that moth was finally discovered. Figure 18.16 shows more examples of flowers and their pollinators.

Figure 18.15



Flowers contain the reproductive structures of flowering plants.

Figure 18.16



Many flowering plants are pollinated by insects or other animals. Flowers pollinated by bees are often blue or yellow, the

best. Bee-pollinated flowers may also give off a pleasant fragrance to provide suitable bee landing spots. (b) Flowers pollinated by hummingbirds are often red. Hummingbirds have a poor sense of smell and the flowers they pollinate are usually odorless. Hummingbirds hover while feeding, so hummingbird-pollinated flowers may be tubular in shape. (c) Flowers pollinated by bats, which are active at night, are usually white, a color that is easy to see at night. Bat-pollinated flowers have strong odors and grow at the tops of plants for easy access.

Not all flowers smell sweet! Flowers of the “deadly nightshade” smell like rotting meat. Who are their pollinators? Bats that lay their eggs in rotting meat!

Flowering plants surround their seeds with a structure called a fruit. A fruit is an adaptation for spreading seeds. When an animal eats a fruit, the seeds pass through its digestive system and eventually are deposited far from the parent plant. Tasty fruits evolved in certain plants because animals were more likely to eat them. But not all fruits have evolved to be eaten. The burrs that catch on your socks during a hike are also fruits. They hitch a ride until you pull them off and drop them again, far from the parent plant.

Seed plants are very important to human societies. Humans use many different trees for wood, and much of our food comes from seed plants.

stems, leaves, and fruits of flowering plants.

The most massive living organism on Earth is a quaking aspen that has more than 47,000 separate tree trunks covering over 100 acres in Utah. The aspen is named “Pando”—Latin for “I spread.” Although Pando looks like a forest of separate trees, its trunks are all connected to a single enormous root system—and they all have the same DNA. Pando may be 80,000 years old or more!

Check Yourself

Interactive

Question

Check Answer

Question

Fruits are adaptations that help flowering plants spread their seeds. What is one adaptive for a plant to spread its seeds?

Check Answer

Fruits are adaptations that help flowering plants spread their seeds. What is one adaptive for a plant to spread its seeds?

Science and Society

Ethnobotany

Human societies use plants for many things, including medicine, shelter, clothing, and tools. *Ethnobotany* is the study of how people use plants. Although ethnobotany is concerned with all types of plant use, medicinal plants have always been of particular interest.

Ethnobotanical studies have resulted in the development of many important medicines. Aspirin originally came from the bark of willow trees, which has been used for thousands of years to relieve pain. Quinine, a drug used to treat malaria, comes from the bark of cinchona trees, long used in native Peru to treat fever, digestive ailments, and malaria. Artemisinin, another powerful antimalarial drug, is extracted from the sweet wormwood tree, a plant that has been used to treat malarial fevers for more than a thousand years. More recently, Madagascar periwinkle, a plant used by indigenous peoples for diabetes and other conditions, provided the basis for cancer drugs.

Scientists looking for new medicines rely on the knowledge of local healers to find promising plants. But developing drugs from medicinal plants leads to a difficult ethical dilemma: What are the rights of indigenous peoples, and how

rights be protected? The cancer drugs developed from the Madagascar periwinkle produced more than a billion dollars in profit for the pharmaceutical giant Eli Lilly, but not for the traditional societies in Madagascar. Some drug developers attempt to ensure that local peoples share in the benefits. The AIDS Research Alliance found an anti-HIV compound in a Samoan medicinal tree, the group made direct contact with the village where the tree was known and also proposed to share the profits from any drugs that are developed.



Herbs made from the sweet wormwood tree have been used to treat malaria for more than a thousand years in China. The antimalaria drug artemisinin was developed from

Unfortunately, both native plants and invaluable knowledge about them are disappearing rapidly. Native cultures are steadily lost through “modernization,” and countless species are going extinct because of habitat destruction and deforestation. One tragic consequence is that many useful plants will never be known.

Integrated Science 18A: Physics and Chemistry

Moving Water Up a Tree

Learning Objective

Explain how water moves up from a plant's roots to its shoots.

The tallest trees are as tall as 30-story skyscrapers. The highest branches and leaves need water, just like the plant. How do trees and other plants transport water?

against gravity, all the way up to their highest point. Let's take a look.

Unifying Concept

The Gravitational Force [Section 5.3](#) □

In a plant, there are continuous columns of water extending all the way through the xylem—from the highest leaves. These water molecules stick to one another as well as to the walls of the xylem. The attachment of water molecules to other water molecules is called *cohesion*. The attachment of water molecules to other molecules, such as those of the xylem wall, is called *adhesion*. Both cohesion and adhesion are the result of hydrogen bonds, which are formed between the positively charged end of one molecule and the negatively charged end of another molecule. In a water molecule (H_2O), the hydrogen ends are positively charged and the oxygen end is negatively charged.

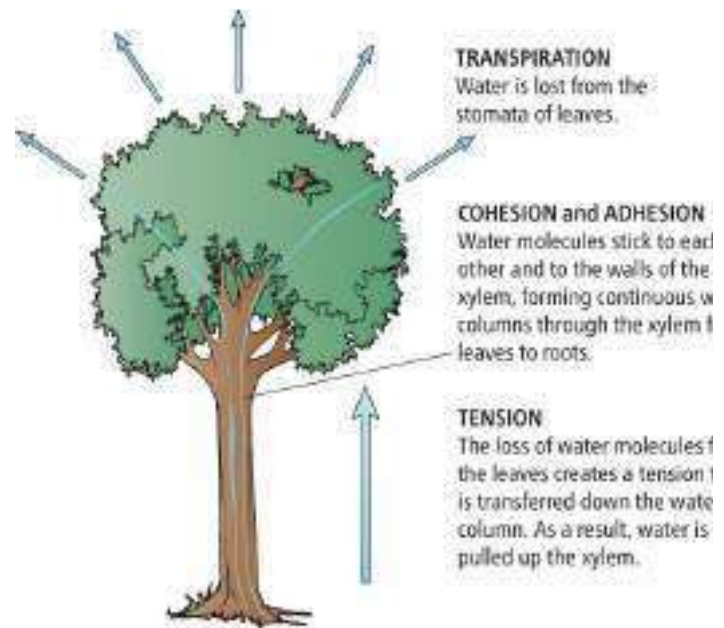
Cohesion and adhesion maintain the continuous columns of water molecules in the xylem. These water columns rise up the plant, much like the way a water column rises in a straw when you drink. How does this happen? The process starts at the leaves, when a plant loses water through

transpiration. *Transpiration* occurs when water evaporates from the moist cells inside a leaf and diffuses through stomata to the outside air. As water is lost from the leaf, tension is transferred all the way down the water column. Water molecules in the leaf pull on water molecules in the xylem, which pull on water molecules farther down and so on all the way down to the roots. Transpiration pulls water up the xylem the way sucking on a straw pulls water up the straw. This mechanism of moving water up a plant is called the *transpiration-cohesion-tension mechanism* (Figure 18.17). Not only does this mechanism move water up tall trees, it does so without any energy input from the plant!

Unifying Concept

The Second Law of Thermodynamics Section 18.2

Figure 18.17



The transpiration-cohesion-tension mechanism that plants use to move water from their roots to their shoots

The tallest tree in the world is a conifer, a c
redwood named “Hyperion.” Hyperion stands
over 115 meters tall. According to one team
of researchers, no tree can grow past a theoretical
limit of 130 meters, the height of a 35-story
skyscraper. Because of gravity and friction
between water and the vessels of a tree’s vascular
system, it would be just too hard to transpire
any higher.

Check Yourself

Interactive

Question

Check Answer

Question

Explain why plants do not need to expend energy to move water through their shoots.

Check Answer

Explain why plants do not need to expend energy to move water through their shoots.

Answer: Transpiration does not require energy from the plant.

18.7 Fungi

Learning Objective

Explain the key features and ecological significance of fungi.

When you keep a loaf of bread too long, you often end up with a fuzzy stuff called mold. Mold is a fungus, a living organism in the group Fungi. And it is doing what you once meant eating your food!

Fungi were once grouped with plants because of their life, but they are actually more closely related to animals. Fungi are heterotrophs that obtain food from other organisms. They release digestive enzymes over organic matter and then absorb the nutrients. This distinguishes them from animals, which ingest their food. Many fungi are decomposers that obtain their nutrients from dead organic material, as the fungus in Figure 18.18 is doing. Fungi, along with bacteria, are the most important organisms in terrestrial ecosystems.

Figure 18.18

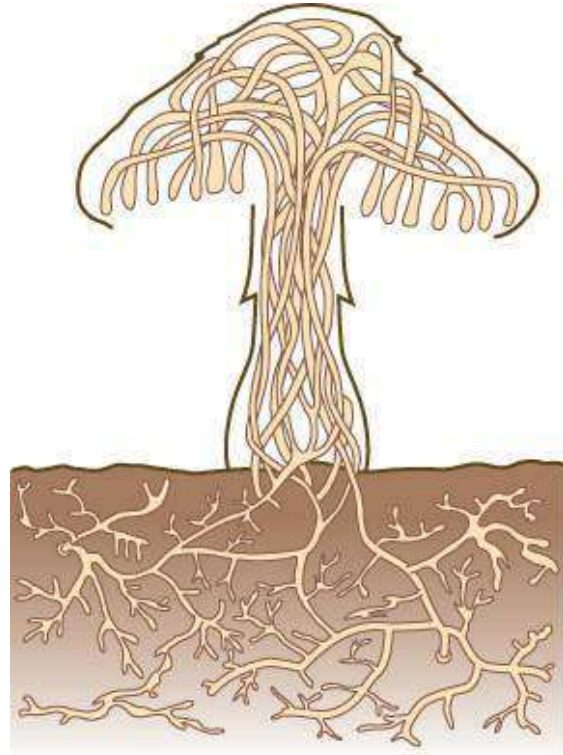


Many fungi are decomposers and obtain their nutrients from dead organic material. This fungus is growing on dead wood. The orange structures are its reproductive structures.

Some fungi, such as yeast, are single-celled organisms, while others are multicellular. Multicellular fungi are composed of bundles of threadlike filaments. Fungi may reproduce either sexually or asexually. Most species use both strategies at some point in their life cycle. Reproduction occurs through the formation of spores, tiny reproductive bodies that can exist in a dormant state until conditions are favorable for growth. Fungal spores spread far and wide mostly by air or water—this explains why mold finds your leftovers no matter how well you hide them. Mushrooms are the spore-producing structures of many fungi. Notice that what we think of as a “mushroom” is

of the entire organism. Most of the fungus actually lives
you can see in [Figure 18.19](#).

Figure 18.19

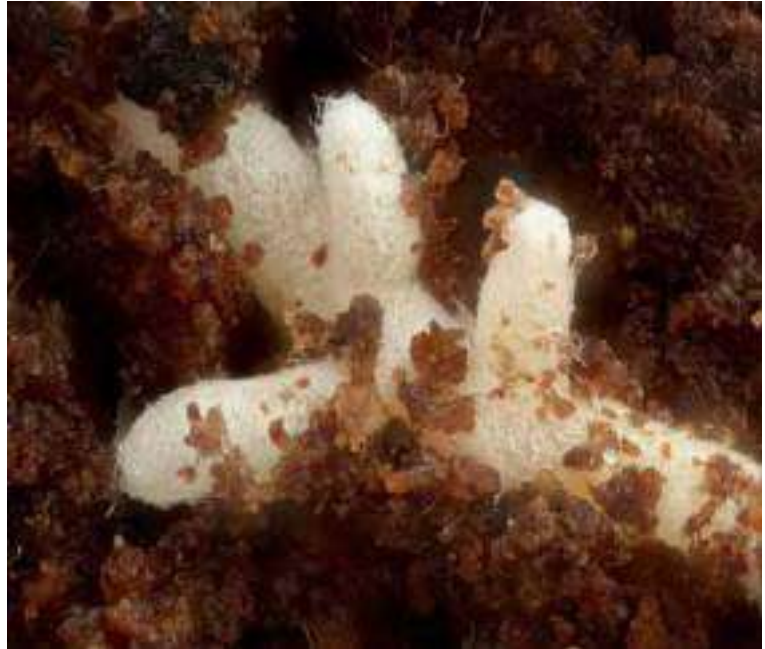


Mushrooms are spore-producing structures in certain fungi. The
organism actually lives underground.

Fungi are essential to the survival and growth of many plants. This is because in most plant species, the roots form associations with fungi. These associations, called *mycorrhizae* ("myco" means "fungus" and "rhizae" means "roots"), benefit both fungus and plant. The fungus r

from the plant while helping the roots absorb water and nutrients from the soil (Figure 18.20).

Figure 18.20



Mycorrhizae are close associations between fungi and the roots of plants. This photo shows a fungus (white) that is completely wrapped around the roots of a pine tree. This association is beneficial to both the plant and the fungus.

Pando the tree may be the most *massive* living organism on the world, but the one with the largest overall size — an underground honey mushroom in Oregon that is 5.6 kilometers (3.5 miles) across. The fungus covers more than 2200 acres! It was discovered when scientists

trying to figure out why large groves of trees were dying. The answer? The fungus was eating them.

Fungi important to humans include yeast, which is used in baking, brewing, and edible mushrooms. Fungi are also used to produce cheeses such as Roquefort and Gorgonzola (the blue spots are billions of tiny fungal spores—enjoy!). Penicillin, the first antibiotic, was originally found in a fungus. Finally, human fungal diseases include athlete's foot, ringworm, and candidiasis.

Watch *Phlyctochytrium* Zoospore Release



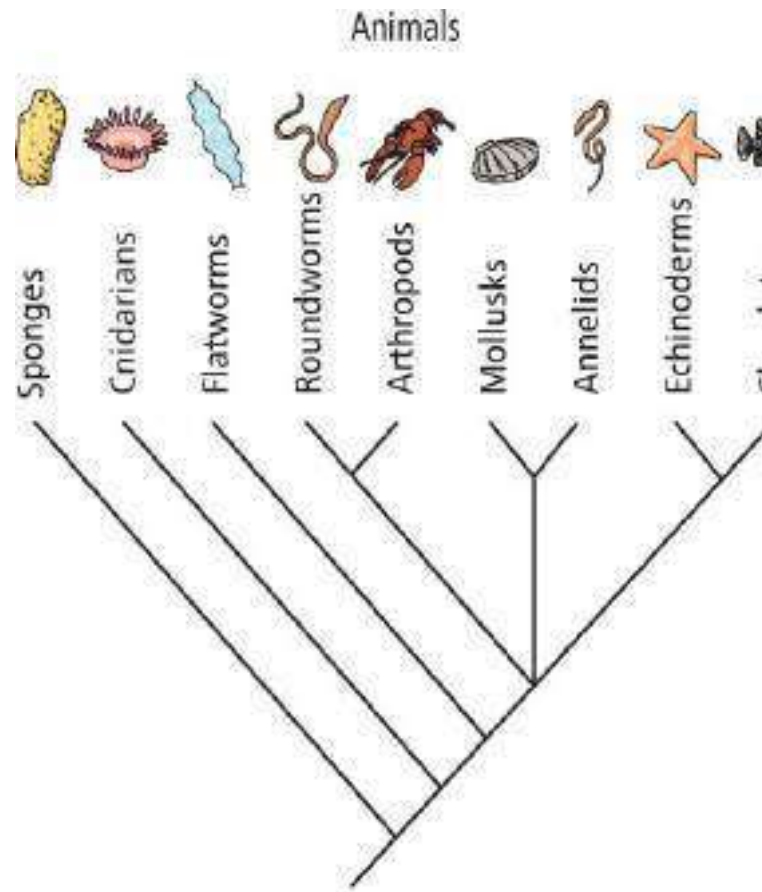
18.8 Animals

Learning Objective

Explain the key features and ecological significance of the major groups of animals.

Animals include organisms as varied as starfish, beetles, and antelope. **Animals** are multicellular, heterotrophic eukaryotes that obtain nutrients by eating other organisms. Animals ingest food into their bodies for digestion. Most animals reproduce sexually, with a diploid stage during most of their life cycle. The gametes—sperm and eggs—are the only haploid stage. Many animals go through a juvenile stage called a *larva* that is markedly different from the adult in form and function. Examples are butterfly caterpillars and frog tadpoles. Most animals have muscles for moving, sense organs for collecting information about their environments, and nervous systems for controlling their actions. The evolutionary tree in **Figure 18.21** shows a tentative hypothesis of the relationships among the major groups of animals.

Figure 18.21



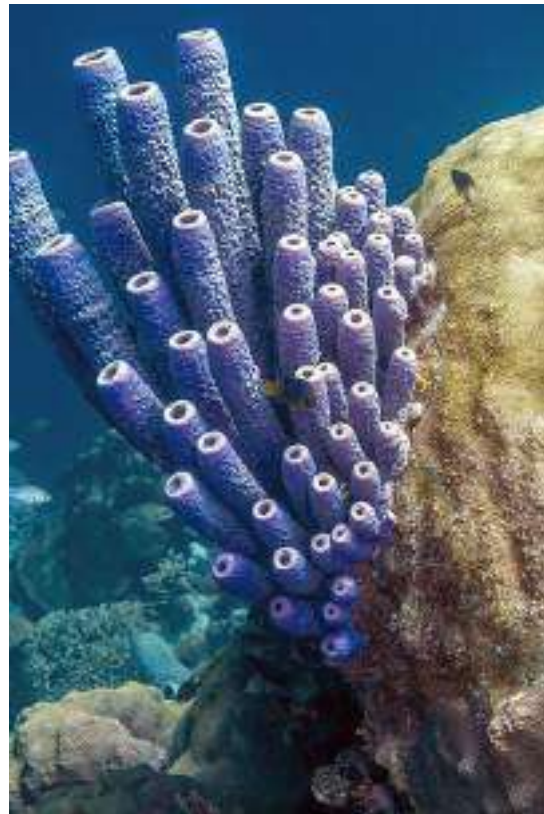
This evolutionary tree shows how the major groups of animals are related to one another.

Sponges

Sponges are sedentary marine animals (Figure 18.22). They have a tubelike shape with a large central cavity. Specialized cells in a sponge beat their flagella to produce a constant flow of water through the animal. Water enters through numerous pores, flows in

central cavity, and goes out the top. This constant current
sponge to catch food. Sponge cells trap bacteria from the
water, and then distribute the nutrients to other cells.

Figure 18.22



This is a purple tube sponge.

Sponges are the only animals that lack tissues, groups of cells
perform a certain function. This allows sponges to do unique things.
For example, if you separate a sponge's cells by passing it through a fine
strainer, the cells will reassemble themselves into a new sponge.

cells will reassemble on the other side, forming a new s
animals can do that.

Cnidarians


Cnidarians (“nye-DARE-ee-uhns”) include animals such as anemones, and corals. Unlike sponges, cnidarians have two layers: an outer layer that protects the body and an inner layer that digests food. These layers are separated by a jellylike mesoglea. Cnidarians use tentacles armed with barbed stinging cells called nematocytes. In many species, the stinging cells release powerful toxins. (A jellyfish can be a danger to ocean swimmers.) Prey are captured in a *gastrovascular cavity* that has a single opening that serves as both mouth and anus. Many cnidarians alternate between a sedentary polyp and a mobile, bell-shaped, medusa stage. Cnidarians such as anemones and corals spend most of their lives as polyps. Cnidaria such as jellyfish spend most of their lives as medusas ([Figure 18.23](#) ).

Figure 18.23



These are moon jellyfish, a species found in coastal waters around the world. The moon jellyfish is a cnidarian in its medusa form.

Unifying Concept

The Ecosystem [Section 21.1](#) 

Integrated Science 18B: Ecosystems

Science and Chemistry

Coral Bleaching and Ocean Acidification

Learning Objective

Explain how coral bleaching and ocean acidification threaten marine life.

Coral reefs are found in tropical oceans, in clear, warm waters with temperatures between 20°C and 28°C (68°F and 82°F). Coral reefs are among the most diverse ecosystems on the planet. Numerous marine species, including many important fish, spend all or part of their lives in coral reefs. Reefs also help protect shorelines from ocean waves. As humans burn more and more fossil fuels, the amount of carbon dioxide in Earth's atmosphere has increased, resulting in global warming and more acidic oceans. How has this affected coral reefs and other marine species?

Corals are cnidarians. They live in colonies of tiny polyps, each wrapped in a calcium carbonate skeleton. Unlike other cnidarians, however, corals are not hunters. They obtain most of their nutrients from the photosynthesizing dinoflagellates that live within their tissues.

that live within their cells. Coral bleaching occurs when corals kick out their dinoflagellates. The corals literally turn white because it is their dinoflagellates that give them their color (Figure 18.24). Coral bleaching is most often triggered by an increase in seawater temperature. High temperatures interfere with photosynthesis in dinoflagellates, causing them to build up in them. This in turn causes the corals to lose their color. Corals can survive for a short time without their dinoflagellates. If water temperatures decrease and the dinoflagellates move back into bleached corals, they can survive. But, if warm temperatures continue for too long, the corals starve to death.

Figure 18.24



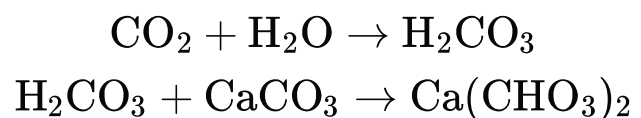
These bleached corals have kicked out their dinof

Mass coral bleaching has become common in recent years due to the high water temperatures associated with global warming. In 2016, an estimated 29% of corals in the Great Barrier Reef—the largest coral reef in the world—bleached. Bleaching was worst in the northern part of the reef, where over 70% of corals died. A second bleaching event

2017, this time striking the middle part of the reef caused another 20% of the corals to die. Overall, the reef has been affected. Unfortunately, as temperatures continue to rise, bleaching is likely to become more widespread and more severe.

Will coral reefs disappear? Corals do vary in their tolerances and in their susceptibility to bleach. For example, certain corals have special fluorescent pigments they use, like sunscreen, to shield their dinoflagellates. Fluorescent corals have survived mass bleaching better than nonfluorescent corals. But, it is uncertain how much warming coral reefs can stand.

High carbon dioxide levels also lead to ocean acidification. Atmospheric carbon dioxide (CO₂) is absorbed by the ocean where it reacts with water to form carbonic acid (H₂CO₃), which lowers the pH of the ocean while also transforming carbonate minerals, such as calcium carbonate (CaCO₃), into more soluble compounds:



Many marine animals—including corals, echinoderms, crustaceans, and mollusks—need calcium carbonate to build their shells. In addition, acidified seawater increases the rate of dissolution of their shells. For these reasons, ocean acidification causes shelled animals to grow more slowly and to have weaker shells. Scientists have observed that shell growth slows in acidified waters and that the larvae of species such as oysters and mussels are smaller. Some plants, including certain photosynthetic species, also have calcium carbonate shells. As seawater becomes more acidic, the growth of these plankton mass decreases. Because photosynthetic organisms form a crucial part of marine food chains, the consequences of ocean acidification could extend across entire marine communities.

Check Yourself

Interactive

Question 1

Check Answer

Question 2

Check Answer

Question 1

Global warming also causes sea levels to rise, mainly because s its temperature increases. How do rising sea levels affect corals

Check Answer

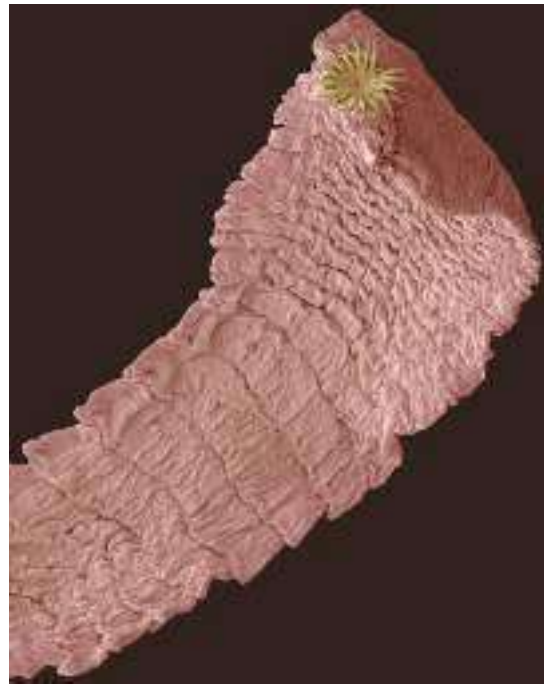
Global warming also causes sea levels to rise, mainly because s its temperature increases. How do rising sea levels affect corals

Answer: Corals are found only in clear, shallow waters, where sunlight for their dinoflagellates to photosynthesize. Rising sea corals to shift to shallower ground or to grow upward quickly Δ

Flatworms

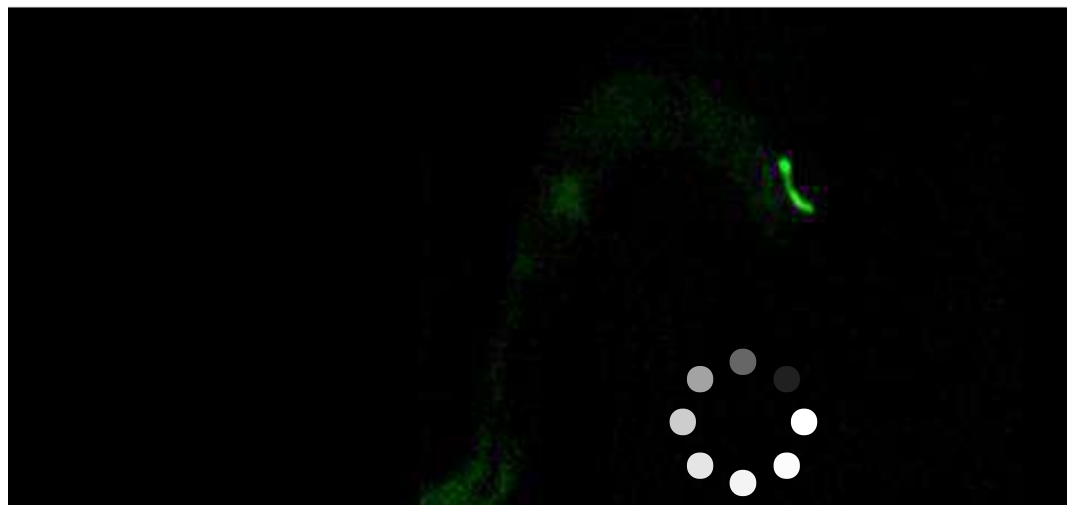
Flatworms are, as their name suggests, flat. They have d “tail” ends as well as “back” and “belly” sides. A single t serves as both mouth and anus, and an elaborately brai tract transports nutrients to the entire body. The flat sh allows oxygen to be absorbed efficiently across the skin Flatworms include many parasites as well as some nonp The most familiar flatworms are tapeworms (Figure 18. ribbonlike worms that live as parasites in the intestines other animals.

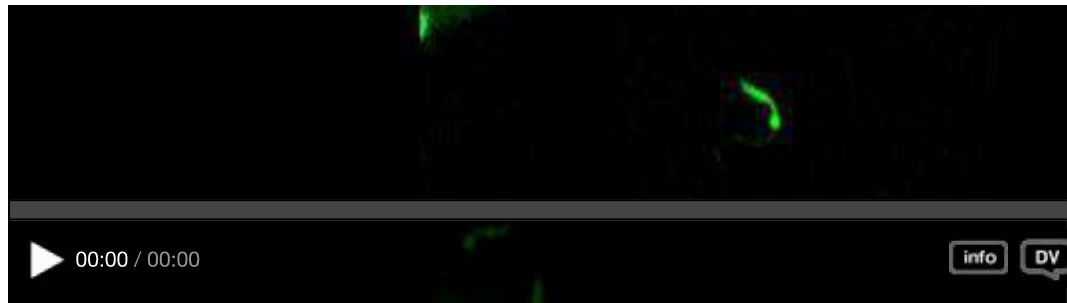
Figure 18.25



This tapeworm has hooks at its head end that help it attach to intestines.

Watch [C. Elegans Crawling](#)





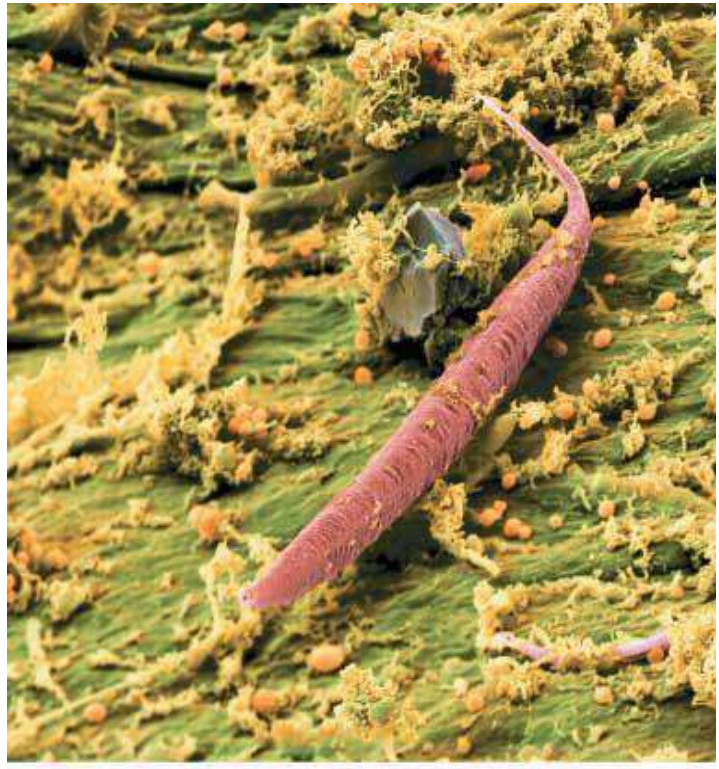
Unifying Concept

The Second Law of Thermodynamics [Section 6.5](#)

Roundworms

Roundworms (not to be confused with the more familiar earthworms) have small, slender bodies with tapered ends and a rounded head (Figure 18.26). They have both a mouth and an anus. Roundworms have a tough outer cuticle that is shed periodically during their life cycle. They eat a variety of things—bacteria, plants, fungi, other animals, and humans. Some specialize on decaying organic material. In many habitats, roundworms are important decomposers. Roundworms have muscles that contract from head to tail. As a result, these worms move like flailing snakes. Roundworms on alternate sides of the body contract. Roundworms are responsible for several human diseases, including hookworm, pinworm, and trichinosis.

Figure 18.26



A roundworm moves through rotting vegetables in a c

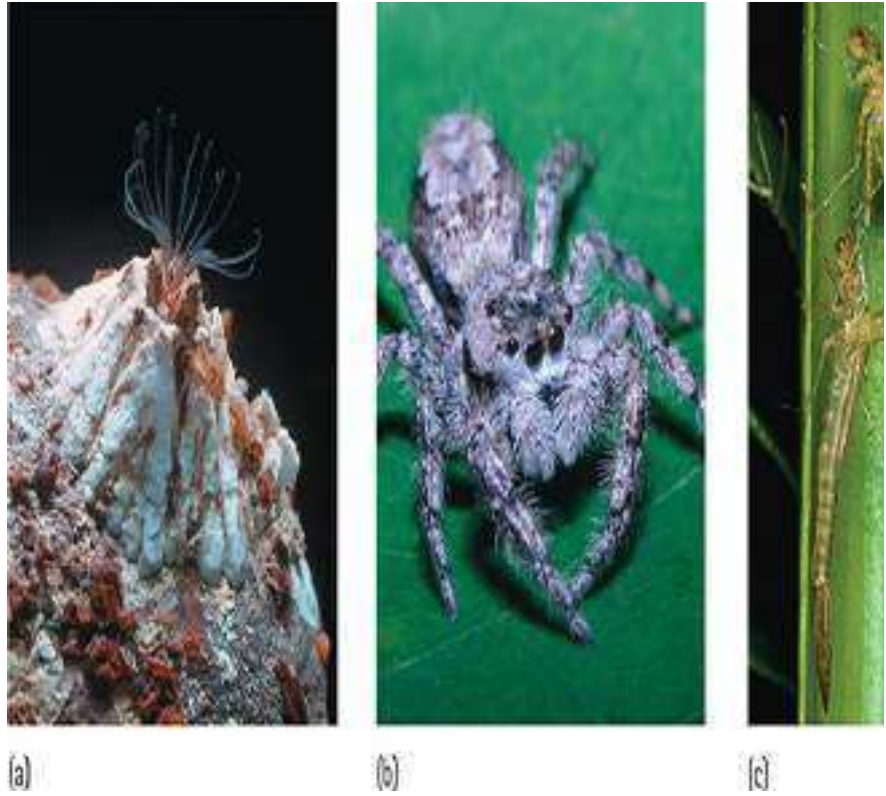
Arthropods

Arthropods include lobsters, barnacles, spiders, scorpions, centipedes, insects, and many other species. They are found in every known habitat on Earth. All arthropods have an exoskeleton called an exoskeleton ⓘ that protects and supports the body. The exoskeleton is incapable of growth and must be shed periodically.

animals grow. The bodies of arthropods are divided into segments, and their legs have bendable joints. Some have been modified during evolution to function as mouthparts or reproductive organs. Arthropods have a brain and well-developed sense organs. Many species pass through a distinct larval stage before growth and development.

The major groups of arthropods are the crustaceans, the chelicerates, and the uniramians (Figure 18.27). *Crustaceans* include species such as lobsters, crabs, shrimp, krill, and barnacles. *Chelicerates* are eight-legged animals such as horseshoe crabs, scorpions, ticks, and mites. *Uniramians* include centipedes, millipedes, and insects. Insects are the most diverse group of living animals on Earth, with more than a million known species and perhaps ten times that number waiting to be discovered. All insects have a three-body parts—a head, thorax, and abdomen—and three pairs of legs. Many also have two pairs of wings. Many insects are important as plant pollinators. Others affect us because they transmit diseases (mosquitoes carry malaria and West Nile virus) or are a

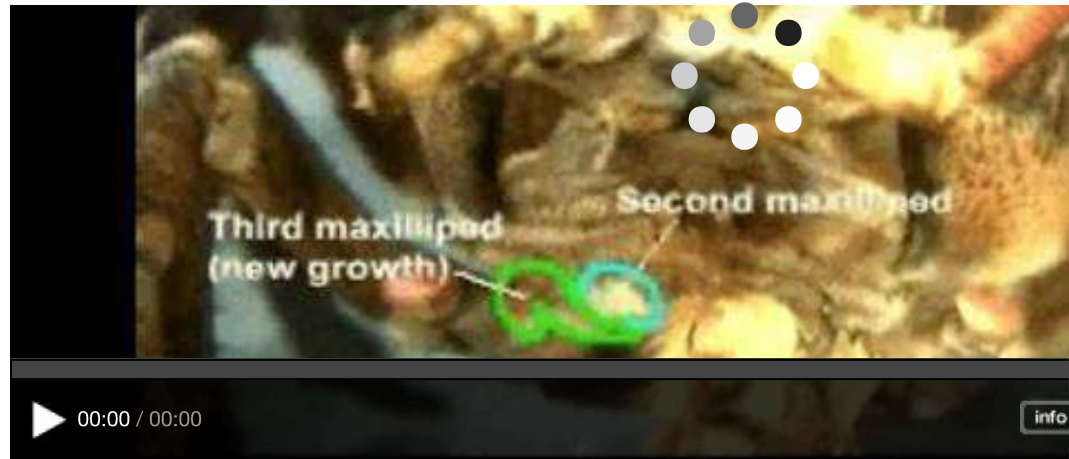
Figure 18.27



Arthropods have segmented bodies and jointed legs. (a) crustacean. Its shell may make you think of mollusks, but jointed legs, which it uses to filter food from the water, is a key feature. (b) This jumping spider is a chelicerate. (c) This insect and a uniramian. Here, it is shedding its exoskeleton.

Watch [Lobster Mouthparts](#)






Science and Society

Disappearing Insects

In the old days, taking a long road trip by car meant every hundred miles or so to clean countless squiggles off the windshield. Now, people can drive hundreds of miles and barely hit any insects at all. Scientists call this “windshield effect,” and they are worried about what happened to all the insects?

A recent study suggests that huge numbers of insects have already disappeared. At a German nature preserve, scientists counted insects by using “malaise traps” like the one in the photo. Insects fly into the bottom of the tentlike



and get funneled to the top of the tent, where they are captured. The results were astounding—insect numbers in the preserve had decreased 76% between 1989 and 2013. It is especially surprising that such a steep decline has occurred in a nature preserve, where habitats are protected and the environment is relatively unpolluted. Insects could be expected to do worse in areas where the effect of humans is greatest, such as cities, suburbs, and rural areas.

The drastic decline of insect populations has been a concern for many scientists. Insects were thought to be less susceptible to human disturbances than most other species. Compared to larger animals, insects need less habitat and can reproduce more quickly. What could be responsible for insect declines? In a German study, researchers were able to eliminate several important candidates—habitat destruction (since it did not occur in protected preserves) and global warming. They now think that pesticide use in adjacent agriculture is most likely responsible for the huge die-offs.

Insects are critical to most ecosystems. They are important as plant pollinators and as prey for other species. Scientists estimate that 80% of plants rely on insects to pollinate.

Insects are also the primary prey for many species of birds, bats, amphibians, and reptiles. The loss of insects not only impacts those species but also entire ecosystems. If insects disappear, many ecosystems will surely collapse.



Students use a malaise trap to collect insects. The structure funnels insects to the top for collection.



Widespread pesticide use is likely one cause of insect disappearances.

Despite their diversity and success, the one thing insects have not achieved is large size: Why are insects so small? The answer lies with how they obtain oxygen. Insects obtain oxygen via tracheae, which are connected to the outside air. Oxygen must diffuse through these tubes to reach the tissues, a strategy that works only in extremely small animals. However, there were much bigger insects during the Carboniferous period, 300 million years ago, when atmospheric oxygen levels were much higher.

much higher than they are today. One Carboniferous dragonfly had a 6-foot wingspan!

The earliest flying insects weren't able to fold their wings back on their bodies. That evolutionary innovation was a key step in insect history. Dragonflies are an example of a modern insect that still retains the original trait. Have you noticed how dragonfly wings stick straight out?

Unifying Concept

The Second Law of Thermodynamics [Section 6.5](#)

Mollusks

Mollusks are soft-bodied animals such as clams, oysters, octopuses, snails, and slugs. Most mollusks have a protective shell, although the shell is tiny in some species (squids) and absent in others (octopuses and slugs). All mollusks have a muscular foot responsible for locomotion, a visceral mass that holds their reproductive organs, and a mantle that secretes the shell. The main groups of mollusks are *Bivalves*, which have two hinged shells, and *Gastropods*, which have a single shell. Other species such as clams, oysters, mussels, and scallops. Mollusks are found in a wide variety of environments, including freshwater, marine, and terrestrial habitats.

sedentary and feed by filtering small particles from the water. Active cephalopods such as squids and octopuses (Figure 18.28) use arms (eight in octopuses and ten in squids) to capture prey. Cephalopods also have well-developed brains and eyes. Gastropods have a single, spiral shell and include species such as snails, limpets. Most gastropods are herbivores.

Figure 18.28



This common octopus is a cephalopod, a type of mollusk.

Annelids

Annelids are a group of segmented worms that include earthworms and leeches (Figure 18.29), and other species. Annelids have two types of movement: some that go around the body and others that go head-to-tail. This allows for great flexibility of motion—for example, an earthworm can move one part of their body while keeping the rest still. Earthworms are important decomposers that feed by ingesting large amounts of organic matter and absorbing the available nutrients. Their burrowing activities help to aerate soil, supplying it with oxygen. Leeches are parasitic and feed on blood. They have blade-like teeth for cutting through the skin and secrete anticoagulants that prevent blood from clotting. Leeches are sometimes used in medicine today. During certain surgeries, leeches are used to keep blood from clotting. The anticoagulants they make are still more effective than those that humans have invented.

Figure 18.29



The leech is an annelid that feeds on blood. The leech is sometimes used for medical purposes.

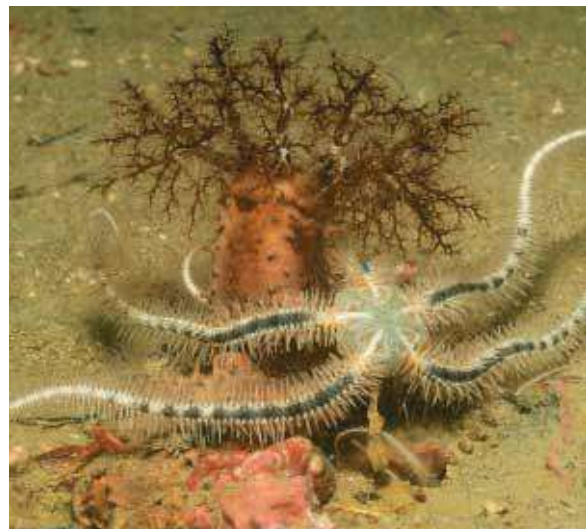
Echinoderms

Echinoderms include starfish, sea urchins, and sea cucumbers (18.30). All echinoderms have an internal skeleton, or made of small, interlocking plates. They use small, suck called *tube feet* to move and stick to rocks. Starfish also to pry open the shells of bivalves. Most echinoderms live on the floor and move very ... very ... slowly.

Watch Earthworm Locomotion



Figure 18.30



Two echinoderms in the Adriatic Sea: a brittle star and

Watch Echinoderm Tube Feet



Chordates

The *chordates* include tunicates, lancelets, and vertebrates, which humans belong to. Chordates share four key features: a spinal cord that runs along the back of the body, a notochord, a bendable rod that supports the back, gill slits, and a tail.

beyond the anus. These features are not apparent in all (e.g., humans don't have tails) but are generally present in development (human embryos do go through a tailed stage).

Tunicates are sedentary marine species also known as sea squirts (Figure 18.31). They feed by filtering small particles from the water. Lancelets are small, blade-shaped, swimming marine species that burrow themselves in sand. Like tunicates, lancelets filter food from the water.

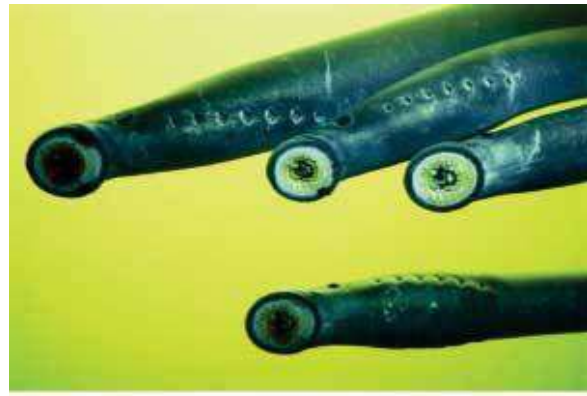
Figure 18.31



It may not be obvious at first glance, but these sea squirts are chordates and close relatives of the vertebrates.

Vertebrates are animals with backbones. The vertebrate groups of fishes as well as amphibians, reptiles, and mammals know that the earliest vertebrates had mouths but not jaws. A few jawless vertebrates are still in existence. Lampreys, which suck blood from other fish, are shown in [Figure 18.32](#) □

Figure 18.32



The earliest vertebrates did not have hinged jaws. Modern lampreys retain this condition. These individuals are clinging to a host with their circular mouths.

Cartilaginous fishes include sharks, skates, and rays. Their skeletons are made of cartilage rather than bone. Sharks are apex predators. Their unusual *electroreceptive organs* help them detect electric currents in the muscles and nerves of nearby prey.

Ray-finned fishes include most of the animals we think of as salmon, bass, and so on. Ray-finned fishes have a sac in called a *swim bladder*. The swim bladder is filled with gas to make the fish's density the same as the density of water so a ray-finned fish doesn't sink or float, which gives it great maneuverability in water. Cartilaginous fishes, which do not have swim bladders, actually sink if they stop swimming.

Unifying Concept

Density [Section 2.3](#)

At first glance, *lungfishes* ([Figure 18.33](#)) and *coelacanth* are ray-finned fishes. However, they are actually more closely related to terrestrial vertebrates such as amphibians, reptiles, and mammals. The bones in their fins are arranged serially, like those in the limbs of terrestrial vertebrates, rather than as rays emanating from a central fin. Although only a few species remain, these species are of great interest to biologists because they provide clues about how tetrapods evolved.

Figure 18.33

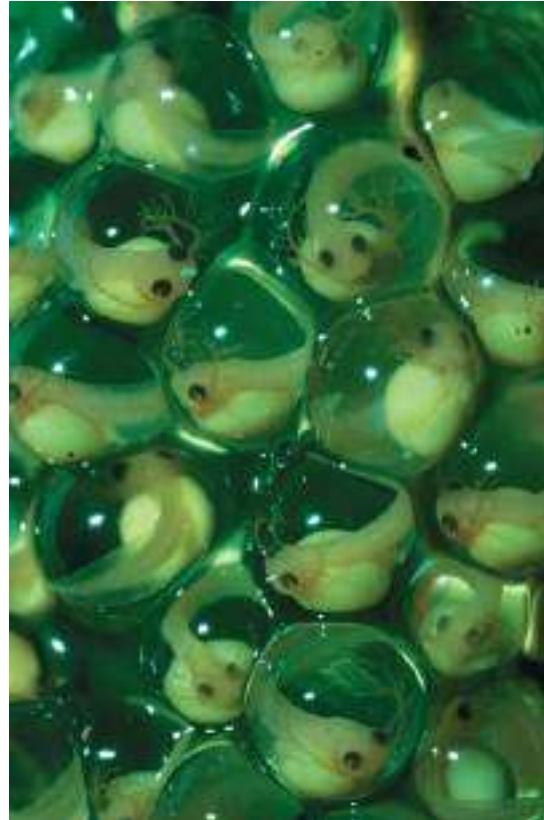


Lungfishes may look like ray-finned fishes, but they are related to terrestrial vertebrates. Note this lungfish's un
have features in common with the legs of terrestrial ver

Amphibians include salamanders, frogs, and caecilians, limbless species. The name *amphibian* refers to the fact use both aquatic and terrestrial habitats. In many amph larvae metamorphose into terrestrial adults. For example tadpoles often metamorphose into terrestrial frogs. However amphibians are entirely aquatic, and many are entirely Amphibians are restricted to moist habitats because the of living cells that dry out. Amphibian eggs do not have require moisture (Figure 18.34). In the last few decades amphibian species have suddenly gone extinct, and humans experienced huge population declines. What is especial

that many species, such as the remarkable golden toad have disappeared from protected nature reserves.

Figure 18.34



Amphibian eggs have no shells, and so they require moisture from drying out. These are frog eggs.

Figure 18.35



The golden toad is one of many amphibian species that have become extinct in the last few decades.

Reptiles (including the feathered ones—birds) and mammals and Amniotes have two traits that enable them to live in diverse habitats. First, their skin is made of dead cells, which helps prevent water loss. Second, their eggs have shells, which keep them from drying out.

Reptiles include turtles, lizards and snakes, crocodilians (see [18.36](#)). Turtles have protective shells that are actually part of their body (Imagine squeezing your entire body inside your rib cage). Reptiles are a large and diverse group found in a wide array of terrestrial

Snakes are a group of lizards that have lost their legs and have evolved adaptations for subduing large prey and swallowing them whole. They are exceptional in that they have evolved the ability to swallow large prey whole (one of the adaptations for flight include wings, feathers, and hollow bones for lightness).

Flight has evolved three separate times in vertebrates: in birds, bats, and the extinct pterodactyls.

Figure 18.36



(a)



(b)

Snakes and birds are reptiles, a group that also includes crocodilians. (a) Many snakes have adaptations for prey or food items. This snake is eating an egg. (b) Birds have evolved the ability to fly. This is a great blue heron.

All reptiles except birds are ectotherms. An **ectotherm** regulates its body temperature. For example, lizards bask in the sun to warm up and retreat to the shade to cool down. The body temperatures of ectotherms vary, to some extent, depending on environmental conditions. Birds and mammals are endotherms. An **endotherm** maintains a constant, high body temperature by breaking down food. Metabolism releases heat, which warms the body. Because an endotherm breaks down food to release heat, it has to eat more than an ectotherm of the same size. This is why you can feed a pet snake once a week, but a pet mouse daily.

Ectotherms and endotherms were once called “cold-blooded” and “warm-blooded,” but these terms are not accurate. For example, some desert lizards have body temperatures higher than 38°C (100°F), hotter than the body temperatures of most birds and mammals.

Unifying Concept

The Second Law of Thermodynamics [Section 6.5](#)

Mammals have hair and feed their young milk. The majority live on land, but bats fly, and seals and whales are partially aquatic. There are three major groups of mammals. *Monotremes*, such as the platypus and spiny echidna, lay eggs. *Marsupials*, such as koalas, and kangaroos, give birth to very immature live young. Marsupials crawl up into their mother's pouch and attach to a nipple where they eat and continue to develop ([Figure 18.37](#)). *Eutherians*, which include most living mammal species, also give birth to live young; however, newborn eutherians are more mature than newborn marsupials.

Figure 18.37



A baby koala sleeps in its mother's pouch.

Check Yourself

Interactive

Question

Check Answer

Question

Dispersal is important for most living organisms. How do animal dispersal strategies compare with those of plants?

Check Answer

Dispersal is important for most living organisms. How do animal dispersal strategies compare with those of plants?

Answer: Most animals are able to move. The ones that are sessile (some bivalves, barnacles, and so forth) release their eggs into the

History of Science

Classifying the Platypus

The first dried platypus specimen reached England in 1799 and created an immediate sensation. The animal had a ducklike bill, webbed front legs, claws, and a covering of thick fur. It did not have nipples like birds, it had a cloaca—a single opening for the reproductive, excretory, and digestive systems. The platypus seemed an impossible cross between a bird and a mammal. Quickly, attention focused on one key question: How do platypuses reproduce? Did they lay eggs or give birth to live young?

In 1821, naval surgeon Patrick Hill reported that c Australian Aborigines were familiar with the platy described it as laying eggs in nests on the water in 1824, the anatomist Johann Meckel found man on a platypus—the glands opened directly to the nipples. But this led to another puzzle: How coul with a ducklike bill suckle? In 1831, platypus nest broken eggshells were found, and milk was seen the skin of a female platypus’s abdomen. In 1834 anatomist Richard Owen examined the mouth of platypus and concluded that it could suckle in th Plus, he found milk in the baby’s stomach. Finally female platypus was shot while in the process of To those who had yet to be convinced, this was c platypus was indeed a mammal that lays eggs.



The platypus is an egg-laying mammal.

Today, the platypus is classified in the mammalia Monotremata, which means “one hole” and refers to the animal’s single exit for the reproductive, excretory, and digestive systems. Only one other creature belongs to this group—the spiny echidna, the platypus’s closest relative on Earth.

Integrated Science 18C: Earth and Space Science

Where Are All the Male Turtles?


Learning Objective

Explain how global warming can affect species where sex depends on temperature.

In most vertebrates, the sex of an organism is determined by the chromosomes it inherits. For example, in many

females inherit XX chromosomes and males inherit XY chromosomes. However, this is not the case in all animals. In turtles, alligators, some lizards, and some fish, sex is determined by the temperature of the environment during development. This is known as *temperature-dependent sex determination*. In many turtles, eggs that develop at lower temperatures produce males, whereas eggs that develop at higher temperatures produce females. Turtles can influence the sex of their offspring through their choice of nest site. A study found that in cooler areas, females chose nest sites that received more sun exposure, whereas in warmer areas, they chose nest sites in the shade. These behaviors help them achieve nest temperatures that add both males and females to the population. But could global warming affect the sex ratio of turtles?

Global warming is causing temperatures to increase in many parts of the world. A 2018 study looked at Pacific sea turtles in Northern Australia (Figure 18.38). Scientists were shocked to find that, in this population, there were 1.5 female turtles for every 1 male turtle! This was far worse than what was anticipated. By looking at only older turtles, researchers were able to determine that the sex ratio in the population



biased for decades. In the 1970s and 1980s, females outnumbered males, but only by a ratio of about every male. The bias is much more extreme today

Figure 18.38



These Pacific green sea turtles are swimming near Barrier Reef in Australia. The combination of temperature-dependent sex determination and global warming is a serious problem for this population, which has 116 females for every 1 male.

Will turtles be able to keep up with global warming? Turtles have lived on Earth a long time, and they have survived through temperature changes in the past. What is different now is the rate of temperature change is unusually rapid. Global warming also presents other challenges for sea turtles. Beach erosion can kill turtle eggs, and rising seas can drown some traditional nesting sites. Turtles do have a few things working in their favor. First, not all sea turtle populations are as drastically affected as the Northern Australia population. Another Pacific green sea turtle hatchery, where temperatures have been less extreme, the sex ratio of females to males is about 1. Second, because male turtles often mate with multiple females, having more females is better for the population than having too many males.

Check Yourself

Interactive

Question

Check Answer

Question

Turtles have survived despite past changes in Earth's climate. If global warming will likely not be a problem for turtles?

Check Answer

Turtles have survived despite past changes in Earth's climate. If global warming will likely not be a problem for turtles?

Integrated Science 18D: Ph

How Birds Fly

Learning Objective

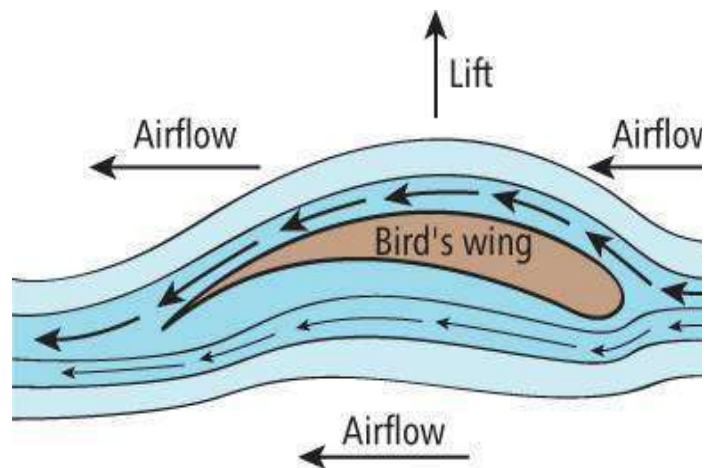
Explain how birds fly.

Bird flight has always fascinated humans. Without a model, would we ever have dreamed up the airplane? Can something heavier than air stay aloft?

Shape is the key. The wings of birds are *airfoils*—a shape that causes air to flow faster over the top of the

under the wing (Figure 18.39). This is because, as air flows through the air, air molecules have a greater distance to travel over the wing and so move faster. Bernoulli's principle (Appendix E) tells us that when the speed of air increases, its pressure decreases. This means that the air pressure above the wing is lower than air pressure below the wing. The result is an upward force called *lift*. Lift balances gravity and keeps birds in the air.

Figure 18.39



The shape of birds' wings causes air to flow faster over the top of the wing than under the wing. This produces lift. Lift balances gravity, enabling birds to stay in the air.

In order to generate lift, birds must move forward by flapping their wings. When a bird pulls its wing downward, it pushes air down and back. According to Newton's third law, if a bird pushes air backward, the air pushes it forward. As birds pull their wings back, they produce *drag*, a force that drives them backward. Birds twist their wings during the upstroke to reduce drag, something similar when you swim the breaststroke. On the downstroke, you push your arms back and your legs forward. On the upstroke, you pull your arms in to

Unifying Concept

Newton's Third Law [Section 3.4](#) □

Some birds are able to stay in the air for a long time without flapping their wings. This is called *soaring*. You often see eagles and vultures soar. Soaring is possible because they are floating on top of a *thermal*, a mass of rising air that is like sitting on top of a geyser but (luckily for them) is more controlled.

Check Yourself

Question

Check Answer

Question

Which produces more lift as it flies: an eagle or a sparrow?

Check Answer

Which produces more lift as it flies: an eagle or a sparrow?

18.9 Viruses and Prions

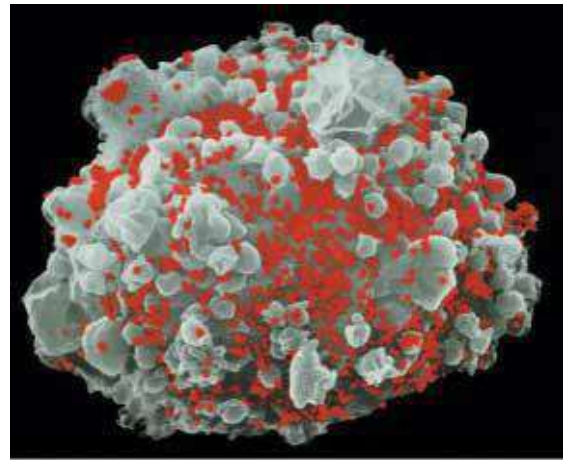
Learning Objective

Describe how viruses and prions cause disease.

A virus is a small piece of genetic material wrapped in a protein coat. Viruses are on the border between living and nonliving organisms. They are made of cells, and they can reproduce only within a host cell. They have genes and they evolve. Where did viruses come from? Scientists believe viruses originate when little pieces of genetic material somehow evolve the ability to move from one cell to another. That is, that viruses have probably originated many times.

Many viruses have normal double-stranded DNA, but some are made of single-stranded DNA, single-stranded RNA, or double-stranded RNA. Viruses reproduce by infecting a host cell and using the cell's resources to copy their genetic material and build viral proteins. The new viruses are then assembled to form new viruses. All forms of life, from plants to animals—are infected by viruses. Human immunodeficiency virus (HIV), the virus that causes acquired immunodeficiency syndrome (AIDS), is shown infecting a human immune cell in **Figure 18.9**.

Figure 18.40



This human immune cell is infected with HIV, the virus that causes AIDS. The cell is covered with viral particles that will soon spread to other cells.

Are any viruses beneficial to their hosts? Not that many. However, certain viruses are useful to humans. For example, viruses are used in many DNA technologies.

Viruses are responsible for many human diseases, including the common cold, flu, AIDS, and smallpox. One feature of viruses is that they mutate very quickly. This explains why there are always new strains to catch and why the flu comes back, in a different form, every year.

Viruses can be used to make food safer. The Food and Drug Administration has approved a mixture of six viruses to kill E. coli bacteria in ground beef.

be sprayed on ready-to-eat meats such as cold cuts and sausages. These viruses attack dangerous *Listeria* bacteria that cause food poisoning,

Prions are proteins that are incorrectly folded. (Remember, proteins are folded strings of amino acids. In prions, the folding has gone wrong.) Prions cause mad cow disease and the related Jakob disease in humans. Both these diseases cause severe damage to the brain. Prions infect cells and then “reproduce” by converting normally folded proteins into the incorrectly folded form. Prions are spread through contaminated meat. Cooking, which kills bacteria and viruses, does not kill prions.

Summary of Terms (Knowledge)

For instructor-assigned homework, go to
www.masteringphysics.com

Animals □

A group of multicellular, heterotrophic eukaryotes that use their bodies for digestion.

Archaea □

One of the three domains of life, consisting of many different prokaryotic organisms that are more closely related to eukaryotes than to bacteria; some archaea are adapted to extreme environments.

Autotrophs □

Living organisms that convert inorganic molecules into organic molecules.

Bacteria □

One of the three domains of life, consisting of an extreme of prokaryotic organisms.

Ectotherm □

An organism that uses behavior to regulate its body temperature may vary to some extent.

Endoskeleton □

An internal skeleton, such as that found in echinoderms

Endotherm □

An organism that maintains a constant, high body temperature by breaking down food, releasing heat.

Eukarya □

One of the three domains of life, consisting of eukaryotes whose cells have a nucleus: animals, fungi, plants, and

Evolutionary tree □

A diagram that shows the relationships among a set of

Exoskeleton □

An external skeleton, such as that found in arthropods.

Flower □

The reproductive structure of flowering plants.

Fruit □

In flowering plants, a structure surrounding the seeds that helps to spread the seeds.

Fungi □

A group of heterotrophic eukaryotes that obtain food by secreting digestive enzymes over organic matter and then absorbing the nutrients.

Heterotrophs □

Living organisms that obtain energy and organic molecules by consuming other living organisms or other organic materials.

Plants □

A group of autotrophic, multicellular, terrestrial eukaryotes that obtain food through photosynthesis.

Pollen ☐

In seed plants, immature male gametophytes wrapped in coatings; it ultimately produces sperm in flowering plants.

Protists ☐

A miscellaneous group of eukaryotic organisms that include eukaryotes that are not plants, animals, or fungi.

Seed ☐

In seed plants, a structure consisting of a plant embryo, and a tough outer coating.

Virus ☐

A small piece of genetic material wrapped in a protein coat and reproduces within a host cell.

Reading Check Questions (Comprehension)

18.1 Classifying Life

1. What criteria are used to classify species in the classification system?
2. How did scientific ideas about evolution change how biologists classify organisms?
3. What information do scientists use to construct phylogenetic trees?

18.2 The Three Domains of Life

4. What are the three domains of life?
5. To which domain of life do eukaryotes belong?

18.3 Bacteria

6. Explain how bacteria that are autotrophs and chemotrophs obtain food.
7. How do bacteria reproduce? Do bacteria ever eat other material?
8. Why is bacterial decomposition important to life?

18.4 Archaea

9. Which features of archaeans suggest they are more closely related to eukaryotes than to bacteria?
10. Why are some archaea described as “extremophiles”?

18.5 Protists

11. What are protists?
12. What is a diatom, and why are diatoms important as marine organisms?
13. Name three kinds of multicellular photosynthetic protists.
14. Heterotrophic protists move to capture prey. Describe the different ways these protists move.

15. Describe how *Plasmodium*, the protist that causes malaria, infects humans. Also describe the symptoms of the disease.

18.6 Plants

16. What are the two components of the plant vascular system? Describe the function of each?
17. Why are mosses restricted to living in moist environments?
18. How is pollen transferred from one plant to another? Describe the process in flowering plants?

18.7 Fungi

19. How do fungi obtain food?
20. What are fungal spores?
21. Why are fungi essential to the growth and survival of plants?

18.8 Animals

22. How do animals obtain nutrients?
23. What are some features of arthropods?

24. Describe the three major groups of mollusks.
25. Why must amphibians live in moist habitats?
26. What is the difference between an ectotherm and an endotherm?
Which vertebrates are ectotherms, and which are endotherms?
27. How do monotremes differ from other mammals?

18.9 Viruses and Prions

28. What is a virus? How do viruses reproduce?
29. What are prions? How do they “reproduce”?

Think Integrated Science

18A—Moving Water Up a Tree

30. What type of chemical bond is responsible for the cohesion of water molecules?
31. Why are cohesion and adhesion important to water transport in plants?
32. What is transpiration? How does transpiration drive the movement of water up the xylem?

18B—Coral Bleaching and Ocean Acidification

33. What single factor is most frequently responsible for coral bleaching?
34. Why do corals turn white during bleaching episodes?
35. Explain why ocean acidification threatens shell-forming organisms.

18C—Where Are All the Male

36. What is temperature-dependent sex determination?
37. Why might global warming be a problem for species with temperature-dependent sex determination?
38. Is there any evidence that global warming has affected sex ratios in turtles?

18D—How Birds Fly

39. How are birds able to stay in the air when they are not flapping?
40. How is Newton's third law related to how birds fly?
41. How are some birds able to stay in the air without flapping their wings?

Think and Do (Hands-On Application)

42. Go for a walk and take notes on the flowers you see. Can you guess which pollinators they use? Look for yellow flowers that may be pollinated by bees. Look for tubular shaped flowers that may be pollinated by hummingbirds. Do you see any white flowers that are closed during the day? These may be pollinated by nocturnal species such as moths. If you wait long enough, you may see pollinators visit the flowers of the same species each time?
43. Let's explore water transport in plants. Place a celery stalk in a beaker with some water. Add a few drops of blue food coloring to the water, and stir gently. Check the celery every hour and let the stalks sit overnight. What do you observe? Cut the bottom of a celery stalk. Can you see the xylem?
44. Let's grow mold! Obtain some bread slices and paper bags. Keep the bread in the bags so that you won't get too many spores during the course of the experiment.

it take for mold to grow? Can you see the filamentous spores?

45. We know that birds stay in the air due to lift, which is produced by the difference in air pressure above and below wings. This air-pressure difference is, in turn, the result of air flowing more quickly over the top of the wing than under the wing. Let's experiment with airflow and air pressure using a piece of tissue. Hold the tissue vertically and blow on one side. The side you blow on is analogous to the top of the wing where the air flows faster. What happens to the tissue? Does it stay horizontal? Can you produce enough lift to keep the tissue horizontal?

Think and Compare (Analysis)

46. The groups in the Linnaean system are phylum, class, genus, kingdom, domain, and family. Rank them in order, from the one that includes the largest number of species to the one that includes the fewest species.
47. Examples of the three main groups of plants are ferns, trees, and mosses. Rank them in order, from most dependent on living in a moist habitat to least dependent on living in a moist habitat.



A



B



C

Think and Solve (Mathematical Application)

48. Suppose a species of bacteria divides once every hour. If you start with a single bacterium on your unrefrigerated cheese sandwich at 8:00 AM. Show that when you eat your sandwich for lunch at noon, there will be 4096 bacteria on your sandwich.
49. The lightest and heaviest flying birds are the bee hummingbird, which weighs about 1.6 grams, and the great bustard of Europe and Asia, which can weigh as much as 230 pounds. Show that the bee hummingbird produces about 100 times as much lift when it flies, whereas the great bustard produces only about 100 times as much lift.



The bee hummingbird and the great bustard are the lightest and heaviest flying birds, respectively. The bee hummingbird produces about 100 times as much lift when it flies, whereas the great bustard produces only about 100 times as much lift.

less than a penny!

Think and Explain (Syntheses)

18.1 Classifying Life

50. If two species belong to the same order, do they belong to the same class? Do they have to belong to the same phylum?
51. Which is more arbitrary: classifying organisms based on their evolutionary relationships or based on their "size"? Defend your answer.
52. Is an eagle a reptile? Defend your answer.

18.2 The Three Domains of Life

53. How are the three domains of life—Bacteria, Archaea, and Eukarya—related to one another? To which domain do you belong?
54. Scientists are working on separating the Protist groups. Explain why.

55. What is the difference between a heterotroph and a chemoautotroph?
Name a group of living things that consists exclusively of heterotrophs and one that consists exclusively of chemoautotrophs.
Name a group that includes both heterotrophs and chemoautotrophs.
56. What is a chemoautotroph? What does a chemoautotroph have in common with a plant? How does a chemoautotroph differ from a plant in how it obtains food?

18.3 Bacteria

57. Why would life on Earth be impossible without bacteria?
58. Bacteria reproduce asexually. However, they sometimes exchange DNA with other bacteria. Explain some of the ways this can happen.
59. The photo below shows soil bacteria (yellow) feeding on dead plant matter (orange). What is the advantage of being able to feed on dead matter as many bacteria do?



60. What are some ways in which bacteria are useful?

18.4 Archaea

61. You are studying some microbes that were collected from the Pacific Ocean. So far, you can tell that the microbes are prokaryotes rather than eukaryotes. How can you tell if they are bacteria or archaea?
62. How do certain archaea benefit animals such as humans?
63. What are some extreme environments in which archaea thrive?

18.5 Protists

64. We saw that life on Earth would be impossible without eukaryotes. Would life on Earth be impossible without eukaryotes?
65. Are protists single celled or multicellular? Use evidence to defend your answer.
66. Are protists autotrophs, heterotrophs, or both? Use evidence to defend your answer.
67. Which protists likely gave rise to plants? Which gave rise to animals?

18.6 Plants

68. What are the three major groups of plants? Identify each in the photo below.



69. Of the three major plant groups, which is most living in a moist habitat? Why? Which is least d
70. Some plants, including many grasses, have sma with no petals (see photo). How do you think t pollinated?



71. Some people are allergic to pollen. Do you thin plants or wind-pollinated plants are more likely allergies? Why?

18A—Moving Water Up a Tree

72. Compare the cohesion of water and the adhesion are they similar? How are they different? How c role in moving water up a tree?

73. How can a plant gain water by losing water? Explain transpiration and tension in moving water up a
74. Can a plant control water flow in its tissues? What transpiration-cohesion-tension mechanism can plant itself?

18.7 Fungi

75. What do fungi and animals have in common? Explain
76. What are you eating when you eat a mushroom?
77. Truffles are rare, expensive mushrooms used in cooking. So far, people have been unable to farm them, so they must collect them from the wild, often using sniffer dogs to sniff out the delicacies. The best place to look for truffles is near the roots of certain trees. Why are they found in association with oak trees?



18.8 Animals

78. The bluefire jellyfish in the photo has caught a
different strategies used by cnidarians to obtain



79. How do the muscles of roundworms and earthworms differ?
What does this mean about the way each animal moves?
80. Why is a salamander more dependent on living in water than a lizard?
81. Many snakes can survive eating just once every year. Why can't birds do this?

18B—Coral Bleaching and Ocean Acidification

82. What kinds of living things are corals? How do they get their nutrients?
83. Explain why increasing carbon dioxide levels in the atmosphere results in ocean acidification.
84. Write a letter to Grandpa telling him how global warming threatens corals and other marine life.

18C—Where Are All the Male

85. Alligators also have temperature-dependent sex determination. However, their system is a bit different from that of turtles: Low and high temperatures both result in female offspring, whereas a narrow range of intermediate temperatures produces males. Could global warming result in a shortage of alligators?
86. If temperature-dependent sex determination worked the same way in turtles, so that low temperatures produced female turtles and high temperatures produced male turtles, would you expect a shortage of turtles?

be more of a problem for turtles or less of a problem for your answer.

87. All turtles reproduce by laying eggs. There are : turtles. Could live bearing evolve in species with dependent sex determination?

18D—How Birds Fly

88. What is lift? How much lift does a bird have to flight? How does a bird generate this lift?
89. Birds have hollow bones, an adaptation for flight inside of a pelican bone in the photo below. How bones make it easier for birds to fly?



90. Why are tiny hummingbirds such good fliers? Is it easier for a small bird to stay in the air than for a large bird? The amount of lift a bird generates depends on the area of its wings, and a bird's weight depends on its volume.

18.9 Viruses and Prions

91. Viruses straddle the line between living and non-living. How do viruses resemble living things? What features do they lack?
92. What are some examples of viruses that make us sick? The fact that viral genes mutate very quickly have consequences for humans?
93. What are prions? What kinds of diseases do prions cause?

Think and Discuss (Evaluation)

94. Of the three domains of life, Bacteria and Archaea consist of prokaryotes, whereas Eukarya consists of eukaryotes. Why do we lump Bacteria and Archaea together and call them Bacteria?
95. Chemical dispersants are sometimes used to break oil slicks into tiny droplets. Explain the advantages of using chemical dispersants using the concepts of surface area and volume. What are the drawbacks to using chemical dispersants?
96. Bacteria generally reproduce asexually. What are the advantages of asexual reproduction?
97. Most living organisms reproduce sexually, but some use some other mechanism for exchanging genetic material. What is the advantage of sexual reproduction or genetic recombination?
98. Do plants have to use energy to obtain the carbon needed for photosynthesis?
99. When you buy fresh flowers, you should cut them underwater to prevent an air bubble from forming in the stem. What would happen if an air bubble entered the stem?

100. Imagine that you are being interviewed by an ethnobotanist about how you use plants. What do you tell her? Ethnobotanists are interested in everything related to plants, so don't stop at the plants you eat. How else do you use plants and plant products? Clothing? Tools? Medicine? Decoration?

Readiness Assurance Test (1)

Readiness Assurance Test

Interactive

If you have a good handle on this chapter, if you really do, then to score 7 out of 10 on this RAT. If you score less than 7, you need to review before moving on.

Choose the BEST answer to each of the following:

10 questions

1. 1.

Which of the following are used to show relationships among things?

kingdoms

Incorrect.

Press enter after select an option to check the answer

evolutionary trees

Correct.

Press enter after select an option to check the answer

scientific names

Chapter 19

Human Biology I—Control and Development



19.1 Organization of the Human Body 

19.2 Homeostasis 

19.3 The Brain 

SCIENCE AND SOCIETY: *Football Brain Injuries*

TECHNOLOGY: *Mapping the Brain in Action: Fun*

19.4 The Nervous System

INTEGRATED SCIENCE 19A: PHYSICS AND CHEMISTRY: *How*

How Neurons Work 

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19.5 Hormones

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19.7 The Skeleton and Muscles

TECHNOLOGY: *A Mind-Controlled Robotic Arm* 

NOT EVERYONE can “do an air” on a skateboard, but v that are nearly as impressive on a daily basis. How can fold laundry without even thinking about it? What part working when you write a poem or solve a math proble tell that a strawberry is tasty but a rotten egg isn’t? Why to touch your nose even with your eyes closed? In the r we’ll see how the human body maintains exquisite cont systems and allows us to function in a complex world.

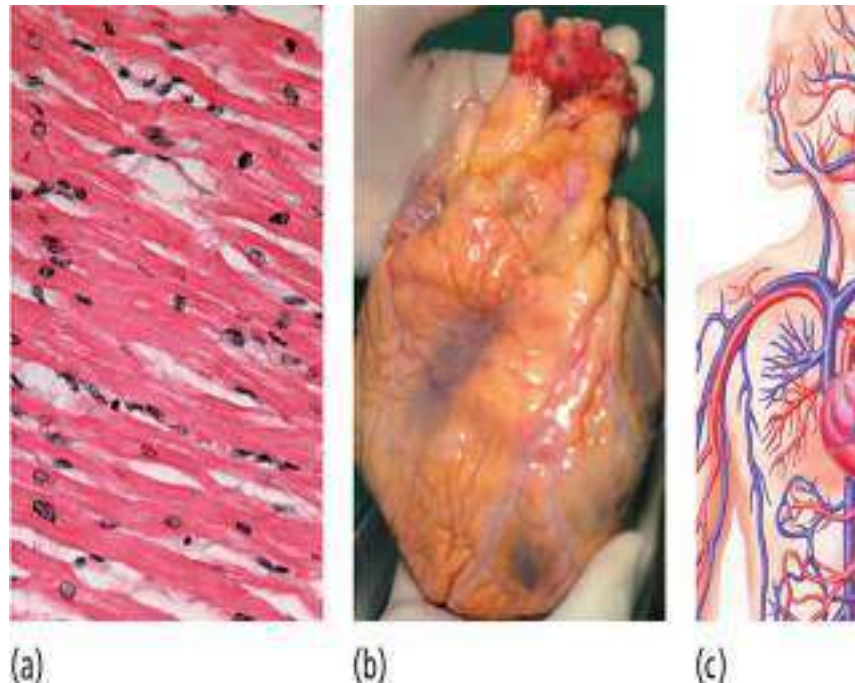
19.1 Organization of the Human Body

Learning Objective

Describe tissues, organs, and organ systems, and examples of each.

You look at the traffic light and step off the curb. As you walk, you consider whether you want tacos or a sandwich for lunch. You breathe in, bringing oxygen into your body, and then breathe out, removing carbon dioxide. Blood, pumped by your heart, travels through your blood vessels. At the same time, immune cells circulate through your body, ready to respond to a cut on your finger, eating up invading bacteria. At any given moment, your body is involved in a huge number of different activities. The cells in your body are organized into tissues, organs, and organ systems (Figure 19.1).

Figure 19.1



In the human body, cells are organized into tissues, org systems. (a) Many muscle cells make up muscle tissue. muscle tissue from a human heart. (b) The heart is an c has just been removed from a donor and will soon be t recipient.) (c) The circulatory system is made up of the blood vessels. The circulatory system transports nutrier wastes to different parts of the body.

A tissue ⓘ is a group of similar cells that performs a cer There are four main types of tissue in the body. *Epitheli* sheets of tightly packed cells that cover the internal and of the body. Skin is an example of epithelial tissue. *Con* consists of cells scattered within an external matrix. *Bo* blood are all connective tissues. *Muscle tissue* is made u

able to contract, or shorten. Three types of muscle tissue are found in the body. Skeletal muscle is responsible for voluntary movements. Smooth muscle functions in the internal organs of the digestive system and in certain blood vessels. Cardiac muscle produces the heartbeat. Nervous tissue transmits information from one place in the body to another. Nervous tissue is found in the brain, spinal cord, and peripheral nerves.

Multiple tissues combine to make an **organ**, a structure that has a specific function. The heart, stomach, and brain are examples of organs. Each of these organs is made up of multiple tissues. The heart (1) is surrounded by epithelial tissue on the outside and with it on the inside; (2) contains blood vessels carrying blood; (3) contains connective tissue; (4) has walls made up largely of cardiac muscle; (5) contains nerves, made of nervous tissue, that help to coordinate its function.

An **organ system** is a set of organs that work together to perform a particular bodily function. For example, the circulatory system transports nutrients, gases, and wastes throughout the body. The human body has ten major organ systems: nervous, sensory, endocrine, muscular and skeletal, circulatory, respiratory, digestive, reproductive, and immune. In the next two chapters, we'll look at what they do.

19.2 Homeostasis

Learning Objective

Use examples to describe homeostasis.

Whether you are swimming in icy waters or hiking through heat, your body temperature stays close to 37°C (98.6°F). The ability to maintain a relatively stable internal environment is an example of homeostasis, the process by which all living organisms, and a huge amount of the body's activity, are directed toward maintaining it.

As just one example, your cells need a certain amount of oxygen to function. Your lungs and heart maintain a normal level of oxygen supply this oxygen. If your activity level increases—say, you start to catch a bus—your cells use up more oxygen. What happens? Your body responds by breathing harder to take in more oxygen and increasing your heart rate to move that oxygen to your cells. Once your activity returns to normal and your oxygen use decreases, your heart rate slows again.

To go back to body temperature, when it's cold outside pile on more clothes, or wrap your arms around your body to reduce heat loss. In addition, less blood is sent to your limbs and extremities, so they lose heat faster than the core of your body. (This explains why your fingers and toes often feel most cold when you're cold.) You may also shiver to generate heat (Figure 19.2a). On the other hand, when it's hot outside, you take off your clothes, look for shade, and sweat. Also, more blood goes to the extremities and to the face to help with heat loss at shedding heat. (This explains why your face turns red when you're hot.)

Figure 19.2



Your body responds to changing conditions in ways that maintain homeostasis. (a) When you're cold, you shiver to warm

you're hot, you sweat to cool down.

Controlling body temperature is an example of feedback regulation, changes in one variable affect a second variable, changes in the second variable in turn affect the first variable, variables are related in a *feedback loop*. In this example, temperature trigger specific responses that in turn affect temperature. Homeostasis is often maintained by a type of regulation called *negative feedback*. In negative feedback a response that counters the stimulus. So, if body temperature decreases, the response will cause body temperature to increase. On the other hand, if body temperature increases, the response will cause body temperature to decrease back to normal.

Unifying Concept

Feedback Loop

Oxygen supply and body temperature are only two of the things the body carefully regulates. The amount of water in the body, the concentration of nutrients and waste products in the blood, and the concentrations of important ions inside and outside cells are also regulated.

these and many other variables are carefully regulated ;
maintaining homeostasis.

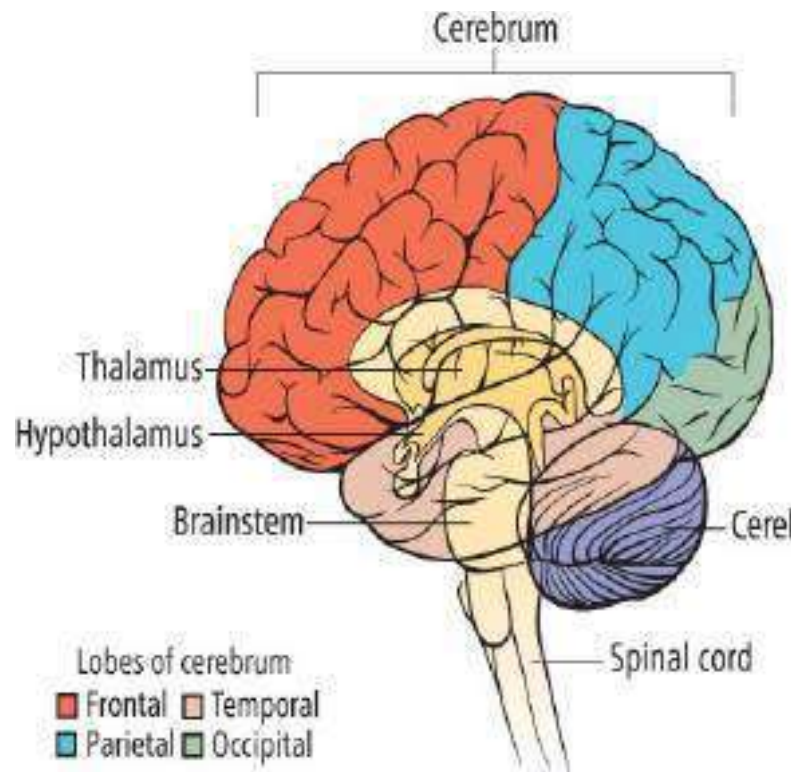
19.3 The Brain

Learning Objective

Describe the structure and function of the brain.

Your brain makes you who you are. All of your thoughts and desires come from your brain. Your brain also controls many activities—both conscious ones such as choosing a shirt or a soccer ball and unconscious ones such as breathing, blinking, and digestion. Your brain “heads up” your nervous system. It consists of five main parts (Figure 19.3):

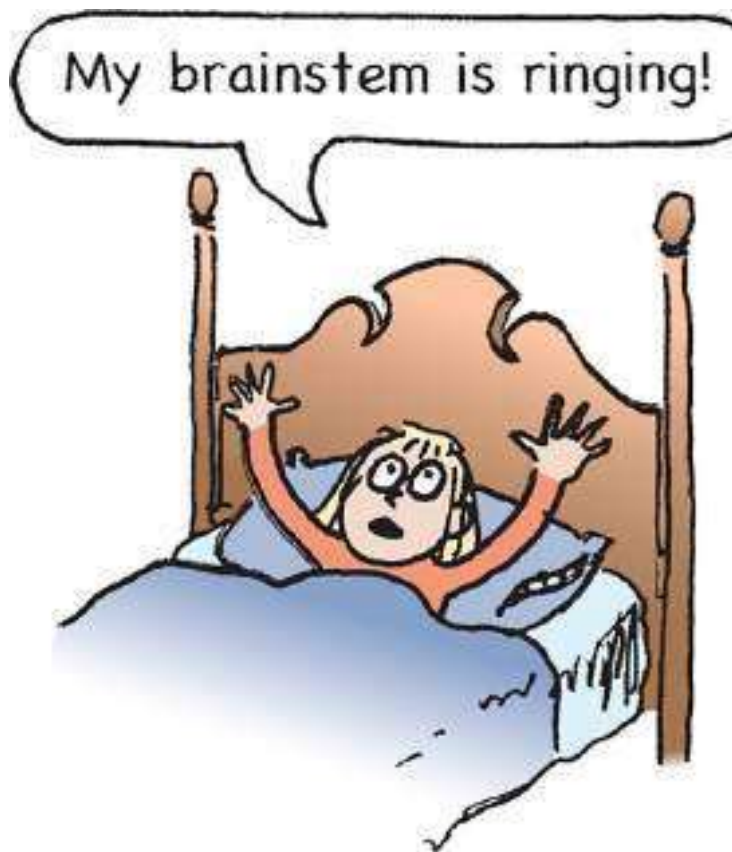
Figure 19.3



The major parts of the human brain are the brainstem, cerebrum, thalamus, and hypothalamus.

1. *The brainstem.* Can you imagine how much less done if you had to remember to breathe every 1 good thing the brainstem does this for you. The connects the spinal cord to the rest of the brain of the body's basic, involuntary activities, such respiration, and digestion. The brainstem also every morning, bringing your body from sleep (Figure 19.4).

Figure 19.4



The brainstem controls the transition between sleep and

- 2. *The cerebellum.*** The cerebellum controls balance, coordination, and fine movements. It also controls you perform "without thinking." Consider bicycling: when you first learn how to ride a bike, you think very much about what your arms and legs are doing, and your movements are awkward. With enough practice, though, you can

easily—“without thinking.” When you do something without thinking, it means the cerebellum has taken over.

3. *The cerebrum.* The cerebrum is the largest part of the brain and contains more than 10 billion neurons! The cerebrum is responsible for high-level functions such as reasoning, problem solving, language, and creativity. Your personality is controlled by your cerebrum. The cerebrum collects information from the senses and controls all the conscious, voluntary actions of the body. The cerebrum has a right hemisphere (right side) and a left hemisphere (left side). The right hemisphere controls the left side of the body, and vice versa. This means that when you use your right hand, it's actually the left hemisphere of your brain that controls that action.

Most of the information processing that occurs in the brain takes place in the cerebral cortex, the thin layer of gray matter on the surface of the cerebrum. “Wrinkles” in the cerebral cortex give the brain its familiar convoluted appearance and increase the area available for information processing. Each hemisphere consists of four lobes that are responsible for different activities. The *frontal lobes* deal with reasoning, planning, and voluntary movements, and speech. The *parietal lobes* process sensory information about temperature, touch,

The *occipital lobes* process what you see—that is information. The *temporal lobes* deal with sound and comprehend language.

The control of certain cognitive functions is done by either the right or left cerebral hemisphere. The left hemisphere is more adept at math, reasoning, language, and detail-oriented tasks. The right hemisphere is more adept at spatial reasoning, emotional processing, and music. This distinction is the basis of the popular conception of “left-brained” people who are analytical, and attentive to detail and “right-brained” people who are intuitive, flexible, and creative.


4. *The thalamus.* The thalamus receives information from different parts of the brain. It sorts and filters this information and then passes it on to the cerebrum.
5. *The hypothalamus.* The hypothalamus is responsible for emotions such as pleasure and rage. It also controls bodily functions such as hunger, thirst, and sex drive and regulates body temperature and blood pressure. Another function of the hypothalamus is to control your body’s internal clock, which tells you when it is day and when it is night. The hypothalamus performs these functions using molecules called hormones, which we discuss later in this chapter.

Science and Society

Football Brain Injuries

According to a 2018 Gallup poll, football is America's most popular sport. However, its popularity has declined over the past decade. Although many causes likely contributed to this decline, a major factor is the increasing evidence that the sport leaves many players with permanent and devastating brain injuries.

A 2017 study by Dr. Ann McKee looked at the brains of deceased National Football League (NFL) players and found that 110 of them were affected by chronic traumatic encephalopathy (CTE). CTE is a disease in which abnormal tau protein accumulates in the brain, forming clumps that cause brain cells to deteriorate. CTE was originally diagnosed in boxers and was thought to be caused by repeated blows to the head. The high prevalence in former football players shows that repeated blows—not just the bigger hits that result in concussions—can cause severe damage over time.



Symptoms of CTE include dementia, memory loss, poor judgment, impulse-control problems, paranoia, anxiety, depression, confusion, and the deterioration of motor skills. Sufferers of CTE also have an increased suicide risk. There is no cure for CTE, although some symptoms, such as depression, can be treated.

McKee cautions that the brains in her study are not representative of the NFL as a whole. Because all were donated by players' families for study, they are biased toward football players who experienced more severe symptoms. Nonetheless, the numbers are stark.

Unfortunately, the dangers extend to more casual tackle football. A Boston University study showed that youth who played tackle football before age 12 had more cognitive and behavioral problems than those who started football later in life. In light of these and other studies, more and more families are opting not to let their child play tackle football. Many youth football leagues are now considering banning tackling during games, and some youth, high school, and even college leagues ban tackling during practice.




Football players suffer repeated blows to the head, damage to the brain, and lead to a variety of symptoms, dementia, and memory loss.

Technology


Mapping the Brain in Action: Functional MRIs

Traditional lie-detector tests are not always dependent on things like pulse, blood pressure, breathing,



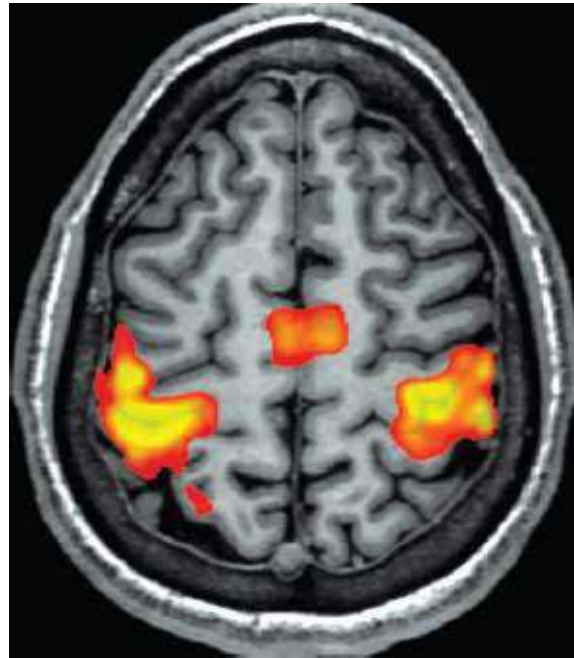
skin conductance (sweating) to give away the guilty who is nervous but telling the truth may fail, and one who stays calm may pass. But liars may find a new technique to fool. *Functional magnetic resonance imaging* (fMRI), which shows which parts of the brain are activated during different activities—and it shows that the brains of liars are quite different from those of truth tellers.

How does fMRI work? fMRI builds on the earlier technique of magnetic resonance imaging (MRI). MRI makes use of the fact that every hydrogen atom in the body—and therefore every water molecule—is a tiny magnet. (This is because a spinning charged particle, including the spin of the nucleus of a hydrogen atom, produces a magnetic field.) When living tissue is placed in the field of a strong magnet, the hydrogen atoms line up the same way a compass needle aligns with Earth's magnetic field. A radio wave is then used to "bump" the atoms, knocking them slightly out of alignment. As the atoms bounce back to their natural alignment with the magnetic field, they release a small amount of energy that can be detected and recorded. Because different body tissues have different concentrations of hydrogen, different tissues release different amounts of energy, allowing a very detailed image to be constructed.



MRI, fMRI constructs images based on different concentrations of water molecules in different parts of the body. However, the focus is on blood. Like other cells, neurons in the brain use more energy when they're active, and so need more oxygen. In order to accommodate this need, blood flow to active areas of the brain is increased. This increase can be detected and converted into an image of active areas.

So, what happens in the brain when people lie? In a study, volunteers were given a playing card—the five of clubs and a \$20 bill. They were told they could keep the money if they managed to fool the computer into thinking they had the five of clubs. fMRI maps were made of the brain while volunteers told the truth by denying they had the five of clubs and while they lied by denying they had other cards. The maps were compared. Lying caused increased activity in several areas of the brain, including those responsible for attention, monitoring errors, and inhibiting natural tendencies. This suggests that lying requires the inhibition of a natural tendency to tell the truth, as well as increased effort and attention. It is interesting that telling the truth did not increase activity in any particular areas. Lying appears, overall, to be much harder work than telling the truth.



Functional magnetic resonance imaging (fMRI) allows researchers to compare activity levels in different parts of the brain during different activities. Active areas are shown in orange and red.

fMRI is too expensive to be used regularly for clinical purposes. However, it has been a valuable tool for figuring out which areas of the brain are responsible for different sensations, emotions, and activities. fMRI has already contributed to our understanding of how people remember information, make decisions, gamble, recognize faces, and respond to pain. Other researchers have even used fMRI to reconstruct the thoughts that went through people's brains while they watched

Researchers hope that one day a similar technique to record what people see when they dream.

Check Yourself

Interactive

Question 1
Check Answer
Question 2
Check Answer
Question 1

Io is reading a book. Which lobes of the cerebrum is she using?



Check Answer

Io is reading a book. Which lobes of the cerebrum is she using?



19.4 The Nervous System

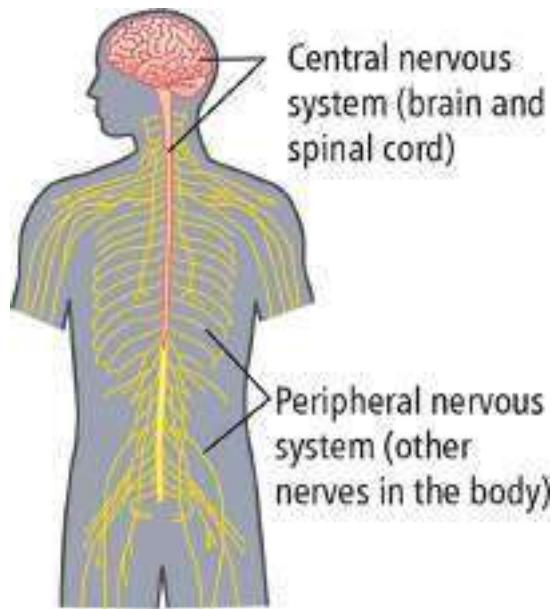
Learning Objective

Describe the structure and function of the nervous system.

You're eating cornflakes and reading the sports page. Your clock and see that you're late for class. Immediately, you're in overdrive. Your heart starts to pound and you begin to run out the door, run down the steps—and trip. Pain shoots through your knee, but you pull yourself up and continue your race to drop into your seat. Your heart rate gradually slows, and you relax. This entire sequence of actions and responses is controlled by your nervous system.

The *nervous system* collects information about the body and external environments and controls the body's activities into two parts. The *central nervous system* includes the brain and spinal cord, and the *peripheral nervous system* includes all the other parts of the body (Figure 19.5).

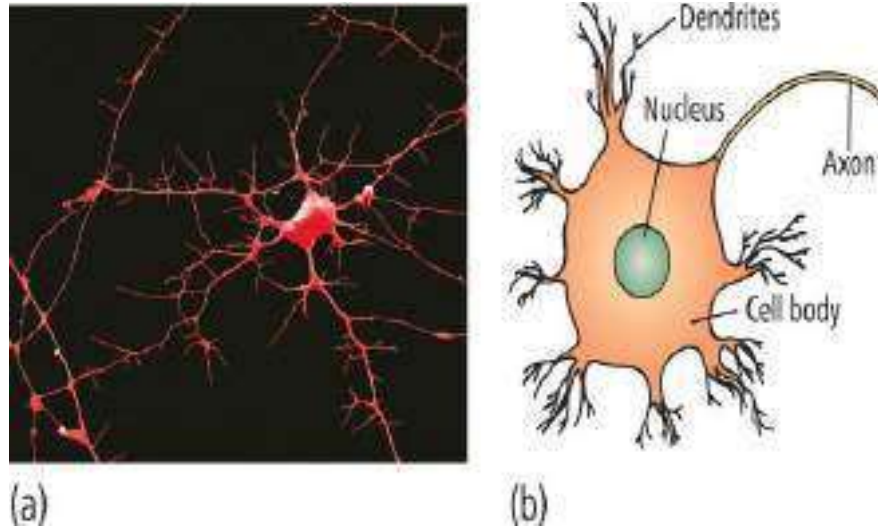
Figure 19.5



The central nervous system consists of the brain and spinal cord, and the peripheral nervous system includes all the other nerves in the body.

The nervous system includes two different kinds of cells: neurons and glial cells (Figure 19.6). A **neuron** is a specialized cell that receives and transmits electrical signals from one part of the body to another. A typical neuron has three parts: (1) *dendrites* receive information from other neurons or cells, (2) the *cell body* contains the nucleus and other organelles, and (3) the *axon* transmits information to other cells. *Glial cells* support, insulate, and protect neurons. The brain actually has 10 to 50 times more glial cells than neurons.

Figure 19.6



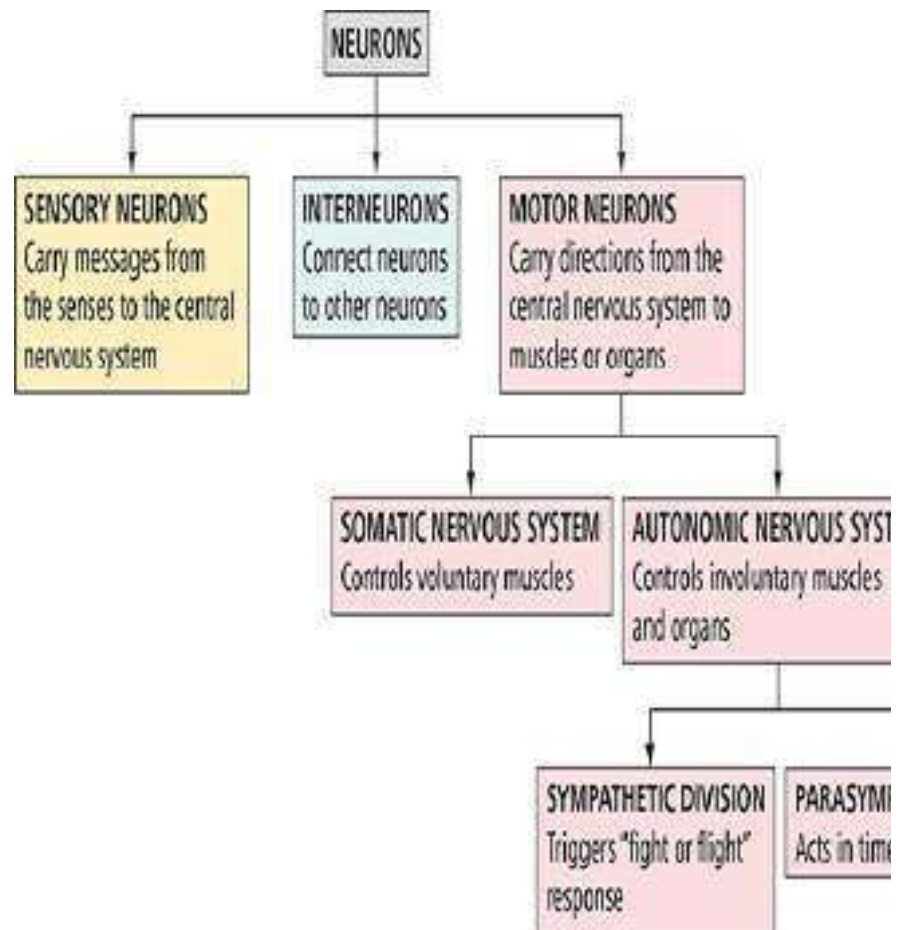
(a) Neurons transmit electrical signals from one part of another. The red cells shown here are neurons. (b) Neuron. The diagram shows the cell body, dendrites that receive information from other cells, and an axon that transmits information to other cells.

Kinds of Neurons

There are three types of neurons: sensory neurons, interneurons, and motor neurons (Figure 19.7). *Sensory neurons* carry information from the senses to the central nervous system. The neurons that carry information from your eyes to your brain are sensory neurons. The neurons that carry information about your run to class, sensory neurons told you how long time on the clock and the pain of hitting your knee on a curb. *Interneurons* connect neurons to other neurons. Interneurons exist exclusively within the central nervous system. *Motor neurons*

directions from the central nervous system to muscles c
your run to class, motor neurons directed the motion of
motor neuron also made your heart beat faster.

Figure 19.7



Neurons are divided into different types based on their

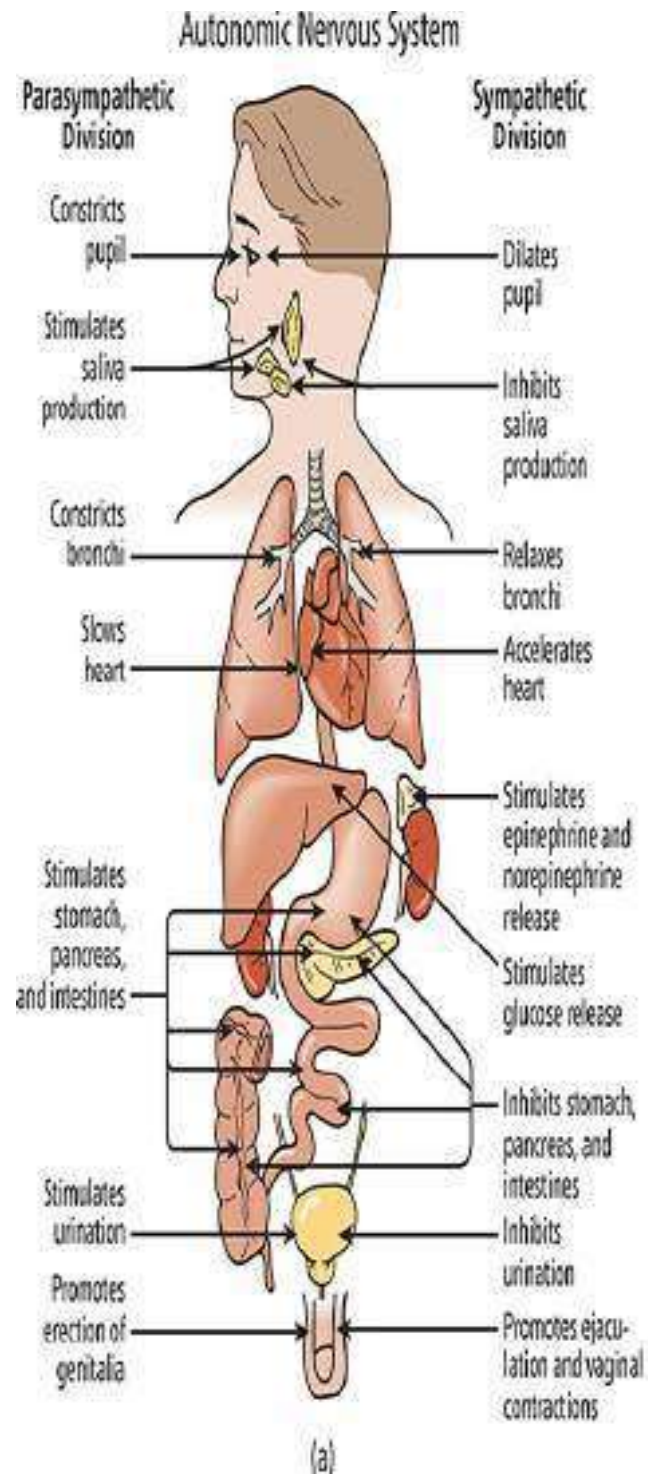
Motor neurons belong to either the somatic nervous system or the autonomic nervous system. Motor neurons in the *somatic* nervous system control voluntary actions, such as running to class. They provide instructions to your voluntary muscles, such as those in your arms, legs, and fingers. Motor neurons in the *autonomic* nervous system control involuntary actions. These neurons control involuntary muscles (such as heart or stomach muscle). Making your heart beat faster is part of your autonomic nervous system.

You can decide to bend your elbow, but you can't decide to make your heart beat faster. That's the difference between the somatic and autonomic nervous systems.

The autonomic nervous system includes a sympathetic division and a parasympathetic division (Figure 19.8). The *sympathetic* division prepares your body for danger. It triggers a "fight or flight" response. "Fight or flight" refers to the fact that when you're threatened, you can either run away ("flight") or stay and "fight." The sympathetic division speeds up your heartbeat when you realize you're in danger, speeding the transport of oxygen to your muscles. The parasympathetic division slows down digestion and other activities that are unimportant during emergencies. The *parasympathetic* division works during calmer times. Its effects are the opposite of the sympathetic division.

sympathetic nervous system—it calms you down. Your nervous system took over after you got to class and wei

Figure 19.8



(b)

The autonomic nervous system has a sympathetic division and a parasympathetic division. (a) The sympathetic division is for danger—it initiates the “fight or flight” response. The

division acts in a directly opposed way and operates in
Is this man's sympathetic nervous system working hard

Check Yourself

Interactive

Question 1
Check Answer
Question 2
Check Answer
Question 1

You stand at the edge of a pool and wonder whether the water is
swim. What kinds of neurons do you use to find out?

Check Answer

You stand at the edge of a pool and wonder whether the water is
swim. What kinds of neurons do you use to find out?

Answer: You use a motor neuron to dip your toe into the pool.

Integrated Science 19A: Physics and Chemistry

How Neurons Work

Learning Objective

Explain how a neuron transmits and receives information.

How a Neuron Fires

Is the human body like a toaster? Well, it is in one way. Like a toaster or a computer, your body relies on electrical signals to do its work.

In neurons, the electrical signals are changes in the electric potential, across the cell membrane. A neuron has an electric potential across its cell membrane because the net charge inside a neuron is different from the net charge outside. This electric potential is called a *membrane potential* because it is the cell membrane that keeps the charged particles separate.

Unifying Concept

The Electric Force [Section 7.1](#) 

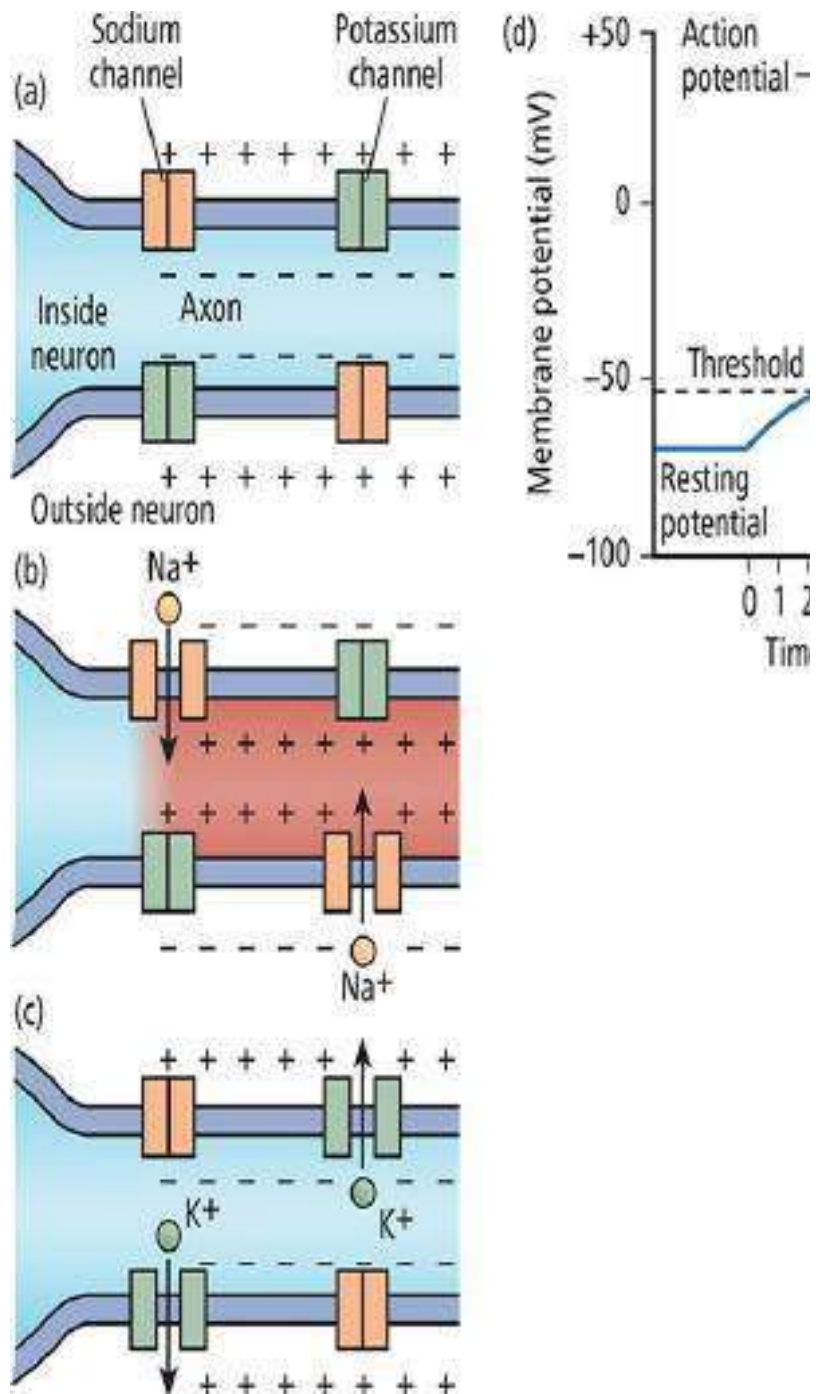
When a neuron is not signaling, it is at its *resting potential*. The resting potential of a neuron is negative. Why? For most cells, neurons have more potassium ions inside the cell than outside and more sodium ions outside the cell than

overall effect of these concentration gradients is to establish a negative resting potential. (You may recall that the sodium-potassium pump maintains these concentration gradients by using active transport to move sodium ions out of cells and potassium ions into cells.) Second, neurons contain many negatively charged ions, including proteins and organic molecules. As a result, the inside of a neuron is normally negatively charged and the outside of a neuron is normally positively charged, creating a resting potential of about -70 millivolts (mV) across the cell membrane.

A neuron sends information by signaling, or “firing.” How does this happen? A neuron is stimulated when its membrane potential is increased. If a neuron’s membrane potential reaches a certain *threshold* value—about -55 mV—voltage-gated channels in the neuron’s cell membrane suddenly open, allowing positively charged sodium ions to move into the neuron. (Sodium ions move into the neuron because there are more sodium ions outside the cell than inside.) The influx of positively charged ions causes the membrane potential to spike and become positive. This spike is called an **action potential**. The action potential is the neuron’s way of signaling, or “firing.” Once the spike occurs, the s

channels quickly close and the potassium channels
Positively charged potassium ions flow out of the
flow out because there are more potassium ions
than outside), causing the membrane potential to
resting potential. The sequence of events in an action
is shown in **Figure 19.9**.

Figure 19.9



The action potential is the neuron's way of signaling. Neurons have a negative resting potential. The inside of the neuron is negatively charged, and the outside is positively charged. (b) During an action potential, sodium channels in the neuron's cell membrane open. Sodium ions move

neuron, causing the membrane potential to become more positive. Sodium channels close, and potassium channels close. Potassium ions move out of the neuron, causing the membrane potential to return to resting potential. (d) This graph shows how the membrane potential changes during an action potential. Resting potential is negative. When the neuron is stimulated, the membrane potential increases slowly. Once it reaches threshold, the action potential happens. Sodium channels open, causing the membrane potential to rise sharply. The membrane potential decreases when potassium channels open. It returns to resting potential.

An action potential is an all-or-nothing event—a neuron either fires or it doesn't. A neuron cannot fire "harder" or "softer" depending on how intense the stimulus is. However, it does fire more frequently. For example, touch sensors in your skin fire slowly with little pressure (tick ... tick ... tick ...) and quickly with lots of pressure (tick-tick-tick-tick-tick).

Check Yourself

Question 1
Check Answer
Question 2
Check Answer
Question 1

What causes sodium channels to open, initiating an action potential?

Check Answer

What causes sodium channels to open, initiating an action potential?

Answer: A stimulus that increases the membrane potential to its threshold.

How an Action Potential Is Propagated

An action potential doesn't spike everywhere on a neuron's membrane at once. It begins at one end of the axon, near the cell body, and then travels down the axon. How does this happen?

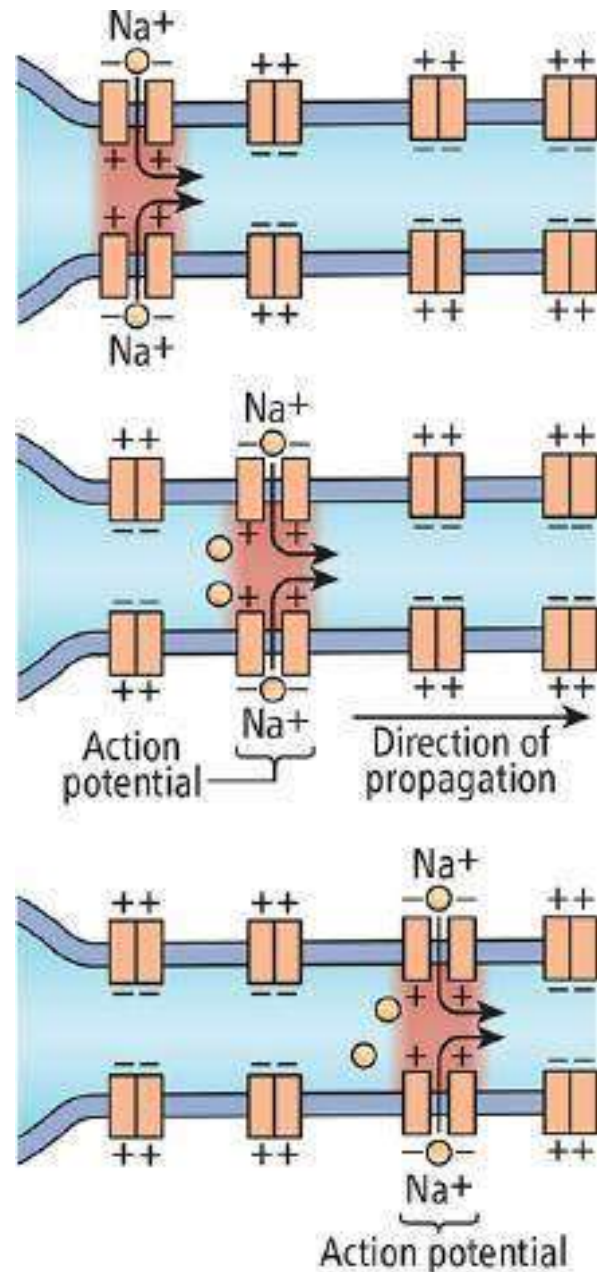
Unifying Concept

The Second Law of Thermodynamics [Section 6.5](#)

When an action potential begins, sodium ions enter the axon at the end that is closest to the cell body. These ions diffuse into the axon along the axon. Because the sodium ions are positively charged, they cause the local membrane potential to increase. When it reaches the threshold, an action potential is triggered.

membrane potential reaches threshold, a new action potential begins along the axon, begins. The process is similar to the way dominoes fall: The first domino knocks down the next one, and so forth. Similarly, an action potential travels down the entire axon (Figure 19.10).

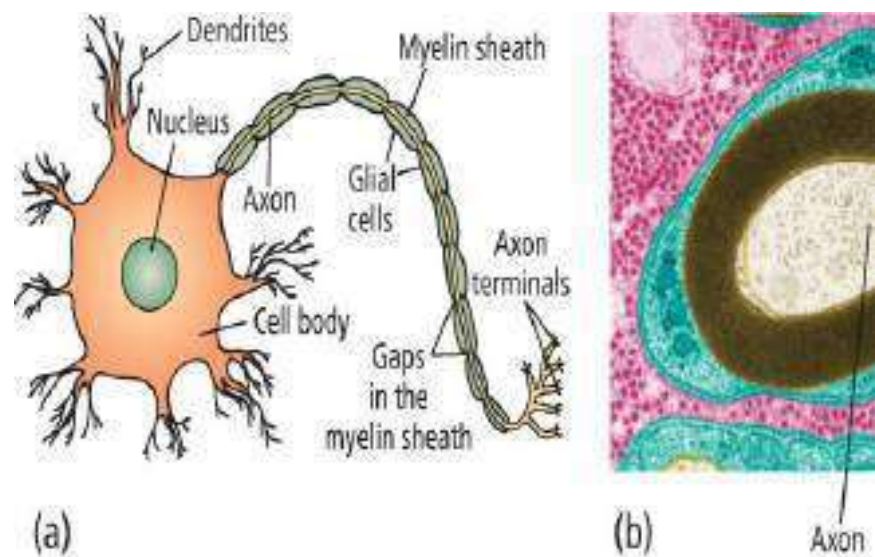
Figure 19.10



Action potentials are propagated down an axon. The action potential starts near the cell body. Sodium ions that enter the neuron at one point on the axon, initiating an action potential farther along the axon, continue to move down the axon until it reaches the end of the axon.

Some axons, like the one shown in **Figure 19.11**, are surrounded by a *myelin sheath* that allows the neuron's signal to be transmitted quickly. The sheath consists of glial cells wrapped around the axon, insulating it with multiple layers of cell membranes. There are periodic gaps in the sheath, and the action potential jumps from one gap to the next.

Figure 19.11



(a) A myelin sheath surrounds some axons, enabling them to transmit signals faster. (b) The myelin sheath consists of glial cells wrapped around and around an axon, as shown in this micrograph. The dark brown ring is the myelin. (The green in (a) is the cytoplasm of the neuron.)

In the disease *multiple sclerosis*, the body's immune system attacks and destroys myelin in the central nervous system. The symptoms of multiple sclerosis vary depending on the parts of the brain and spinal cord affected. Symptoms can include problems with fatigue, dizziness, tremors, bladder and bowel control, vision, muscle control, and balance.

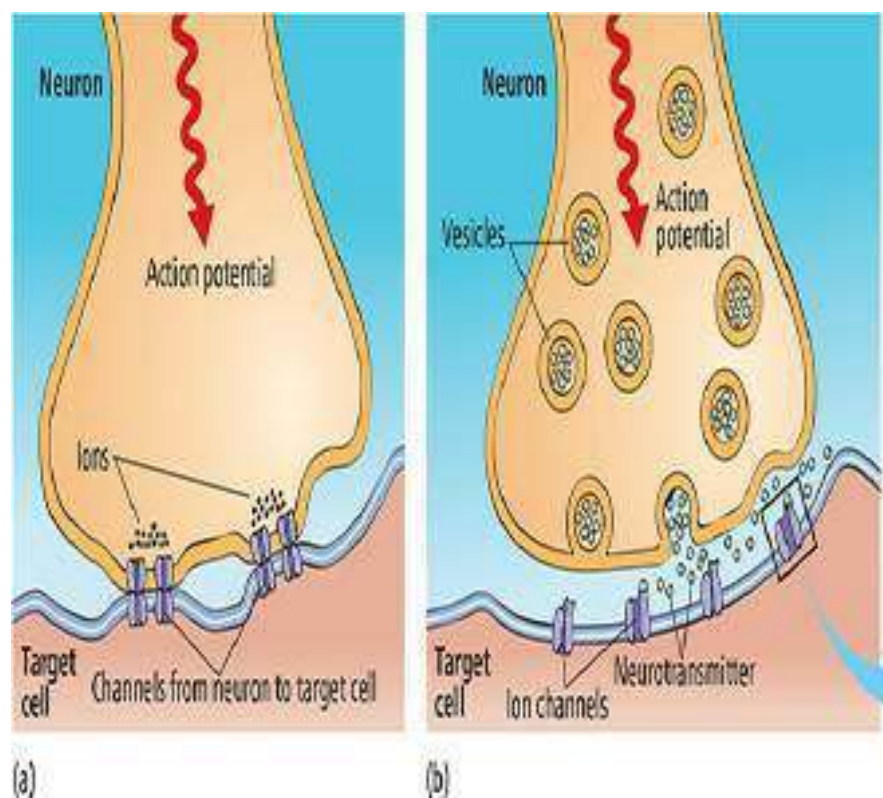
How a Neuron Communicates with Another Cell

So far, we have seen what happens during an action potential. An action potential travels down an axon. What happens when an action potential arrives at the end of an axon? At the end of an axon, the axon connects with one or more target cells and passes information to them. A target cell can be another neuron or a cell that does something like a muscle cell or organ cell. A connection between a neuron and a target cell is called a synapse. There are two types of synapses: electrical and chemical synapses.

In an *electrical synapse*, tiny channels in the cell membranes connect a neuron to a target cell. When the neuron is active, ions move through these channels into the target cell, starting an action potential.

potential in the target cell (Figure 19.12a). Because they are so quickly, electrical synapses are very fast. Electrical synapses are found in places where speed is important. For example, in the heart, electrical synapses allow many muscle cells to contract nearly simultaneously to produce the heartbeat. Despite their speed, though, electrical synapses are fairly rare in the body.

Figure 19.12



(a) In an electrical synapse, ions move through the channels from a neuron to a target cell and start an action potential in the target cell. In a chemical synapse, a neuron uses a neurotransmitter to communicate with a target cell. When an action potential arrives at the end of a neuron, it causes vesicles containing neurotransmitters to fuse with the cell membrane and release the neurotransmitters into the synaptic cleft. The neurotransmitters then bind to receptors on the target cell, opening ion channels and starting an action potential in the target cell.

the neurotransmitter is released. The neurotransmitter target cell and binds to receptors on the target cell's membrane, causing ion channels to open. Ions enter the target cell and change the membrane potential.

Unifying Concept

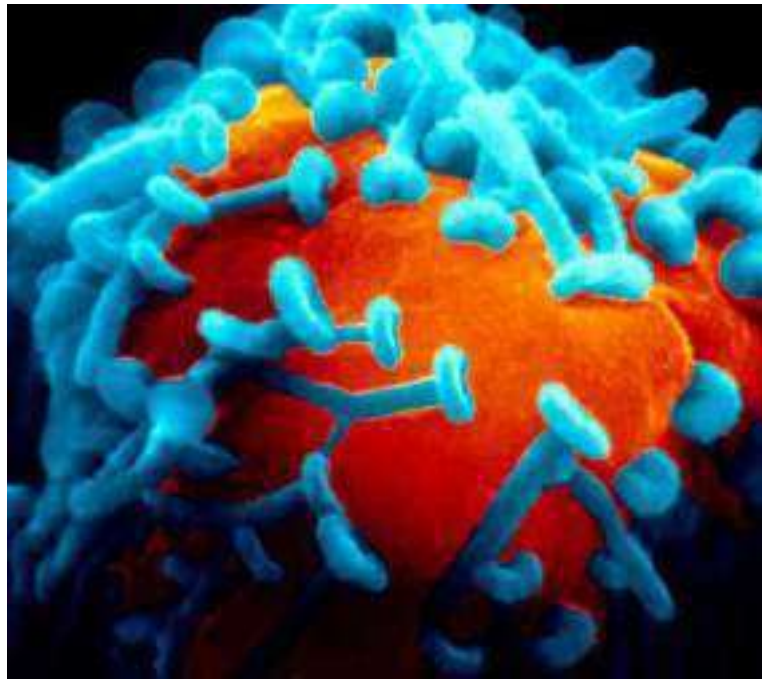
The Second Law of Thermodynamics [Section 6.5](#)

Most synapses are *chemical synapses*. Chemical synapses are more common than electrical synapses, but they allow for a finer degree of control. In a chemical synapse, a neuron communicates with a target cell by releasing small molecules of *neurotransmitter*. When an action potential reaches the end of an axon, vesicles containing neurotransmitter fuse to the axon membrane ([Figure 19.12b](#)). Neurotransmitter molecules diffuse into the narrow space between the axon and the target cell. There, the neurotransmitter molecules bind to receptors on the target cell's membrane. The binding causes ion channels to open, and ions enter the target cell.

The membrane potential of the target cell may increase or decrease depending on the type of ion that enters. An *excitatory signal* increases the target cell's membrane potential and makes the target cell more likely to fire. An *inhibitory signal* decreases the target cell's membrane potential and makes the target cell less likely to fire.

and makes it less likely to fire. A target cell may receive many other neurons (Figure 19.13). In fact, a typical r between 1,000 and 10,000 synapses with other neurons the sum total of their effects, the neuron will either react and fire, or not.

Figure 19.13



Axons from many different neurons (blue) have synapses on a target cell (red). Some of these signals make the target cell more likely to fire, whereas others make it less likely to fire.

The effect of a neurotransmitter on a target cell ends when the neurotransmitter is removed. Neurotransmitter molecules are degraded by enzymes, taken up by the original neuron into vesicles, or collected and broken down by glial cells. Some medications affect neurotransmitter function. For example, antidepressants are selective serotonin reuptake inhibitors that prevent neurons from taking up the neurotransmitter serotonin after it has been released at synapses. As a result, more serotonin is available to bind to and stimulate target neurons.

Check Yourself

Interactive

Question 1

Check Answer

Question 2

Check Answer

Question 1

What is the advantage of an electrical synapse over a chemical synapse?

Check Answer

What is the advantage of an electrical synapse over a chemical synapse?

Answer: An electrical synapse is faster than a chemical synapse.

Question 2

Integrated Science 19B: Ph


How Fast Can Action Potentials Travel?

Learning Objective

Explain how axon size and myelination affect how quickly an action potential travels.

For a squid escaping from a hungry shark, speed is the essence. How quickly the signal to *Move!* gets from the muscles is the difference between life and death. How do you make an action potential go faster?

Action potentials travel faster if the sodium ions that carry the signal move more quickly down an axon. How quickly ions move down an axon depends on Ohm's law, which states that current = voltage/resistance. The lower the resistance, the higher the current and the faster the action potential travels. Unlike other materials, an axon has lower resistance if it is thicker. This is because a thick axon resists current less than a thin one. In the same way, a wide pipe resists water flow less than a narrow pipe. So, one way to get a fast action potential is to have a thick axon.



thick axon. Thick axons have in fact evolved many different animals, including cockroaches, earthworms, and squid. The squid giant axon is nearly a millimeter in diameter and conducts action potentials very quickly—at a speed of up to 100 meters/second. Compare this to a typical axon, which conducts action potentials at a speed of only a few meters/second.

Unfortunately, you can't pack very many giant axons into an animal; they simply take up too much space. Vertebrates and some other animals have evolved a different way to conduct action potentials quickly—myelination. In a myelinated axon, the action potential is not regenerated at every point along the axon. Instead, the action potential “jumps” from one node of Ranvier to the next, saving time. A myelinated axon with a diameter of only 20 micrometers conducts action potentials as fast as the squid giant axon.

Check Yourself



Question

Check Answer

Question

Would an action potential move more quickly down a thick myelinated axon or a thin myelinated axon?

Check Answer

Would an action potential move more quickly down a thick myelinated axon or a thin myelinated axon?

Integrated Science 19C: Chemistry

Endorphins

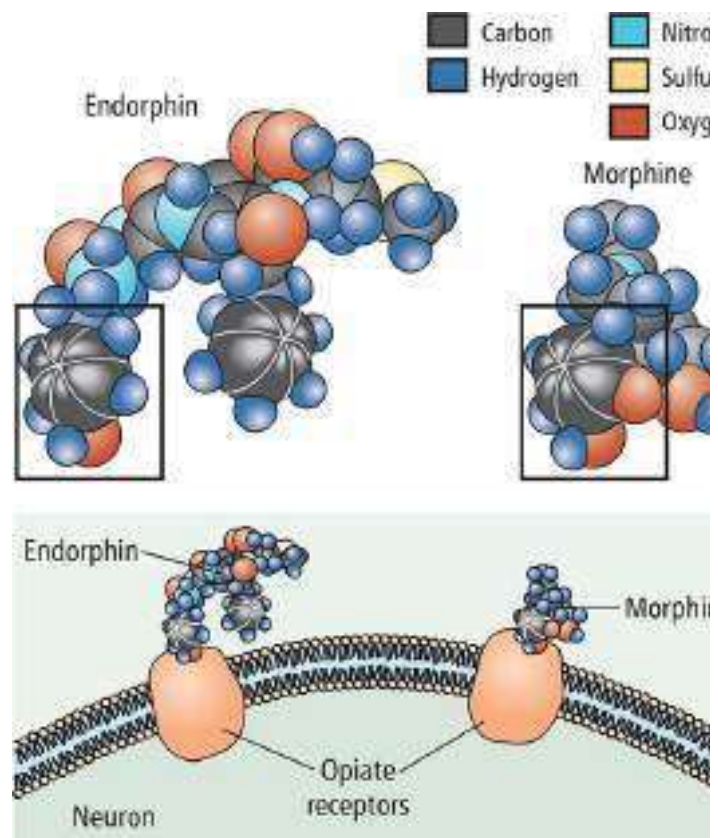
Learning Objective

Describe the function of endorphins.

What do chocoholics and long-distance runners have in common? Just maybe, an addiction to endorphins. Endorphins are neurotransmitters released by the brain during stress or pain. Endorphins bind to opiate receptors, the same receptors used by drugs such as morphine, opium, and heroin. These drugs resemble endorphins in their chemical structure and so are able to bind to

receptors (Figure 19.14). In fact, endorphins were discovered after scientists identified the receptor for morphine. They realized that the body must make a molecule of its own that could use the receptor.

Figure 19.14



The boxed part of the endorphin molecule binds to the same receptors as morphine. Morphine resembles endorphins in this part of its chemical structure and can bind to the same receptors.

Like opiates, endorphins decrease pain and bring of euphoria. It is this euphoria that runners call “r Endorphin release is also associated with laughter acupuncture, massage, and deep meditation. Fin foods—notably chocolate and chili peppers—incl endorphin release. That’s comfort food indeed.

Check Yourself

Interactive

Question

Check Answer

Question

In what way does the chemical structure of opiates such as morphine resemble the structure of endorphins?

Check Answer

In what way does the chemical structure of opiates such as morphine resemble the structure of endorphins?

Integrated Science 19D: Pr

The Senses

Learning Objective

Describe how human sense organs convert information from the environment into action potentials that can be understood by the brain.

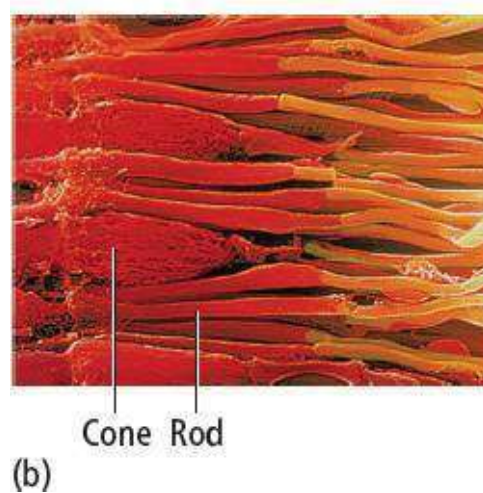
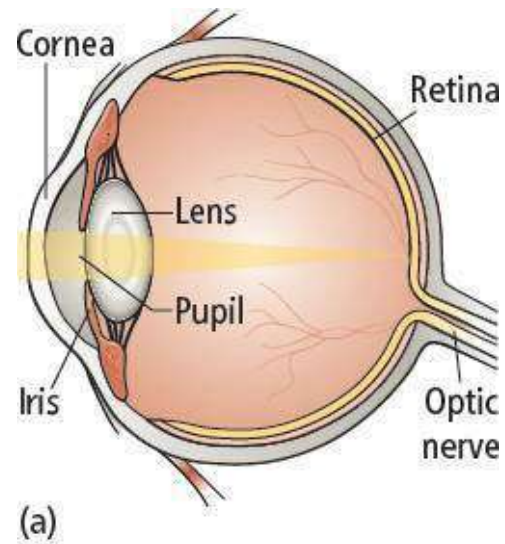
Your senses are your connection to the world. What would happen if you couldn't see, hear, smell, touch, or taste? Or if you couldn't tell, without looking at them, where you were? What if pain didn't warn you of danger or if your senses takes information from the environment—sound, touch, or molecules—and converts it into action potentials that are sent to the brain. As you will see, the brain accomplishes this in its own way.

Vision

Light enters your eyes (Figure 19.15a) through a tough layer called the *cornea*, which is continuous with the *lens* of the eyes. Light then passes through a small hole, the *pupil*, of the eye that gives you your eye color, surrounds the *iris* of its size. In bright light, the pupil is small. In dim light, the

to let in more light. From the pupil, light passes through the lens, which focuses light on the *retina* at the back of the eyeball. The retina contains light-sensitive cells called rods and cones (Figure 19.15). When light hits the rods and cones, it changes the action potential they transmit to the brain. The bundle of neurons that carries signals from the retina to the brain is called the *optic nerve*.

Figure 19.15



(a) The eyes convert light into action potentials. (b) Rods and cones are the light-sensitive cells in the eyes. As you can see, both are named for their shape.

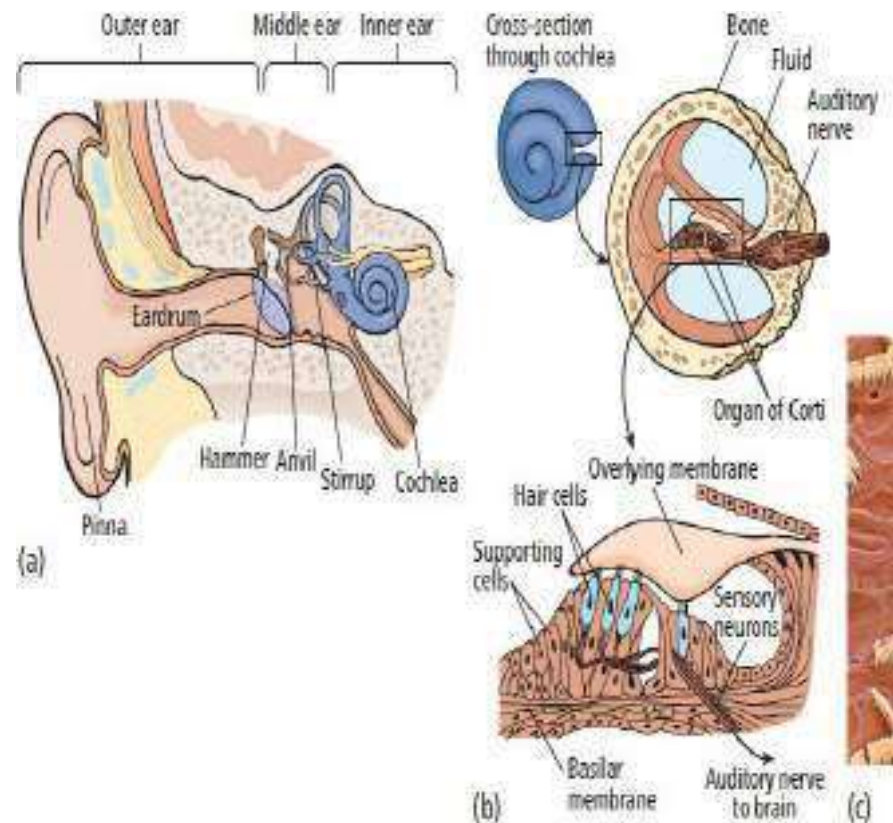
The two types of light-sensitive cells in your eyes, rods and cones, have different functions. *Rods* are very sensitive to light and are important for seeing in dim light. Rods cannot discriminate colors, so they allow you to see only black, white, and shades of gray.

dark room, you cannot see the difference between a narrow maroon shirt. (Most people are so used to this, however, they don't even realize they've lost their color vision!) Rods also are good at making out fine details, which is why your night vision is very sharp. *Cones* detect color. Your eyes have three types of cones that respond most strongly to red, green, and blue light. All colors we see are made up of different combinations of these three types. Color blindness results from having a nonfunctioning version of one of the cone types. Rods and cones make up 70% of the sense organs in the eye, evidence that vision is our best-developed sense.

Hearing

The ear consists of three parts: the outer ear, middle ear, and inner ear (Figure 19.16a). Sound waves move through the air to the ear and hit a cartilaginous flap on the side of the head. The pinna funnels the sound waves and they move toward a thin membrane of skin—the eardrum. Sound waves make the eardrum vibrate, just the way blowing on a piece of paper makes it shake. The eardrum's vibrations move three small bones—the hammer, the anvil, and the stirrup—in sequence. These bones amplify the vibrations, making them more powerful. The ossicles then transfer the vibrations to the fluid-filled inner ear.

Figure 19.16



(a) The ear includes the structures of the outer ear, middle ear. (b) Sound-sensitive cells are contained in the organ of Corti. Vibrations in the inner ear vibrate the basilar membrane of the organ of Corti, causing sensory "hairs" to brush against the overlying membrane and bend. The bending opens ion channels, starting action potentials. This microscope photo shows the "hairs" (yellow) in the

Technology

Visual Prostheses for the Blind

Will blindness one day be as easy to treat as a toothache? Scientists are beginning to develop visual prostheses to give vision to the blind. The most promising strategy available involves mounting a small camera on a pair of eyeglasses and implanting an array of *electrodes*—devices that conduct electric currents—behind the retina. A chip in the eye sends wireless signals to the electrodes, which do the work of rods and cones: They use visual information from the camera to stimulate intact neurons at the back of the retina, which then pass visual information to the brain. Although retinal prostheses are still being tested, volunteers with prostheses have been able to detect light, locate and count objects, and distinguish between simple objects such as a fork and a spoon. As the technology advances, retinal prostheses may allow patients to navigate unfamiliar locations, recognize faces, and read text.

Because retinal prostheses require functional retinal neurons, they are useful only in cases where blindness results from the loss of rods and cones. This is the case for *retinitis pigmentosa*, the leading cause of inherited blindness in the world.

related macular degeneration, the leading cause of blindness in the industrialized world. For patients who do not have functional retinal neurons, researchers are pursuing other strategies. For example, some scientists are exploring the possibility of directly stimulating the optic nerve or even the part of the brain that interprets visual information. Stay tuned.



In this retinal prosthesis, a chip processes images captured by a camera connected to a pair of eyeglasses. Information is then transmitted wirelessly to a chip implanted behind the eye, which is connected to electrodes that stimulate the retina.

Unifying Concept

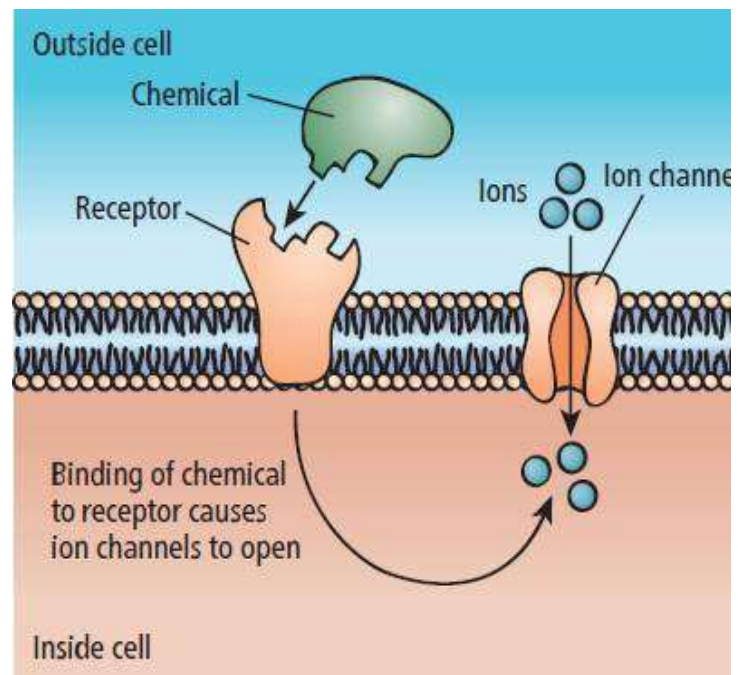
Waves Section 8.1

In the inner ear, sound vibrations enter the cochlea, a c holds the organ of Corti. The *organ of Corti* contains the responsible for hearing. Fluid vibrations in the inner ea of Corti's basilar membrane, causing sensory "hairs" en brush against an overlying membrane and bend (Figure bending causes ion channels to open, initiating action p transmitted by the auditory nerve to the brain. Note the hearing cells are not like the hairs on your head; they a of sensory cells that happen to be shaped like hairs (Fig can distinguish different noises—the high pitch of a sire pitch of a jackhammer—because different parts of the o respond to different pitches.

Smell and Taste

The senses of smell and taste work through chemorecep **chemoreception**, chemicals bind to receptors in the c chemosensory cells. The binding causes ion channels to initiates action potentials (Figure 19.17).

Figure 19.17



Smell and taste are examples of chemoreception. Chemoreceptors on the cell membrane of chemosensory cells, channels to open. The ions initiate action potentials.

The sensory cells for smell lie in two patches at the top passages. Each patch is about the size of a dime. Humans have 1000 different kinds of chemosensory cells for smell, each with one or a few different kinds of receptors. Because different chemicals trigger different combinations of sensory cells, however, humans can distinguish well over 10,000 distinct odors.

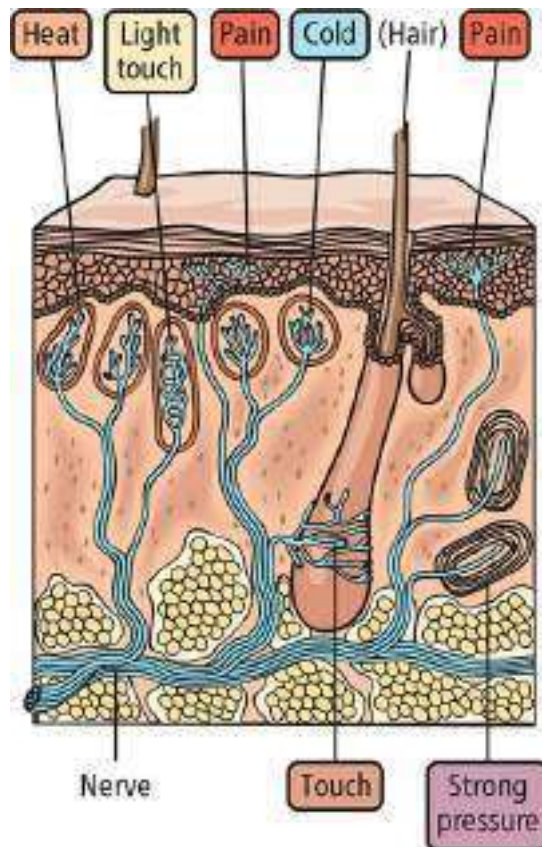
One interesting thing about the sense of smell is that it is sometimes linked to emotionally powerful memories. How can a smell bring back a memory? The part of the brain that is very close to two important parts of the brain: the hippocampus and the amygdala. The hippocampus is responsible for memory, and the amygdala is involved with emotion. Using fMRI experiments have shown that smells can trigger memories and experiences. This is not the case for our other senses.

Taste cells cluster in small bumps called taste buds. Taste buds are located on your tongue, on the insides of your cheeks, and on the roof of your mouth. Humans distinguish five basic tastes: sweet, salty, bitter, and umami. *Umami* is the Japanese word for “delicious” and describes the flavor found in foods such as meat, mushrooms, and asparagus. Monosodium glutamate, or MSG, has a strong umami taste. It is interesting that, when you are hungry, your taste buds are more sensitive to salt and sugar, and this in turn makes food taste better. Hunger does not affect your ability to taste bitterness, which helps you identify toxic foods. In addition, your experience of food is not just “taste”—comes partly from your sense of smell. That’s why food doesn’t have nearly as much “taste” when you have a stuffy nose.

Touch

Your sense of touch is actually several different senses. You know about stimuli such as pressure, temperature, and pain. The sensory cells for touch are shown in **Figure 19.18**. Pressure is sensed by the bending of “hairs” on sensory cells, opening ion channels and generating action potentials. You have separate sensory cells for detecting light and heavy pressure. Temperature-sensing cells have ion channels that are affected by heat or cold. Some temperature sensors respond to heat, while others respond to cold. The chemical menthol (found in peppermint) stimulates cold receptors—it is this coincidence, not an increase in temperature, that explains the cool feeling you get from menthol.

Figure 19.18



Sensory cells in the skin are responsible for the various

Pain sensors respond to stimuli that damage the body. These cells require strong stimulation before they respond. Hot tissues release chemicals called *prostaglandins* that increase the sensitivity of pain receptors. You might remember that aspirin works by interfering with prostaglandin production. Pain sensors become more sensitive with continued stimulation. This makes them different from most other sensory cells, which become desensitized to repeated stimulation. (This is why you stop noticing the

house or feeling the weight of your backpack as you walk. Many people believe that some types of chronic pain result from pairings of senses that have become abnormally sensitive.

Other Senses

You have other senses in addition to the big five. *Proprioception*—muscles, tendons, and joints tell you where different parts of your body are. You can try out this sense by closing your eyes and touching your nose with your finger. (You may be too used to this ability to be impressed, but consider the fact that you can't easily touch your own nose with your eyes closed!) Finally, the *vestibular system* tells you about body rotation and movement as well as which way

Have you noticed that humans have more “white eyes” than other mammals? Scientists believe that humans evolved this trait because it allows one person to tell if another person is looking. This is adaptive in a social environment like ours, where people live closely and cooperate with other people.

Check Yourself



Question 1

Check Answer

Question 2

Check Answer

Question 1

When you are outside at night, looking at a starry sky, are you using your rods or your cones?

Check Answer

When you are outside at night, looking at a starry sky, are you using your rods or your cones?

Answer: You are using your rods, which allow you to see in dim light.

Technology

Adding to Your Senses

Our five major senses contribute greatly to our perception of the world. But they detect only a small fraction of the stimuli around us. Can technology add to our senses?

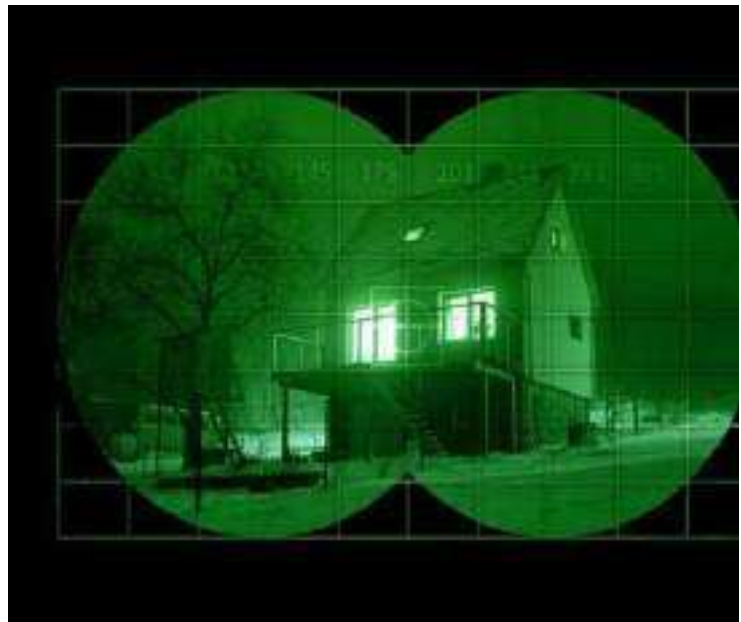
Some older technologies already expand the kinds of stimuli our senses can detect. Night-vision goggles are sensitive to tiny amounts of light that our eyes normally cannot detect. They also detect light in the infrared spectrum, which is

wavelengths that are longer than those of visible light. Hot objects give off more infrared light than cool objects. Night-vision goggles provide people with a kind of "heat vision" that can detect animals, people, or other heat sources.

Night-vision goggles are easy to put on and take off. Other sensory technologies are more fully integrated into the body. For example, some people have tiny magnets implanted in their fingertips to help them detect magnetic fields. The magnets move when a magnetic field is encountered. One application is being able to detect the magnetic fields around a microwave, such as microwaves. Others use them with devices that produce magnetic fields in response to music or other sounds. This allows for a new way to experience sound. A magnetic field may be of particular use in the military because many weapons and other dangers produce magnetic fields. Another application of sensing magnetism is the implantable compass, which is used with navigation. This compass is embedded under the skin and attached to a small protruding wire, which brushes against the skin when the user faces north.

Perhaps the most ambitious attempts to add to the human sensory repertoire relate to echolocation, a sense found in some animals.

dolphins, and a few other animals. In echolocation, sound waves are emitted, bounce off objects in the environment, and be sensed and interpreted. Bats famously use echolocation to fly through their environment at night and to locate prey in the air. To allow humans to echolocate, engineers designed a device that sends out ultrasonic sound waves and then detects them when they bounce back. The device transmits information to implanted electrodes in the brain. Echolocation technology is already good enough that a blind researcher can walk around the lab with his eyes closed.



Night-vision goggles are only one technology that enhances human senses.



19.5 Hormones

Learning Objective

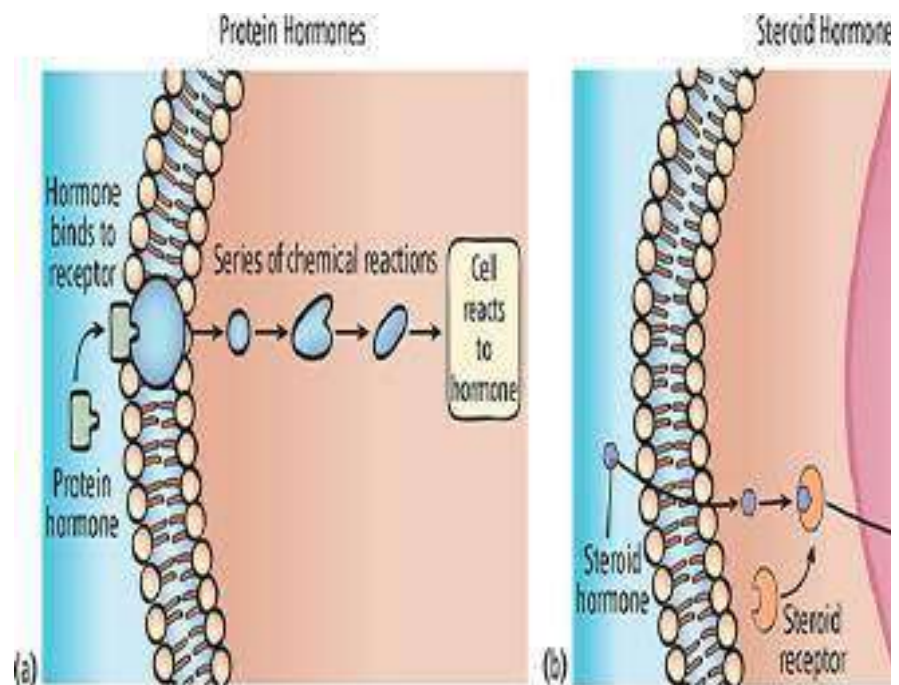
Describe the structure and function of the human endocrine system.

While the nervous system handles rapid actions and reactions, hormones of the endocrine system regulate activities that occur over longer time periods. For example, hormones regulate your growth and development, prepare you for reproduction, determine your metabolism, and tell you whether it is night or day. Hormones play an important role in maintaining homeostasis in the body. What are hormones and how do they work?

A **hormone** is a molecule that gives instructions to target cells. Hormones are produced in one place in the body, released into the bloodstream, and received by target cells elsewhere in the body. Hormones come in two types. *Protein hormones* are, as their name suggests, proteins made from amino acids. *Steroid hormones* are made from cholesterol.

Protein hormones and steroid hormones work in different ways. Protein hormones bind to receptors on the cell membranes of target cells. This binding starts a series of chemical reactions that result in the cell's response to the hormone (Figure 19.19a). Steroid hormones pass through the cell membrane and bind to receptors inside target cells. These receptors may be in a target cell's cytoplasm or nucleus. The hormone-receptor complex then binds to DNA in the nucleus and initiates gene transcription (Figure 19.19b).

Figure 19.19



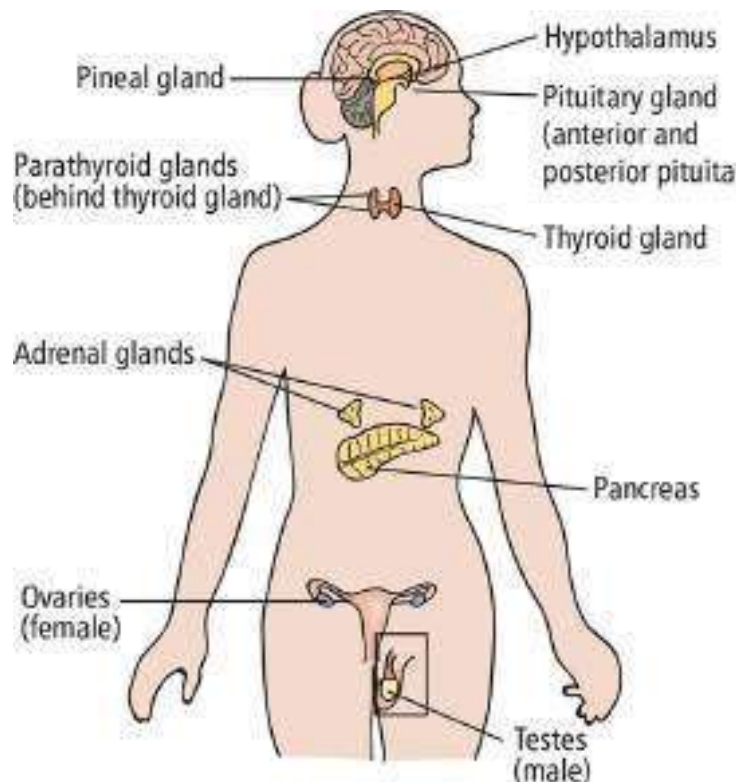
(a) Protein hormones bind to receptors in the cell membrane. This starts a sequence of events that result in the cell's response to the hormone. (b) Steroid hormones enter the cell and bind to receptors inside the cell.

bind to receptors in the cytoplasm or nucleus. Together receptor directly affect gene transcription.

Endocrine Organs and Their F

Let's look at the human endocrine organs ([Figure 19.20](#) hormones they make.

Figure 19.20



Human endocrine organs include the hypothalamus, pi (anterior and posterior pituitary), thyroid gland, parath;

adrenal glands, pancreas, ovaries and testes, and pineal

The *hypothalamus* is a part of the brain; it is the endocrine control center. Many of the hypothalamus's hormones regulate the activity of another endocrine organ, the anterior pituitary. Some hormones are released from the hypothalamus directly into the bloodstream, while others are released into the anterior pituitary, which is located just underneath the hypothalamus. The hypothalamus also makes hormones that are stored and released from the posterior pituitary (discussed below).

The *anterior pituitary* is sometimes called the “master gland” because many of its hormones regulate the activity of other endocrine organs. For example, anterior pituitary hormones tell the thyroid, sex organs, and adrenal glands to release their hormones. The anterior pituitary also makes growth hormone and prolactin. Growth hormone, as its name suggests—it promotes growth. Too little results in dwarfism, and too much results in gigantism (discussed below). *Prolactin* stimulates milk production in nursing mothers.

Figure 19.21



This composite picture shows dwarfism (*upper left*) and relative to a person of normal size (*right*). Dwarfism can result from too little or too much growth hormone.

The *posterior pituitary* stores and controls the release of *antidiuretic hormone* by the hypothalamus. *Antidiuretic hormone* helps regulate water in the body. Specifically, it helps the body conserve water by instructing the kidneys to produce urine that is more concentrated. Alcohol inhibits the release of antidiuretic hormone. This causes the body to produce more urine—and sometimes become dehydrated after consuming alcohol. *Oxytocin* stimulates contraction of the

childbirth. Women whose labor does not progress, or whose labor is induced, may be given pitocin, a synthetic form of oxytocin, to stimulate contractions.

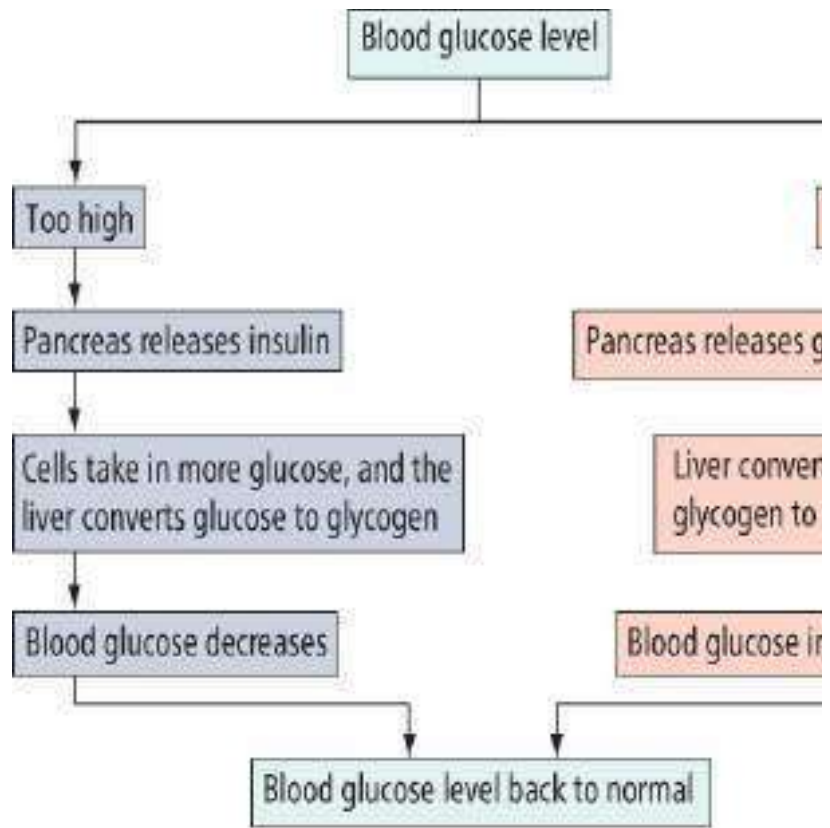
The *thyroid gland* makes thyroid hormones. *Thyroid hormones* are important in metabolism, growth, and development. For example, thyroid hormones are necessary for proper brain development during childhood. Thyroid hormones contain iodine, and getting too little iodine can lead to developmental problems. This is why iodine is added to table salt. The thyroid gland also makes *calcitonin*, which helps regulate calcium levels in the blood.

The *parathyroid glands*, which lie next to the thyroid gland, make parathyroid hormone. *Parathyroid hormone* increases calcium levels in the blood. It does this in three ways: It causes calcium to be released from bones, increases calcium absorption in the intestine, and decreases calcium excretion in urine. Maintaining appropriate calcium levels in the blood is important for many reasons. For example, you learned in this chapter that muscles require just the right amount of calcium to function properly.

The *adrenal glands*, located above the kidneys, make epinephrine (called adrenaline) and norepinephrine. *Epinephrine* and *norepinephrine* are involved in the “fight or flight” response. Signals from the nervous system trigger the release of these hormones. The *adrenal glands* also produce glucocorticoids and mineralocorticoids. *Glucocorticoids* increase glucose levels in the blood; at certain times, you need to deliver more glucose, the molecule that gives you energy, to your cells. *Mineralocorticoids* help regulate water and salt levels.

The *pancreas* makes insulin and glucagon. These hormones regulate the amount of glucose in the blood. *Insulin* decreases blood glucose levels in two ways: It tells body cells to take in glucose, and it tells the liver to convert glucose into the storage substance glycogen. *Glucagon* increases blood glucose levels. *Glucagon* tells the liver to break down glycogen and release glucose. The control of blood glucose levels is a negative feedback and homeostasis: High blood glucose levels cause insulin to be released, and insulin causes blood glucose levels to return to normal. Low blood glucose levels cause glucagon to be released, and glucagon causes blood glucose to increase back to normal (Figure 19.22).

Figure 19.22



Negative feedback enables the body to maintain appropriate glucose levels. If blood glucose levels are too high or too low, the endocrine system responds and brings the levels back to normal.

Unifying Concept

Feedback Loop [Section 19.2](#)

The disease *diabetes* results when the pancreas doesn't release enough insulin or when the body's cells do not respond to insulin. In both cases, blood glucose levels become abnormally high. Symptoms include thirst, fatigue, weight loss, blurred vision, and frequent urination.

the hands and feet. People who have diabetes have to check and monitor their blood glucose levels. Some require regular insulin.

The sex organs—*ovaries* in women and *testes* in men—produce sex hormones. Both women and men make all three types of sex hormones: estrogens, progestins, and androgens. Women make more estrogens and progestins. These hormones regulate ovulation and the menstrual cycle and are involved in pregnancy. Estrogen also promotes bone development and fat storage in the hips and thighs. Men make more androgens. Androgens such as testosterone are required for sperm production. Androgens also promote the development of male sexual characteristics such as facial hair and increased muscle mass. This last effect of androgens that tempts some athletes to use anabolic steroids—synthetic versions of testosterone—to improve performance. Unfortunately, steroids also have many negative effects. They can cause aggressive behavior, mood swings, and depression. In men, steroids also cause shrinking of the testicles, decreased sperm count, baldness, and breast development. In women, steroids disrupt the menstrual cycle, deepen the voice, and promote the growth of facial hair. In adolescents, steroids stunt growth and accelerate puberty.



Science and Society

Fathers and Testosterone

After a man becomes a father, his testosterone level drops. This was the conclusion of a study that measured testosterone levels in more than 600 men when they were 21 years old and again 5 years later. Although testosterone levels drop in all men, those who had children showed a greater drop. Moreover, fathers who spent the most time taking care of their children showed the largest drops. Researchers believe that reducing testosterone is adaptive for fathers because high testosterone promotes aggressive behavior, and lower levels help maintain the family and promote effective child-rearing. This evolved hormonal response also suggests that humans have long been involved in caring for their children, and that men have not done it alone.

Data from the same study showed that men with high testosterone levels were more likely to become fathers in the first place. Apparently, high testosterone levels help a man find a partner, but low testosterone levels help him successfully raise a family.



An evolved hormonal response—lower testosterone—allows fathers to successfully raise families.

The *pineal gland* produces the hormone melatonin. Melatonin acts as the body's internal clock, telling you when it is day and night. Using light cues from the eyes, the pineal gland releases melatonin during the night hours. This is why some people use melatonin supplements to help with sleep.

The major endocrine organs and the hormones they produce are summarized in [Table 19.1](#).

Table 19.1 Major Endocrine Organs and The Hormones They Produce

Endocrine Organ	Hormone	Hormone Type	Effect
Hypothalamus	Makes hormones that regulate the anterior pituitary and hormones released by the posterior pituitary (see below)		
Pituitary gland			
Anterior pituitary	Growth hormone	Protein	Stimulates growth
	Prolactin	Protein	Stimulates milk production
	Multiple hormones that stimulate other endocrine organs	Protein	Stimulate endocrine organs and testes, thyroid glands
Posterior pituitary (releases hormones made by hypothalamus)	Antidiuretic hormone	Protein	Promotes retention of water
	Oxytocin	Protein	Stimulates contraction of smooth muscle
Thyroid gland	Thyroid hormones	Protein	Stimulate growth and development and regulate metabolism
Parathyroid glands	Calcitonin	Protein	Decreases blood calcium
	Parathyroid hormone	Protein	Increases blood calcium
Adrenal glands	Epinephrine and norepinephrine	Protein	Promote "fight or flight" response
	Glucocorticoids	Steroid	Increase blood glucose
	Mineralocorticoids	Steroid	Regulate water and salt balance
Pancreas	Insulin	Protein	Decreases blood glucose
	Glucagon	Protein	Increases blood glucose
Sex organs			
Testes	Androgens	Steroid	Support sperm formation and secondary sexual characteristics
Ovaries	Estrogens	Steroid	Maintain female reproductive system and promote female secondary sexual characteristics
	Progesterone	Steroid	Promote uterine lining
Pineal gland	Melatonin	Protein	Regulates internal clock

Check Yourself

Interactive

Question

Check Answer

Question

Some hormones come in pairs with opposing effects. Each pair homeostasis in the body by regulating the amount of an important molecule—often through feedback regulation. What are two pairs with opposing effects?

Check Answer

Some hormones come in pairs with opposing effects. Each pair homeostasis in the body by regulating the amount of an important molecule—often through feedback regulation. What are two pairs with opposing effects?

19.6 Reproduction and Dev

Learning Objective

Describe the key events in human reproduction and development.

Where do babies come from? Without reproduction, humans and other species—would quickly go extinct.

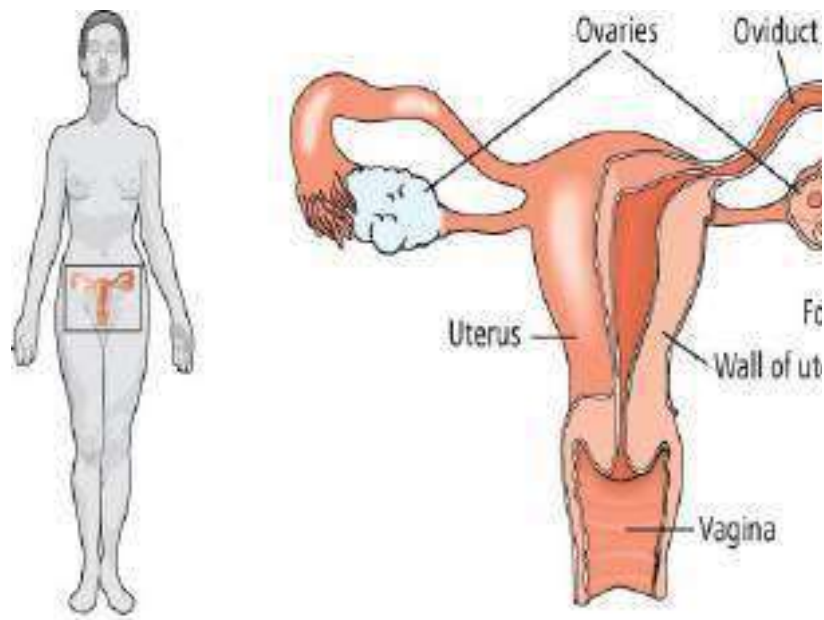
Human Reproduction

Human reproduction begins with the production of *gametes*—eggs in women and sperm in men. Eggs and sperm are produced through *meiosis*. They are haploid cells with only half the usual number of chromosomes. At **fertilization**, egg and sperm join together to form a zygote that develops into a new human being. Let's start by looking at the female and male reproductive systems.

In females, eggs are made in the *ovaries* (Figure 19.23) which are made up of many *follicles*, which are developing eggs surrounded by a layer of cells.

support cells. During each menstrual cycle, a single follicle releases an egg in a process called **ovulation**. The egg is large and contains lots of nutrients stored in its cytoplasm. Eggs are large because they are the result of unequal meiosis: During cell division, one cell (the egg) receives almost all the cytoplasm, while the other cells (the polar bodies, which degenerate) receive very little cytoplasm. After ovulation, the egg is swept into the *oviduct*, where cilia sweep it toward the uterus. Fertilization takes place while the egg is still in the oviduct. The fertilized egg then continues to the *uterus*, where it implants and continues to develop.

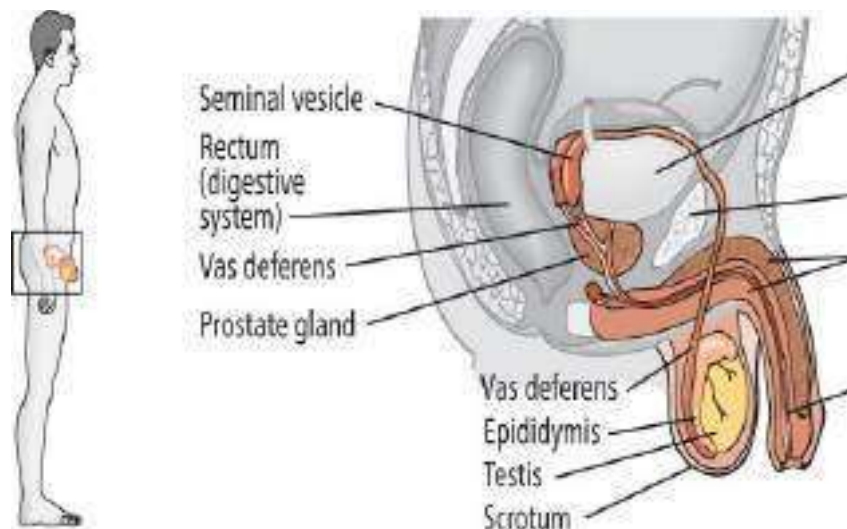
Figure 19.23



The female reproductive system.

In males, sperm are made in the *testes*, which are located (Figure 19.24). The scrotum hangs away from the body to keep the testes at a temperature lower than body temperature. This is necessary for sperm production. From the testes, sperm enter the *epididymis*, where they complete development and become mobile. Each sperm cell has a head that contains DNA, mitochondria, and enzymes for penetrating the egg. Sperm also have a tail for swimming. During intercourse, sperm travel along the *vas deferens* to the *urethra* inside the penis. Sperm are ejaculated from the urethra. In addition to sperm, semen contains fluids from the *seminal vesicle* and *prostate gland* that nourish sperm and protect them from the environment of the vagina. There are about half a billion sperm in each ejaculate.

Figure 19.24

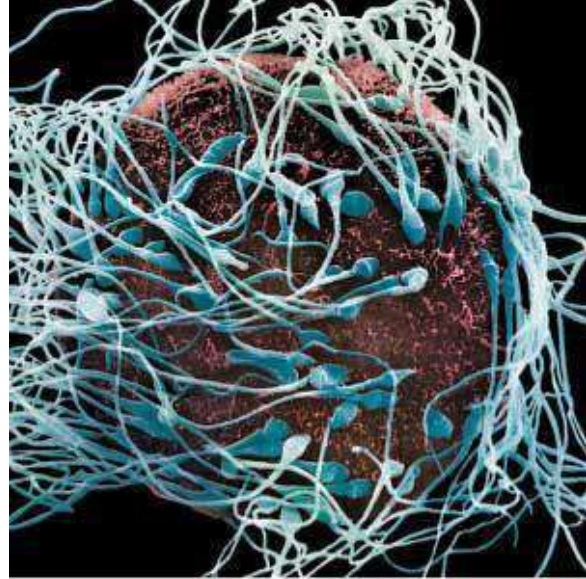


The male reproductive system.

If a man is trying to father a child, he should think about wearing boxers rather than briefs. It's not just about comfort. Briefs can hold the scrotum too close to the body, which keeps the testes too warm for sperm production.

After sexual intercourse, sperm swim up the oviduct to meet the egg (Figure 19.25). The egg is covered by a jellylike layer called the zona pellucida. Enzymes released from the heads of many sperm eat away at the zona. When a single sperm finally reaches the egg's cell membrane, the membranes of egg and sperm fuse. At this point, the zygote undergoes changes that make it impenetrable to additional sperm, assuring that the fertilized egg doesn't end up with too many chromosomes.

Figure 19.25



Sperm surround a human egg.

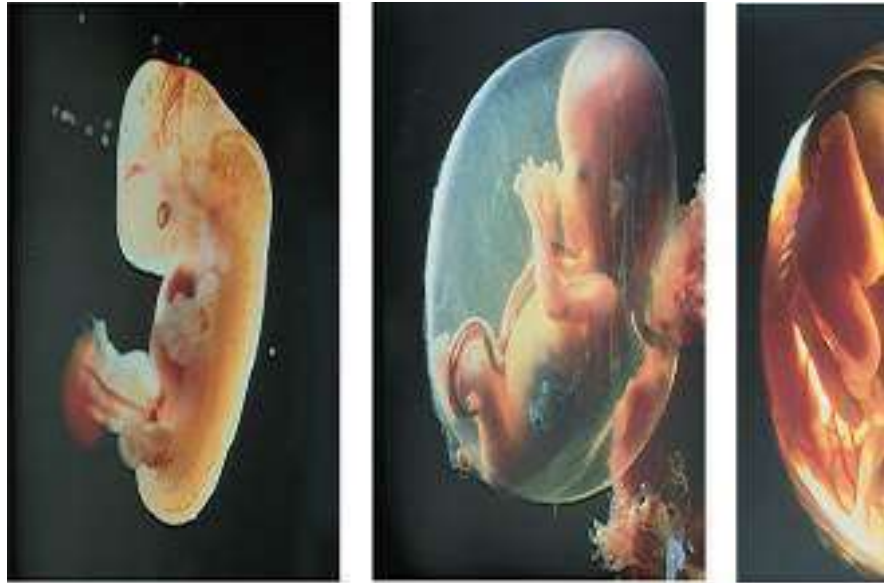
Human Development

After fertilization, the egg begins to divide through mitosis. About 6 days after fertilization, implantation occurs in the uterus. The developing egg has become a hollow ball of cells called the blastocyst. The blastocyst forms the embryo, the future baby. The blastocyst forms structures that protect and nourish the embryo: the amnion and the embryonic portion of the placenta. The amnion is a membrane that surrounds the embryo. It is filled with a liquid that cushions and protects the developing embryo. This liquid is called amniotic fluid. It ruptures when a pregnant woman's "water breaks".

The **placenta** provides oxygen and nutrients to the de and carries away wastes. The placenta consists of both maternal tissues. Maternal blood and embryonic blood direct contact in the placenta; however, they are close to the exchange of nutrients and wastes. The placenta also estrogen and progesterone (a progestin). These hormones ovulation and maintain the uterus in its nurturing condition pregnancy.

The 9 months of pregnancy are divided into three 3-month. During the first trimester, all of the embryo's major organs develop. Further development, as well as most of the fetal occurs in the second and third trimesters. Three stages of development are shown in **Figure 19.26**.

Figure 19.26



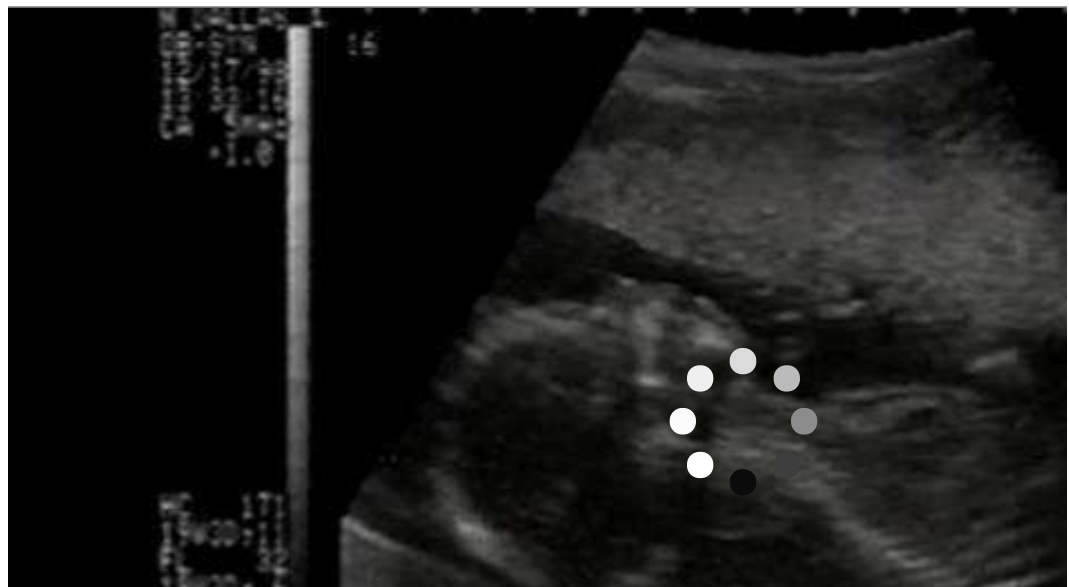
(a)

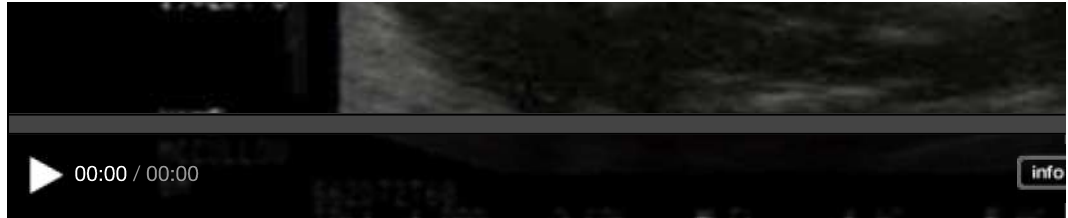
(b)

(c)

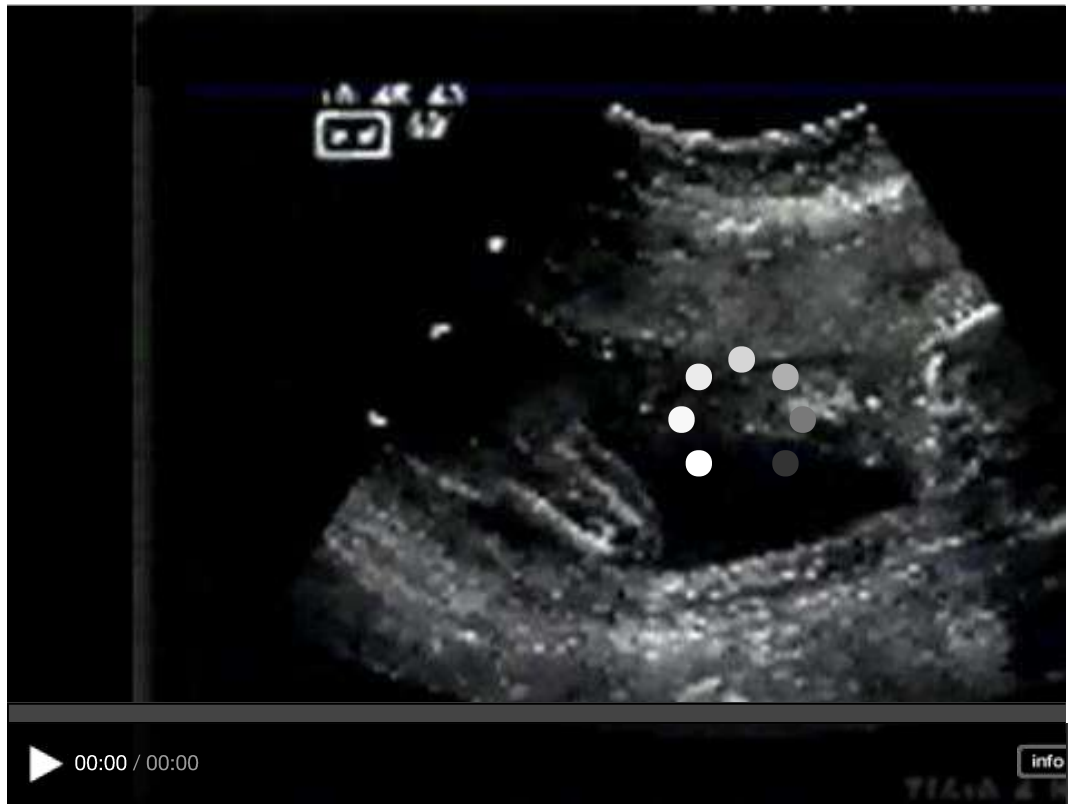
(a) This is a human embryo at 5 weeks. (b) This is a human embryo at 10 weeks. By the end of the first trimester, all the major organs and parts have developed. (c) This is a human embryo at 20 weeks.

Watch [Ultrasound of a Fetus I](#)





Watch Ultrasound of a Fetus II



Check Yourself

Interactive

Question

Check Answer

Question

If you place an unfertilized egg with its zona pellucida removed containing many sperm, what is the likely result?

Check Answer

If you place an unfertilized egg with its zona pellucida removed containing many sperm, what is the likely result? _____

19.7 The Skeleton and Muscles

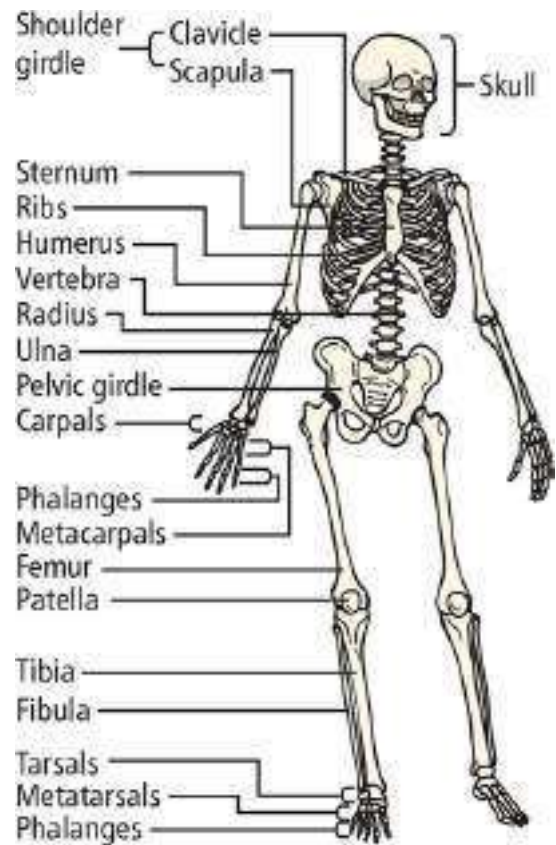
Learning Objective

Describe the structure and function of the skeletal system and skeletal muscles.

The Skeleton

The human skeleton, shown in [Figure 19.27](#), is made of bones and cartilages that protect and support the body. Adults have 206 bones in all. Babies are born with more, but many of these fuse together as they grow. Besides bones, the skeleton includes several cartilages, the external ears (pinnae) and the tip of your nose.

Figure 19.27



The human skeleton includes 206 bones (in adults) as well as cartilages.

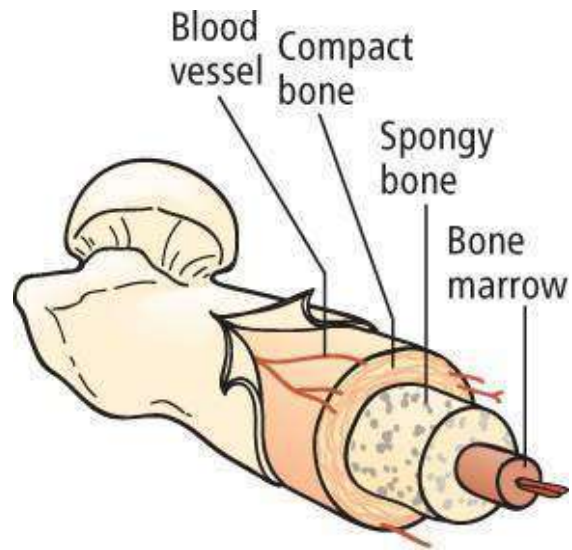
The largest bone in the body is the femur, or thigh bone, and the smallest is the stirrup, a bone in the middle ear that is only a quarter of a centimeter long.

One function of the skeleton is to protect the body. The skull protects the brain, the vertebrae protect the spinal cord, and the ribcage protects the heart and lungs.

A second function of the skeleton is to support the body and help the muscles move it. *Joints* are movable connections between bones. Some joints, like the elbow and knee, act like hinges and allow movement in only one direction. Other joints, like the one between the femur and the tibia, resemble a ball and socket and allow for a greater range of motion. In a ball and socket joint, the ends of connecting bones are covered with smooth cartilage and enclosed in a fluid-filled capsule. The fluid lubricates the joint so the bones can move smoothly, without rubbing against each other. Arthritis is a condition where the tissues of the joint become inflamed, and there is too much fluid. Both the inflammation and excess fluid can lead to bone damage.

Bones are made up of three layers. First, there is a strong outer layer of *compact bone*. Compact bone surrounds a lighter layer of *spongy bone*. Spongy bone surrounds a jellylike substance called *bone marrow* (Figure 19.28). *Red bone marrow* makes red and white blood cells and is part of the circulatory system. *Yellow bone marrow* stores fat. Like all other parts of the body, bones are made of living cells. These cells secrete a calcium-containing matrix that gives bones both strength and flexibility.

Figure 19.28



In bones, compact bone surrounds a layer of spongy bone, which in turn surrounds the bone marrow.

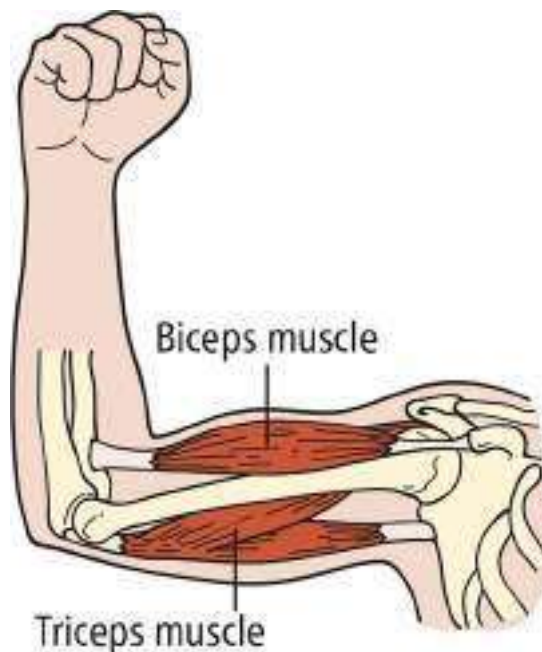
Muscles

You have more than 600 muscles in your body, including those in your face. You use these muscles for everything from smiling to eating sandwiches. In fact, almost any time you say that you are doing something, you are doing it with your muscles.

Muscles work by contracting, or shortening. Many of your muscles are connected to bones via *tendons*. When these muscles contract, they pull on your bones, moving you. Because muscles can only pull, you have many pairs of muscles with opposing effects. For example, you have muscles that pull your arm up and muscles that pull it down.

biceps muscle pulls on the inner part of your forearm, b
forearm up toward your shoulder (Figure 19.29). You
pulls on the back end of your forearm (it attaches to the
the end of your elbow) and straightens the arm.

Figure 19.29

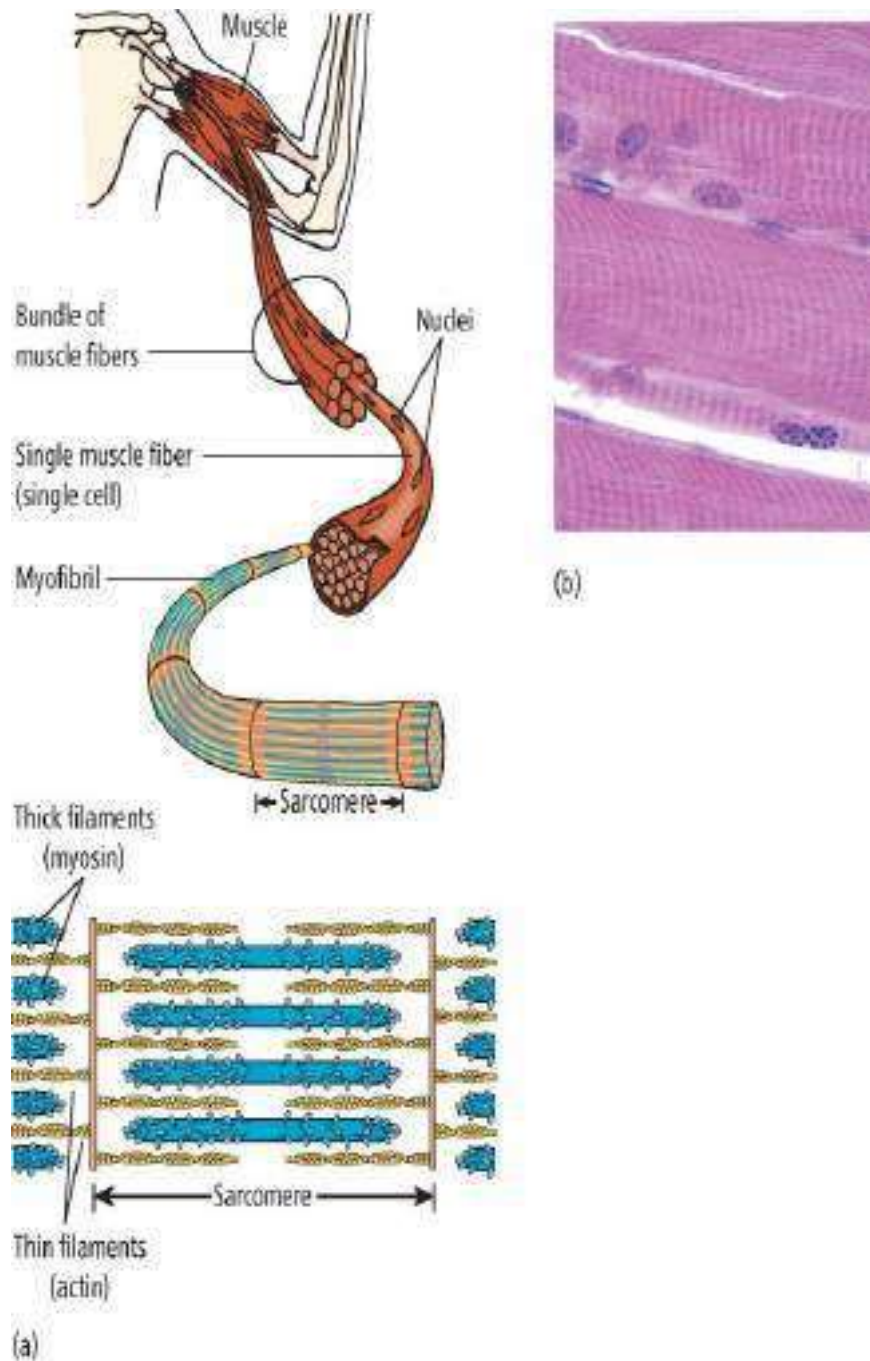


The biceps and triceps muscles move the forearm in op
The biceps bends the forearm, and the triceps straighte

How does a muscle contract? Let's start by looking at it
muscle (Figure 19.30) consists of bundles of long mus
muscle fiber is actually a single cell with multiple nucle

contains bundles of smaller elements called *myofibrils*.]
made up of a series of contractile units called sarcomer
are made up of carefully arranged fibers of two proteins
actin and thick filaments of *myosin*. When a muscle con
and myosin filaments slide past each other, shortening
sarcomere. Let's look at how this happens.

Figure 19.30

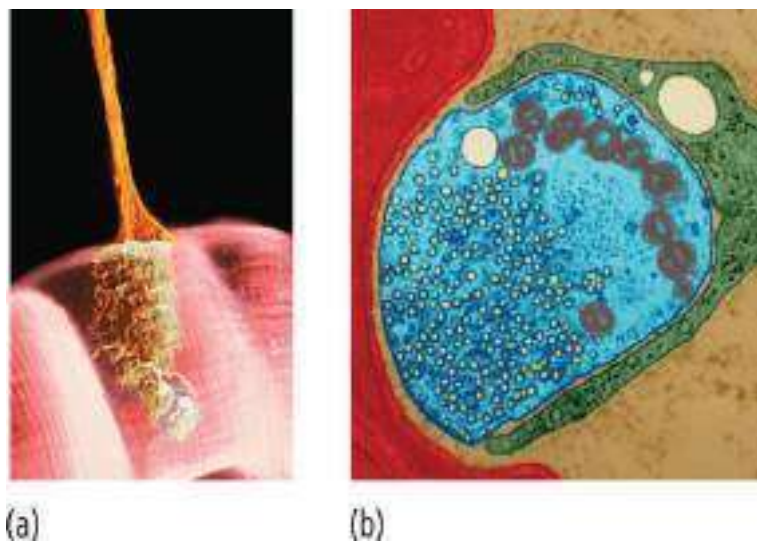


(a) A muscle is made up of bundles of muscle fibers. A contains smaller fibers called myofibrils. A myofibril co sarcomeres arranged end to end. Two proteins in the sa and myosin, allow sarcomeres—and consequently muscle (b) Skeletal muscles have a “striated” or striped appearance appearance of the sarcomeres. The darker oval shapes a

When you lift weights, you don't increase the number of muscle fibers in your muscles. That number stays the same. Instead, your muscles get bigger because the muscle fibers become thicker.

A muscle contracts when it receives a signal from a motor neuron. When an action potential in the motor neuron arrives at a chemical synapse connecting the neuron to a muscle cell, the action potential causes the release of the neurotransmitter *acetylcholine* at the synapse (Figure 19.31). Acetylcholine then binds to receptors on the muscle cell membrane, starting an action potential in the muscle cell.

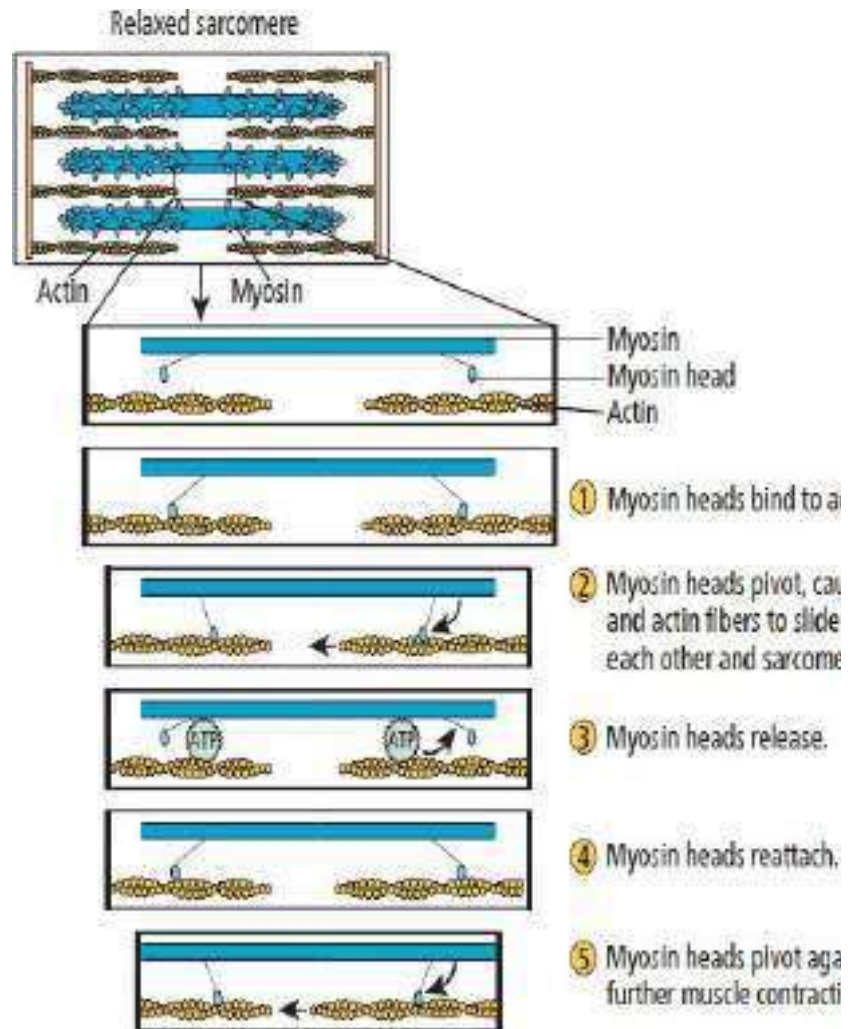
Figure 19.31



(a) This photo shows a motor neuron (orange) and its skeletal muscle cells (red). (b) This is a closeup view of the synapse. The neuron is shown in blue, and the muscle cell is shown in red. Small vesicles containing the neurotransmitter acetylcholine are shown moving from the neuron to the muscle cell. (The larger brown structures in the neuron are mitochondria. The green cell surrounding the neuron is a Schwann cell.)

An action potential in a muscle cell causes calcium ions to be released from the muscle cell's endoplasmic reticulum (a cell organelle). Calcium ions enable a series of "heads" on the myosin fibers to attach to actin filaments (Figure 19.32). The myosin heads attach and pivot, pulling the actin filaments. Each pull shortens the length of the sarcomere by about 10 nanometers—and, consequently, the length of the muscle fiber. After pulling, the myosin heads release, extend, attach, and pull again. This cycle repeats until the signal to contract ends or until the muscle is fully contracted. Muscle contraction requires energy: ATP. ATP provides the energy for the myosin heads to release actin, an essential step in the cycle.

Figure 19.32



During contraction, the myosin heads bind to actin, pivot (pull on actin), release, reattach, and pull again. (For simplicity, one myosin head is shown on each side. In reality, many myosin heads are present.) This process causes the sarcomere to shorten, resulting in muscle contraction.

Once the motor neuron stops signaling, acetylcholine is removed from the muscle cell, and the muscle cell's endoplasmic reticulum releases calcium ions.

calcium. Without calcium, the myosin heads are unable and the muscle relaxes.


Technology

A Mind-Controlled Robotic Arm

More than 2 million Americans have lost a limb, either during warfare or through accidents. Many of them benefit from the use of a prosthetic, which can help with a variety of daily activities. How do prosthetics work?

The most advanced commercially available prosthetics respond to the tiny electrical signals given off by an amputated limb. These prosthetics allow people to manipulate food, carry groceries, handle delicate objects, and even climb walls.

Researchers are now developing robotic arms with direct connections to the brain. These arms are connected to surgically implanted electrode arrays in the motor cortex area of the brain. The robotic arm can then be trained to perform specific tasks.



respond to the same neurons that originally control the muscles.

Some of the latest robotic arms also provide sensory feedback. Pressure sensors in the arm are connected by wires to specific areas in the brain. A blindfolded volunteer outfitted with a robotic arm was able to say which robotic fingers were touched. He was even able to tell when researchers tried to “fool” him by touching two fingers at the same time.

Robotic arms with direct connections to the brain are becoming useful not only for those who have lost a limb but also for people with amyotrophic lateral sclerosis (ALS), a form of Lou Gehrig disease, and stroke victims. In ALS, the neurons that control voluntary muscle movement gradually die, making such movements impossible. However, the brain and thought processes remain intact. In stroke, damage to certain parts of the brain prevents some movements. However, uninjured parts of the brain are able to learn how to control a prosthetic.



This “thought-controlled” prosthetic arm includes implanted on the chest to control movement and the shoulder to transmit sensory information.

Several well-known toxins work by interfering with the between neurons and muscles. Curare, an arrow poison American tropics for hunting, binds to acetylcholine receptors, preventing acetylcholine itself from binding. Curare and then death as the respiratory muscles become paralyzed. A powerful nerve gas sarin prevents acetylcholine from binding after muscles contract. Muscles are stimulated continuously.

become exhausted. Again, death occurs through asphyxiation as respiratory muscles stop working. In 1995, sarin was used in an attack on the Tokyo subway that killed 13 people and hospitalized others, many of whom are still suffering the consequences. Sarin was also used by the Syrian government to attack civilians in a controlled area in 2017. The attack killed over 80 people, including children.

Muscle contraction also explains rigor mortis, the stiffness that sets in after death. After death, calcium ions leak from the endoplasmic reticulum of muscle cells. Myosin binds to actin, and the muscles contract. Once the available ATP is used up, the myosin heads are unable to disengage, and the muscles remain contracted.

Check Yourself

Interactive

Question 1

Check Answer

Question 2

Check Answer

Question 1

Why is calcium necessary for muscle contraction?

Check Answer

Why is calcium necessary for muscle contraction?

Answer: Calcium enables the myosin heads to attach to actin.

Summary of Terms (Knowledge)

For instructor-assigned homework, go to
www.masteringphysics.com

Action potential □

A signal from a neuron or other cell that occurs when the membrane potential becomes positive.

Chemoreception □

A way of sensing that occurs when chemicals bind to receptor sensory cells, initiating action potentials.

Fertilization □

The joining of an egg and a sperm to form a diploid cell into a new organism.

Homeostasis □

The maintenance of a relatively stable internal environment.

Hormone □

A molecule that gives instructions to the body; it is produced in the body, released into the blood, and received by target cells elsewhere in the body.

Neuron □

A cell that receives and transmits electrical signals from one part of the body to another.

Organ □

A structure in the body that has a specific function.

Organ system □

A set of organs that work together to perform a particular function.

Ovulation □

The release of a mature egg cell that occurs once during the menstrual cycle.

Placenta □

The organ that allows nutrients and wastes to be exchanged between a pregnant woman and a developing embryo.

Sarcomeres □

The contractile units of muscle cells.

Synapse □

A connection between a neuron and a target cell.

Tissue □

A group of similar cells that performs a certain function

Reading Check Questions (Comprehension)

19.1 Organization of the Hum

1. What are the four main types of tissues in the h
an example of each.
2. Multiple tissues combine to make a(n)___, a stru
that has a specific function.
3. What is an organ system?

19.2 Homeostasis

4. What is homeostasis?
5. Give some examples of variables for which the
homeostasis.

19.3 The Brain

6. What are some of the functions of the brainstem?
7. Which part of the brain is responsible for balance and coordination?
8. Why can damage to one side of the cerebrum affect the functioning of the opposite side of the body?
9. Describe the functions of each of the four lobes of the cerebrum.

19.4 The Nervous System

10. Which structures make up the central nervous system?
11. A typical neuron has dendrites, a cell body, and an axon. Describe the function of each of these parts.
12. What are the functions of sensory neurons, interneurons, and motor neurons?
13. What kinds of functions are controlled by the somatic nervous system and the autonomic nervous system?

19.5 Hormones

14. What are the two types of hormones? How do they produce an effect in a target cell?
15. Why is the anterior pituitary sometimes called the master gland?

16. What hormone made by the hypothalamus helps regulate the amount of water in the body? What is its effect?
17. Which endocrine organ produces the hormone that triggers the “fight or flight” response?

19.6 Reproduction and Development

18. What is unusual about the process of meiosis that occurs in the egg?
19. How do sperm get past the zona pellucida that surrounds the egg?
20. What is the function of the placenta?
21. When during pregnancy do an embryo’s major organs develop?

19.7 The Skeleton and Muscles

22. What are the functions of the skeleton?
23. How does a signal from a motor neuron result in the contraction of a muscle?

24. At what point in the process of muscle contract required?

Think Integrated Science

19A—How Neurons Work

25. What is a membrane potential?
26. What happens to the membrane potential of a neuron during an action potential?
27. Why is an action potential described as an all-or-none event?
28. What causes an action potential to travel down an axon?
29. How does an electrical synapse work?
30. How does a chemical synapse work?

19B—How Fast Can Action Potentials Travel?

31. Why do action potentials travel more quickly down myelinated axons than thinner ones?
32. Why haven't any animals evolved large numbers of unmyelinated axons?

33. How does myelination speed the propagation of action potentials?

19C—Endorphins

34. What are endorphins, and what causes cells to release them?
35. Why do endorphins have effects similar to those of morphine and heroin?
36. What is the effect of endorphins?

19D—The Senses

37. What are the two types of light-sensitive cells in the retina, and how do they differ from each other?
38. Describe how sound waves enter the ear and are processed by the brain to allow you to hear.
39. How are action potentials generated in chemoreceptors?
40. What are proprioceptors?

Think and Do (Hands-On Application)

41. You have a *blind spot* where your optic nerve exits the eye. Because of the presence of the optic nerve, there are no photoreceptor cones in this spot. Why is there no obvious blind spot in your field of vision? The brain cleverly fills in this area with information from surrounding areas. Let's locate your blind spot. Draw a small dot on the left side of a piece of paper. Mark an 'x' on the right side. The x should be about 6 inches from the dot. Now hold the paper in front of you at arm's length with your right eye and look at the x with your left eye. Slowly move the sheet of paper closer to your face. At some point the dot will disappear. Why? What is happening that prevents you from seeing the dot?
42. Is what you think of as "taste" largely smell? Cut a piece of pear, a piece of apple, and a piece of banana. Hold one of the pieces of fruit in your hand. Hold your nose, and chew. Can you tell what the fruit is? Now release your nose and allow yourself to sniff. Can you tell what the fruit is? Now can you tell which is which? This exploration

performed with different flavors of jellybeans o
different kinds of baby food, and so on.

Think and Compare (Analysis)

43. Rank the following from the smallest to the largest organization: organ, organ system, tissue, cell.
44. The membrane potential is the electric potential across the membrane of a neuron. Rank the following from smallest to largest electric potential: resting potential, membrane potential during action potential, threshold.
45. Rank the two types of light-sensitive cells, rods and cones, in terms of (a) ability to see in dim light, (b) ability to see details, and (c) ability to distinguish different colors.

Think and Solve (Mathematical Application)

46. Two different types of neurons transmit pain signals to your central nervous system. The faster type transmits signals at 100 m/s, and the slower type transmits signals at 0.5 m/s. The distance from your hand to your central nervous system is about 1 m. How long does it take for you to become aware of a type of pain in 0.04 s, and that you become aware of another type of pain after only 2 s. (You may have noticed that when you do something like touch a hot stove, you feel a sharp pain first, followed by a slow throbbing pain.)
47. The human retina has an area of about 1000 mm². About 120 million rods and 6.5 million cones are found there, showing about 131,500 sensory cells per square millimeter.
48. You have about 1000 different kinds of smell receptors. Each of these receptors is a distinct protein coded for by a gene. The Human Genome Project revealed that humans have about 19,000 genes. Show that about 5.3% of your genes are dedicated to helping you smell.

49. The egg is a large cell and contributes almost all present in a fertilized egg. The sperm contributes its set of chromosomes. Just how much bigger is it than a human sperm? The human egg is about 120 micrometers in diameter. The head of a human sperm is about 5 micrometers in diameter (and, if you are curious, a human sperm is 50 micrometers long). Show that the volume of a human egg is 15,625 times larger than the volume of a human sperm. (Note that the formula for the volume of a sphere is $\frac{4}{3}\pi r^3$.)

Think and Explain (Synthesis)

19.1 Organization of the Human Body

50. Is the brain a tissue, an organ, or an organ system? Give your answer.
51. The stomach is an organ. Describe some of the structures that make up the stomach.

19.2 Homeostasis

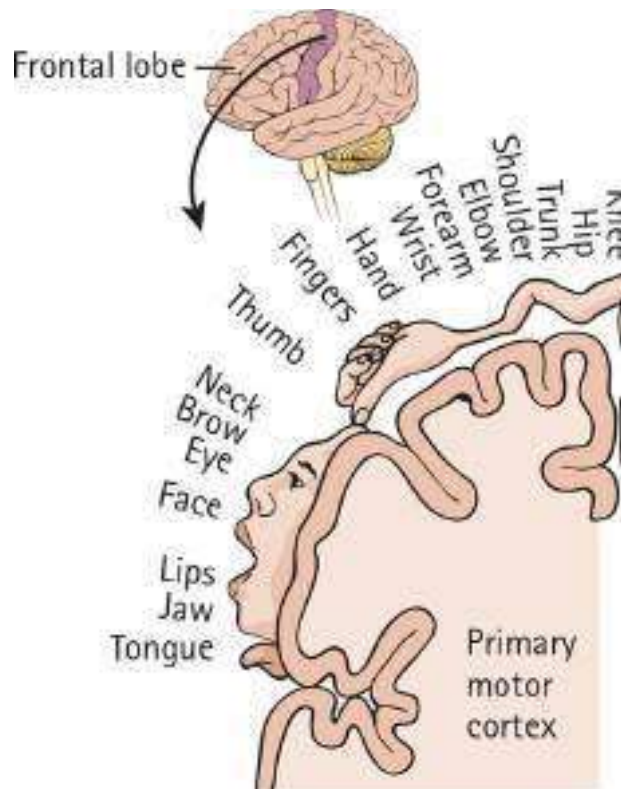
52. Why do you shiver when you are cold?
53. One aspect of homeostasis is maintaining the amount of water in the body. How does the body regulate water balance? Thirsty is an important aspect of maintaining homeostasis.
54. When you exercise, your cells use more oxygen and your heart works harder. Is this an example of negative feedback? Give your answer.

55. This man is cooling off after an intense run. He to drink some of the water in his water bottle to sweating, pouring water on yourself, and drink homeostasis.



19.3 The Brain

56. When you move your body, is your cerebrum in control of your motions? What other parts of your brain are involved? Explain.
57. Why is the surface of your brain wrinkled?
58. The figure shows a map of the motor control area found in the frontal lobe of the cerebrum. Why is the part of the brain responsible for controlling the hands and lips so large? Why is only a small part of the brain responsible for controlling the trunk?



19.4 The Nervous System

59. Describe the structure of a typical neuron.
60. Of the three types of neurons—sensory neurons and interneurons—which type goes to your bicep to tell you to bend your elbow? Which type tells your feet feel cold?
61. What happens during the “fight or flight” response?
62. Is a neuron that slows your heartbeat part of the autonomic nervous system? Is this neuron part of the somatic nervous system?

or parasympathetic division?

19A—How Neurons Work

63. What is an action potential? Describe how the membrane potential changes during an action potential.
64. What role do sodium channels and potassium channels play in an action potential?
65. What would be the effect of removing the myelin sheath from the axon of a neuron?
66. Do neurotransmitters enter the target cell? If not, how do they have an effect on the target cell?
67. What determines whether a target cell responds to a neurotransmitter?

19B—How Fast Can Action Potentials Travel?

68. Why is Ohm's law important to how quickly an action potential travels down an axon?

69. Humans do not have any axons that approach the giant axon in diameter. Why not?

19C—Endorphins

70. How were endorphins discovered?
71. Did the opiate receptors evolve to respond to norepinephrine, and why do they respond to morphine?
72. Endorphin molecules and morphine molecules are structurally alike (see [Figure 19.14](#)). Why do they have similar effects on the brain?

19D—The Senses

73. Many nocturnal animals have only rods in their retinas. In addition, many have a reflective layer of tissue behind the retina that bounces light back toward the retina. You can see the “eyeshine” of the cat in the photo below. How do these features help animals see at night?



74. Are your rods or cones more important for reacting to light? Defend your answer.
75. If you accidentally hit your eye, you may “see” a flash of light. Why?
76. In some people, the bones of the middle ear stick together. This can result in deafness. Why?
77. You eat an apple. What senses are involved? Explain.



19.5 Hormones

78. Suppose you know that the receptor for a hormone you are studying is found in the target cell's cytoplasm. Is it a protein hormone or a steroid hormone?
79. On a brilliant, sunny day, you take a long hike through the country. You sweat a lot, losing a lot of water. What hormone does your body release? Why?
80. Why does your body release insulin after you eat?
81. What is diabetes? What are the symptoms of diabetes?

19.6 Reproduction and Development

82. What are the roles of mitosis and meiosis in human development?
83. Vasectomy is a form of male sterilization in which each vas deferens is removed. How does this cause preventing a man from fathering children?
84. Does a fertilized human egg make anything other than an embryo?
85. Does a mother's blood mix with her baby's during pregnancy? Explain your answer.

19.7 The Skeleton and Muscle

86. What are the functions of bone marrow?
87. If muscles can only pull, not push, how is it possible to both bend your arm as well as straighten it?
88. Curare is an arrow or dart poison used by certain tribes in hunting. The darts in the photo shown are poisoned with curare. Curare binds to acetylcholine receptors on muscle cells. How does curare cause death?



89. What causes rigor mortis, the stiffening of the b

Think and Discuss (Evaluation)

90. Does maintaining homeostasis of body temperature require feedback regulation? Explain.
91. Animals vary in how “wrinkled” their brains are. Some animals have very wrinkled brains, while others have smooth brains. What would you predict about an animal that has a wrinkled brain rather than a smooth one?
92. You talk with a friend on the telephone. Which part of your brain do you use?
93. If a signaling neuron has an excitatory effect on another neuron, does it increase or decrease the membrane potential of the target neuron? Defend your answer.
94. Stars come in different colors depending on their surface temperatures. But when you look up at a starry night sky, stars look like they are the same color. Why?
95. Osteoporosis is a disease that primarily affects postmenopausal women, causing decreased bone density and brittle bones that are vulnerable to fracture. The hormone calcitonin is used to treat osteoporosis. Why?

96. Jet lag describes the fatigue and disorientation that occurs when flying across many time zones. What causes jet lag? How does the body eventually adjust to a new time zone? Is there such a thing as "train lag" or "bicycle lag"?
97. How has natural selection acted on testosterone levels? Is there an ideal testosterone level for all phases of life?
98. Only one sperm fertilizes an egg. If this is the case, why is sperm count a factor in infertility?
99. Each time myosin heads pull on actin, the sarcomere shortens only about 10 nm (10^{-9} meter). Given that, how do muscles produce large motions with your muscles?
100. Explain what happens when you wiggle your toe. Describe the decision to wiggle your toe, which occurs in your brain, with a description of the activity of your muscles.

Readiness Assurance Test (1)

Readiness Assurance Test

Interactive

If you have a good handle on this chapter, if you really do, then to score 7 out of 10 on this RAT. If you score less than 7, you need to review before moving on.

Choose the BEST answer to each of the following:
10 questions

1. 1.

Skin consists of sheets of tightly packed cells that cover the surface of the body. Which type of tissue is skin?

muscle tissue

Incorrect.

Press enter after select an option to check the answer

epithelial tissue

Correct.

Press enter after select an option to check the answer

nervous tissue

Incorrect.

Press enter after select an option to check the answer

connective tissue

Incorrect.

Press enter after select an option to check the answer

Chapter 20

Human Biology II—Care and Maintenance



20.1 Integration of Body Systems 

20.2 The Circulatory System 

TECHNOLOGY: *Transplanting Bone Marrow in the Treatment of Cancer* □

INTEGRATED SCIENCE 20A: CHEMISTRY: *Hemoglobin* □

INTEGRATED SCIENCE 20B: PHYSICS: *Blood Pressure* □

20.3 Respiration □

INTEGRATED SCIENCE 20C: PHYSICS: *Inhalation and Exhalation* □

20.4 Digestion □

TECHNOLOGY: *Manipulating the Microbiome* □

20.5 Nutrition, Exercise, and Health □

SCIENCE AND SOCIETY: *What Are the Odds? Calculating Health Risks* □

20.6 Excretion and Water Balance □

INTEGRATED SCIENCE 20D: CHEMISTRY AND PHYSICS: *Concentrating Urine* □

20.7 Keeping The Body Safe: Defense Systems □

SCIENCE AND SOCIETY: *The Placebo Effect* □

WHETHER YOU play world-class tennis—or just sit and
phone—your body is hard at work. In this chapter, we f
and maintenance of the human body. As we explore th
many things. What makes the “lub-dubb” sound of the
possible to forget to breathe? Which part of your body
hiccups? Is swallowing a voluntary or involuntary actio
your body defend you against bacteria, viruses, and oth
cause disease? And how do vaccines keep you from get

20.1 Integration of Body Systems

Learning Objective

List examples of organ systems working together to perform important body functions.

The body's organ systems rarely act alone. Most of the body's functions require the efforts of two or more organ systems. For example, the job of keeping the body supplied with oxygen is split between two organ systems: The respiratory system brings oxygen in from the air, and the circulatory system transports it to the tissues. Similarly, the removal of cellular wastes requires the coordinated efforts of the circulatory, respiratory, and excretory systems. The circulatory system transports wastes from the tissues, and the respiratory and excretory systems remove wastes from the body via exhalation and urine production. In this chapter, we will look at how organ systems work together to maintain the body. Among their many tasks are two of the most important: obtaining energy for the body's activities and protecting the body from disease.

20.2 The Circulatory System

Learning Objective

Describe the structure and function of the circulatory system.

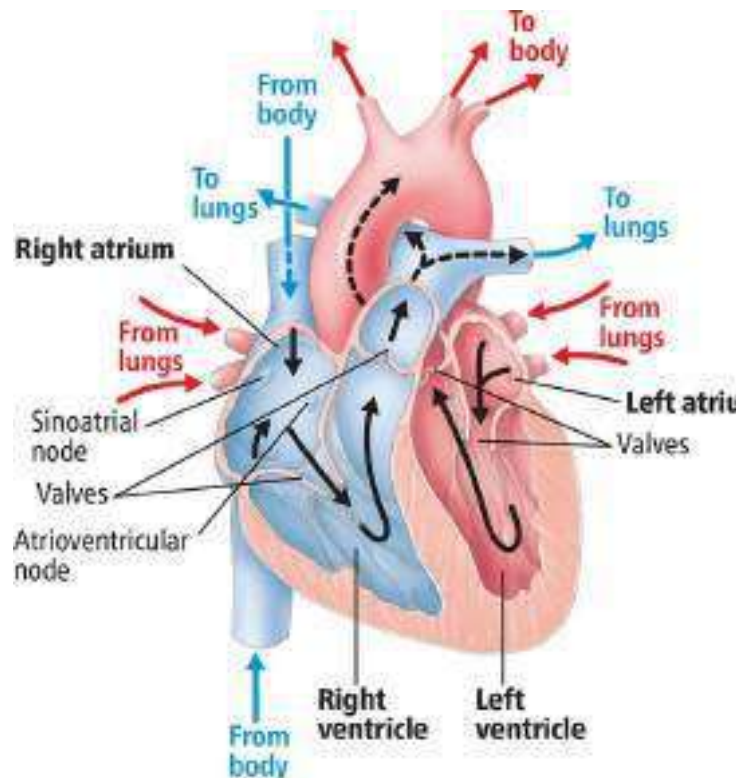
Wouldn't it be nice if everything you needed came right to your door? Running low on milk? Here come a couple of gallons now. Need some oranges? There should be some along any minute. Broccoli? A lucky day. And no need to take the garbage out either. Your circulatory system will make its own way to the dump.

Is this a couch potato's dream come true? Maybe, but it's the life of your cells. Your circulatory system brings you what they need, and it removes all the garbage they have to get rid of. The circulatory system delivers oxygen and nutrients, takes away waste, transports special items such as hormones and immune cells, and handles mail service rolled into one. The circulatory system consists of three parts: the heart, blood vessels, and blood.

The Heart

The heart ([Figure 20.1](#)) is a muscular pump that drive body. It is about the size of a clenched fist and has four chambers: right atrium, right ventricle, left atrium, and right side of the heart pumps blood to the lungs, where up. The left side pumps blood to the body.

Figure 20.1



The heart has four chambers, labeled in bold. The arrows show blood flows throughout the heart. Heart valves keep blood from flowing backward.

Heart muscle does not need a neuron to tell it to contract like voluntary muscles do. Instead, the heart contracts on its own. Each heartbeat begins on its own in a part of the right atrium called the *sinoatrial node*, or *pacemaker*. The pacemaker initiates an action potential that sweeps quickly through the right and left atria, which contract simultaneously, driving blood into the ventricles. The action potential also travels to the *atrioventricular node*. From the atrioventricular node, the signal passes to the two ventricles, which also contract simultaneously, driving blood out through blood vessels.

Because the atrioventricular node conducts action potentials more slowly, there is a delay between the contraction of the atria and the contraction of the ventricles. This is why each heartbeat consists of two sounds: the miraculous “lub-dubb ... lub-dubb ... lub-dubb ...” that we hear every minute of our life. The “lub” occurs when the two atria contract; the “dubb” occurs when the two ventricles contract. Note, however, that the heart doesn’t thud like the heartbeats of a hammer. (The heart’s thud is the heartbeats of a hammer. (and leg muscles don’t thud when they contract!) The heart has *valves* that snap shut after each contraction. Heart valves

tissue between the atria and the ventricles, and between the ventricles and blood vessels. These valves prevent blood from flowing back.

The heart beats about 70 times a minute. This adds up to more than 100,000 heartbeats a day.

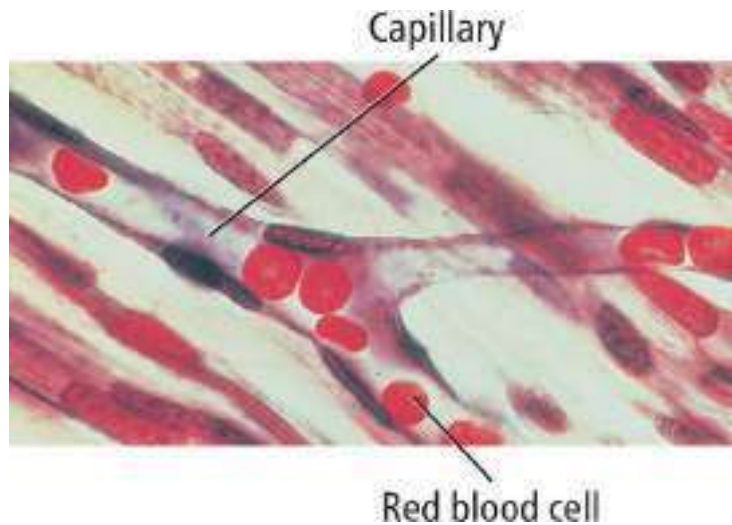
Blood Vessels

Blood travels throughout the body in tubes called *blood vessels*. *Arteries* are blood vessels that carry blood away from the heart. They have thick walls that contract when blood is pumped, then bounce back. You can feel this contraction and recoil by feeling the pulse at your wrist or temple. As blood moves into smaller vessels called *arterioles*. Each arteriole has a layer of smooth muscle around it that controls its diameter. The different diameters of different arterioles allows the body to control how much blood different tissues receive. Tissues need more blood when they are working harder. For example, when you've just eaten a meal, the body is digesting it, arterioles that go to the digestive organs in the stomach are sending more blood to those organs.

From the arterioles, blood flows into capillaries (**Figure 1.10**). **Capillaries** are tiny, thin-walled blood vessels from which

are exchanged between blood and body tissues. Oxygen moves from blood to body tissues, while carbon dioxide products move from body tissues to blood. Some molecules of oxygen and carbon dioxide move via diffusion. Others move via facilitated diffusion or active transport, or they are moved in vesicles using endocytosis or exocytosis. In order to allow for this exchange, capillaries have very thin walls—often only a

Figure 20.2



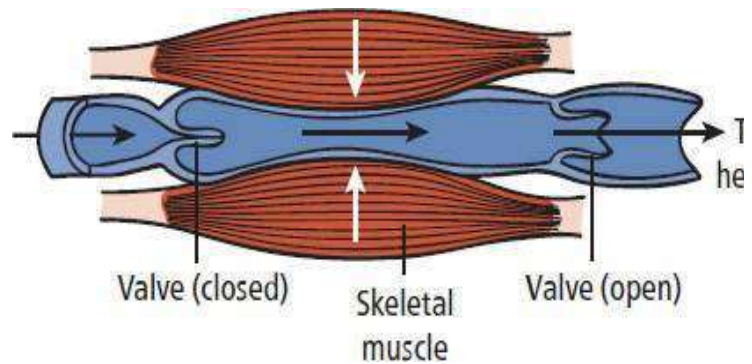
Capillaries are tiny, thin-walled blood vessels where molecules are exchanged with body tissues. You can see some red blood cells in the capillary.

Unifying Concept

The Second Law of Thermodynamics **Section 6.5**

From the capillaries, blood enters small *venules* and the
These are the blood vessels that carry blood toward the
contractions of your voluntary muscles, such as your leg
squeeze blood along your veins (**Figure 20.3**). This is
ankles sometimes swell if you sit or stand for too long
Valves in the veins help make sure blood does not flow

Figure 20.3

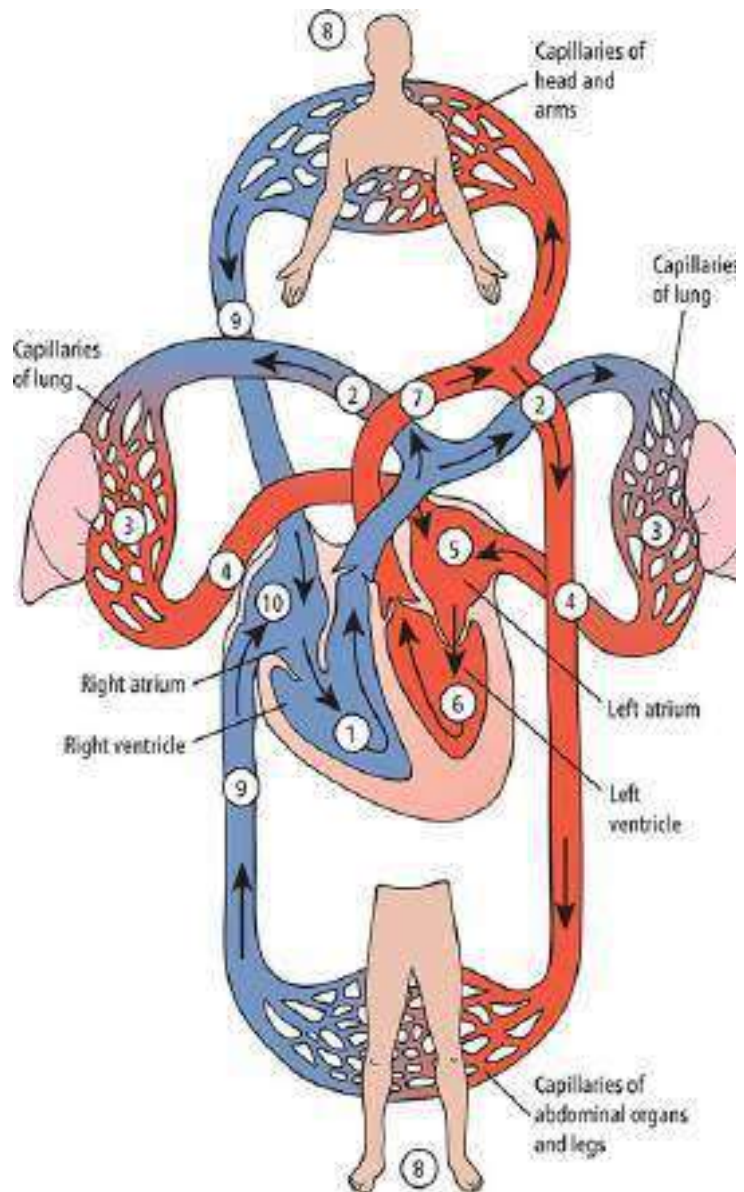


The contractions of your voluntary muscles squeeze blood
veins. Valves make sure the blood doesn't flow backwa

How Blood Flows Around the

Like all good food, garbage, and mail services, the circulatory system does not move blood haphazardly around the body but follows a specific path (Figure 20.4). The path of blood flow allows the circulatory system to efficiently carry out one of its primary tasks, delivering oxygen to the body. How does blood flow? Let's start with blood returning to the heart. Blood returning from the body contains low oxygen and is *deoxygenated*. This deoxygenated blood flows from the superior and inferior vena cava into the right atrium of the heart. The right atrium pumps it to the right ventricle, which pumps it out through arteries that go to the lungs. In the lungs, blood picks up oxygen and drops off carbon dioxide. Blood is

Figure 20.4



This figure shows the path of blood flow around the body. Blue indicates deoxygenated blood, and red indicates oxygenated blood.

Oxygenated blood flows back to the heart through the inferior vena cava to the right atrium. The right atrium pumps blood to the right ventricle, which pumps it out through the pulmonary artery to the capillaries of the lung. Deoxygenated blood flows back to the heart through the pulmonary vein to the left atrium. The left atrium pumps blood to the left ventricle, which pumps it out through the aorta to the capillaries of the head and arms and the capillaries of the abdominal organs and legs.

in the blood diffuses into the cells of all your tissues; every cell needs oxygen. After carrying oxygen to the tissues, the blood becomes deoxygenated again and returns to the heart. The entire process takes about one minute.

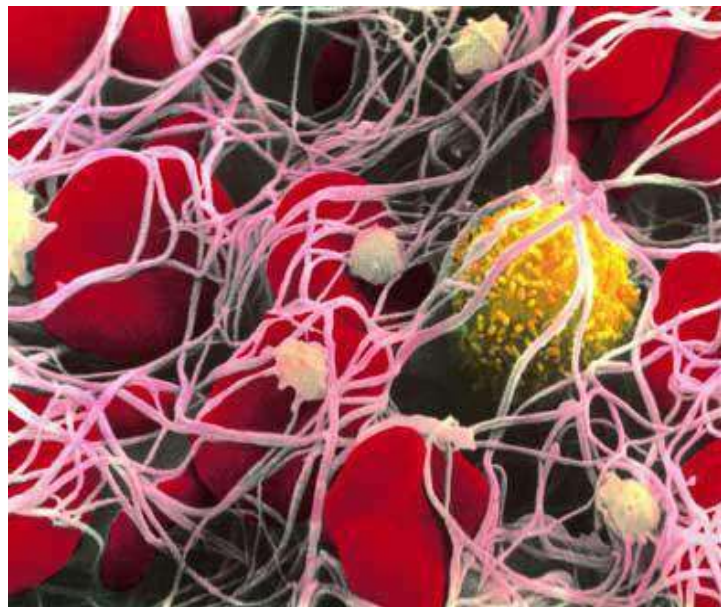
Blood

Now that we know how blood moves around the body, let's look more closely at blood itself. You have about 11 pints of blood in your body, which makes up about 8% of your body weight. A little less than half of this is *plasma*. Plasma is mostly water, but it also contains various molecules such as proteins, hormones, glucose, other nutrients, and wastes.

The rest of your blood is made up of cells—red blood cells, white blood cells, and platelets. **Red blood cells** transport oxygen to the tissues. Red blood cells contain numerous molecules of **hemoglobin**, which binds to and transports oxygen. Each red blood cell has as many as 300 million molecules of hemoglobin in a single red blood cell. Each hemoglobin molecule can carry up to four oxygen molecules. **White blood cells** are part of the immune system and help defend the body against disease. We'll learn more about white blood cells in a later chapter.

are involved in blood clotting. When body tissues are damaged, they attach to damaged blood vessels and release special clotting factors. These clotting factors convert proteins in blood plasma into a substance called *fibrin* (Figure 20.5). Fibrin prevents red blood cells from leaking out of the damaged blood vessels. The disease hemophilia is associated with a deficiency in blood clotting, and is caused by mutations that affect clotting factors.

Figure 20.5



Clotting prevents blood from leaking out of damaged blood vessels. The photo shows red blood cells tangled up in threads of fibrin. The green structures are platelets, and the yellow cell is a white blood cell.

Check Yourself

Interactive

Question 1

Check Answer

Question 2

Check Answer

Question 1

Which chambers of the heart contain oxygenated blood? Which deoxygenated blood?

Check Answer

Which chambers of the heart contain oxygenated blood? Which deoxygenated blood?

Answer: The left atrium and left ventricle contain oxygenated blood. The right atrium and right ventricle contain deoxygenated blood.

Technology

Transplanting Bone Marrow in Fight Against Cancer

Bone marrow, a spongy tissue found inside bone, contains *blood-forming stem cells* that produce red blood cells, white blood cells, and platelets. In the disease leukemia, cancerous cells that describe cancers of these blood-forming tissues, abnormal cells—often white blood cells—grow out of control. One treatment for leukemia is a bone marrow transplant. In a bone marrow transplant, the patient's diseased bone marrow is replaced with healthy bone marrow from a donor.

transplant, the patient's cancerous bone marrow is replaced with healthy bone marrow from a donor. Bone marrow transplants may also be useful in other types of cancer after aggressive chemotherapy or radiation therapy depletes the patient's bone marrow as a side effect of treatment.

During a bone marrow transplant, a patient receives either their own stem cells, harvested before cancer treatment, or stem cells from a donor. If stem cells are received from a donor, the donor's bone marrow must be a close genetic match to the patient. Without this close genetic match, graft-versus-host disease could happen: The patient's immune system could attack the transplanted cells, or white blood cells made by the donor's marrow could view the patient's body as foreign. For many patients, a sibling provides a good genetic match. Donors may also be found through an international bone marrow registry.

The recipient of a bone marrow transplant receives the stem cells directly into the bloodstream. These stem cells migrate to the bone marrow and begin to function a few weeks after the transplant. It can be some time before the new stem cell population is fully functional, however, and the patient may experience side effects during this period.

immune function usually does not return to normal years.



After a bone marrow transplant, it takes several years for a patient's immune system function to return to normal. This child is wearing a "biological isolation garment" to prevent infection during play.

Integrated Science 20A: Chemistry

Hemoglobin

Learning Objective

Describe the structure and function of hemoglobin

Every human red blood cell contains about 300 million molecules of hemoglobin, the oxygen-carrying protein. What is the structure of hemoglobin? A hemoglobin molecule is made up of four smaller subunits. Each subunit contains a heme group that includes an iron atom at its center (Figure 20.6). It is this iron atom that binds to oxygen. Consequently, each hemoglobin molecule can carry up to four molecules of oxygen.

Figure 20.6



Hemoglobin is made up of four subunits. Each subunit contains a heme group with an iron atom at its center.

When oxygen binds to one of the four subunits in a hemoglobin molecule, the other three subunits are altered in that their affinity for oxygen increases—that is, they become more likely to bind oxygen. As a result, most hemoglobin molecules will carry the maximum number of oxygen molecules away from the lungs. Similarly, when one subunit releases an oxygen molecule at a body tissue, the other three subunits become more likely to give up their oxygen molecules, ensuring that oxygen is passed efficiently to body tissues.

The oxygen affinity of a hemoglobin molecule also varies depending on its local environment. For example, a lower pH (a more acidic environment) decreases hemoglobin's oxygen affinity. Why is this adaptive? An active, working muscle makes and uses more ATP and so releases more carbon dioxide during cellular respiration. Because carbon dioxide reacts with water in the blood to form carbonic acid, the presence of high levels of carbon dioxide decreases the pH of the blood. Lower pH decreases the oxygen affinity of local hemoglobin, causing it to release oxygen to the tissues.

molecules, making it easier for them to unload oxygen in working tissue.

Unifying Concept

Feedback Loop [Section 19.2](#) 

Hemoglobin also has high affinity for the toxic gas carbon monoxide (CO). Carbon monoxide is toxic precisely because it binds to hemoglobin even more strongly than oxygen. Extended exposure to carbon monoxide “fills up” the binding sites, leaving no place for oxygen to bind. Carbon monoxide is found in car exhaust and cigarette smoke, and it is also produced by some gas appliances. Because the gas is odorless, many people keep a carbon monoxide detector in their homes.

Check Yourself

Interactive

Question
Check Answer
Question

Why is it important to consume enough iron? What happens if you don't consume enough iron?

Check Answer

Why is it important to consume enough iron? What happens if you don't consume enough iron?

Answer: Iron is an essential component of hemoglobin. People

Integrated Science 20B: Ph

Blood Pressure

Learning Objective

Explain what blood pressure is and describe the dangers of high blood pressure.

A common procedure when visiting your doctor is to have your blood pressure measured—you may remember the cuff placed around your arm that tightens and then releases (Figure 20.7). What exactly is blood pressure, and how do doctors measure it? **Pressure** is defined as the force exerted over a unit of area (e.g., newtons per square meter).

pressure is a measure of the pressure your blood against the walls of your arteries. This pressure is blood to flow through your blood vessels. Pressure depends on depth of the liquid (e.g., pressure is greatest at the bottom of a lake and least at the surface), which pressure in your heart is measured in your upper about level with your heart. Blood pressure is highest in arteries near the heart. It then decreases as blood flows through the arteries to the arterioles, capillaries, and veins. It is lowest just before blood returns to the

Figure 20.7



A doctor checks her patient's blood pressure.

When your blood pressure is measured, two separate values are reported. The *systolic blood pressure* is the maximum pressure in your arteries, which occurs when the ventricles of the heart are contracting. The *diastolic blood pressure* is the minimum blood pressure in your arteries, which occurs when the ventricles are filling with blood and your heart is at rest between beats. Blood pressure is reported as the systolic pressure “over” the diastolic pressure. A normal blood pressure is anything less than 120/80 mmHg—that is, a systolic pressure that is 120 mmHg or less, and a diastolic pressure that is 80 mmHg or less. Notice that the units for blood pressure are mmHg (millimeters of mercury), which is a unit of pressure that it takes to push a column of mercury up 1 millimeter. Although mmHg is not a metric unit, it became standard because mercury was used in the most accurate pressure gauges. This unit of measurement is widely used in medicine.

A person with high blood pressure has a heart that works very hard. High blood pressure is associated with many health problems.

problems, including heart disease, heart attacks, kidney disease, and strokes. Unfortunately, high blood pressure is fairly common today. Many people develop this condition with age. A variety of other factors can contribute to high blood pressure, including stress, smoking, lack of exercise, an unhealthy diet, and alcohol consumption. High blood pressure is usually treated with medication.

Check Yourself

Interactive

Question

Check Answer

Question

Heart failure is a condition in which the heart gradually becomes unable to effectively pump enough blood to the body. Early symptoms include getting out of breath easily. Why can high blood pressure contribute to heart failure?

Check Answer

Heart failure is a condition in which the heart gradually becomes

20.3 Respiration

Learning Objective

Describe the structure and function of the human respiratory system.

Maybe it's only when you're huffing and puffing that you think about breathing. Still, breathing in and out is something you do as 17,000 times a day! Breathing is your body's way of taking in oxygen, which is needed for cellular respiration, the process cells use to produce energy in the form of ATP. Through breathing, your respiratory system moves oxygen from the air into your lungs. From the lungs, the circulatory system, which then delivers it to all your cells. It also allows your respiratory system to get rid of carbon dioxide, a waste product of making ATP.

The Path of Air

The respiratory system is shown in [Figure 20.8](#). Air enters through your nose. (You can also breathe in through your mouth.)


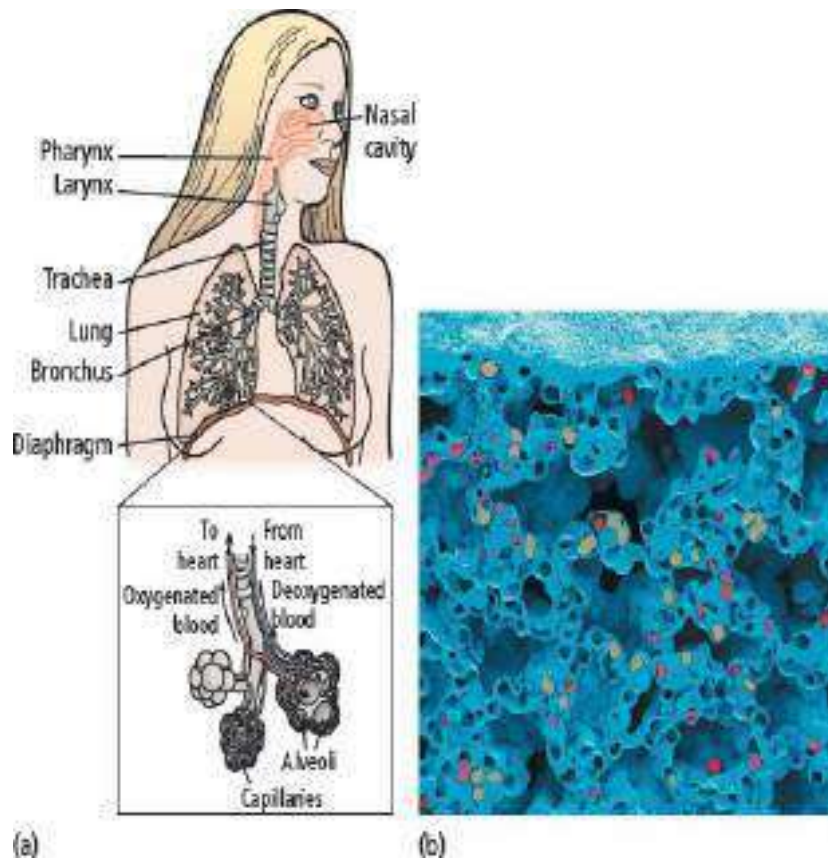
this is a useful backup because otherwise a stuffy nose (rhinitis) would be a problem. Hairs in your nostrils trap dust and other particles. Air enters through the nasal passages, where it is moistened by mucus and warmed by a network of capillaries. In the nasal passages, your sense of smell also captures odor molecules present in the air. From the nostrils, the air moves through the *pharynx*, the part of the throat at the top of the esophagus and windpipe. It then proceeds through the larynx, the voice box, and down the *trachea*, or windpipe. The trachea is stiffened by rings of cartilage. The rings keep the trachea from collapsing. The trachea branches into two tubes called *bronchi* that lead to the left and right lungs. Each bronchus branches into smaller and smaller tubes that finally end at tiny sacs called alveoli , where gas exchange occurs.

Figure 20.8



(a) The respiratory system brings oxygen into the body and removes carbon dioxide. Gas exchange occurs in the lungs, in tiny air sacs called alveoli. (b) This photo (a scanning electron micrograph) shows a section through the lung. Blood vessels surround the alveoli. The empty spaces in the photo are the alveoli. Red blood cells (red) and other cells (yellow) are also visible.

Unifying Concept

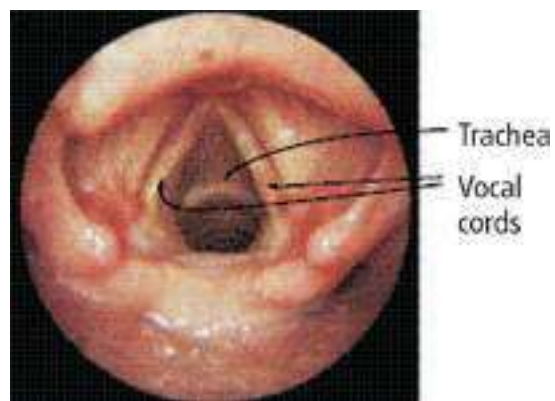
The Second Law of Thermodynamics [Section 6.5](#)

Your lungs contain about 300 million alveoli. Each alveolus is surrounded by a net of capillaries. Both the alveolus and the surrounding capillaries are

have extremely thin walls, consisting of only a single fl allows gas exchange to happen through diffusion. Gas down their concentration gradients—oxygen diffuses into the blood, and carbon dioxide diffuses from the blood into the alveolus.

When you exhale, air reverses its path. Air moves from the alveoli through tubules to the bronchi, trachea, and nasal passage through the nose. As air passes the larynx, it may vibrate (Figure 20.9). This makes the sound waves that allow you to speak and sing. In order to make different sounds, you control the tension of your vocal cords, as well as other muscles in your throat and cheeks.

Figure 20.9



Vibrations in your vocal cords produce the sounds that you hear. You control the sounds you make by loosening or tightening your vocal cords and by moving the muscles of your lips, tongue, and throat.

Unifying Concept

Waves Section 8.1

Integrated Science 20C: Physics

Inhaling and Exhaling

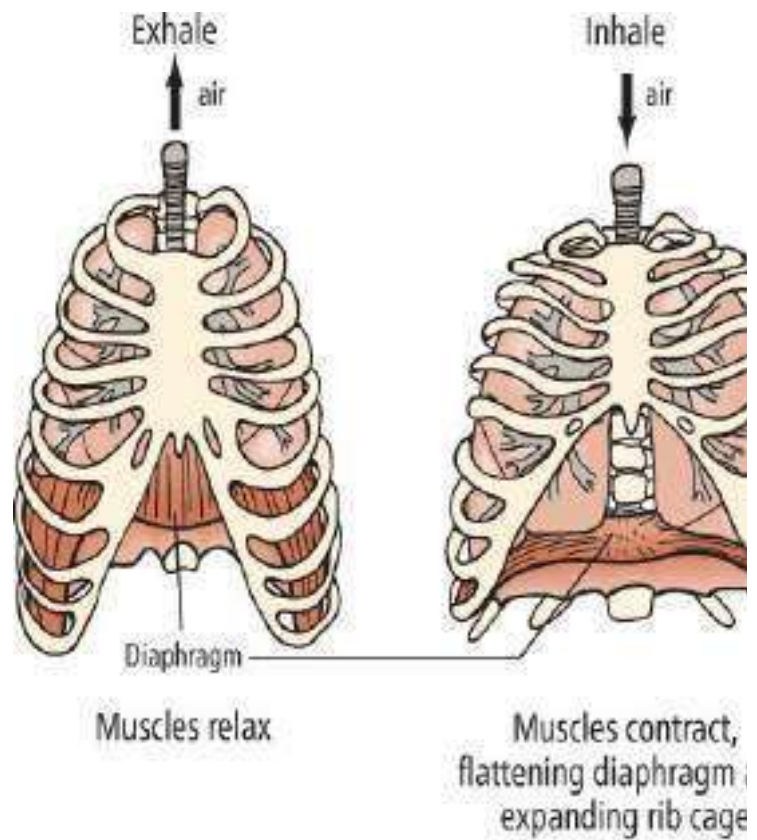
Learning Objective

Describe how humans inhale and exhale.

How do you inhale and exhale? Your lungs sit inside your rib cage in an air-filled pocket called the *thoracic cavity*. The bottom of the thoracic cavity is covered by a sheet of muscle called the **diaphragm**. The contraction and relaxation of the diaphragm cause inhalation and exhalation. When the diaphragm is relaxed, it is dome shaped (Figure 2). When you inhale, you contract your diaphragm. The muscles between your ribs shorten, and the diaphragm flattens, increasing the volume of the thoracic cavity. The muscles between your ribs

contract, pulling the rib cage up and out from the further increases the volume of the thoracic cavity. As the volume of the thoracic cavity increases, the air pressure inside it decreases and becomes lower than the pressure outside the body. Since air will move from an area of higher pressure to an area of lower pressure, air enters the lungs, filling the alveoli. This process is similar to the way a pump sucks in air when you pull back its plunger.

Figure 20.10



When you inhale, your diaphragm contracts and your rib cage expands. This increases the volume of the thoracic cavity, causing air to flow into your lungs. When you exhale, your diaphragm and rib muscles relax, pushing air out of your lungs.

When you exhale, the diaphragm and rib muscles relax, decreasing the volume of the thoracic cavity. This increases the air pressure in the thoracic cavity and pushes air out of your lungs.

You breathe about 12 times each minute. During each breath, only about 10% of the air in the lungs is exchanged with outside air—this is enough to keep your body tissues supplied with oxygen. Of course, you have some control over how often and how deeply you breathe. You don't have to worry about "forgetting" to breathe, though; respiration is controlled automatically by the brainstem, along with many other involuntary activities.

Hiccups are sudden spasms of the diaphragm. Each spasm sucks air in, snapping the vocal cords shut and creating a "hic" noise. Hiccups may last for a few minutes or longer.

caused by any irritation to the diaphragm, i
eating too much or too quickly.

Check Yourself

Interactive

Question

Check Answer

Question

Does it take energy to inhale, to exhale, or both?

Check Answer

Does it take energy to inhale, to exhale, or both?

Answer: It takes energy to inhale. Energy is needed to contract

20.4 Digestion

Learning Objective

Describe the structure and function of the digestive system.

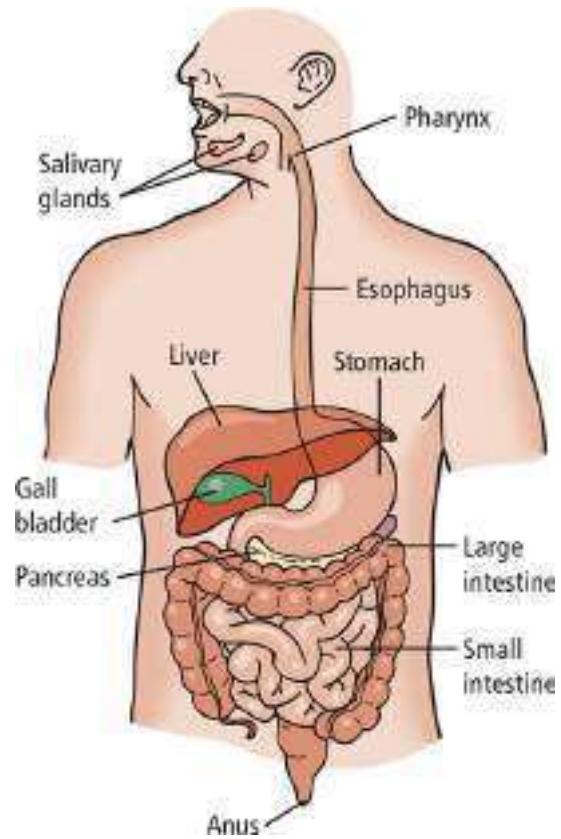
If you go a few hours without eating, you're likely to start feeling hungry. Food provides your body with organic molecules that can be broken down to make ATP, the molecule your cells use for energy. Food also provides many essential molecules that your body cannot synthesize on its own. Finally, the breakdown of food releases heat. This heat is used to maintain a high, stable body temperature, the defining characteristic of mammals and other endotherms.

Although you need food for many reasons, a chunk of food must be broken down into small molecules to travel in your bloodstream or move into your cells. The process of digestion, food is broken down into small organic molecules that can be absorbed and used by the body. You may remember that macromolecules are made up of different kinds of macromolecules—large molecules made up of smaller molecules linked together. During digestion, the large macromolecules in your food are broken down into the small molecules that comprise them. For example, the proteins in food are broken down into amino acids.

into separate amino acids, and the carbohydrates in food are broken down into simple sugars. These small molecules are then absorbed and used by your body.

Digestion takes place in the digestive system, which is shown in [Figure 20.11](#). Did you know that you begin to digest your food as soon as it enters your mouth? You chew food with your teeth, breaking it into small pieces. You also mix your food with *saliva*. Saliva contains an enzyme that breaks down starches. Saliva also moistens food so it can be moved easily around the mouth. Finally, because taste buds can taste only molecules dissolved in liquid, saliva allows you to taste your food. Did you know that eating, or even just thinking about food, causes you to release saliva ([Figure 20.12](#))?

Figure 20.11



The digestive system breaks food down into small molecules absorbed and used by the body.

Figure 20.12



Just thinking about food can cause the release of saliva.

After food is chewed and mixed with saliva, you swallow. The food is pushed into the pharynx. There are two openings: one to the esophagus and one to the trachea. You will not go down the trachea by mistake. A small flap of cartilage at the base of the tongue—the *epiglottis*—covers the trachea when you swallow. This way, food will not get into it. (This is why you cannot breathe while swallowing. Have you ever noticed that?)

Swallowing begins as a voluntary action. The muscles at the top of the esophagus are voluntary muscles. However, at a certain point, the muscles become involuntary. The lower part of the esophagus is made of involuntary muscle, like that found in the rest of the digestive tract.

part of the esophagus, food is pushed down by a moving wave of involuntary muscle contractions known as **peristalsis**. This process squeezes food down the esophagus by constricting behind it along. You do something similar when you squeeze a LifeSaver candy out of its paper-tube wrapper (Figure 20.13).

Figure 20.13



Peristalsis describes the moving wave of muscle contractions that push food down the esophagus. It works a lot like the way you squeeze a LifeSaver® candy out of its wrapper.

Swallowing does not require gravity—peristalsis work necessary. Astronauts in the zero gravity of no trouble swallowing at all. In fact, peristalsis is that you can swallow even while you are upside c

At the bottom of the esophagus, food moves through a shaped muscle, into the stomach. Glands in the stomach *gastric juice*, a highly acidic mixture of hydrochloric acid enzymes (Figure 20.14). These digestive enzymes, along with the churning of the stomach's muscular walls, convert food called *chyme*. Meanwhile, the acidity of gastric juice kill swallow with your food. Gastric juice also contains a p that helps prevent the stomach from digesting its own t leaves the stomach through a second sphincter and ent intestine. Usually, it takes the stomach about 4 hours to

Figure 20.14



The stomach has numerous pits on its inner surface. The glands that release gastric juice.

When you vomit, the acidic nature of your stomach becomes immediately apparent—both from the taste and from the burning sensation left in your throat.

The small intestine is about 20 feet long. In the first part of the small intestine, digestion continues with the breakdown of proteins, carbohydrates, and nucleic acids. Some of the digestive enzymes are made by the small intestine itself. Others are made by the pancreas and sent to the small intestine. Pancreatic enzymes also play a role in neutralizing food, which is highly acidic when it enters the small intestine.

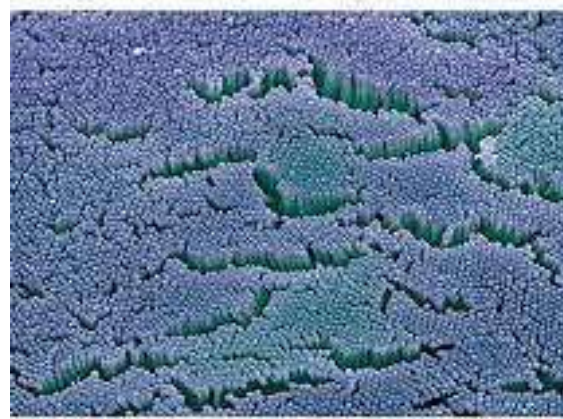
stomach. The small intestine also receives bile, a substance produced by the liver and stored in the gall bladder. Bile is an emulsifier that breaks down fats into tiny droplets that are more easily attacked by enzymes.

The rest of the small intestine is responsible for absorbing nutrients into the body. In order to do this job effectively, the small intestine has a large surface area. The small intestine's inner surface is covered with finger-like projections called *villi*. The villi are covered with even smaller projections called *microvilli* (Figure 20.15). Both the villi and microvilli increase the surface area of the small intestine. If your small intestine were flattened out, it would fill the area of a tennis court! This impressive surface area allows your small intestine to absorb many digested nutrients. Most nutrients are absorbed into the body through facilitated diffusion and active transport. Absorbed nutrients enter capillaries located in each villus and then are carried to all your tissues by the circulatory system.

Figure 20.15



(a)




(b)

(a) Villi are fingerlike projections that increase the surface area of the small intestine. (b) Each villus in the small intestine is covered with smaller projections called microvilli.


Technology

Manipulating the Microbiome




Did you know that your body contains about as many bacteria as it does your own human cells? These bacteria are found in many locations throughout the body, and they make up your microbiome. A healthy microbiome is essential to many aspects of human health. As scientists learn more about the microbiome, they have also discovered new opportunities for treating disease.

Consider *C. diff*, an infection of the digestive tract caused by *Clostridium difficile* bacteria. This infection typically occurs after strong antibiotics wipe out the digestive tract's normal bacteria. Symptoms of *C. diff* include diarrhea, abdominal cramps, and fever. Although many cases of *C. diff* are treated with antibiotics, other cases are more resistant. When regular treatments fail, doctors will often try to restore normal gut bacteria using a fecal transplant from a healthy person. The donor, who may be a relative or friend of the recipient, is carefully screened. You will be happy to know that the transplant does not typically require that the donor ingest the bacteria. Instead, fecal material is usually transplanted into the recipient's large intestine. This treatment has been found to be very effective.



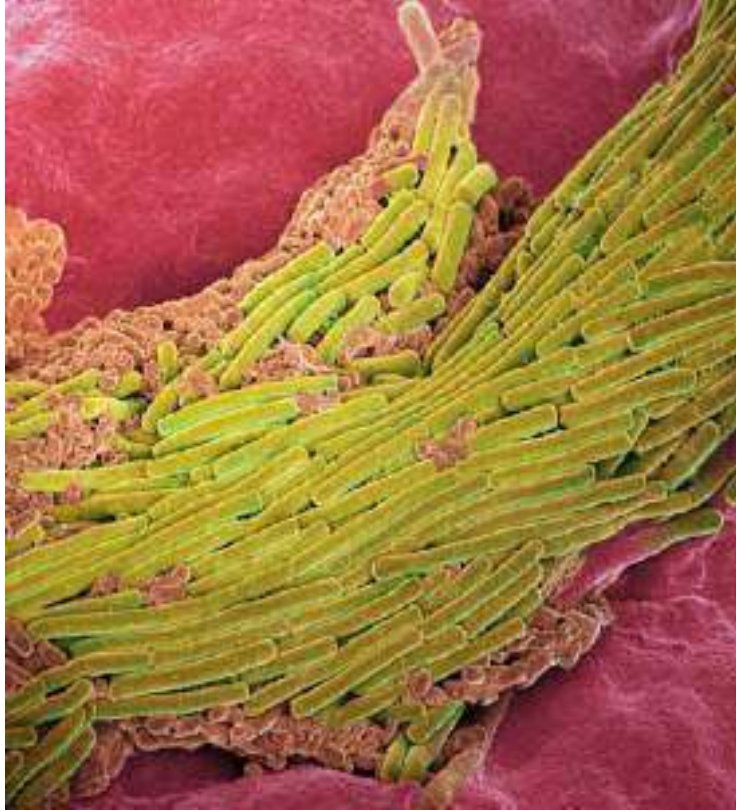
The gut microbiome is important in many other health conditions. For example, scientists have observed differences between the microbiomes of thin and obese people. This suggests that “correcting” the gut microbiome in obese people helps them lose weight. One idea is that certain unhealthy bacteria allow the “wrong” kinds of bacteria to prosper. These bacteria somehow cause the body to absorb excess calories from other foods, particularly plant foods, promoting a healthy gut microbiome. The gut microbiome has also been linked to digestive issues such as irritable bowel syndrome and inflammatory bowel disease. Scientists are working on treatments for these conditions that involve wiping out a patient’s faulty gut microbiome and replacing it with appropriate “good” bacteria.

Manipulating other parts of the human microbiome can also help treat other health conditions. Transplanting “good” bacteria may help with skin disorders such as atopic dermatitis, associated with itchy rashes, and psoriasis, in which skin cells form scales and red patches. Manipulating the mouth microbiome could help prevent the growth of bacteria that cause cavities. Additionally, the microbiome is being studied as a potential treatment for diseases such as diabetes and for



conditions such as schizophrenia, obsessive-compulsive disorder, and attention-deficit/hyperactivity disorder.

The U.S. National Institutes of Health (NIH) are currently sponsoring the Human Microbiome Project, which is focused on describing the healthy human microbiome. Scientists are studying the microbiomes of 300 healthy individuals, looking at the bacteria of the nose, mouth, skin, digestive, urinary, and reproductive tracts. The hope is that this work will enable scientists to develop treatments for patients whose microbiomes have been disrupted by antibiotics, environmental factors, or other factors, in order to bring these back to normal.



C diff infections, caused by the bacteria shown here, are often treated by transplanting fecal material—and its associated “good” bacteria—from a healthy person.



Transplanting “good” skin bacteria could help treat conditions such as psoriasis.

After the nutrients are absorbed, what is left of your food goes to the large intestine. In the large intestine, some more water is absorbed into the body. Huge numbers of bacteria live in the large intestine, where they feed on some of the undigested matter. The bacteria make important vitamins, including vitamins B and K. These bacteria are an important part of your microbiome. Your microbiome includes all the bacteria that live in and on your body. In recent years, scientists have gradually realized how important a healthy microbiome is.

to human health. From the large intestine, feces are eliminated through the anus. Feces are composed of living and dead cells as well as indigestible materials such as plant cellulose.

Check Yourself

Interactive

Question

Check Answer

Question

How does bile help you digest your food?

Check Answer

How does bile help you digest your food?

Answer: Bile breaks fats into tiny droplets. Fats, which are hydrophobic, stay clumped together. By separating fats into tiny droplets, bile

20.5 Nutrition, Exercise, and

Learning Objective

Explain how nutrition and exercise contribute to lifestyle.

You now know how the body obtains the oxygen and nutrients to fuel its activities. These demanding functions are performed day out by the circulatory, respiratory, and digestive systems. How do lifestyle contribute to the functioning of these and other systems? What can you do to live a healthier life?

Let's start with a healthy diet. You need a certain number of calories to support your activities. Recall that a food calorie is actually a kilocalorie, or 1000 calories (the heat needed to change the temperature of 1 kg of water by 1°C). These food calories provide the energy that cells use to make ATP. Most people need between 1500 and 2500 calories a day—the exact number depends on your body size and activity level.

You also need certain nutrients that your body can't make. For example, humans cannot make 9 of the 20 amino acids

proteins. This is why you need to eat a “complete protein” that contains all the amino acids—regularly. Meat is a complete protein. Beans and rice when eaten together, an important part of vegetarian diets. Soybeans and quinoa are two other plants that are complete proteins.

Humans also require a number of vitamins and mineral amounts. *Vitamins* are organic molecules that are essential components of certain enzymes. The body needs many but let’s look at just a few. Vitamin C, found in citrus fruits, leafy vegetables, and certain other foods, helps the body heal and repair wounds. Vitamin A, which you get from carrots, milk, and other foods, is important for proper eye function; it enables the eyes to adjust to dim light; insufficient amounts can lead to blindness and other problems. Vitamin K, which is found in leafy vegetables and synthesized by bacteria in the intestines, is important for blood clotting. Insufficient amounts of vitamin K can result in hemorrhaging. Vitamin D is important for bone growth and other activities. Your body produces some vitamin D when ultraviolet light from the Sun strikes your skin. Vitamin D is found naturally in many foods, however, and recent studies suggest that many people do not get enough vitamin D.

Scientists believe that the need for vitamin D drove the evolution of light skin in human populations that live near the equator. In these areas, sunlight is weak during winter months. Light skin allows the body to absorb more ultraviolet light so that it is able to make more vitamin D.

Minerals are inorganic substances required as components of body tissues. Important minerals include calcium for bone health, phosphorus for ATP, and iron for hemoglobin. Mineral deficiencies can lead to a variety of health issues.

Beyond calories and nutrients, does it matter what you eat? Unfortunately, some of the things people like to eat, such as fats, aren't very good for them. Why would humans evolve to eat foods that aren't good for them? Most likely, people eat these foods because they evolved under a different set of circumstances, where such food were much less readily available.

In fact, more than two-thirds of Americans today are either overweight or obese. This has resulted in an increasing number of people with metabolic syndrome, a set of characteristics that greatly increases the risk of heart disease, stroke, and type 2 diabetes. *Metabolic syndrome* is associated with two main features: carrying extra weight and

middle and upper parts of the body and insulin resistant body tissues to adequately respond to the hormone insulin. Insulin resistance results in higher blood sugar levels as well as fat storage. In addition to diet, factors that may also contribute to insulin resistance include aging, genetics, and lack of exercise.

Science and Society

What Are the Odds? Current Major Health Risks

According to the latest data, in 2016, life expectancy in the United States was 81.1 years for females and 78.6 years for males. The overall life expectancy was 78.6 years. What are the current major health risks?

Heart disease is the leading cause of death in the United States, followed by cancer. The 10 leading causes of death in the United States are listed below, along with work for comparison.

Leading Causes of Death in the United States (2016)
from the U.S. Centers for Disease Control

	Total Deaths	Pe
1. Heart disease	633,842	
2. Cancer	595,930	
3. Chronic lung diseases (emphysema, chronic bronchitis, etc.)	155,041	
4. Accidents (unintentional injuries)	146,571	
5. Stroke	140,323	
6. Alzheimer's disease	110,561	
7. Diabetes	79,535	
8. Influenza and pneumonia	57,062	
9. Kidney disease	49,959	
10. Intentional self-harm (suicide)	44,193	

Leading Causes of Death Worldwide (2015 Data World Health Organization)

	Total Deaths (millions)	Per
1. Heart attacks	8.76	
2. Stroke	6.24	
3. Lower respiratory infections	3.19	
4. Chronic lung diseases	3.17	
5. Lung cancers	1.69	
6. Diabetes	1.59	
7. Alzheimer's disease	1.54	
8. Diarrheal diseases	1.39	
9. Tuberculosis	1.37	
10. Road accidents	1.34	

So, what makes up a healthy diet? The U.S. Department of Agriculture's "MyPlate" offers some guidelines (Figure 20.16). The diagram emphasizes the importance of sitting down to a well-planned meal. The plate is covered with fruits and vegetables, and another portion is taken up by whole grains. Other recommendations include getting some protein from healthy sources, such as beans and...

back on salt, sugar, and solid fats; eating an appropriate number of calories; and exercising.

Figure 20.16



The USDA's "My Plate" emphasizes fruits and vegetables and healthy sources of protein.

Exercise is a crucial part of any healthy lifestyle (Figure of human history, daily life provided people with plenty activity. This was true when most people belonged to hunter-gathering societies and when most people worked on farms for a large fraction of the world's population, but not all cars, television, and the Internet have brought many pe

sedentary, couch-potato lifestyle. Many people now have
their way to get the physical activity they need to stay h

Figure 20.17



Even people with busy lives should make time for exercise.
Gilman, busy father of three, shoots baskets in San Francisco
Gate Park.

What are the benefits of exercise? Regular exercise reduces the risk of heart disease, high blood pressure, colon cancer, breast cancer, osteoporosis, diabetes, obesity, and many other health conditions. Exercise improves the performance of the heart and lungs, maintains joint flexibility, and increases muscle mass and bone density. It also contributes to strength and balance and helps people stay active as they age. Exercise is good for mental health too: It helps reduce stress, and anxiety, and even helps you sleep better. Overall, regular exercise is a good thing.

20.6 Excretion and Water Balance

Learning Objective

Describe the structure and function of the excretory system.

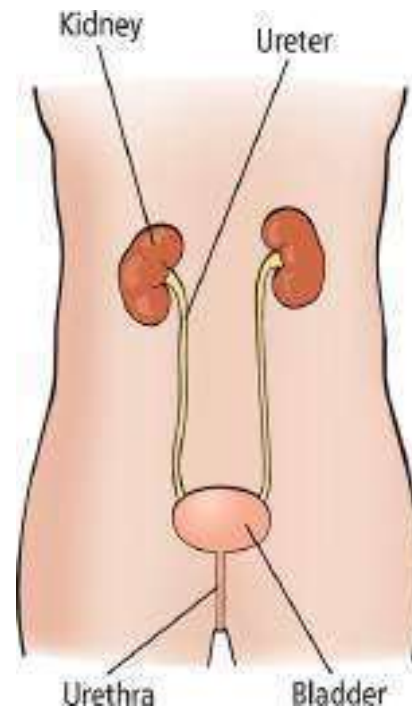
As cells go about their activities, they generate wastes. What do cells do with these wastes—they let them diffuse into the bloodstream. But where do the wastes go from there? How do we get rid of them? This is the job of the excretory system.

Unifying Concept

The Second Law of Thermodynamics [Section 6.5](#)

The excretory system, shown in [Figure 20.18](#), filters your blood, removing wastes while leaving useful molecules in the bloodstream. The excretory system also controls how much water, sodium, and calcium, and other substances the body keeps. Did you know that the entire blood supply moves through your kidneys 16 times a day? The result is something we're all familiar with—about 6 cups of urine.

Figure 20.18



The excretory system consists of the kidneys, ureters, bladder, and urethra.

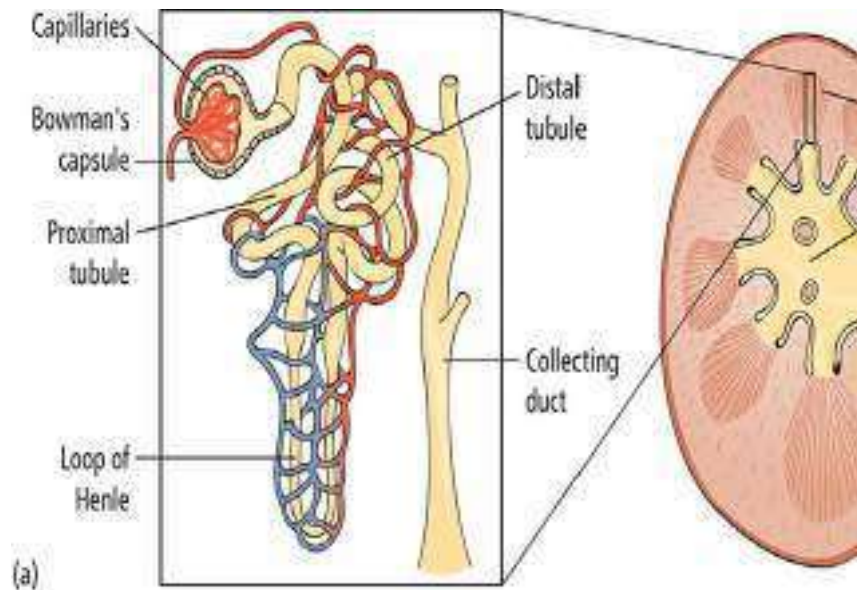
One of the most important wastes found in urine is *urea*. Nitrogenous wastes are broken down to make ATP, ammonia, a nitrogenous waste, is produced. Because ammonia is highly toxic, the liver immediately converts it to urea, a less toxic waste. The urea is then transported into the bloodstream for excretion.

How does excretion happen? The process begins in the kidney. The kidney contains about a million structures called nephrons. A **nephron** ⓘ is the functional unit of the kidney. What goes on in a nephron?

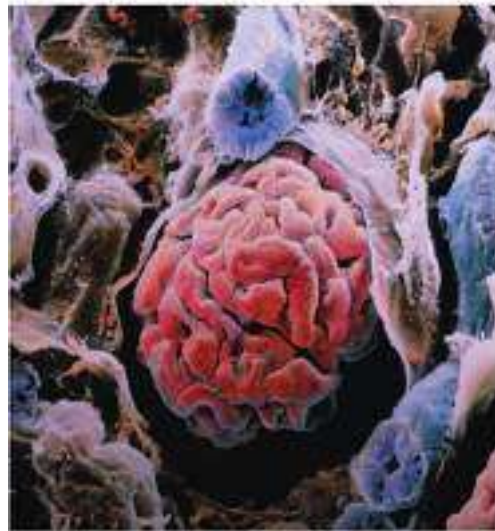
nephron is more or less blood plasma, and what comes look at how this happens.

Each nephron is associated with a cluster of capillaries. The first part of the nephron, a cup-shaped structure called *capsule*, surrounds the capillaries. Blood pressure pushes blood out of the capillaries and into Bowman's capsule. The fluid that enters the capsule is called the *filtrate*. At this point, the filtrate is essentially blood plasma.

Figure 20.19



(a)



(b)

(a) The kidney is made up of about a million functional nephrons. (b) This photo shows part of a nephron. The capillaries is shown in red, and Bowman's capsule, in blue. The purple structures are cut sections of the tubules.

From Bowman's capsule, the filtrate enters the *proximal proximal tubule* is like a sorting machine. "Good" molecules—such as ions, glucose, vitamins, and amino acids—are reabsorbed into the blood so that the body can keep them. "Bad" wastes are transported from the blood to the filtrate. The movement of substances into and out of the proximal tubule occurs through active transport, a process that requires energy. This is one of the reasons why the proximal tubule uses a significant amount of energy.

After moving through the proximal tubule, the filtrate enters the *loop of Henle*, a hairpin-shaped loop. In the loop of Henle, water and sodium are reabsorbed from the filtrate. This helps the body save water.

From the loop of Henle, the filtrate moves into the *distal tubule*. In the distal tubule, more wastes are transported into the filtrate.

Finally, the filtrate moves down the *collecting duct*. In the collecting duct, more water is absorbed from the filtrate. How much water is absorbed depends on whether antidiuretic hormone is present in the blood. If antidiuretic hormone is present, more water is absorbed from the filtrate into the body. As a result, urine becomes more concentrated.

The filtrate—which is now urine—flows from the collecting *renal pelvis* (see [Figure 20.19](#)). The renal pelvis is like a funnel that catches the drippings of a million nephrons. From the renal pelvis, urine goes down a tube called the *ureter* to the bladder. The bladder is a sac where urine is temporarily stored. When the bladder is full, urine flows down the *urethra* and out the body.

Did you know that diabetes used to be diagnosed by testing urine? Urine with a lot of sugar in it attracts ants. But urine becomes sugary only if glucose has built up to very high levels in the blood—that is, if a person has diabetes. Glucose is a “good” molecule that is normally absorbed by the kidneys, but when blood glucose levels are very high, the kidneys can’t absorb all of it, and some ends up in the urine.

Check Yourself

Interactive

Question

Check Answer

Question

We have now looked at all the organ systems that help the body organ systems provide the raw materials for making ATP (such oxygen)? Which organ systems get rid of the wastes (such as ca urea)?

Check Answer

We have now looked at all the organ systems that help the body organ systems provide the raw materials for making ATP (such oxygen)? Which organ systems get rid of the wastes (such as ca urea)?

Integrated Science 20D: Chemistry and Physics

Concentrating Urine

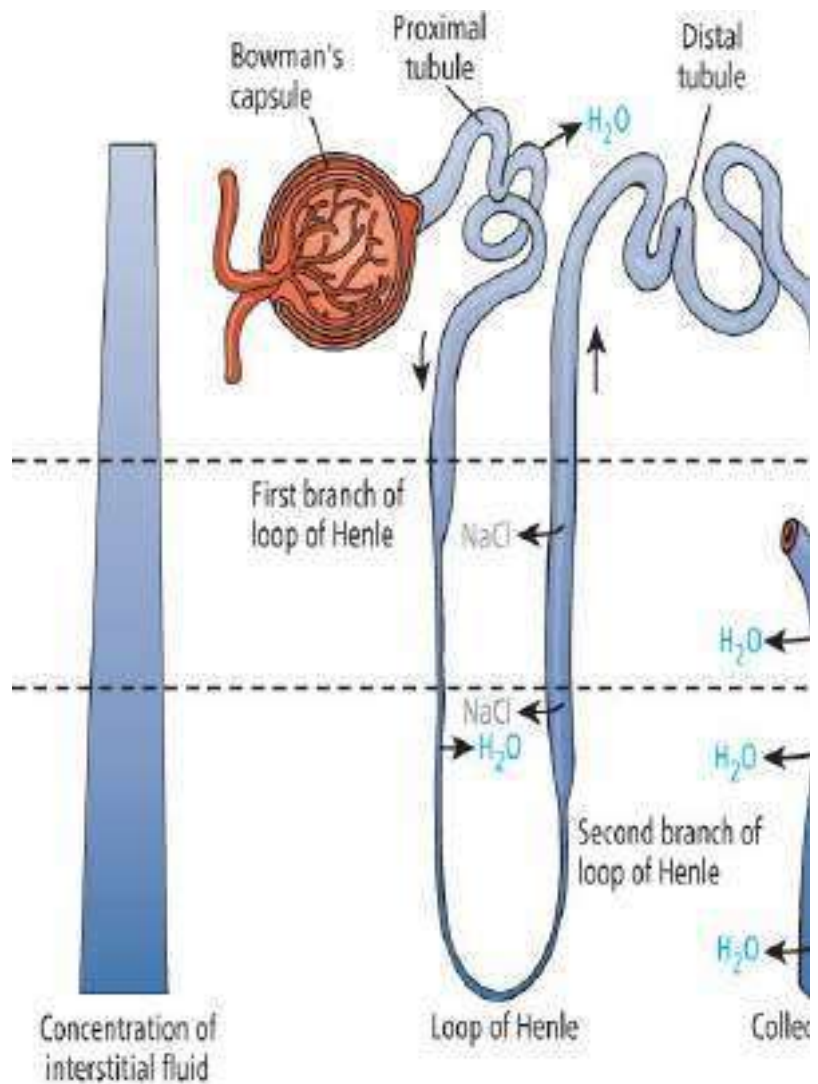
Learning Objective

Explain how urine becomes more concentrated in the nephron.

How do the kidneys concentrate urine? Without this process, we would lose too much water from the excretion.

In the kidneys, water is absorbed from the filtrate of the nephron: the loop of Henle and the collecting process relies on a solute concentration gradient “top” of the nephron to the “bottom” (Figure 20.2 concentration is *low* near the top of the nephron the bottom of the nephron.

Figure 20.20



A solute concentration gradient allows water to be reabsorbed from the filtrate in the loop of Henle and in the collecting duct.

As the filtrate flows down the first branch of the loop of Henle, it becomes surrounded by tissues where solute concentration is high. Remember that osmosis, the diffusion of water, moves water to areas where solute concentration is high. This means that in the first branch of the loop of Henle, water moves out of the filtrate and into the surrounding tissues, which makes the filtrate more concentrated, as you can see in the darkening of the filtrate in [Figure 20.20](#).

Unifying Concept

The Second Law of Thermodynamics [Section 20.2](#)

The filtrate then makes a hairpin loop and begins the second branch of the loop of Henle. The walls of the second branch are not permeable to water. This prevents water from moving back from the tissues into the filtrate. In the second branch, active transport is used to pump Na⁺ out of the filtrate, making the filtrate less concentrated. The light color of the filtrate at the end of the loop of Henle is the result of this pumping.

After passing through the distal tubule, the filtrate enters the collecting duct. Whether more water is absorbed from the filtrate in the collecting duct depends on how much antidiuretic hormone is present. Antidiuretic hormone causes the collecting duct to become permeable to water. If the collecting duct is permeable to water, then, as the filtrate travels through the duct, water will move out of the filtrate and into the tissue surrounding the duct by the process of osmosis. If antidiuretic hormone is not present, the collecting duct will not be permeable to water and less water will leave the filtrate. The amount of water reabsorbed that occurs in the collecting duct determines how concentrated the urine becomes.

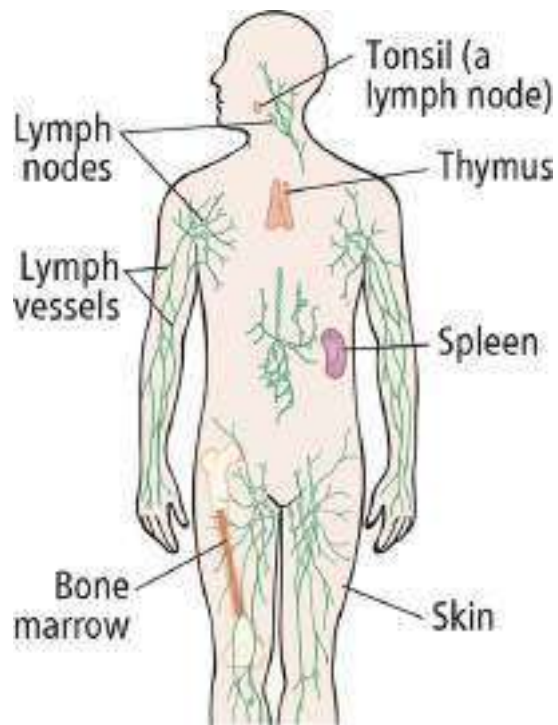
20.7 Keeping the Body Safe Systems

Learning Objective

Describe the structure and function of the human immune system.

Without your body's defenses, you would quickly fall prey to viruses, and other **pathogens**—disease-causing organisms. What protects you is your immune system (Figure 20.21). The immune system includes barriers that keep pathogens out, such as the skin. It also includes many different kinds of immune cells, also called white blood cells. White blood cells move throughout your body, looking for pathogens. White blood cells are made in the bone marrow. They then mature in the bone marrow or thymus. Most white blood cells are found in your circulatory system, lymph nodes, and spleen.

Figure 20.21



The immune system includes the skin, bone marrow, the lymph nodes and vessels. It also includes numerous immune cells in the blood and tissues.

The *lymphatic system* is an important component of the immune system. The lymphatic system includes lymph vessels that, like blood vessels, travel all over the body. Lymph vessels carry a clear fluid called lymph. One function of the lymphatic system is to collect the fluid from blood vessels and return it to the circulatory system. Another function of the lymphatic system is to carry white blood cells, with large numbers in lymph. *Lymph nodes* are structures in which lymph flows, where many white blood cells are concentrated. Lymph

all over the body, including the throat (your tonsils), and swollen lymph nodes are a sure sign that the body is fighting an infection.

Let's look at the two parts of the immune system: the innate immune system and the acquired immune system.

Innate Immunity

The innate immune system includes nonspecific body defenses that work against many different pathogens. These defenses are "innate" because they do not have to be activated by exposure to a specific pathogen—they are ready to go. Three key components of the innate immune system are the skin, the mucous membranes, and white blood cells.

Skin

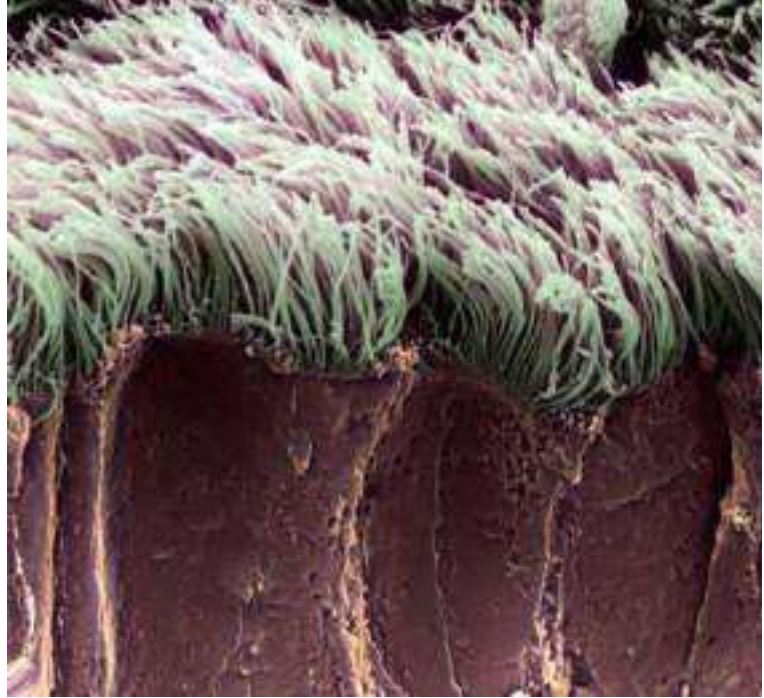
The best way to deal with pathogens is to keep them out of the body in the first place. The skin is a crucial barrier, forming a physical barrier that is hard to penetrate when intact. In addition, skin cells produce antimicrobial substances frequently, making it hard for pathogens to establish a permanent foothold.

follicles in skin also secrete special enzymes and acids to fight bacteria and fungi. In fact, many of your body secretions contain enzymes—for example, saliva, tears, sweat, and milk.

Mucous Membranes

The inside of your body is lined with *mucous membrane*. Mucous membranes are found inside your nose, mouth, and eyes. Mucous membranes line your respiratory, digestive, urinary, and reproductive tracts. Mucous membranes are not as tough as skin; however, all mucous membranes are covered by a layer of *mucus* that helps trap pathogens. Mucous membranes of the respiratory tract also include cilia that move mucus to the pharynx (Figure 20.22). This mucus is swallowed, and stomach acid kills any pathogens. Many mucous membranes are moist. Fluids such as tears, saliva, and urine. These fluids offer protection by washing away pathogen-killing enzymes. In addition, the constant flow of fluids makes it hard for pathogens to gain a foothold.

Figure 20.22



The lining of the respiratory tract includes numerous cilia sweep mucus, along with trapped particles or pathogens, where it is then swallowed.

Innate Immune Cells

What happens when pathogens do get inside the body? Innate immune cells launch an immediate attack (Figure 20.23). Innate immune cells have receptors that recognize molecules—usually carbohydrates or nucleic acids—found in many different kinds of pathogens. In this, a single innate immune cell is able to respond to many different pathogens. All in all, the cells of the innate immune system have several hundred different receptors. If the innate immune system

encounters the same pathogen more than once, its response is more rapid and stronger. The innate immune system retains no memory of pathogens encountered in the past.

Figure 20.23

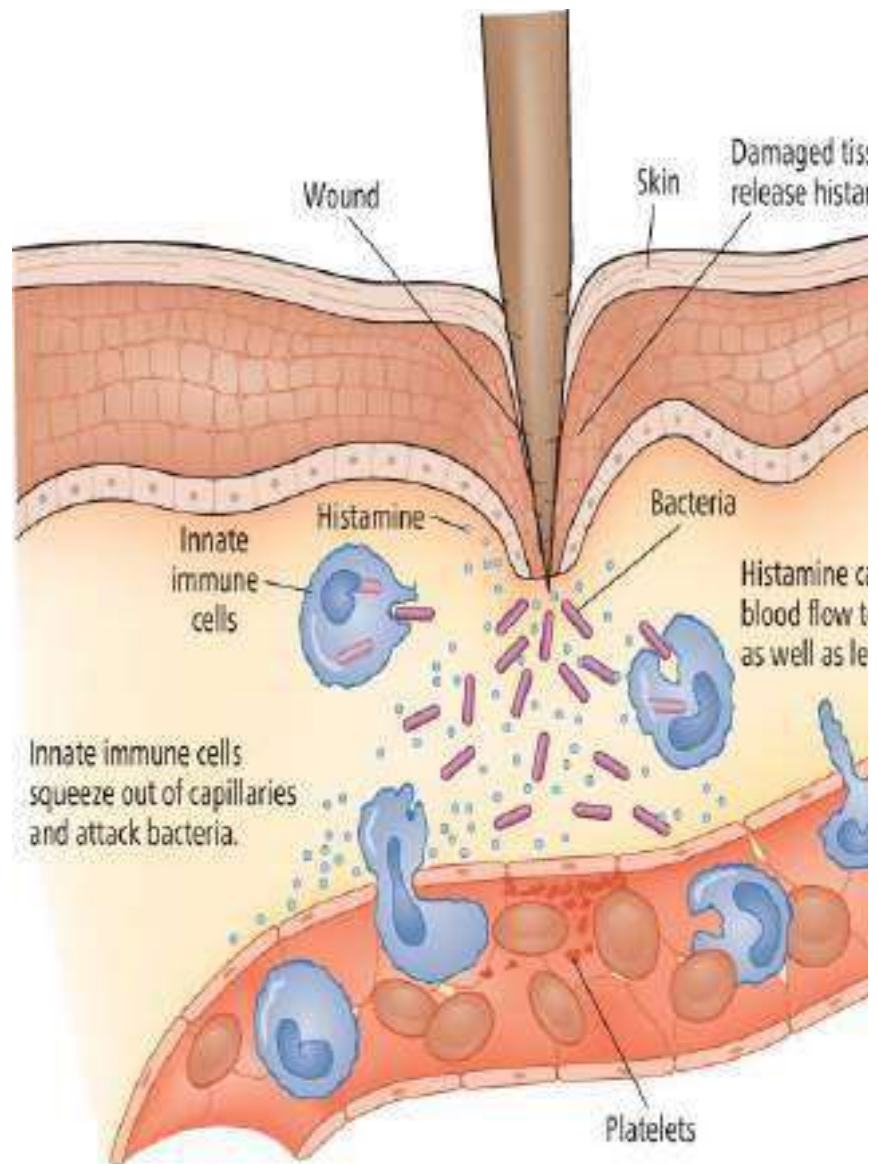


This innate immune cell (tan) is attacking bacteria (pink). The stringlike structures are extensions of the immune cell's cilia, which are searching the environment for pathogens.

One of the most important functions of the innate immune system is to initiate the *inflammatory response*, shown in **Figure 20.24**. You have undoubtedly experienced the inflammatory response many times.

makes your tissues swell and turn red when you cut your knee. During the inflammatory response, damaged tissues release chemicals called *histamines*. Histamines increase blood flow to the injury and also cause local capillaries to leak fluid. This causes swelling, which helps to isolate the wound from surrounding tissues. Histamines also attract innate immune cells. They move out of the capillaries and attack any pathogens they find. The battle between innate immune cells and pathogens produces a substance called pus. Pus consists of dead bacteria, dead and living innate immune cells.

Figure 20.24



The inflammatory response begins when damaged tissue releases histamines, which cause increased blood flow to a wound. Capillaries become leaky and produce swelling. Innate immune cells squeeze out of the capillaries and attack bacteria or other pathogens that enter the body.

Acquired Immunity

The acquired immune system is a set of highly specific defenses. These defenses are described as “acquired” because they only arise after specific pathogens are encountered.

The acquired immune system differs from the innate immune system in several ways. First, a cell that belongs to the acquired immune system does not work against many different pathogens. Instead, each immune cell has receptors that respond to a single antigen, or part of a molecule that belongs to a pathogen. Most antigens are small parts of foreign proteins.

Second, the acquired immune system has many more different receptors than the innate immune system. The innate immune system has only a few hundred different receptors, and the acquired immune system has about 10 million unique receptors! With so many different receptors, it is almost guaranteed that any pathogen that enters the body will elicit a response by one or more acquired immune cells.

Third, the acquired immune system responds more slowly than the innate immune system. Whereas the innate immune system can respond within hours, the acquired immune system takes days to weeks to respond.

responds immediately, the acquired immune response takes time to reach full force. This time is needed to make multiple copies of acquired immune cells that are needed. We will learn more about this process in the following pages.

Next, the acquired immune system retains a “memory” of pathogens encountered in the past. If it meets the same pathogen again, it responds more quickly and more aggressively. The innate immune system does not have this kind of memory. **Table 20.1** summarizes the differences between innate and acquired immunity.

Table 20.1 A Comparison of Innate Immunity and Acquired Immunity

Innate Immune System	Acquired Immune System
Each component can respond to many different pathogens	Each component responds to antigen
Includes hundreds of different receptors	Includes about 10 million different receptors
Has an immediate response	Has a delayed response that reaches full force several days after exposure to a pathogen
Has no memory of past encounters with a pathogen	Has a memory of past encounters with a pathogen; has a faster and more aggressive response to repeat

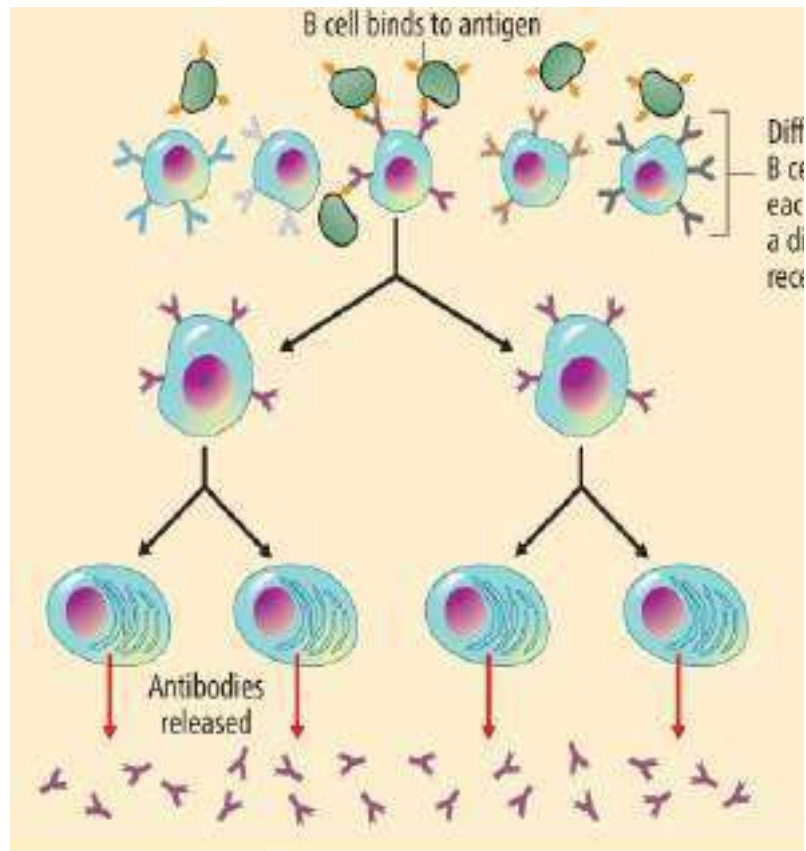
Let's look at how acquired immunity works. The acquired immune system has two kinds of cells: B cells and T cells. Both are made in the bone marrow, but each matures in a different organ—the *bone marrow* for B cells, and the *thymus* for T cells.

B Cells

B cells react to pathogens in bodily fluids such as blood. When a B cell encounters a pathogen and binds to an antigen on its surface, the cell begins to divide. It makes many copies, or *clones*.

20.25). The time it takes to make these clones is what acquired immune response.

Figure 20.25




When a B cell binds to an antigen, the B cell begins to c clones of itself. Mature clones then make and release la antibodies.

The Placebo Effect

A patient with knee pain goes in for surgery. He receives anesthesia, and cuts are made around his knee where surgical instruments will be inserted. Afterward, the surgery appears to be successful—both pain and swelling are diminished. What's unusual about this story? The surgery was a sham. Cuts were made around the patient's knee, but nothing happened after that. Why does the patient feel much better? Because of a phenomenon known as the placebo effect.*

Placebo is Latin for “I shall please.” It refers to the common practice of prescribing sugar pills to patients when doctors otherwise couldn't help. Although this is considered unethical, the fact remains that sugar pills frequently did have a beneficial effect. The *placebo* effect is the improvement patients experience when they are given a treatment that has no relevance to their medical condition.

Placebos appear to work for a wide variety of conditions. They are usually far more effective than no treatment at all. In a study of patients with Parkinson's disease, a placebo was just as well as medication in inducing the release



by the brain. Placebos have also been found to work with modern antidepressants in the treatment of depression.

The placebo effect is certainly real, although placebo works better for some conditions than others. Placebos are particularly effective for conditions related to the central nervous system, including pain, depression, anxiety, headache, fatigue, and gastrointestinal symptoms. For most conditions, placebos have about 30% to 50% effectiveness, nearly as effective as many “real” treatments. Placebo is believed to account for the “success” of certain alternative treatments that have no medical basis.

The placebo effect is one of the oddest phenomena in medicine. What causes it? Several possible mechanisms have been suggested. One is that the placebo effect works through the release of chemicals called endorphins, which bring about a feeling of well-being. Release of the natural opiates would explain why placebos are so effective in treating pain. In fact, placebos do become less effective as painkillers when patients are given a drug that blocks opiate receptors. However, because the placebo

for many symptoms besides pain, this can't be the explanation.

Another idea is that receiving a placebo reduces stress, allowing the immune system to function more effectively. Numerous studies have shown that stress reduces the immune system's capabilities; consequently, stress relief is expected to improve its function. Still, there must be more to the story than this because the placebo effect is not universal. A sham treatment does not help with *all* your ailments, only the one you think you're being treated for.

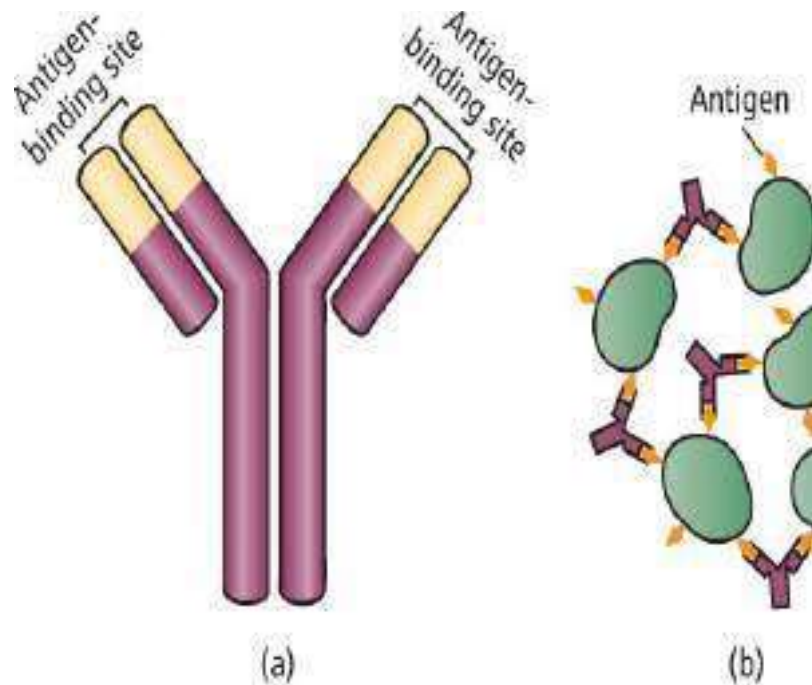
There is no getting around the fact that people's expectations are somehow central to the placebo effect. Some researchers have argued that the placebo effect is a conditioned response. A patient has, through numerous experiences with medical injections, and so on, been conditioned to expect a positive effect after medical treatment. And, somehow, the brain's reward system has become wired to provide this.

It is interesting that studies have also demonstrated a "nocebo effect," sometimes called the placebo effect's "evil twin." Expectations of negative effects are realized too. In fact, people on placebos often develop negative "side effects."


their treatments. Side effects of real medications sometimes be caused by the nocebo effect as we have shown that patients who are warned of specific effects tend to experience them more often than are not warned. The nocebo effect can be even more dangerous. One study showed that women who believed they were vulnerable to heart disease were four times more likely to have heart disease than women who did not believe they were vulnerable, even though they had similar risk factors. Never underestimate the power of the mind.

Once the clones are ready, they begin to make and release antibodies. An **antibody** is a large, Y-shaped protein that has two antigen-binding sites (Figure 20.26a). An antibody binds to an antigen in a very specific way, with a fit like a lock and key. A single B cell can make a huge number of antibodies—as many as 2000 different types. These antibodies travel around the body binding to antigens and neutralizing pathogens they encounter.

Figure 20.26



(a) Antibodies are large, Y-shaped proteins that include binding sites. (b) Because antibodies each have two binding sites, they can cause pathogens (shown here as green ovals) to clump together.

But what happens after an antibody binds to an antigen? Antibodies interfere with a pathogen's ability to function. Bound antibodies can prevent viruses from entering cells. Bound antibodies also mark pathogens, so that they can be destroyed by other immune cells. Antibodies may also clump together (see [Figure 20.26](#) )—these clumped pathogens are easy targets for other immune cells.

Some of the clones made by B cells are *memory cells*. Memory cells stay in the body for a long time—years or even a lifetime. If the body encounters the same pathogen again, the memory cells initiate a quick attack. Pathogens may be eliminated from the body before they even develop. This is why people catch many diseases only once and are immune for life.

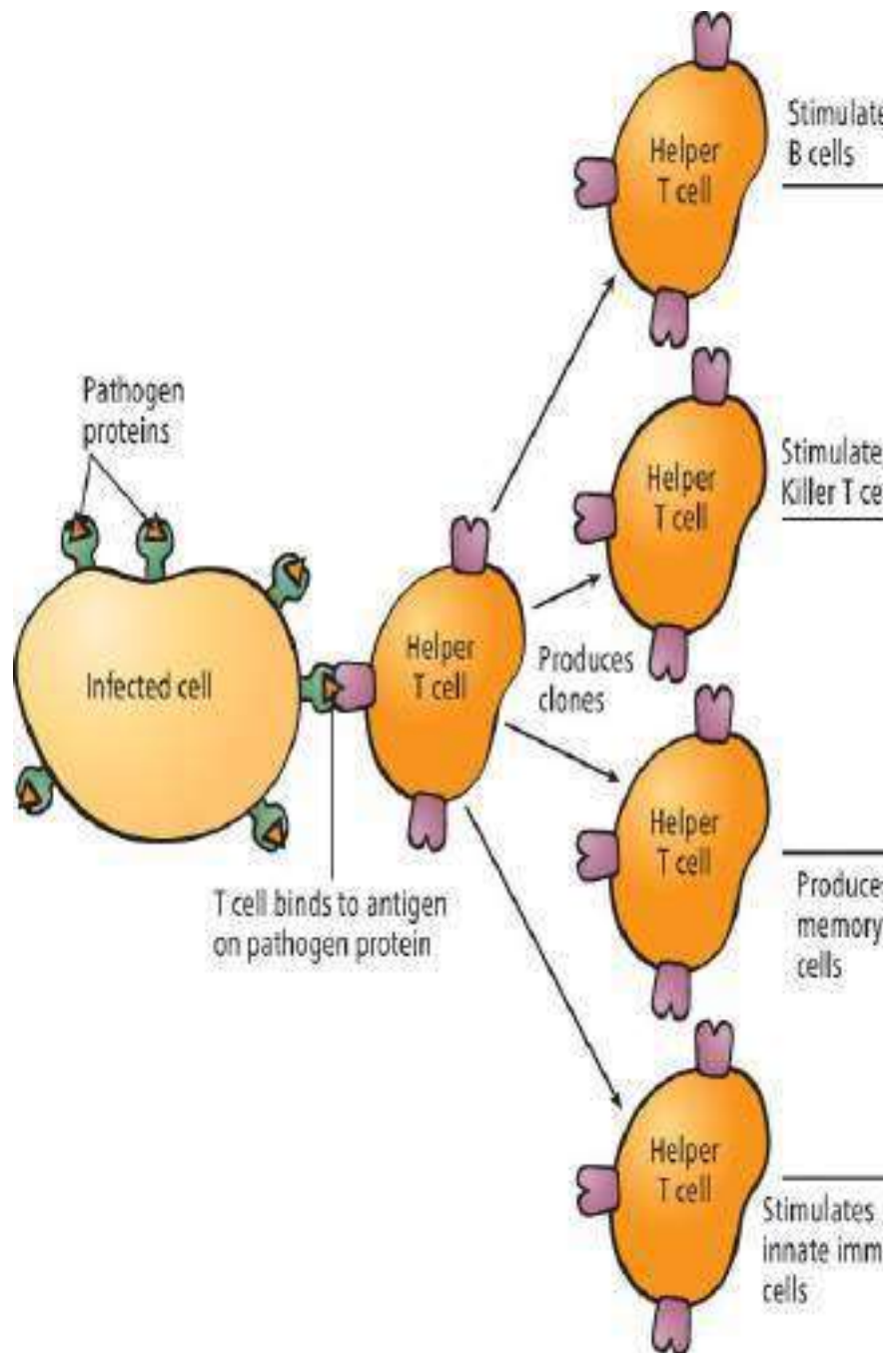
T Cells

T cells attack pathogens that are inside the body's cells and also the body's own malfunctioning cells. Because viruses enter the body when they infect your body, T cells are very important in fighting viral infections. T cells are also important in destroying cancer cells and abnormal body cells.

When a body cell is infected by a pathogen, the cell displays fragments of the pathogen's foreign proteins on its surface the way a ship displays a distress flag (Figure 20.27). The display of foreign proteins is a signal to the body's T cells. A type of T cell called a *helper T cell* binds to an antigen on the pathogen protein and begins to divide and form clones. Helper T cell clones then initiate many different activities: They stimulate B cells to produce clones that

against the pathogen. They also stimulate *killer T cells*, a cells, to divide and produce clones. The killer T cells bind proteins and then, as their name suggests, kill infected pathogens from coming out to infect new cells. Helper stimulate cells of the innate immune system. Finally, they produce memory cells that remain in the body for a long time against a return of the pathogen.

Figure 20.27



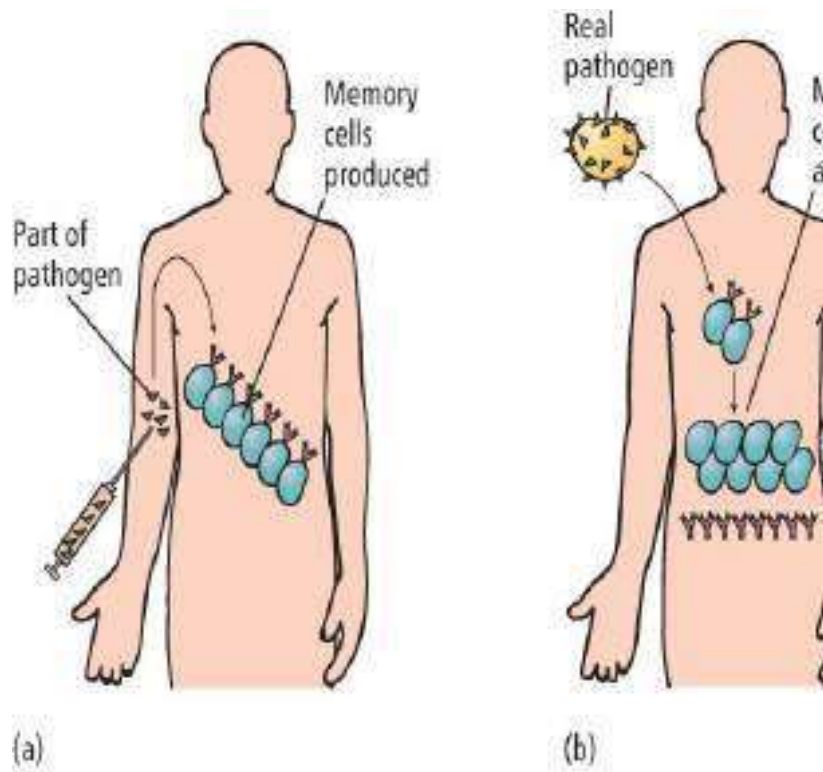
T cells target pathogens that are inside the body's cells. They display pathogen proteins the way a ship might display a flag. A helper T cell binds to an antigen on the pathogen protein and produces clones that initiate a variety of immune activities.

Vaccines

Vaccines protect you from disease by making use of your immune system's "memory" for pathogens it has encountered. A vaccine exposes your body to a pathogen's antigens, —it does not infect you with the pathogen itself!

Most vaccines contain either dead pathogens or weakened pathogens. A vaccine also may use only part of a pathogen, such as a virus's protein coat or a bacterium's flagellum. Your acquired immune system reacts to antigens in the vaccine just as it would to a real pathogen. That is, the acquired immune system makes memory cells. If the real pathogen ever appears, the acquired immune system is ready to attack ([Figure 20.2](#))

Figure 20.28



(a) Vaccines work by introducing dead pathogens, weak parts of a pathogen into the body. The acquired immune system responds and produces memory cells. (b) If the actual pathogen enters later, the memory cells initiate a rapid, aggressive attack.

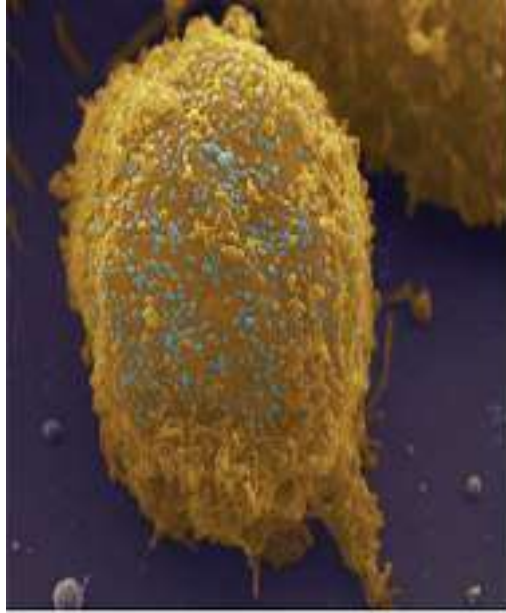
Vaccines are still the best way we have to fight most viruses. Many drugs have been developed to attack pathogenic bacteria, but it has been harder to develop drugs that work well against viruses. Don't forget your vaccinations!

Diseases of the Immune System

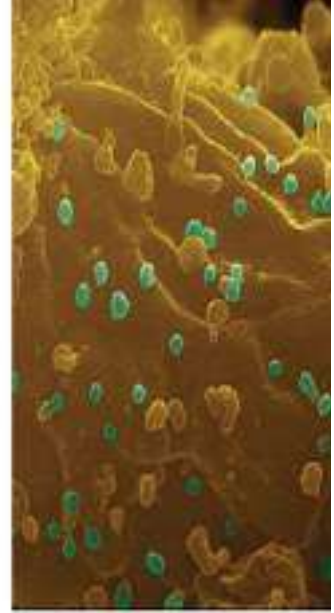
The immune system normally has no problem recognizing its own cells. In *autoimmune diseases*, the immune system identifies its own body cells as foreign and attacks them. *Type 1 diabetes* occurs when the immune system attacks and destroys the insulin-producing cells in the pancreas. *Multiple sclerosis* occurs when immune cells destroy the myelin sheaths surrounding neurons. *Lupus* is a debilitating disease in which the immune system attacks a wide range of healthy tissues.

Acquired immunodeficiency syndrome, or AIDS, is a disease caused by the *human immunodeficiency virus*, HIV. (The “acquired” in this disease refers to the fact that immunodeficiency is acquired during a person’s lifetime rather than being inherited.) HIV attacks and destroys particularly helper T cells (Figure 20.29). With these cells compromised, infections and cancers that are normally kept in check can off have a chance to overwhelm the body.

Figure 20.29



(a)



(b)

(a) HIV emerges on the surface of an infected helper T cell. The blue particles are HIV virions. (b) HIV emerges on the surface of many infected helper T cells. The blue particles are HIV virions.

Check Yourself

Interactive

Question 1

Check Answer

Question 2

Check Answer

Question 1

How does the inflammatory response help defend your body ag

Check Answer

How does the inflammatory response help defend your body ag

Answer: During the inflammatory response, the tissues surround the injury, helping to isolate it from the rest of the body. The inflammatory response brings innate immune cells to the site of injury so that they can fight off other pathogens.

* Patients who participate in these types of studies—which are usually controlled trials to test the effectiveness of a surgery, drug, or other treatment—are aware that they are in a study and that they might be assigned to a placebo treatment group. If the treatment performs no better than the placebo (as occurred in this case), the treatment is not effective. Testing treatments against placebos is important because the placebo effect can be very powerful. If there is already a proven treatment for a condition, however, new treatments can be tested against the established placebo.

Summary of Terms (Knowledge)

For instructor-assigned homework, go to
www.masteringphysics.com

Acquired immune system

A set of highly specific body defenses that respond to specific pathogens.

Alveoli

The tiny sacs in the lungs where gas exchange occurs.

Antibody

A large, Y-shaped protein that binds to a pathogen's antigens on the pathogen or marking it for destruction.

Antigen

A molecule or part of a molecule belonging to a pathogen recognized by cells of the acquired immune system.

Arteries □

Blood vessels that carry blood away from the heart.

Capillaries □

Tiny, thin-walled blood vessels from which molecules are exchanged between blood and body tissues.

Diaphragm □

The sheet of muscle that covers the bottom of the thoracic cavity. Its contraction and relaxation cause inhalation and exhalation.

Digestion □

The breakdown of food into small organic molecules that can be absorbed and used by the body.

Hemoglobin □

A protein found in red blood cells that binds to and transports oxygen.

Innate immune system □

A set of nonspecific body defenses that work against many pathogens.

Lymph □

A clear fluid inside lymph vessels that contains large numbers of white blood cells.

Nephron □

The functional unit of a kidney; it filters waste molecules from the blood and produces urine.

Pathogens □

Disease-causing agents such as bacteria, viruses, or other microorganisms.

Peristalsis □

A moving wave of muscular contractions that moves food through the digestive tract.

Platelets □

Blood cells that function in blood clotting.

Pressure □

The force exerted over a unit of area, such as a square r

Red blood cells □

Blood cells that transport oxygen to body tissues.

Veins □

Blood vessels that carry blood toward the heart.

White blood cells □

Blood cells that are part of the immune system.

Reading Check Questions (Comprehension)

20.1 Integration of Body Systems

1. Which two organ systems work together to supply oxygen?
2. How does getting rid of cellular wastes require efforts of multiple body systems?

20.2 The Circulatory System

3. What stimulates the heart to beat?
4. What makes the “lub-dubb” sound of the heart?
5. Which blood vessels are responsible for nutrient exchange with tissues?
6. Trace the path of blood through the body, beginning with returning from the tissues to the heart. Be sure to label the chambers of the heart.

7. What are the three types of blood cells, and what are the functions of each?

20.3 Respiration

8. Trace the path of air as it moves to the alveoli.
9. What structures in the trachea help keep it open?
10. How do the structures of the alveoli and their surrounding capillaries facilitate gas exchange?

20.4 Digestion

11. What does digestion accomplish?
12. What are the functions of saliva?
13. What prevents food from going into the trachea when it is swallowed?
14. What happens to food while it is in the stomach?
15. What structures increase the surface area available for nutrient absorption in the small intestine?

20.5 Nutrition, Exercise, and Health

16. Why is it important for you to eat a complete protein?
17. What are some of the important minerals you can get from your food?
18. What is metabolic syndrome?
19. What are some of the benefits of exercise?

20.6 Excretion and Water Balance

20. What is urea?
21. How does fluid move from the circulatory system to the nephron?
22. What happens to the filtrate in the proximal tubule?
23. What is the function of the loop of Henle?

20.7 Keeping the Body Safe: Immune Systems

24. What are two functions of the lymphatic system?
25. What features of skin make it good at keeping pathogens out of the body?
26. Why is a single innate immune cell able to respond to different pathogens?

27. What is an antigen?
28. Where in the body are the pathogens to which
Where in the body are the pathogens to which
29. What is the function of a memory cell?

Think Integrated Science

20A—Hemoglobin

30. What is the structure of hemoglobin? Which part of the hemoglobin molecule binds to oxygen?
31. How many oxygen molecules can one hemoglobin molecule carry?
32. Explain how hemoglobin's oxygen affinity is affected by pH, and how this change in oxygen affinity is a result of the Bohr effect.

20B—Blood Pressure

33. What is blood pressure?
34. What is the difference between systolic blood pressure and diastolic blood pressure?
35. What health issues are associated with high blood pressure?

20C—Inhaling and Exhaling

36. What is the diaphragm? What is its role in inhalation and exhalation?
37. What happens to the volume of the thoracic cavity when you inhale? What about when you exhale?

20D—Concentrating Urine

38. During excretion, what two parts of the nephron absorb water from the filtrate?
39. Why does water move out of the filtrate in the thick part of the loop of Henle?
40. What happens to the filtrate in the second part of the loop of Henle?
41. How does antidiuretic hormone help determine how much water is absorbed from the filtrate as it passes through the collecting duct?

Think and Do (Hands-On Application)

42. Your heart rate is the number of times your heart beats per minute. It changes over the course of the day as you move and it increases or decreases. Begin by measuring your heart rate. Ideally, you should do this when you first wake up in the morning. Now measure your heart rate during different activities. What is it when you're reading quietly, walking or doing chores around the house? Find your target heart rate while you are exercising. Are you in your target zone for effective cardiovascular exercise? You can find your target zone by following these directions: First calculate your maximal heart rate:

$$\text{Maximal heart rate} = 220 - \text{your age}$$

Then calculate your heart rate reserve:

$$\text{Heart rate reserve} = \text{maximal heart rate} - \text{resting heart rate}$$

You are in your target zone if you are using between 60% and 80% of your heart rate reserve:

Low end of target zone: 60% (heart rate reserve)

High end of target zone: 80% (heart rate reserve)

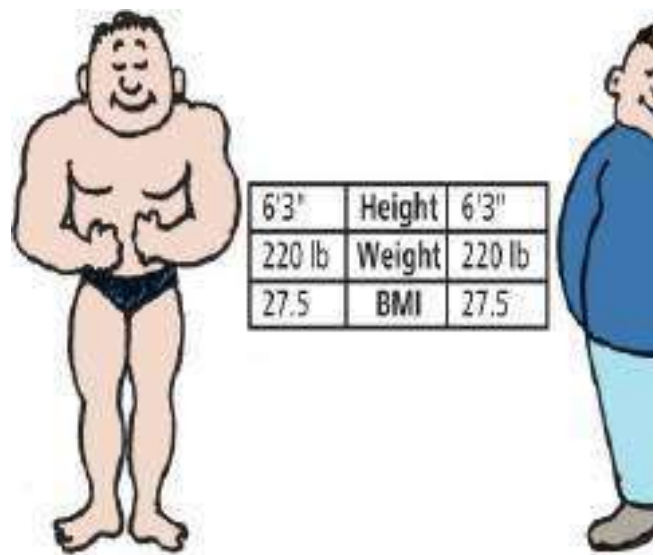
43. How healthy is your diet? Write down everything you eat and drink for a day. Note the number of calories you consume. How many calories do you consume per day? How does this compare to that recommended by MyPlate? What are you eating too much of? Not enough of?
44. The body mass index (BMI) adjusts your weight for height. You can calculate your BMI as follows:

$$\begin{aligned} \text{BMI} &= \frac{\text{your mass in kilograms}}{(\text{your height in meters})^2} \\ &= \frac{\text{your weight in pounds}}{(\text{your height in inches})^2} \end{aligned}$$

What does BMI mean? BMI provides an approximation of whether a person is underweight or overweight.

BMI	
Below 18.5	Underweight
18.5–24.9	Normal
25.0–29.9	Overweight
30.0 and above	Obese

Note, however, that BMI does not measure body composition. The figure below should convince you.



Think and Compare (Analysis)

45. Rank the following from highest oxygen content to lowest: blood in the pulmonary artery, blood inside the alveoli, a working arm muscle, arterial blood, and capillaries that supply the arm muscle.
46. Rank the following from highest blood pressure to lowest: capillaries, veins, arteries, arterioles, and the aorta.

Think and Solve (Mathematical Application)

47. Show that your blood supply can carry as many molecules of oxygen. Here's some information useful: You have 25 trillion red blood cells. Each contains 300 million molecules of hemoglobin. hemoglobin can carry four molecules of oxygen
48. A red blood cell has no nucleus and is therefore the proteins necessary to maintain itself. Because blood cells have a relatively short life span of about 120 days. Given that we have about 25 trillion red blood cells, more than 208 billion red blood cells die and are replaced each day. Also show that, in the 20 seconds it took you to solve this problem, about 48 million red blood cells died.
49. A typical person has a heart rate of 70 beats per minute and takes about 12 breaths in a minute. Show that her heart beats about 42,000 times an hour, 100,800 times a day, and 36.8 million times a year. Show also that she takes about 720 breaths per hour, 17,280 breaths per day, and 6.3 million breaths per year.

Think and Explain (Synthesis)

20.1 Integration of Body Systems

50. How does reproduction require the integrated work of multiple organ systems?
51. How does playing tennis or jumping rope require the integrated work of multiple organ systems?



20.2 The Circulatory System

52. In a developing embryo, the heart begins to beat before developing nerves reach it. How is the embryonic heart able to beat without nervous system control?
53. Why are the atria of the heart less muscular than the ventricles? Why is the left ventricle more muscular than the right ventricle?
54. The pumping of the heart does most of the work to move blood around the body. How do your skeletal muscle movements contribute to this process?
55. Where in the body is blood most oxygenated?
56. How does the body control the amount of blood that different tissues receive?

20A—Hemoglobin

57. How does the structure of hemoglobin help ensure that each hemoglobin molecule carries four molecules of oxygen (the maximum number) away from the lungs?
58. How does the structure of hemoglobin help ensure that oxygen-poor tissues, which require more oxygen, get the oxygen they need?

59. Why is carbon monoxide toxic? What effect does it have on the body?

20B—Blood Pressure

60. Why does blood pressure decrease as blood flows from capillaries to veins?
61. High blood pressure sometimes can lead to an aneurysm on the left side of the heart. Why?
62. High blood pressure is usually treated with medication. What kinds of high blood pressure medications are diuretics? ACE inhibitors. Diuretics help the body get rid of excess water. ACE inhibitors help blood vessels relax and dilate. How could each of these medications help reduce blood pressure?

20.3 Respiration

63. Which functions, other than acquiring oxygen for metabolism, require the work of the respiratory system?
64. Describe the structure of the lungs, as well as how the structure allows the lungs to perform their function in respiration.

65. What role does diffusion play in respiration?

20C—Inhaling and Exhaling

66. How does the shape of the diaphragm change v
What role does this play in breathing?

67. What role do the rib muscles and rib cage play
exhaling?

68. What is the role of air pressure in inhaling and

69. Is breathing a voluntary or involuntary action?

20.4 Digestion

70. As food moves down your esophagus, your eso
Why doesn't this cause the trachea, which lies a
become closed off?

71. Having the openings to both the trachea and th
pharynx is problematic because it can lead to cl
any advantages to this arrangement?

72. What are the functions of gastric juice?

73. What happens to food in the small intestine?

74. Is it true that bacteria live in our large intestine there?

20.5 Nutrition, Exercise, and F

75. What is the difference between a vitamin and a



76. What role has evolution played in human food effect does this have on us today?



77. What factors make a person more likely to develop metabolic syndrome? What are some of the health risks associated with metabolic syndrome?

20.6 Excretion and Water Balance

78. What waste materials are produced during the production of ATP? What body systems are responsible for removing these wastes from the body?
79. How does the endocrine system interact with the excretory system?

80. What is the difference between elimination (feces) and excretion (urine)? What is the body getting rid of in each process?

20D—Concentrating Urine

81. Does concentrating urine require energy? If so, where does the energy come from?
82. What would happen if NaCl were not pumped out of the thick ascending loop of Henle as it passed through the second branch of the loop? How does pumping NaCl out of the filtrate contribute to the concentration of urine?
83. Kangaroo rats live in very dry environments, so they have adapted for them to conserve water. They are known to have a very long loop of Henle. Explain how a long loop of Henle is adaptive in a kangaroo rat.

20.7 Keeping the Body Safe: Immune Systems

84. How does the lymphatic system support the work of the circulatory system? How does it support the work of the immune system?

system?

85. How do tears help defend your body against pathogens? This explains why people with allergies sometimes have itchy eyes?



86. Why is the innate immune system described as non-specific? Why is the acquired immune system described as specific?
87. What are some differences between the innate and the acquired immune system?
88. Allergies occur when the immune system is abnormally sensitive to particular substances. Why do people sometimes take antihistamines for their allergies? Can you guess what an antihistamine does?
89. If a virus infects your body, will only one type of cell be infected? In other words, does a single virus have exactly one target cell?
90. How does a vaccine protect you from disease?

Think and Discuss (Evaluati

91. Several of your senses provide examples of how systems work together to accomplish important systems are involved in hearing? In smelling? In



92. How do the arterioles react when you are running? When you are sitting at your desk and doing homework?
93. You use energy to contract your diaphragm and you breathe. Is energy also required for gas exchange? the transport of oxygen and carbon dioxide mo

the air inside the alveoli and the blood in the surrounding capillaries?

94. Why shouldn't you talk with your mouth full (not impolite)?
95. If you hold a piece of cracker in your mouth with your tongue, the cracker will dissolve. However, this doesn't happen with a piece of meat. Why?
96. Why do you think people like to eat sweets, fats, and other foods that are not very good for them? Do you think that the human taste for these and other foods might evolve?
97. The liver is an organ that plays important roles in many body systems. What role does the liver play in digestion? What does it play in excretion?
98. A cell in your body breaks down an amino acid and generates a molecule of ammonia, a nitrogen-containing compound. Describe what happens to this ammonia molecule.
99. What do you think explains the placebo effect?
100. The leading causes of death in low-income countries are listed in the following table. Compare them with the leading causes of death in the United States provided earlier in the text.

Leading Causes of Death in Low-Income Countries (2 World Health Organization)

- 1. Lower respiratory infections**
- 2. Diarrheal diseases**
- 3. Stroke**
- 4. Heart attacks**
- 5. HIV/AIDS**
- 6. Tuberculosis**
- 7. Malaria**
- 8. Preterm births**
- 9. Birth asphyxiation or trauma**
- 10. Road accidents**

Readiness Assurance Test (1)

Readiness Assurance Test

Interactive

If you have a good handle on this chapter, then you should be a 10 on this RAT. If you score less than 7, you need to study further.

Choose the BEST answer to each of the following:
10 questions

1. 1.

The right ventricle of the heart pumps blood to

the right atrium.

Incorrect.

Press enter after select an option to check the answer

arteries that go to the lungs.

Correct.

Press enter after select an option to check the answer

arteries that go to body tissues.

Incorrect.

Chapter 21

Ecology



21.1 Organisms and Their Environments □

TECHNOLOGY: Camera Traps □

21.2 Population Ecology □

MATH CONNECTION: *Exponential and Logistic Growth* □

21.3 Human Population Growth □

21.4 Species Interactions □

SCIENCE AND SOCIETY: *Biodiversity, Nature's Policy* □

SCIENCE AND SOCIETY: *Invasive Species* □

INTEGRATED SCIENCE 21A: EARTH SCIENCE
Ecosystems □

TECHNOLOGY: *LiDAR Mapping* □

INTEGRATED SCIENCE 21B: CHEMISTRY AND
SCIENCE: *Materials Cycling in Ecosystems* □

INTEGRATED SCIENCE 21C: PHYSICS: *Energy*
Ecosystems □

INTEGRATED SCIENCE 21D: PHYSICS AND C
Energy Leaks When Organisms Eat □

21.5 Change in an Ecosystem □

SCIENCE AND SOCIETY: *Wangari Maathai and Sustainable Development* □

NO LIVING creature exists in a vacuum—all organisms living and nonliving things around them. The study of this is called *ecology*. As we delve into ecology, we'll learn not do some animals, such as the elephant, produce only a every few years, while others, such as the razor clam, re 100 million eggs at a time? How can certain shrimp crawl mouth without being eaten? Why are there more zebra in the African savanna? Is it true that a disturbance can increase a habitat's biodiversity? What about the ecolog species? How many people live on Earth today? Will the population continue to grow, or is it likely to crash one planting a tree be the key to world peace?

21.1 Organisms and Their Environments

Learning Objective

Describe the different levels of ecological study.

Ecology is the study of how organisms interact with their environment. An organism's environment includes nonliving, or *abiotic*, features such as temperature, sunlight, rain, rocks, and ponds. An organism's environment also includes *biotic* features—other living organisms.

Ecology can be studied at many different levels, including individual, population, community, and ecosystem. Students at the individual level may ask how an organism's anatomy, physiology, and behavior help it function in its environment. For example, why do some plants invest more energy in building root systems, while others invest more energy in their stems and leaves (anatomy)? Or, why do some seeds have a high oil content while others have a high carbohydrate content (physiology)? Or, how do gulls divide their time between different feeding strategies: begging for handouts from

foraging at sea (behavior)? Because individual-level studies focus on adaptation, there is often considerable overlap with population biology.

A **population** is a group of individuals of a single species living in a specific area. The raccoons in Berkeley, California, are a population, as are the snow leopards of Central Asia and the orange-flanked bush robin of Langtang National Park, Nepal (Figure 21.1). At the population level, ecologists are often interested in the size of a population and how population size changes over time. In addition, population ecologists study how a specific population uses resources, including the types of foods that are eaten and the types of habitats that are used.

Figure 21.1



Biologist Pamela Yeh holds an orange-flanked bush robin in Langtang National Park, Nepal. The bird will be measured, weighed, and given a unique identifying leg band before being released.

A **community** ⓘ consists of all the organisms that live in an area. For example, the ecological community in an Idaho brushland might include sagebrush, prickly pear cactus, insects, squirrels, badgers, lizards, mountain lions, coyotes, and many kinds of microorganisms. At the community level, biologists often study how species interact with one another. They may study who competes for resources in a community or investigate how different species compete.

An **ecosystem** ⓘ consists of all the organisms that live in an area *and* all the abiotic features of their environment. At the ecosystem level, ecologists look at links between the biotic and abiotic world. For example, some ecosystem ecologists study the cycling of resources such as water and carbon between living organisms and their environment. Others look at how energy moves through ecosystems. Examples of ecological studies at different levels of organization are shown in **Figure 21.2** □.

Unifying Concept

The Ecosystem

Figure 21.2



Ecologists study different kinds of questions. (a) An individual-level study: How do fireflies use light signals to attract mates? (b) A population-level study: How many giant pandas live in the forests of central China? Is this number increasing or decreasing? (c) A community-level study: Who eats whom in a grassland? (d) An ecosystem-level study: How does an important resource cycle between the biotic and abiotic parts of an ecosystem?

Check Yourself

Question 1

Check Answer

Question 2

Check Answer

Question 1

An ecologist studies how hyenas and lions compete for food in savanna. Is this a study at the population, community, or ecosystem level?

Check Answer

An ecologist studies how hyenas and lions compete for food in savanna. Is this a study at the population, community, or ecosystem level?

Answer: This study examines how two different species interact.

Technology

Camera Traps

“Camera traps” take automated photos of animals through the equipment’s field of vision. They are equipped with an infrared sensor that detects the heat of warm objects such as large birds and mammals. To capture animal activity, the cameras can be outfitted with a flash. Camera traps are placed near streams, watering holes, or other areas where animals are likely to pass. Some are encased in a protective overhang to keep them dry. Most often, they are

the base of a tree, usually less than a meter above the ground. Photos are time-stamped with the date and time of the encounter.

Once set up, a camera trap is left to run and checked periodically. Cameras may need to be moved from one location to another periodically, since animals that have been startled by a camera's flash may avoid returning to the same spot in the future. Camera traps not only determine what animals are present in an area but can help with assessing population size by tracking individual animals over time. Population is growing or shrinking.



A camera trap set less than a meter above ground view of local animals.

One ambitious project recently used camera trap mammal populations in the Phnom Prich Wildlife Cambodia. Forty camera traps took photos for an between 3 and 119 nights. Together, a total of 2,7 trap nights captured 707 separate encounters with species, revealing which mammals inhabited which the sanctuary. Different species were found in wet the forest compared to in drier areas, providing evidence preserving different types of habitats would help sanctuary's biodiversity.

The Phnom Prich study also showed how human affected mammal ranges and activity patterns. Few encounters occurred in areas that were within a kilometer of villages located at the sanctuary's borders. In areas the villages, it was also found that many species normally active both day and night shifted toward nocturnal lifestyle, probably to avoid human activity.



A camera trap catches a barking deer as it approaches a waterhole in Malaysia.



A bear caught by a camera trap.



21.2 Population Ecology

Learning Objective

Compare exponential and logistic population growth models and describe how these are connected to a population's demographic history.

Population ecologists are often interested in how big a population is, as well as in how population size changes over time. Some ecologists count the total number of individuals in a population. At other times, they prefer to measure the *population density*, the number of organisms per unit area.

Population Growth

Four factors determine how a population's size changes over time: the birth rate, the death rate, the rate of immigration into the population, and the rate of emigration out of the population. Births and immigration increase population size. Deaths and emigration decrease population size. Whether a population is increasing or decreasing in size depends on the balance of these four factors.

depends on the relative contributions of the four factors; how populations in the natural world grow are exponential logistic growth.

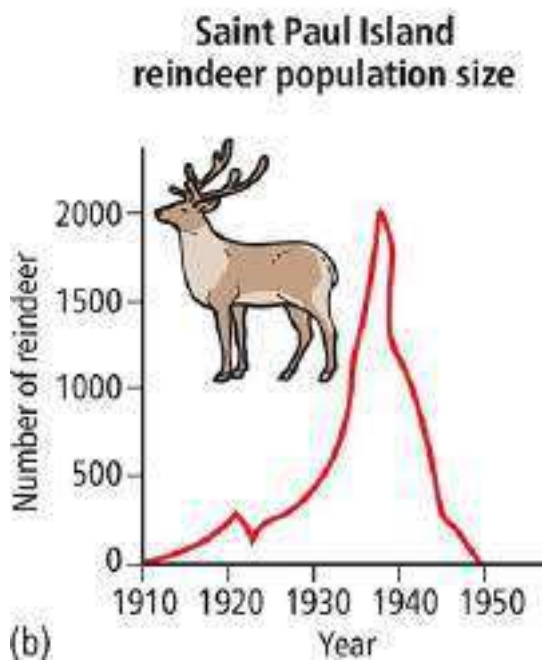
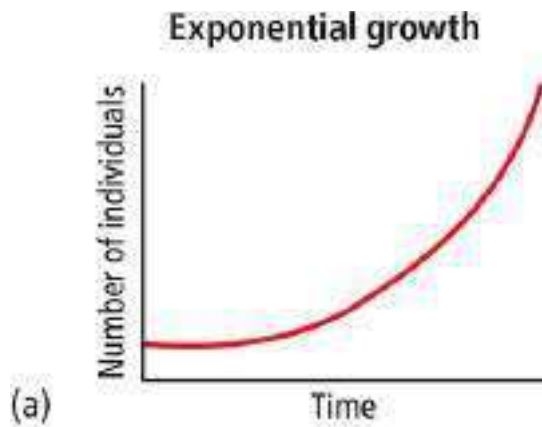
Exponential Growth

Exponential growth occurs when a population grows a certain amount of time (Figure 21.3). For example, a population that grows by 10% each year, or one that doubles each decade, grows exponentially (see Appendix D). As you can see from the graph in Figure 21.3, a population that is growing exponentially increases in size much more quickly as time goes on.

Unifying Concept

Exponential Growth and Decay Appendix D

Figure 21.3



(a) In exponential growth, a population grows at a fixed rate of time. Population size increases faster and faster, as you can see the way the curve gets steeper and steeper. (b) This graph shows exponential growth followed by a crash in the Saint Paul Island reindeer population.

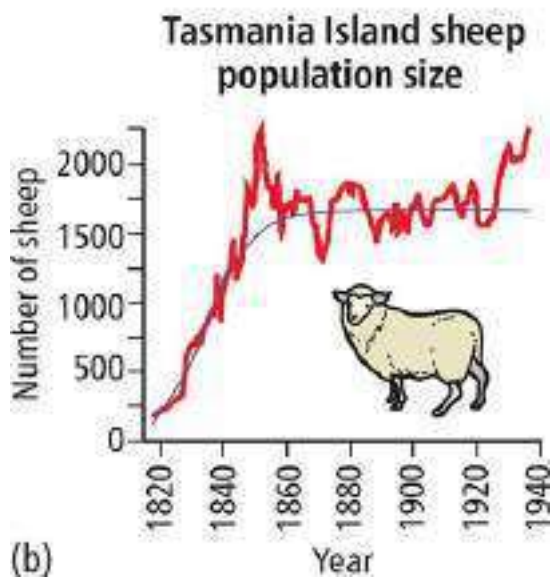
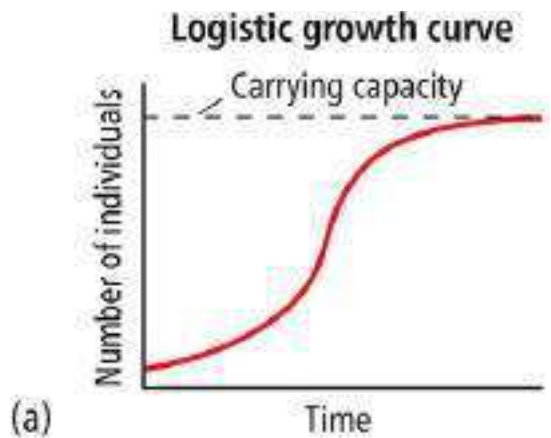
What kind of population grows exponentially? Exponential growth occurs when a population has unlimited resources. In this case, population growth is exponential, and a bigger and bigger population produces more and more offspring. Although resources are unlimited in the real world, they are sometimes extremely plentiful. For example, organisms may find very plentiful resources in a new habitat, and their population may begin to grow exponentially. When reindeer were introduced on Saint Paul Island near Alaska, the reindeer population grew exponentially for many years (see Figure 53.10). However, exponential growth cannot continue forever. On Saint Paul Island, the reindeer eventually ran out of food and the population crashed.

Exponential growth is often seen in populations that live in favorable environments. These populations may go through cycles of growth and crash. Good conditions start exponential growth, but when resources run out, the population crashes. When good conditions return, the population explodes again, and so on.

Logistic Growth

Logistic growth ⓘ occurs when population growth slows as the population approaches the habitat's carrying capacity (carrying capacity ⓘ is the maximum number of individuals that a habitat can support). For example, a pond may be able to support 250 trout, for example. Or, a field may be able to support 35 weasels per square kilometer.

Figure 21.4



(a) In logistic growth, population growth slows as the population approaches the carrying capacity of its habitat. (b) This is logistic growth in the Tasmanian sheep population.

Math Connection

Exponential and Logistic Population Growth

Under exponential growth, a population grows at a constant amount of time. One way to describe exponential growth is the following equation

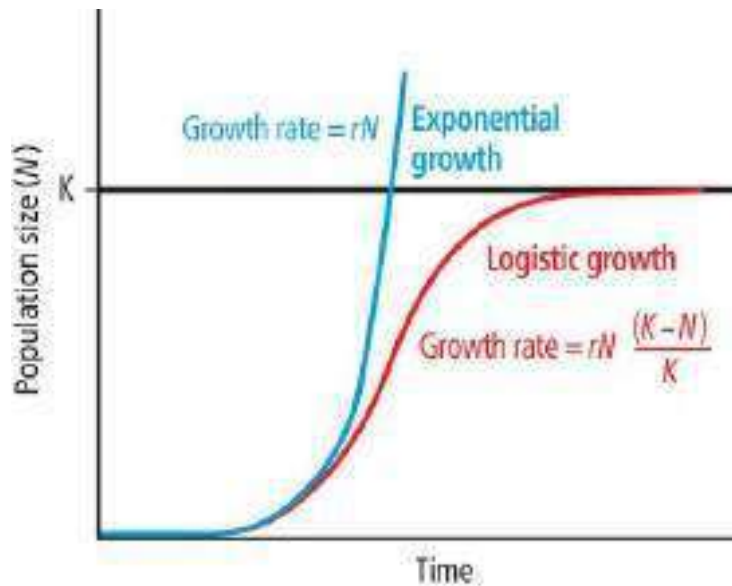
$$\text{Growth rate} = rN$$

In this equation, the growth rate is the number of individuals added during a specific amount of time, N stands for population size, and r stands for the population's rate of increase, or how many offspring, on average, an individual contributes to the population during a specific amount of time. As you can see in the equation, the growth rate is higher if r is high. It is also higher if N is greater—that is, if the population size is larger. This is why a population that is growing exponentially grows more and more quickly over time.

Now let's consider logistic growth. Under logistic growth, population growth slows as the population size approaches the carrying capacity of the habitat. The equation for logistic growth is

$$\text{Growth rate} = rN \frac{(K - N)}{K}$$

In this equation, r again stands for the rate of increase. N stands for the population size. The new variable K is the carrying capacity, the maximum population size the environment can support. Comparing the equations for exponential and logistic growth, we see that the only difference is that logistic growth has an extra $(K - N)/K$ term. What is the effect of this term? When the population size is very small compared to the carrying capacity (that is, when N is much smaller than K), $(K - N)/K$ is close to 1. This means that when the population is small, logistic growth is similar to exponential growth. You can see this in the figure. However, as N gets larger (as the population gets closer to the carrying capacity K), the term $(K - N)/K$ becomes smaller and smaller. This means that as the population size increases, the growth rate decreases. When $N = K$ (when the population is equal to the carrying capacity), $K - N = 0$ and the growth rate is zero. The population stops growing.



A comparison of exponential and logistic population growth. Under exponential growth, the population size grows fast. Under logistic growth, the population growth initially follows exponential growth. Then growth slows as the population approaches the carrying capacity of the habitat.

Problem


Let's compare growth rates under exponential and logistic growth. (a) Suppose a population is growing exponentially with rate of increase $r = 2$. What is the growth rate when population size $N = 1, 10, 20, 30, 40,$ and 50 ? (b) Now suppose the population is growing logistically with rate

$r = 2$ in a habitat where carrying capacity is 100. (a) Calculate the growth rate when population size $N = 1, 10, 20, 30, 40,$ and 50 ? (c) For both exponential and logistic growth, describe how the growth rate changes as the population size increases.

Solution

(a) For exponential growth, growth rate $= rN$
 For logistic growth, growth rate $= rN(K - N)/K$

Population size	(a) Growth Rate Under Exponential growth	(b) Growth Rate Under Logistic
1	2	1
10	20	18
20	40	32
30	60	42
40	80	48
50	100	50



(c) Under exponential growth, the growth rate of the population size increases. Under logistic growth, the growth rate starts out low, increases as the population size increases, and then decreases as the population size approaches the carrying capacity. When the population size equals the carrying capacity, the growth rate is zero.

Why would population growth slow as the population size approaches carrying capacity? There are many possible reasons. When the population is large, there may be more competition for resources such as food and space. This could make it more difficult to get enough resources to reproduce, causing birth rates to fall. Or, crowded conditions could increase the death rate.

In the real world, logistic growth is often seen in stable populations. The growth in the Tasmania Island sheep population is shown in Figure 21.4b.

Check Yourself



Question

Check Answer

Question

A population of shorebirds occupies a habitat where there are a safe nesting sites. What kind of population growth do you expect population?

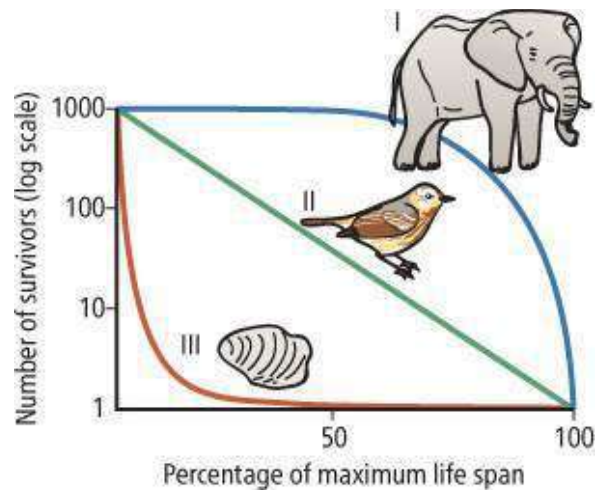
Check Answer

A population of shorebirds occupies a habitat where there are a

Life History

How a population grows depends in part on its *life history* schedule of survival and reproduction. This information is provided by a population's *survivorship curve*, which shows the proportion of a population that survive to a given age. Let's look at kinds of survivorship curves, shown in [Figure 21.5](#).

Figure 21.5



Three different survivorship curves. Type I organisms have low death rates early in life—most individuals live to an advanced age. Type II organisms have steady mortality throughout life. Type III organisms have high death rates early in life—few survive to adulthood.

Type I organisms have low death rates early in life, with most individuals surviving until fairly late in life. Elephants have Type I survivorship curves. Most elephant calves survive to adulthood. Type I organisms are typically large-bodied and reach sexual maturity late. They produce few offspring and devote significant resources to each offspring. For example, a female elephant takes about 10 years to reach sexual maturity, gives birth to a calf only every 5 years or so, and provides extensive parental care.

Type III organisms have high death rates early in life, with few surviving until late in life. Razor clams have Type III survival. Razor clams die early in life, and few survive to adulthood. These organisms typically reach sexual maturity early, produce many offspring, and devote few resources to each. For example, a razor clam may reach sexual maturity in the first year of life and produce 100 million eggs, releasing them into the water with no parental care. So, whereas elephants produce a small number of expensive offspring (expensive in the sense that the parents devote many resources to each offspring), razor clams make many "inexpensive" offspring.

Type II organisms fall between Type I and Type III. They experience a steady death rate throughout life—individuals die early in life as late in life. Many songbirds show Type II survival.

How is life history related to population growth? The production of "inexpensive" offspring is associated with exponential growth in unstable environments of exponential growth, life and death are subject to chance events. Producing many offspring is adaptive because it is more likely that at least some of the offspring will survive in a poor environment. Also, when conditions are good, there will be many offspring.

take advantage of plentiful resources. On the other hand, “expensive” offspring is associated with logistic population growth in stable environments. In these environments, many populations reach their carrying capacity. Consequently, an offspring that receives parental investment is more likely to be able to compete with other members of the population and successfully survive and reproduce. Table 21.1 summarizes some typical characteristics of Type I and Type III populations.

Table 21.1 Type I Versus Type III Populations



Type I Populations

- Large bodies
- Reach sexual maturity late
- Few “expensive” offspring
- Long life expectancy
- Live in stable environments
- Logistic population growth

Type III Populations

- Small bodies
- Reach sexual maturity early
- Many “inexpensive” offspring
- Short life expectancy
- Live in unstable environments
- Exponential population growth

Check Yourself

Interactive

Question

Check Answer

Question

What kind of life history characterizes humans?

Check Answer

What kind of life history characterizes humans?

Answer: Humans have a Type I survivorship curve. Most humans live a long life. Humans also have most of the other characteristics of Type I.

21.3 Human Population Growth

Learning Objective

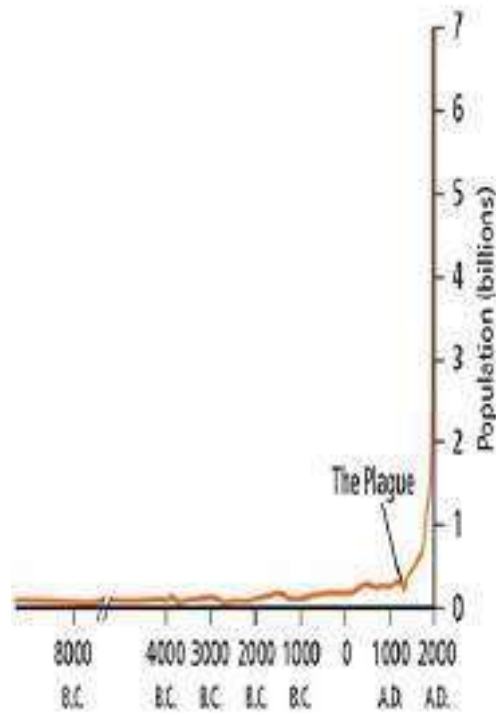
Describe how the global human population has changed over time, and how human population size is expected to change in the future.

The World Population

More than 7 billion people live on Earth today—the end of thousands of years of growth (Figure 21.6a). Where is the population headed? Will it crash as resources run out? Or will growth slow down and slide toward carrying capacity?

Figure 21.6

Global human population size



(a)

Projected future human population



(b)

(a) The human population grew exponentially for thousands of years (with the exception of the occasional dip, such as during the plague in the 14th century). (b) Current projections suggest that population growth may slow considerably in the second half of the 21st century. However, the human population is expected to reach about 10 billion by the year 2100.

Source: United Nations, Department of Economic and Social Affairs, Population Division, *World Population Prospects: The 2017 Revision*.

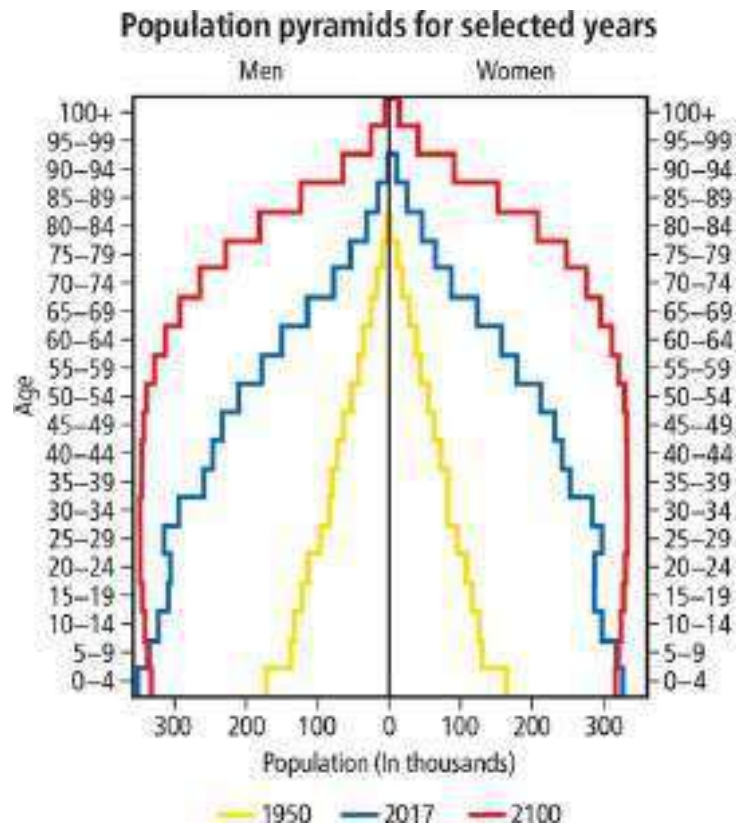
According to some scientists, humans came with a narrow genetic breadth of extinction about 74,000 years ago, when a massive explosion of the Sumatran volcano Toba darkened the sky and cooled the Earth.

skies for 6 years. Following the explosion, the world population may have dropped to as few as 2000

According to United Nations projections, the world human population is expected to increase throughout the 21st century and end at 10 billion by 2100. However, growth is expected to slow during the second half of the century (Figure 21.6b). These projections assume that fertility rates will continue to decline in high-fertility countries and that death rates will continue to decline everywhere.

We can learn how a population is growing from its age structure, which is the distribution of people's ages within the population. The age structure of the global population at three different points in time can be seen in Figure 21.7. In 1950, the age structure diagram resembled a pyramid. This was a sign of a rapidly growing population, where the majority of the population was young. In 2017, the age structure was less pyramid-shaped and more uniform. Compared to 1950, the population has aged and population growth has slowed. The projected age structure for 2100 shows that the global population is expected to be even more uniform, indicating that growth will slow further.

Figure 21.7



Age structures show the distribution of ages within a population. In 1950, most of the world population was young, and population growth was rapid. By 2017, the world population had aged, and population growth had slowed. By 2100, the world population is expected to be even older.

Source: United Nations, Department of Economic and Social Affairs, *Population Prospects: The 2017 Revision*.

The slowdown in population growth can be explained by a process called the *demographic transition*—a shift from high birth and death rates to low birth and death rates. The death rate typically declines as a result of medical advances such as better healthcare, improved sanitation, and the development of vaccines.

and immunization against childhood diseases. After so
rate also declines.

According to the U.S. Census Bureau, the popula
United States on October 9, 2018 was 328,763,50
occurs in the country every 8 seconds. One death
every 12 seconds. Net migration into the country
person every 29 seconds. This adds up to a net g
person every 13 seconds. (Check <https://www.ce>
popclock for updates.)

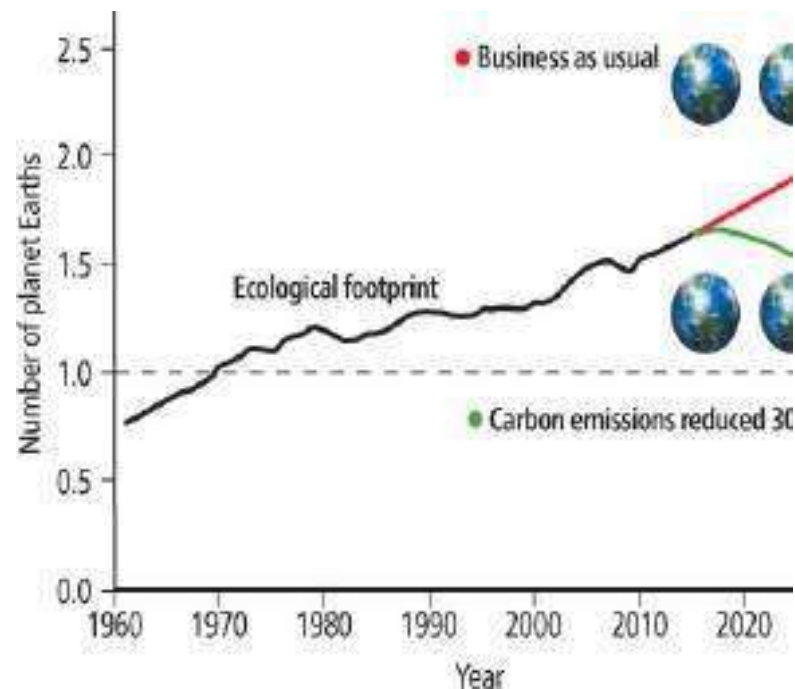
Ecological Footprint

Although population growth has slowed, human popul
continues to increase, and there are now more humans
ever before. At the same time, demand for Earth's reso
continues to increase. An *ecological footprint* is a measur
land and water area a human population needs in orde
resources it consumes. The size of this footprint takes i
population's use of water, soil, energy, food, and other
Measuring ecological footprints allows us to understand

consumption compares with what Earth can provide. The first step toward the goal of sustainable development.

For more than 40 years, the global human population has been in an *ecological overshoot*, consuming more resources each year than Earth can provide. In fact, we would need 1.7 Earths to sustain our current consumption. And, if current trends continue, we will need 2.5 Earths by 2030 (Figure 21.8).

Figure 21.8



This graph shows how our global ecological footprint has grown over the last 60 years. We are now using the resources that it would take to sustain 1.7 Earths.

Earths to provide. If present trends continue, we will so equivalent resources of 2 Earths.

Global overconsumption means that Earth's resources are depleted. We can already see evidence of this in water shortages, collapsed fisheries, and widespread deforestation. In addition, overuse of energy, especially fossil fuels, has led to global warming. If Earth's resources begin to run out, it will no longer be possible to support the billions of people who live here. The likely result is environmental degradation as well as starvation.

Of all the continents in the world, North America has the largest ecological footprint. In fact, if everyone in the world consumed resources as the average American, we would need the equivalent of 2.5 Earths. It is vital for us to reduce consumption, increase energy efficiency, and explore green energy alternatives.

21.4 Species Interactions

Learning Objective

Describe the ways species interact within comm

Lions eat zebras, eagles and storks fight over fish, and s
mouths of eels. Within communities, species interact in

Food Chains and Food Webs


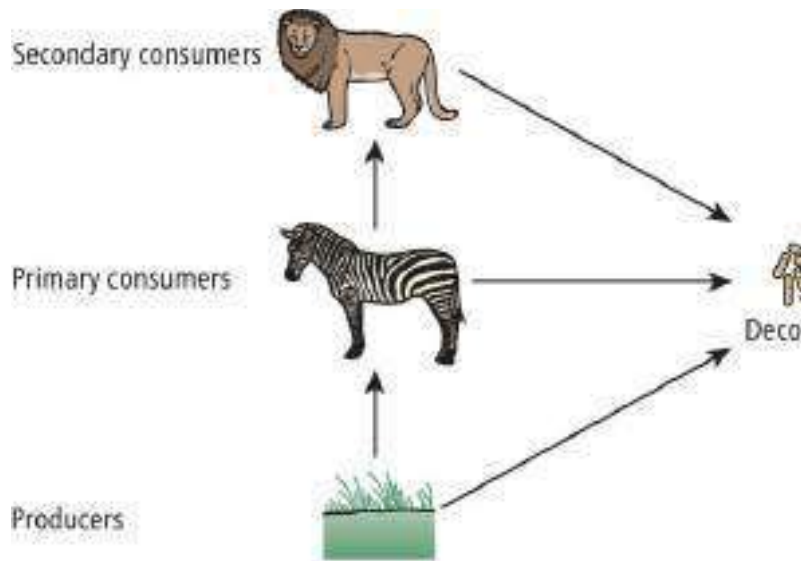
One important set of species interactions is who eats w
interactions can be shown in a *food chain* that contains 1
levels (Figure 21.9 .

Figure 21.9



This food chain includes producers (grass), primary consumers (zebras) and secondary consumers (lions). Decomposers consume matter from all levels of the food chain.

At the bottom of a food chain are producers. A **producer** is an organism that makes organic molecules using inorganic molecules. In almost all communities, the producers are photosynthetic organisms such as plants.

A **consumer** obtains food by eating other organisms. A *primary consumer* eats producers. Herbivores, such as zebras or rabbits, are primary consumers. A *secondary consumer* eats primary consumers. Carnivores, such as lions and wolves, are secondary consumers. In most communities, there are consumers that eat at even higher levels.

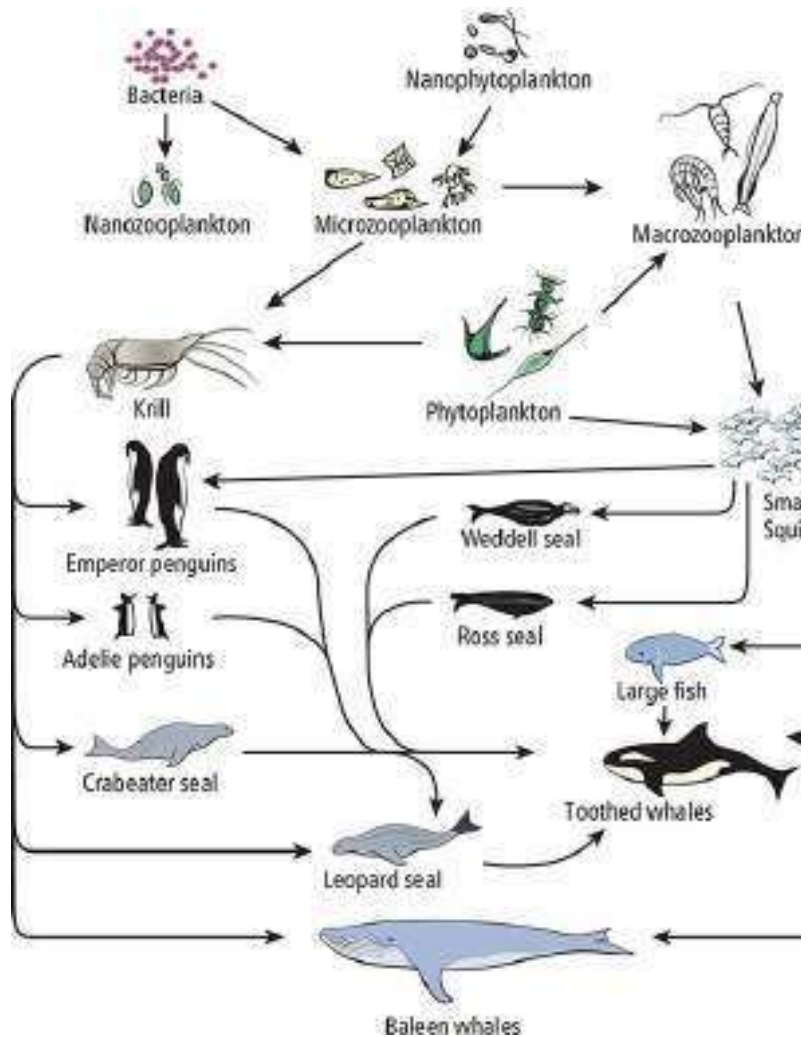
food chain. The species at the top of a food chain is called *predator*.

Humans are not preyed on by other species. We are not predators.

A decomposer obtains food by eating dead organic matter. Bacteria are important decomposers in many communities.

Most ecological communities are complicated enough that they are more accurately described as *food webs*. Figure 21.10 shows a food web in the Antarctic aquatic community.

Figure 21.10



The Antarctic aquatic food web. Can you find the top p community?


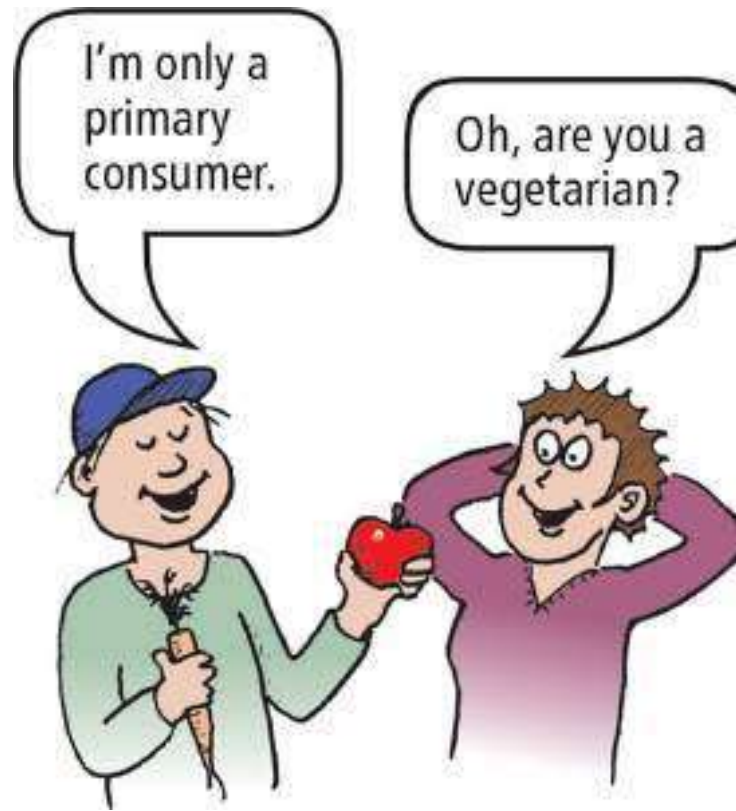
Where are humans on the food chain? Most humans ar eat at many levels of the food chain. We eat plants, ani decomposers, such as certain mushrooms. Of course, s a more restricted diet (Figure 21.11 )

Figure 21.11



Most humans eat at many levels of the food chain, but some eat a more restricted diet.

Check Yourself

Interactive

Question

Check Answer

Question

Can an organism be a producer *and* a consumer?

Check Answer

Can an organism be a producer *and* a consumer?

Answer: Actually, yes. There are some parasitic plants that both produce and obtain nutrients from their hosts—other plants. This makes them both producers and primary consumers. There are even some predaceous

Competition

Competition between organisms of different species is called *interspecific competition*. Some instances of interspecific competition are easy to identify—such as when animals battle over food (Figure 21.12). However, living things don't have to fight each other directly to compete. In fact, species within a community compete for the same resource and this resource exists in limited supply. For example, plants growing near each other may compete for limited resources such as sunlight, water, and soil nutrients.

Figure 21.12



An eagle and a stork fight over food.

A species' niche ⓘ within a community is the total set of resources it uses. This includes the food it eats, the water space it occupies, and any other resource the species uses. We say that two species in a community compete any time their niches overlap.

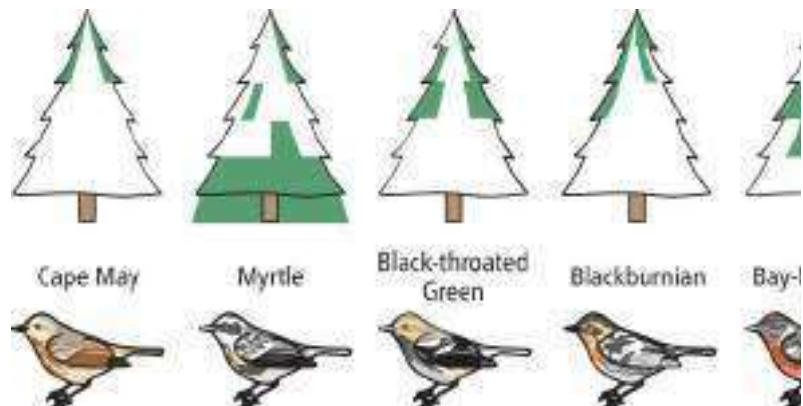
What is the result of competition? One result of interspecific competition is evolution. Many organisms have evolved adaptations to better compete with other species. For example, some plants that compete for sunlight have evolved large leaves with a large surface area. Others have evolved to grow upward quickly, so that they can reach the sunlight.

chance of overshadowing their competitors. Certain plants produce special chemicals that prevent a competitor's seeds from

It is interesting that, although species frequently compete in a community can have *exactly* the same niche. Other species that is better at acquiring and using resources outcompete other species and eventually drives it to extinction. Nonetheless, ecologists have sometimes found species that appear to have identical niches in a community. On closer inspection, however, it has turned out that niches are not exactly identical. One of the most famous examples occurred in a group of birds now known as MacArthur's warblers. Ecologist Robert MacArthur studied five warbler species in the coniferous forests of the Northeast United States. All five species lived in the same trees, and all five species ate insects. Did they have identical niches? By watching the warblers closely, MacArthur discovered crucial differences in how the species used resources. Each species of warbler used a different part of the tree, and each had a different way of hunting for insects (Figure 21.13). How did MacArthur's warblers come to have such similar, yet nonidentical, niches? Ecologists believe that the niche differences were produced by evolution through natural selection. Individuals of each warbler species were more

surviving and reproducing if they competed less with other species. Over time, this caused the species' niches to diverge.

Figure 21.13



The five species of MacArthur's warblers initially appeared to occupy the same niche—they all live in the same coniferous forests and feed on insects. However, closer inspection revealed that their niches differ in significant ways. For example, each species occupies a different part of the tree, as shown here (shaded in green). Each species has evolved a different way of hunting for insects.

Science and Society

Biodiversity, Nature's Insurance

Biodiversity describes the number and variety of species in a community. Are communities with greater biodiversity more stable? There are good reasons to expect that a community that has only one producer is in big trouble if that producer has a bad year. A community that has many producers is much less likely to have them all do the same thing at the same time.

Ecologist David Tilman tested the link between biodiversity and community stability. Tilman and his students managed several hundred equal-size plots of land in the Michigan grasslands. For 11 years, they counted the number of species living on each plot. Tilman found that plots with more species were less affected by drought, showed less year-to-year variation in total plant cover, and were less vulnerable to invasion by new species. All of these findings suggest that greater biodiversity results in greater stability. Plots with more species also showed greater productivity—that is, greater total aboveground mass of all plants combined. Stability and productivity are considered good indicators of how well an ecosystem is functioning.



A community with greater biodiversity is more stable and productive.

Why would a diverse community be more stable and productive? In a community with greater biodiversity, species share a given role. Because different species respond differently to changing environmental conditions, one species may do well when another species is doing poorly. A diverse community might be more productive because different species make use of different resources. This means that available resources are likely to be used more completely in a diverse community. The more complete use of resources leads to higher productivity.

also explain why new species have a harder time
diverse community.

Unifying Concept

The Scientific Method [Section 1.3](#) 

Symbiosis

In *symbiosis*, individuals of two species live in close association with one another. There are three kinds of symbiosis: parasitism, commensalism, and mutualism.


Parasitism describes a relationship that benefits one member of the interaction and harms the other. Fleas, ticks, and tapeworms are parasites that obtain nutrients from their hosts ([Figure 21.14a](#) ). Parasitism benefits the parasite, which gets nutrients and a home, while the host is harmed. Pathogens such as bacteria or viruses are parasites.

Figure 21.14



The three types of symbiosis are parasitism, commensalism, and mutualism. (a) Parasitism: A tick feeds on human blood. (b) Commensalism: A remora hitchhikes on a shark. (c) Mutualism: Cleaner shrimp removes parasites from the mouth of an

Commensalism is a form of symbiosis that benefits one species while having no effect on the other. The remora is a small fish that attaches itself to a shark using a suction cup (Figure 21.14b). It feeds on small scraps of food left over when the shark eats. It also receives protection from its host. (Would you bother a fish hanging off a shark?) The remora neither benefits nor harms the shark.

Humans and dogs have a mutualistic relationship. Both species benefit from its association with the other.

Mutualism is a form of symbiosis that benefits both species. Cleaner shrimp and eels have a mutualistic relationship. The cleaner shrimp enters the eel's mouth, and the shrimp eats the parasites there. Both species benefit—the shrimp obtains food, and the eel is free of parasites. Sometimes, eels even “wait in line” for a cleaner shrimp. Another example of mutualism is mycorrhizae, the close relationship between fungi and plant roots. The fungi help the plant absorb minerals from the soil, and the plant provides nutrients for the fungi.



A species that lives in close association with another species and has a response to that partner. Many parasites, for example, have special adaptations for attaching to their hosts. Of course,

evolve in response to parasites. As we saw, eels have evolved a symbiotic relationship with cleaner shrimp in order to get rid of the

Check Yourself

Interactive

Question 1

Check Answer

Question 2

Check Answer

Question 1

This reed warbler is feeding a large cuckoo chick. Cuckoos lay eggs in the nests of other species, and the parents then raise the cuckoo chick as their own. (The cuckoo mother removes an egg before leaving her nest so that the host chick will often eject the remaining eggs from the nest after it hatches.) What type of symbiotic relationship do these two species have?



Check Answer

This reed warbler is feeding a large cuckoo chick. Cuckoos lay eggs in the nests of other species, and the parents then raise the cuckoo chick as their own. (The cuckoo mother removes an egg before leaving her nest so that the host chick will often eject the remaining eggs from the nest after it hatches.) What type of symbiotic relationship do these two species have?

Science and Society

Invasive Species

When the brown tree snake arrived in Guam from Guinea, it found a snake's paradise—plentiful food of forest birds and their eggs and not a single natural predator in sight. The snake quickly spread through the small island. Now it is found in startling numbers; in favorable habitats, there can be as many as 5000 individuals per square kilometer. Where the brown tree snake thrives, however, it devastates the island's unique bird fauna. A dozen species are now extinct, and many others are endangered.

An *invasive species* is a species that has moved from its natural habitat to a new area, where it proceeds to do a lot of ecological damage. Although many species were intentionally introduced in the past, the introduction of nonnative species today is usually accidental, occurring when organisms hitchhike on a ship or airplane.

Invasive species are responsible for the decline of many native species worldwide. More than a third of the species listed as endangered under the U.S. Endangered Species Act are threatened wholly or partly because of an invasive species. Some invasive species also have significant economic impacts.

The zebra mussel is an invasive species that has entered the eastern United States since its accidental introduction in 1988. Zebra mussels clog water pipes at power plants and water treatment facilities, causing billions of dollars in damage annually. They also threaten native freshwater biodiversity by competing with them for food; most of these native species are now listed as endangered.



Brown tree snake climbing in Guam



Invasive zebra mussels are attached to a freshwater
Lake Michigan.



Signs warn people about spreading invasive mus

Integrated Science 21A: Earth Science

Kinds of Ecosystems

Learning Objective

Describe the major types of terrestrial and ecosystems.

Earth has many different kinds of ecosystems, ar occupied by characteristic suites of organisms. V Earth's ecosystems into two broad categories: te aquatic.

Unifying Concept

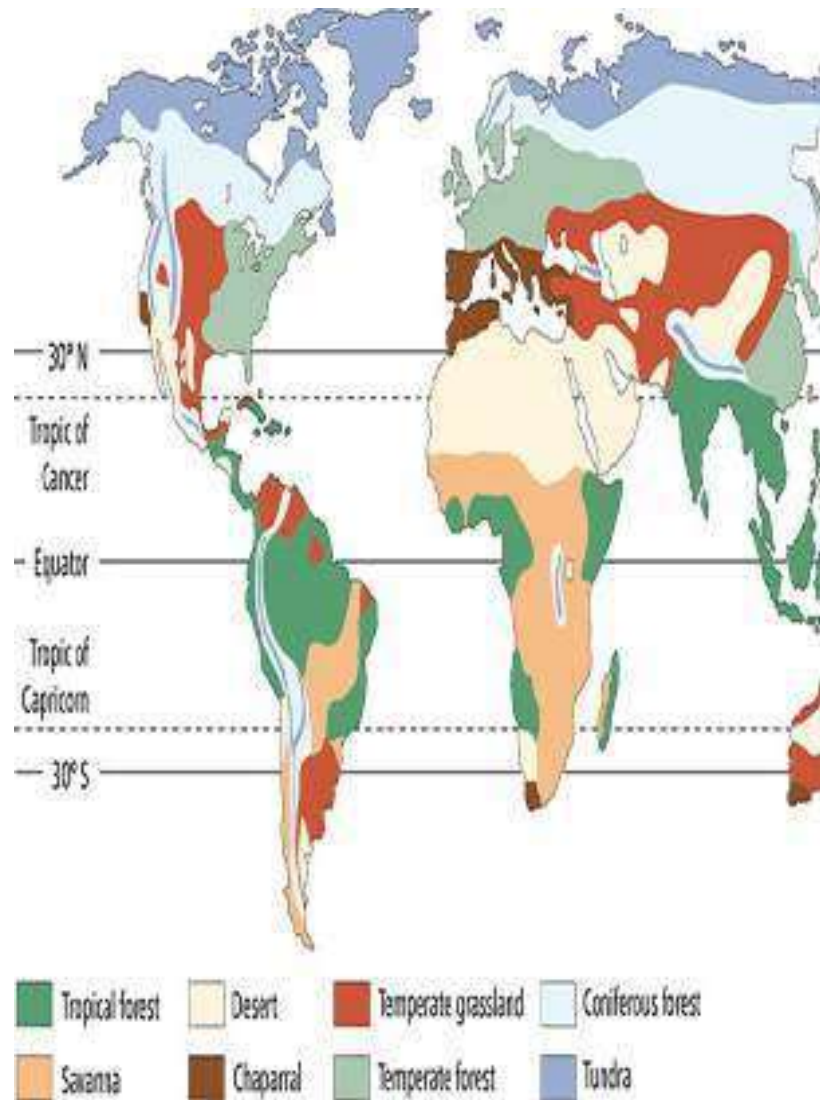
The Ecosystem [Section 21.1](#)

Terrestrial Biomes

The land area of Earth is divided into eight major ecosystems, known as **biomes** (Figure 21.15). occupied by specific types of biological commun importantly, by specific types of plant life. The sa often found in completely different parts of the w example, there are tropical forests—with their tal vegetation, and astounding biodiversity—in the A

of South America, in Southeast Asia, and in eastern western Africa.

Figure 21.15



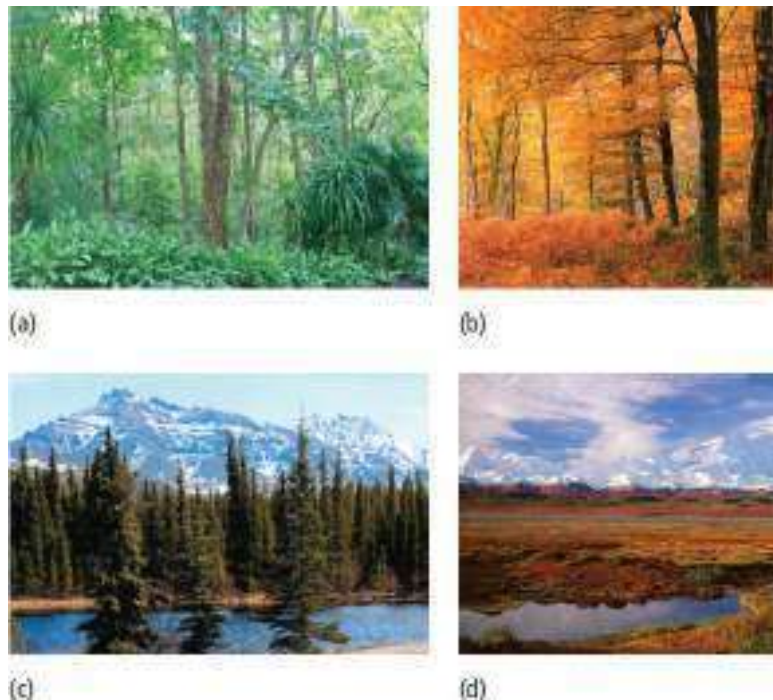
Earth's terrestrial biomes. Each biome is associated with specific climate and with specific types of plant life.

The type of biome found in a certain habitat depends on the climate, including factors such as temperature, rainfall, and the severity of seasonal variation. As a result, *latitude*—distance from the equator—and *altitude*—height above sea level—are two major influences on the distribution of biomes on Earth. For example, sunlight strikes Earth most directly at the equator, warming the air there and causing it to rise. When the air cools, it releases a great deal of moisture as rain. Tropical forests, also known as rainforests, are found near the equator. The dry air that remains then descends toward the poles, creating many of the world's largest deserts. Let's now survey Earth's biomes.

Tropical forests (Figure 21.16a), or rainforests, are found near the equator. Temperatures are warm and constant throughout the year. Tropical forests receive 200 and 400 centimeters of rain a year, distributed between a wet season and a dry season. Tropical forests are famous for their biodiversity—more species are found in this biome than in all other biomes combined. A single square kilometer of tropical forest may contain as many as 100 different species of trees. The tallest trees form a dense canopy, shading the forest floor. Tropical forests have little leaf litter because

material is quickly decomposed. Most of the nutrients in tropical forests are found in the organisms that live there and the soil tends to be poor. Tropical forests are destroyed worldwide for timber and agriculture. Because of the poor quality of the soil, forest that is cleared for farmland can support crops for only a few years.

Figure 21.16



(a) This tropical forest in Thailand shows the dense diversity of plant life found in all tropical forests. (b) In a temperate forest in Devon, England, the season is autumn and the trees are shedding their leaves. (c) A coniferous forest in Denali National Park, Alaska. (d) Tundra in Denali National Park, Alaska. Notice the absence of trees.

Temperate forests (Figure 21.16b) are found in areas that have four distinct seasons, including a warm growing season and a cold winter. Temperate forests receive between 75 and 150 centimeters of rainfall per year. There are usually between 10 and 20 different species of trees per square kilometer. Some of the most well-known temperate forest trees are elm, oak, beech, and maple. The leaves of temperate forest trees are unable to survive the freezing temperatures of winter. Consequently, they are *deciduous*—they drop their leaves in the autumn. This allows the trees to absorb nutrients from their leaves before they are shed. The soil in temperate forests is fertile, and these forests make up a large portion of the world's farmland. In fact, many temperate forests have been converted to farmland to make way for agriculture.

Coniferous forests (Figure 21.16c), or evergreen forests, are found in areas that have long, cold winters and short growing seasons. Coniferous forests are relatively dry, receiving about 50 to 100 centimeters of precipitation per year. Precipitation falls mostly as snow. As their name suggests, coniferous forests are dominated by conifers such as pine, spruce, and fir. The needlelike leaves of conifers are covered with a thick coating of wax and contain special substances that keep them from freezing.

freezing during the winter. In coniferous forests, usually covered with shed needles, and the soil is nutrients. Many coniferous forests are threatened

The melting of permafrost is one of the visible effects of global warming today.

Tundra (Figure 21.16d) is found in areas that experience extreme cold and little precipitation. One of the defining features of tundra is a layer of *permafrost*, or permanently frozen subsoil, beneath the topsoil. The word *tundra* comes from the Finnish word *tunturia*, meaning “treeless.” Trees cannot survive in tundra because of permafrost and a short growing season. Plant life in the tundra includes lichens, mosses, grasses, and flowers. Plants are in close clumps as a defense against cold. The tundra has a relatively low biodiversity.

Savannas (Figure 21.17a) are tropical grassland biomes with a wet climate and a long dry season. Savannas are covered with grass and occasional scattered trees. Plants that live in savanna have long roots for coping with drought. Trees have a thick bark that helps them survive the fires that occur during the dry season. Fires help maintain savanna

preventing tree growth. Living organisms also he
savanna habitats—for example, elephants eat an
and humans burn forests for agriculture. Without
some savannas would grow into tropical forests.
receive a moderate amount of rain, usually betwe
centimeters each year.

Figure 21.17



(a)



(b)



(c)



(d)

(a) A savanna in Serengeti National Park, Tanzan
temperate grassland in South Dakota. (c) The Sor

Arizona. (d) Chaparral in California.

Temperate grasslands (Figure 21.17b) are found in regions that have four distinct seasons, including a hot summer and a cold winter. Compared to savannas, temperate grasslands experience more temperature variation and receive less rainfall, typically between 30 to 90 centimeters per year. Several factors prevent trees from taking over the habitat and turning it into temperate forest, including relatively low levels of precipitation, seasonal drought, fire, and grazing. The soil of temperate grasslands is extremely fertile, making for ideal farmland.

Chaparral (Figure 21.17c) is found in places that have rainy winters and hot, dry summers characterized by frequent fires. Chaparral habitats are dominated by small shrubs, many of which have small waxy leaves that reduce water loss. Chaparral plants also have extensive root systems that help them survive the summer drought.

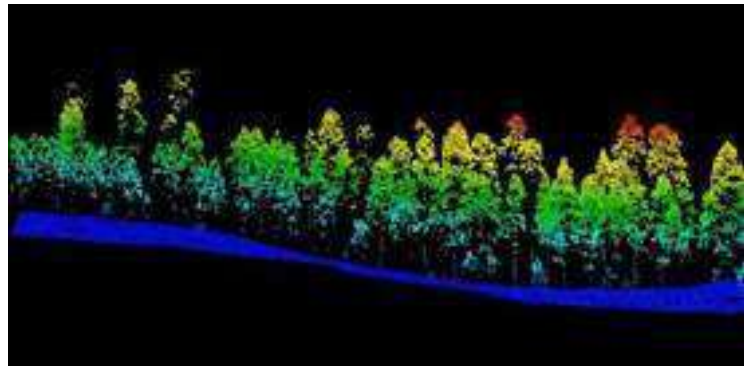
Technology

LiDAR Mapping

How can lasers build three-dimensional maps of an environment? A current answer is with a technology called LiDAR. The term *LiDAR* was originally a combination of *light* and *radar*, but it also stands for *Light Detection and Ranging*. In LiDAR, pulses of infrared light, just outside the visible spectrum, are emitted into the environment. They bounce off surfaces and then return. By measuring exactly how long each pulse takes to return, a highly detailed, three-dimensional map of the environment is created.

LiDAR has a wide variety of practical applications. It is used to study air pollution in cities, since the laser pulses bounce off tiny particles in the air. Autonomous cars also use LiDAR to map out their environment. This technology can also be used to study underwater environments, although in that case a water-penetrating light is used.

LiDAR is especially useful in studying the structure and other ecosystems. Typically, a helicopter or a plane flies over the forest with onboard LiDAR equipment mapping the environment. LiDAR models are often correlated with other kinds of data. Ecologists, for example, measure soil characteristics in various locations in a forest to see how they correlate with tree height.



LiDAR allows for the production of detailed three-dimensional maps. The color coding shows the height of different parts of the forest.



A female lion wearing a GPS tracking collar. Studies combined with LiDAR reveal how animals use ha

Ecologists have also studied how different animals use their habitats by combining LiDAR data with animal tracking technology like Global Positioning System (GPS) collars. The GPS data allowed them to pinpoint the locations of animals in their habitats. Researchers investigated elephant habitat use in a forest in Sarawak, Malaysia. Data showed that the habitat most important to elephants was the flat areas with trees about 13 meters tall. Interestingly, this type of forest typically has been logged and is often considered “damaged” or “degraded.” Because “degraded” forests are a lower priority for conservation, they frequently er

converted to farmland or other uses. Pristine, old-growth forests with much taller trees—the preferred candidates for conversion—turned out to be unsuitable for elephants. The LiDAR study showed that “degraded” forests are crucial habitats for species such as elephants.

Another study combined LiDAR+GPS data to track lion movements and assess how they used their habitats. The study revealed that female and male lions hunted in different habitats and used different strategies. Female lions hunted in groups and preferred open areas with longer lines of sight. Male lions hunted alone, using covered areas that allowed them to ambush their prey.

Deserts (Figure 21.17d) are habitats that receive very little precipitation, usually less than 50 centimeters per year. Although deserts are usually associated with hot climates, cold deserts also exist. In cold deserts, precipitation may fall as snow. Antarctica, the coldest continent, is a desert. Many of the world’s largest hot deserts, including the Sahara and Australian deserts, are found in a band between 30 degrees north latitude and 30 degrees south latitude. Desert plants and animals have adapted to these harsh conditions.

special adaptations for living in dry conditions, such as root systems and the ability to store water. Desert soils are rich in nutrients. This rich soil, combined with a long growing season and plentiful sunshine, makes deserts productive farmland if water is brought in through irrigation.

Aquatic Biomes

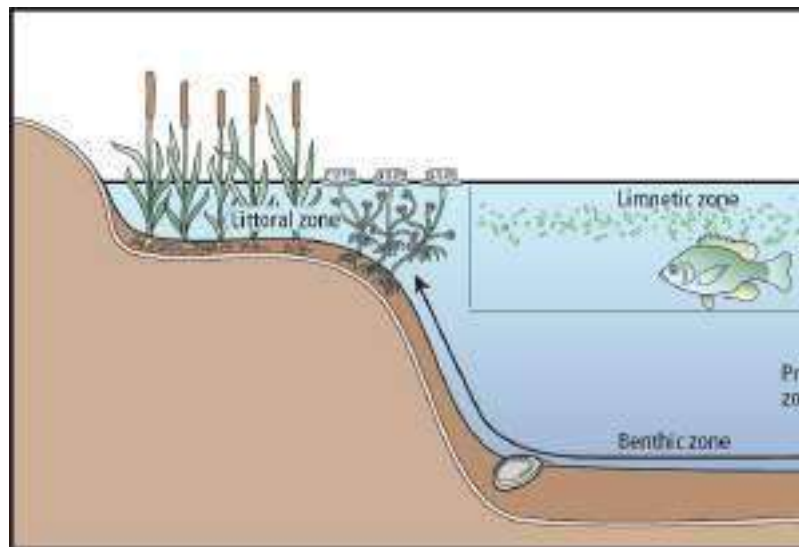
Life originated in the oceans, and many species continue to live in aquatic habitats in both fresh water and salt water.

Freshwater Habitats

Freshwater habitats include the still waters of lakes and ponds and the flowing waters of rivers and streams. Lakes and ponds vary greatly in size and biodiversity. Nonetheless, all can be divided into zones, as illustrated in [Figure 21.18](#). Habitats close to the water surface and to shore are part of the *littoral zone*. The littoral zone is warm because of its exposure to sunlight. Organisms that live in the littoral zone include photosynthetic plants and algae, invertebrates, crustaceans, fishes, amphibians, ducks, and turtles. The *limnetic zone* includes habitats that are close to the water surface but

The limnetic zone is occupied mainly by *plankton*, organisms that float in the water rather than swimming actively through it. Phytoplankton, photosynthesizing plankton—they are the main producers in ponds. Zooplankton are heterotrophic plankton. In some ponds, fish also live in the limnetic zone. The *profundal* zone is the deep-water habitats in ponds and lakes. Most organisms in this zone consume organic debris that drifts down from above. The *benthic zone* describes habitats on the lake bottom. This zone is occupied by organisms such as mollusks, worms, microorganisms, and other living things.

Figure 21.18



Lakes and ponds can be divided into different zones. Each zone is home to distinct kinds of living organisms.

Aquatic species that live in the flowing waters of rivers usually have adaptations that keep them from being washed away. Some species have hooks or suckers for attaching to rocks. Other species are bottom dwellers and are adapted to be good swimmers. As in lakes and ponds, photosynthesizing plants are the main producers in rivers and streams.

Estuaries are habitats where freshwater rivers flow into saltwater. They are found in estuaries, such as marsh grasses and mangroves. Plants that grow there have adaptations for dealing with changing salinity conditions. Estuaries are also home to many fishes, invertebrates, and birds and are important nursery habitats for many fishes and invertebrates.

Figure 21.19

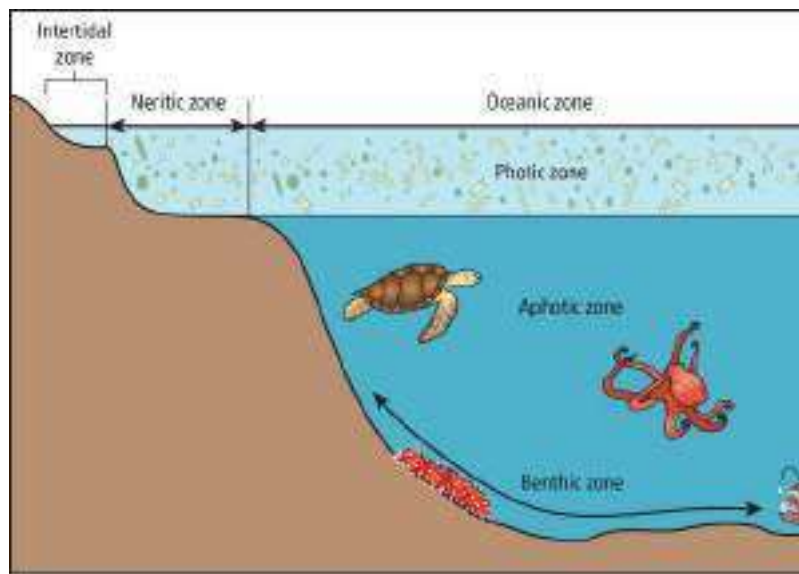


An estuary in southern Florida.

Saltwater Habitats

The oceans offer a wide range of habitats to living organisms. **Figure 21.20** shows the different zones of the ocean. Many marine species are found in the pelagic zone, which is the open water column. The pelagic zone is further divided into two parts. The *photic zone* is close to the water surface and receives enough sunlight to power photosynthesis. The majority of marine organisms are found there. The deeper *aphotic zone* receives little sunlight and is much more limited in food availability and biodiversity.

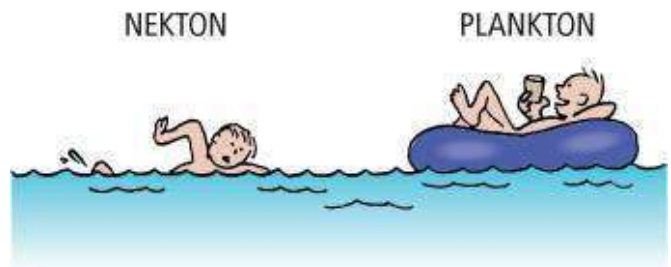
Figure 21.20



The ocean offers a variety of habitats to living organisms. The ocean is divided into different zones based on depth and distance from the shore.

Pelagic species use one of two modes of locomotion. Plankton drift wherever water currents take them. Plankton include lichens, diatoms, dinoflagellates, and the larvae of animals such as sea urchins. The phytoplankton, or photosynthetic main producers in oceanic food chains. *Nekton* swim actively in water. Fish and sea turtles are examples of nekton. Humans are organisms, of course, but when we do get in the water, we can behave like plankton or nekton (Figure 21.21).

Figure 21.21



In the water, humans can behave like nekton or plankton.

Most marine species live in the *benthic zone* on the ocean bottom. Some species may live on the surface of the ocean bottom, like clams and worms.

Ocean habitats also can be categorized based on their c
The *intertidal zone* is closest to shore. As the tide moves
intertidal zone alternates between being submerged un
exposed to air. Intertidal species, such as barnacles, sea
starfish (Figure 21.22), must be able to deal with expc
temperature fluctuations, and waves. Special adaptation
live in this environment. Many intertidal species have t
in crevices to keep from drying out. In addition, all spec
firmly to rocks or other surfaces so that they do not get
the beach. The *neritic zone* describes underwater marine
coasts. Coral reefs, the most diverse marine ecosystems
found in the neritic zone. Habitats in the neritic zone c
of nutrients, which wash into the water from land. Beca
neritic zone is richer in life than the deeper *oceanic zone*

Figure 21.22



Diverse organisms, including starfish, sea anemones, and other organisms, occupy this tide pool.

Check Yourself

Interactive

Question 1

Check Answer

Question 2

Check Answer

Question 1

Scallops live on shallow seafloors. They move by quickly opening their shells, shooting jets of water that propel them in spurts. Are they benthic? Are they nekton or plankton?

Check Answer

Scallops live on shallow seafloors. They move by quickly opening their shells, shooting jets of water that propel them in spurts. Are they benthic? Are they nekton or plankton?

Integrated Science 21B: Chemistry and Earth Science

Materials Cycling in Ecosystems

Learning Objective

Describe how important substances such as water, carbon, and nitrogen cycle back and forth between living organisms and Earth.

A water molecule in a cell on your cheek once boiled in the Indian Ocean. A carbon atom on the skin over your head once floated in the cold air above Antarctica. A nitrogen atom flowing through your veins once sat in the moist soil of a mountain in Peru. Parts of you have been all over the world in places you have never seen with your own eyes! How is this possible?

Living organisms are made up of many substances including water, carbon, nitrogen, phosphorus, sodium, calcium, chlorine, and many others. All these substances move through Earth in a series of **biogeochemical cycles**, going from living organisms to the Earth and back.

forth between the tissues of living organisms and world. The word *biogeochemical* emphasizes the cycle between living organisms (*bio*) and Earth (*geo*), specifically, Earth's atmosphere, crust, and water.

Unifying Concept

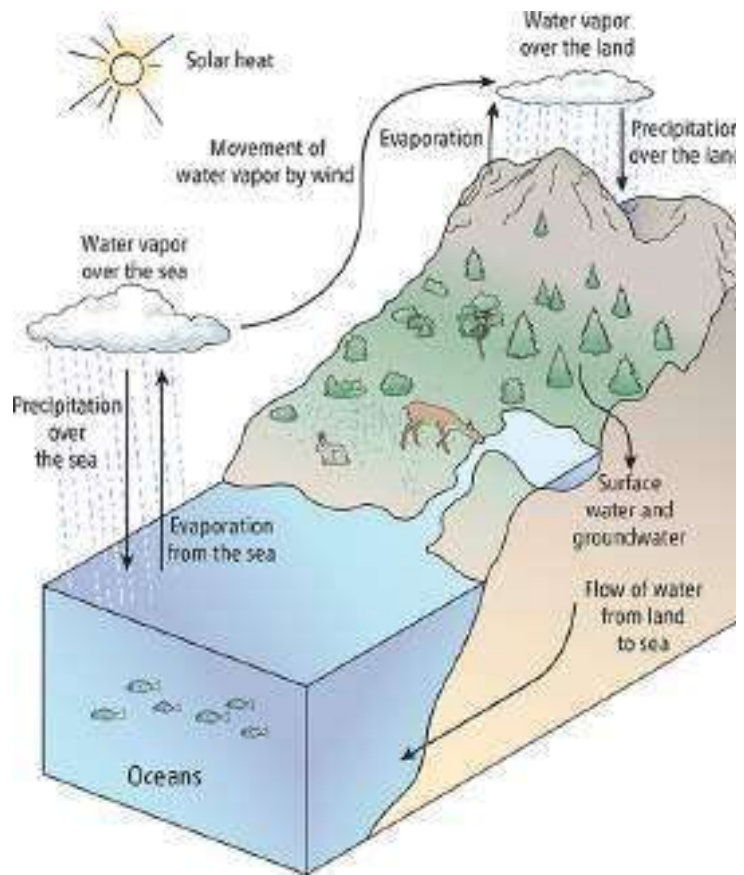
The Ecosystem [Section 21.1](#) □

As a molecule moves through its biogeochemical cycle, it passes through a series of *reservoirs*—that is, places where it stays. For example, a water molecule may sit in the ocean, until evaporation moves it to another reservoir, the atmosphere. It may then fall as precipitation into another reservoir, a lake. The average amount of time a molecule spends in each reservoir—for example, the average time a water molecule spends in the ocean before moving to another reservoir—is known as its *residence time* in that reservoir. Although every substance used by living organisms has a biogeochemical cycle, we will focus on three of the most important: water, carbon, and nitrogen.

Water

All living things need water. About 98 percent of the water is found in oceans, rivers, and lakes. The rest—about 2 percent—is in glaciers, in the polar ice caps, in soil—and in living organisms. The water cycle, shown in [Figure 21.23](#), describes how water moves around Earth. Water evaporates from the oceans into the atmosphere. It is carried around the atmosphere by winds, and then falls back to Earth as rain or snow. Water that falls on land flows back to the oceans through streams, and groundwater.

Figure 21.23



Water cycles through the oceans, atmosphere, and land enters the bodies of living organisms.

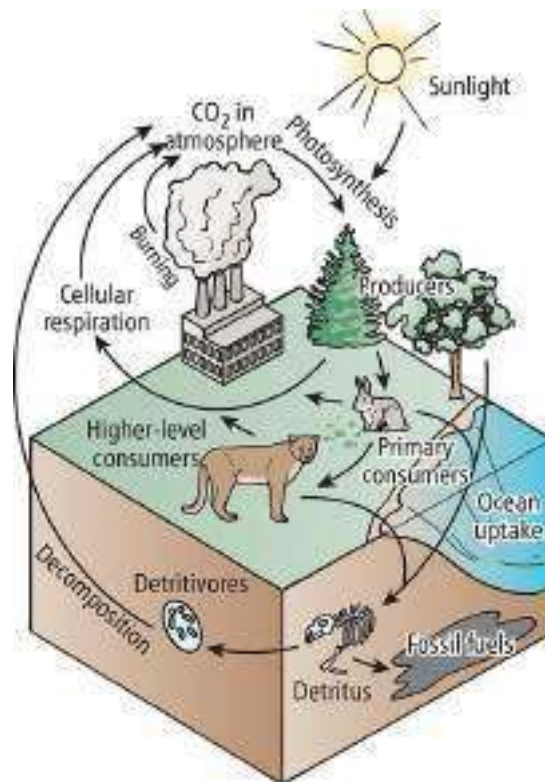
Water enters the biotic world when it is absorbed or sw organisms. Some of this water may pass up the food ch returned to the abiotic environment through processes respiration, perspiration, excretion, and elimination. Pl water when it evaporates inside leaves and then escape stomata to the atmosphere. Did you know that every ti

return water to the atmosphere? If you breathe onto a r piece of glass, you will produce a foggy film of water va

Carbon

Carbon is an essential component of all organic molecu cycle is shown in **Figure 21.24**. Most of the inorganic exists as carbon dioxide and is found either in the atmo dissolved in ocean waters.

Figure 21.24



Carbon is found as carbon dioxide in the atmosphere and through photosynthesis, producers move carbon into the biotic world. Carbon is returned to the abiotic world as carbon dioxide, a product of cellular respiration. Another important component of the carbon cycle is the burning of fossil fuels, which has released a huge amount of carbon previously trapped in the fuels.

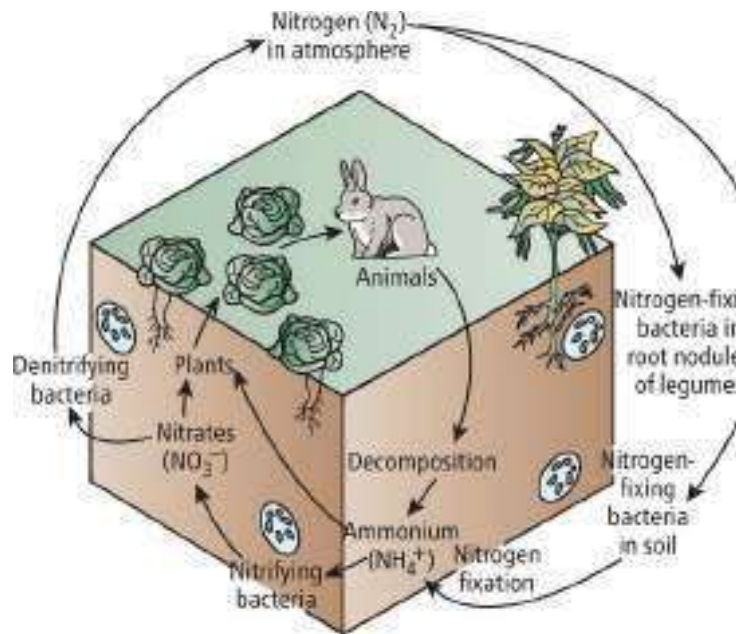
Carbon enters the biotic world during photosynthesis, where other producers use carbon dioxide to make the organic molecule glucose. This carbon becomes available to other organisms in the food chain. Carbon is returned to the abiotic world through cellular respiration, when organisms break down organic molecules (like glucose) and release carbon dioxide.

An important part of Earth's carbon supply is found in fossil fuels like coal and oil. Both coal and oil are formed over long time periods from the remains of dead organisms. (This is why they are called fossil fuels.) Human burning of fossil fuels has released so much carbon into the atmosphere that atmospheric carbon dioxide levels are higher than they have been for 15 million years. Because the atmosphere traps heat on the planet, Earth has warmed noticeably and this warming of Earth is called *global warming*.

Nitrogen

Nitrogen is an essential component of amino acids, DNA, and other organic molecules. The nitrogen cycle is shown in Figure 21.25. Earth's nitrogen exists as nitrogen gas (N_2) in the atmosphere. Nitrogen gas is not a form of nitrogen that most living things can use. Bacteria convert nitrogen into a usable form. *Nitrogen-fixing bacteria* in soil convert nitrogen gas into ammonium (NH_4^+), and *nitrifying bacteria* convert ammonium into nitrates (NO_3^-). Plants absorb nitrogen primarily in the form of nitrates, although they make use of ammonium as well. Nitrogen then moves from plants to animals. Nitrogen returns to the abiotic environment when it is converted back into nitrogen gas by denitrifying bacteria.

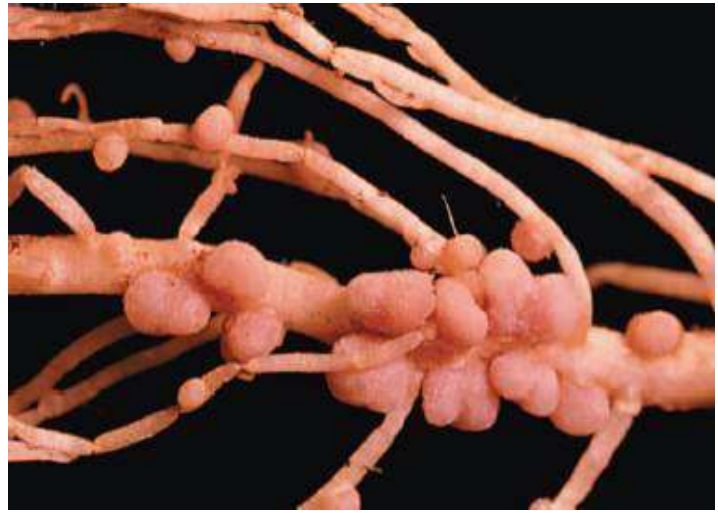
Figure 21.25



Nitrogen is found as nitrogen gas in the atmosphere. Bacteria convert atmospheric nitrogen into forms that can be used by living organisms.

Certain plants, including legumes such as peas, beans, and soybeans, have evolved a mutualistic relationship with nitrogen-fixing bacteria. These plants shelter the bacteria in special nodules in their roots (see [21.26](#)), and the bacteria provide the plants with nitrogen. Farmers often grow legumes with other plants: The excess nitrogen they release enriches the soil and allows other crops to grow better. However, not all plants rely on bacteria for nitrogen—in fact, synthetic fertilizers have been invented for making nitrogen-rich fertilizers. These fertilizers help humans to grow more food and to support larger human populations, but synthetic fertilizers also pollute and damage natural environments.

Figure 21.26



Legumes house symbiotic nitrogen-fixing bacteria in sp
like those shown here.

Check Yourself

Interactive

Question
Check Answer
Question

What living things do you, as a human, rely on to obtain (1) water (2) carbon (3) nitrogen?

Check Answer

What living things do you, as a human, rely on to obtain (1) water (2) carbon (3) nitrogen?

Answer:

1. You don't have to rely on other living things to obtain water directly!

Integrated Science 21C: Plants and Animals

Energy Flow in Ecosystems

Learning Objective

Describe how energy flows through an ecosystem.

All living organisms need energy to survive, grow, and reproduce. Where does this energy come from? In most ecosystems, energy comes ultimately from the Sun. Earth receives a lot of sunlight energy—about 10^{19} kilocalories each day.

Earth's surface every day. Sunlight energy enters the world when plants and other organisms use it to produce organic molecules during photosynthesis. Photosynthetic organisms convert about 1% of the sunlight energy that reaches them into organic matter, such as the cellulose in plants and starches in potatoes. Globally, this adds up quickly enough to make 170 billion tons of organic matter each year.

Biomass is the amount of organic matter in an ecosystem. The rate at which producers build biomass is the *primary productivity*. Different ecosystems vary in primary productivity—for example, tropical forests, swamplands, and reefs have very high primary productivity, whereas tundra have relatively low primary productivity.

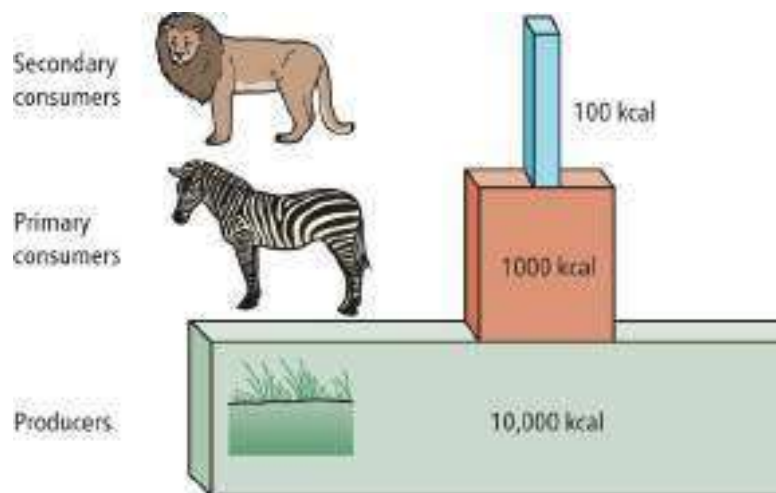
Unifying Concept

The Ecosystem [Section 21.1](#)

Once energy enters an ecosystem as producer biomass (biomaterial), it goes up the food chain, creating biomass in primary consumers, secondary consumers, and so on. But the energy taken in by plants ultimately goes into grass or lions? No. In all ecosystems, only about 10% of the energy from one level of the food chain moves up to the next level.

example, if the producers in one patch of African savanna contain 10,000 kcal of energy, you would expect about 1,000 kcal to be available to primary consumers (such as zebras), and about 100 kcal to be available to secondary consumers (such as lions). This energy flow can be shown in an *energy pyramid*, as shown in [Figure 21.27](#). The shape of the pyramid shows a decrease in energy as you go up the food chain.

Figure 21.27



This energy pyramid shows that the amount of energy available decreases as you move up the food chain.

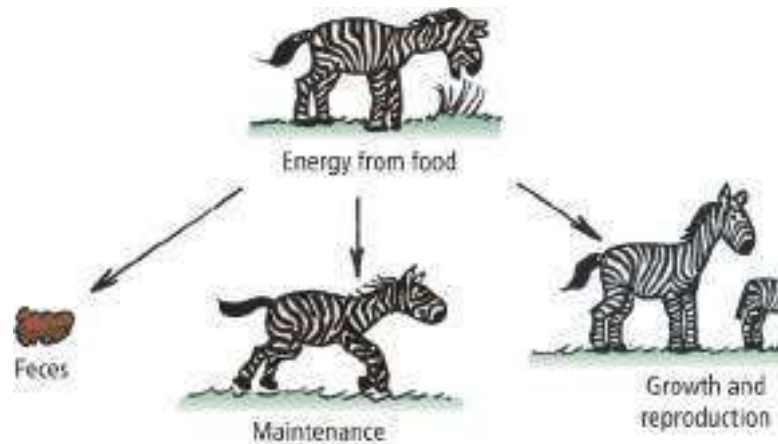
Why does only 10% of the energy at one level of the food chain move to the next level? What happens to the other 90%? What happens to the energy that is not used by some organisms at one level of the food chain and is lost to the environment?

organisms at the next level of the food chain. For some savanna plants are not eaten by zebras, and some are not eaten by lions. If an organism is not eaten, the energy in it cannot move up the food chain. Second, the energy in an organism's food goes into building biomass, but only the energy that is converted into biomass can move up the food chain. For example, when a zebra eats a plant, the energy in the plant is lost in feces and some is used for maintenance. Feces contains organic matter that the zebra can't digest. Maintenance is the energy the zebra uses for its own life—the energy it takes to find food, run, breathe, heat itself, and so on. By the time feces and maintenance have been accounted for, only a fraction of the energy is left for growth and reproduction—for building new biomass (Figure 21.28).

Unifying Concept

The Law of Conservation of Energy [Section 21.1](#)

Figure 21.28



The energy an organism takes in from food goes to feces, maintenance, and growth and reproduction. Growth and reproduction contribute to building biomass, and energy that is converted into biomass can move up the chain.

The energy pyramid explains why the higher levels of a food chain have less biomass—why there is more grass and more zebras than lions: There is less energy available to organisms that eat higher in the food chain, and fewer can be supported. The energy pyramid also explains why the number of levels in a food chain is limited: There is not enough energy to support animals that eat at every level. For example, there is no higher-level consumer that feeds exclusively on lions.

Just as for other consumers, the energy in food does not all go to building biomass. Do all the calories you eat, your weight doesn't change much from one week to the next. Where do calories go? The same place they go for other consumers—into feces and maintenance.

Check Yourself

Interactive

Question
Check Answer
Question

The producers in a patch of pine forest use about 30,000 kcal of energy. If only 10% of the energy at one level of the food chain moves up to the next level, how much energy is available to the primary consumers in the first level? How much energy is available to the secondary consumers?

Check Answer

The producers in a patch of pine forest use about 30,000 kcal of energy. If only 10% of the energy at one level of the food chain moves up to the next level, how much energy is available to the primary consumers in the first level? How much energy is available to the secondary consumers?

Integrated Science 21D: Physics and Chemistry

Energy Leaks When Organism

Learning Objective

Explain why the second law of thermodynamics is important to energy flow in ecosystems.

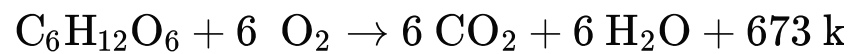
Why is an energy pyramid always a pyramid? That is, why does the amount of energy available always decrease as you move up a food chain? We have already seen two good reasons. First, some organisms at one level of a food chain are not eaten by organisms at the next level of the food chain. And second, some energy from food is lost in feces or goes into cellular maintenance.

A lot of the energy we call “maintenance” is energy that is lost to the environment as heat. This is because, as organisms perform their activities, energy is constantly being lost as heat. Because of the second law of thermodynamics, all natural systems tend to move from organized energy states to disorganized energy states—that is, useful energy turns into unusable energy, or heat. Any time energy is converted from one form into another—including during the chemical reactions in living things—some energy turns into heat.

Unifying Concept

The Second Law of Thermodynamics Section

Let's consider just one set of chemical reactions: reactions that occur during cellular respiration. You remember that living organisms use cellular respiration to break down glucose and make ATP. The chemical reaction for the oxidation of glucose is



—that is, glucose and oxygen react to form carbon dioxide and water, releasing 673 kilocalories of energy per mole of glucose. If this reaction were perfectly efficient in the sense that the entire 673 kilocalories per mole released from glucose would be captured as ATP. Is it?

We know that about 38 molecules of ADP are converted to ATP as the result of burning a single glucose molecule. Each ATP then provides 7 kilocalories per mole when it is broken down into ADP and phosphate during cellular processes. So, $38 \times 7 = 266$, much less than 673. Clearly, a lot of energy is missing! What happened to it? It was lost to the environment as heat. In mammals and birds, heat lost this way accounts for about 20% of the energy lost during cellular respiration.

the maintenance of stable, warm body temperature. This heat is shed eventually to the environment as we consider the fact that every chemical reaction involves some energy loss to the environment, it becomes clear that much energy leaks from one level in the food chain (Figure 21.29). In fact, all the energy that Earth receives from the Sun is eventually lost as heat.

Figure 21.29



The second law of thermodynamics tells us that energy is lost to the environment as heat in every chemical reaction.

Check Yourself

Interactive

Question 1

Check Answer

Question 2

Check Answer

Question 1

What ultimately happens to the energy that goes into the “main” organism?

Check Answer

What ultimately happens to the energy that goes into the “main” organism?

Answer: It is ultimately lost to the environment as heat.

Question 2

21.5 Change in an Ecosystem

Learning Objective

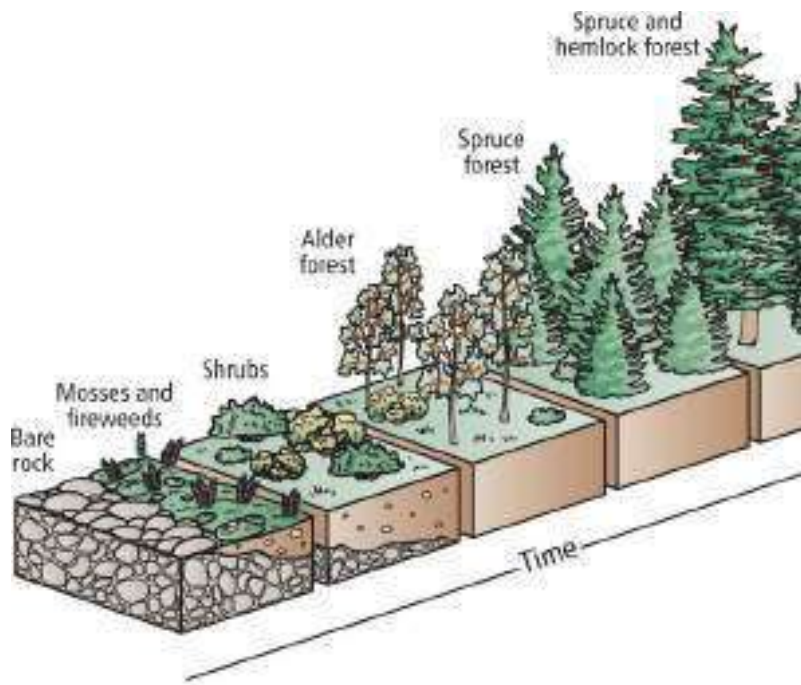
Describe how a disturbance can affect an ecosystem.

In 1883, a huge volcanic explosion tore through the tropical island of Krakatoa. Most of the island was destroyed. The remaining land was covered with ash, barren and lifeless. But within the ash, living organisms, primarily photosynthetic bacteria and cyanobacteria, colonized the island. By 1897, Krakatoa had become a savanna with tall grasses. Only a few species of animals were present: flying insects and birds. By 1919, scattered trees colonized the island. By 1931, a forest had developed. As more trees grew, animal diversity increased. Today, Krakatoa is once again tropical forest.

Krakatoa's history provides an example of ecological succession. **Ecological succession** describes how the community in an ecosystem changes over time. There are two kinds of succession: primary succession and secondary succession.

Primary succession occurs when bare land, devoid of soil, is colonized by successive waves of living organisms. For example, primary succession may begin when new land is formed by volcanic activity or when a glacier's retreat reveals bare rock. The first species to colonize are known as *pioneer species*. Pioneer species often include microorganisms as well as larger organisms such as lichens. Pioneer species must be able to survive with few nutrients and little existing organic matter. They also must be able to deal with harsh sunlight and the variable temperatures that result from the lack of soil. Pioneer species may be succeeded by grasses, shrubs, and trees. At each stage of succession, the activities of earlier waves of colonizers build up nutrients and organic matter, allowing later colonizers to establish. Later colonizers eventually outcompete and displace earlier colonizers. Ecological succession ends with a *climax community* that is stable (Figure 21.30). During the process of succession, the biomass of the ecosystem typically increases, as does the number of species present.

Figure 21.30

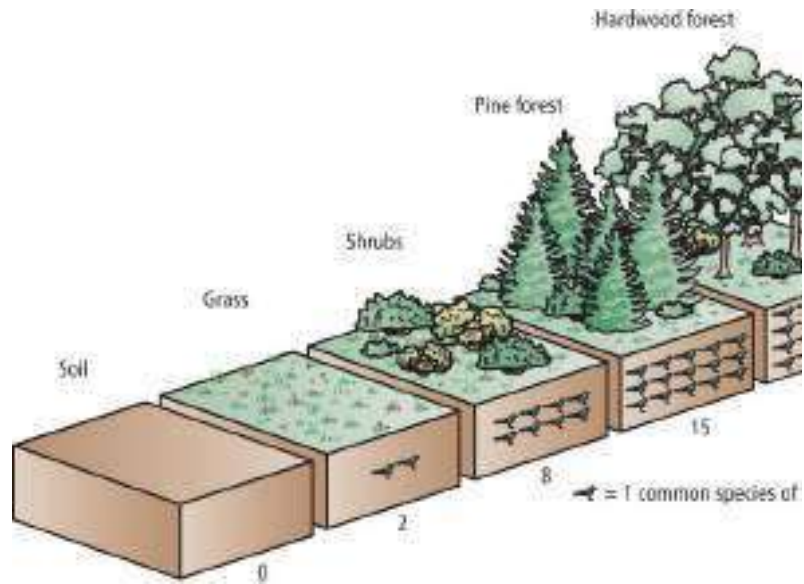


Primary succession after a glacier's retreat in Alaska: Bare rock is covered by mosses and fireweeds, then shrubs, an alder forest, and finally a spruce and hemlock forest. The entire process takes place over about 200 years.

Secondary succession occurs when a disturbance destroys a habitat but leaves the soil intact. Secondary succession occurs after a fire or when old farmland is abandoned. Because soil is present, secondary succession proceeds more quickly than primary succession. With primary succession, biomass and biodiversity typically increase slowly. In secondary succession, biomass and biodiversity increase more rapidly. For example, during secondary succession on abandoned farmland in the southeastern United States, a forest can develop in a few decades.

number of bird species increased as succession progresses (Figure 21.31).

Figure 21.31



In secondary succession on abandoned farmland in the United States, empty fields progressed from grassland to forest, and hardwood forest over the course of more than 100 years. Greater biodiversity—for example, more species of bird—was observed as succession progressed.

All ecosystems experience change. Most ecosystems never experience a cataclysm like Krakatoa's, but smaller disturbances, often on a small area of habitat, are common. Fires, floods, and other events can damage habitats. Even the fall of a large tree can be

significant consequences. In tropical forests, for example, gaps in the canopy that make sunlight—a rare commodity—available to organisms in the understory.

According to the *intermediate disturbance hypothesis*, regular disturbances can actually contribute to biodiversity, as long as they are not too extreme. This is because an intermediate level of disturbance ensures that there will always be habitat at varying stages of recovery, and different species make use of these different habitats. Catastrophic disturbances have more lasting effects. Invasive species can alter ecosystems, as we saw with the brown tree snake in Guam and the zebra mussel in the eastern United States. Human activity can convert one ecosystem into another, as when land is cleared for agriculture or development. Finally, changes in climate, including global warming, will bring big changes to many ecosystems at the same time.

Check Yourself

Interactive

Question

Check Answer

Question

How might global warming cause ecosystems to change?

Check Answer


How might global warming cause ecosystems to change?

Answer: This is a difficult question that many scientists are trying to answer. As Earth gets warmer, entire ecosystems are likely to shift to areas with more appropriate climates. Usually, this means higher latitudes (located farther from the equator) and higher altitudes. However, many organisms may not have an appropriate habitat to shift to. For example, polar bears already live in the Arctic and cannot search for sea ice farther north. In addition, large areas of the world are already overpopulated and have limited resources.

Science and Society

Wangari Maathai and Ecologic Sustainable Development

How much difference can planting one tree make? Nobel laureate Wangari Maathai of Kenya has shown us. She was awarded the 2004 Nobel Peace Prize for “contribution to sustainable development, democracy, and peace,”* founded the Green Belt Movement in 1979, and her grassroots group organizes volunteers—primarily women—to plant trees and protect the environment.



—to plant indigenous trees in forests, wildlife reserves and public places. Tree planting helps to reverse serious problems caused by deforestation, including loss of biodiversity, and decreased water supply. Movement volunteers have planted more than 30 since the group was founded, and the group continues to maintain more than 6000 tree nurseries throughout

Maathai's Green Belt Movement also uses tree planting as an entry point for other activities. By enabling local communities to change their environmental history, the organization empowers people to address issues related to environmental conservation, community consciousness, equity, security, and accountability. Maathai's model has inspired similar groups in other countries, including Tanzania, Ethiopia, and Zimbabwe.

How important is environmentalism to the world? In other words, "Some people have asked what the relationship is between peace and environment, and to them I say wars are fought over resources, which are becoming increasingly scarce across the earth. If we did a better job of managing our resources sustainably, conflicts over

be reduced. So, protecting the global environment
related to securing peace.” Wangari Maathai died



Wangari Maathai plants a tree in Nyeri, Kenya. M
first African woman to win the Nobel Peace Prize
also the first time the award was given for enviroi

* From the Nobel Prize website,

https://www.nobelprize.org/nobel_prizes/peace/laureates/2004/press.h

Summary of Terms (Knowledge)

For instructor-assigned homework, go to
www.masteringphysics.com

Biogeochemical cycles □

The movement of substances such as water, carbon, and nitrogen between living organisms and the abiotic world.

Biomass □

The amount of organic matter in an ecosystem.

Biomes □

Earth's major types of terrestrial ecosystems.

Carrying capacity □

The maximum number of individuals or the maximum that a habitat can support.

Community □

All the organisms that live in a specific area.

Consumer □

An organism that obtains food by eating other organisms.

Decomposer □

An organism that obtains food by eating dead organic matter.

Ecological succession □

Changes over time in the community of species living in an area.

Ecology □

The study of how organisms interact with their environment.

Ecosystem □

All the organisms that live in a specific area and all the abiotic factors of their environment.

Exponential growth □

A model of population growth in which a population grows exponentially per amount of time.

Logistic growth □

A model of population growth in which growth slows as the population approaches the habitat's carrying capacity.

Niche □

The total set of biotic and abiotic resources available to a species in a community.

Population □

A group of individuals of a single species that lives in a specific area.

Producer □

An organism that makes organic molecules using inorganic energy.

Reading Check Questions (Comprehension)

21.1 Organisms and Their Environment

1. What is ecology?
2. Explain the difference between the abiotic features and biotic features of an organism's environment.
3. What is the difference between a community and an ecosystem?

21.2 Population Ecology

4. Describe exponential growth. Under what conditions do organisms grow exponentially?
5. Why do populations that live in unstable environments grow exponentially and then crash?
6. Describe logistic growth. Under what conditions do organisms experience logistic growth?
7. What are the differences between Type I, Type II, and Type III survivorship?

21.3 Human Population Growth

8. Explain how global human population size is expected to change during the 21st century.
9. What is the age structure of a population? What can be learned from a population's age structure?
10. What is an ecological footprint? What does the ecological footprint tell us about how the global human population is consuming resources today?

21.4 Species Interactions

11. What is the name for a diagram of who eats whom in a community?
12. Explain the difference between a producer and a consumer.
13. What is a decomposer? What organisms function as decomposers in most communities?
14. Can two species have the exact same niche in a community? If so, or why not?
15. Define parasitism, and provide some examples.

21.5 Change in an Ecosystem

16. How does primary succession differ from secondary succession?
17. Why are the later colonizers of a habitat dependent on the earlier colonizers?
waves of colonizers?
18. What usually happens to the total biomass in an ecosystem during succession? Does the number of species in an ecosystem usually change as succession continues?
19. How can regular disturbances contribute to the stability of a habitat?

Think Integrated Science

21A—Kinds of Ecosystems

20. What types of living things do scientists use to divide terrestrial habitats into biomes?
21. What climatic factors help determine the location of biomes?
22. Which biome includes more living things than all the others combined?
23. Why are fires important in savannas?
24. Describe the photic zone of ocean habitats.
25. What are some of the challenges that organisms in the intertidal zone face? What adaptations do organisms in the intertidal zone have for dealing with these challenges?

21B—Materials Cycling in Ecosystems

26. What is a biogeochemical cycle?
27. How does carbon enter the biotic world? How does it move from the abiotic world to the biotic world by organisms?

28. What role do nitrogen-fixing bacteria and nitrification play in the nitrogen cycle?

21C—Energy Flow in Ecosystems

29. All organisms need energy in order to grow, reproduce, and perform the activities necessary for survival. Where does the energy ultimately come from?
30. How does sunlight energy enter the biotic world?
31. On average, how much of the energy at one level of a food chain becomes available to the next level? What happens to the rest of the energy?

21D—Energy Leaks When Organisms Die

32. Explain how the second law of thermodynamics applies to energy loss between one level of a food chain and the next.
33. Is energy lost when glucose is converted into ATP during cellular respiration?

Think and Do (Hands-On Applications)

34. Think about the ecology of *you*! What are some features of your environment? What species form your community? How do the abiotic features of your environment affect your life and activities?
35. Model exponential growth using pennies. Think of a single-celled organism that reproduces by dividing each day. On day 1, you have one penny. On day 2, you have 2 pennies. Continue the exercise out to at least 10 days. How many pennies do you have at the end of that time? Now graph showing the number of pennies on the y -axis and the day on the x -axis. Does your graph look like the graph of exponential growth?
36. A number of online websites, such as <https://www3.epa.gov/carbon-footprint-calculator/>, can help you calculate your personal ecological footprint. Use the website to calculate your ecological footprint. What are some things you could do to reduce your ecological footprint?

37. Draw a food web that includes humans. What are the things we eat? Are we primary consumers? Secondary consumers? A top predator?

Think and Compare (Analysis)

38. Rank the following from lowest in the food chain to highest in the food chain: secondary consumer, primary consumer, predator, producer.
39. Rank the following biomes from least precipitation to most precipitation: coniferous forest, desert, tropical forest.

Think and Solve (Mathematical Application)

40. Suppose that you have a logistically growing population with a per capita rate of increase $r = 2$ in a habitat where carrying capacity is $K = 1000$. Suppose also that the habitat is overpopulated, that is, the population size is larger than the carrying capacity. (Note that N is larger than the carrying capacity.) Use the equation for logistic growth,
$$\text{growth rate} = rN(K - N)/K,$$
 to show that the population growth rate is negative—that is, the population is decreasing.
41. In a population of songbirds, 100 young are born each year in the year 2010. Each year, 10 individuals die. Make a table showing how many individuals are alive in each year from 2010 to 2015. Draw a survivorship curve for the population. Do you think this population has Type I, Type II, or Type III survivorship?
42. In a population of insects, 1 million young are born each year in the year 2010. Each year, 95% of the living individuals die. Make a table showing how many individuals are alive in each year from 2010 to 2015 (you can round off your answers). Now draw a survivorship curve for the population. Do you think this population has Type I, Type II, or Type III survivorship?

survivorship curve for the population. Does this have Type I, Type II, or Type III survivorship?

43. A patch of grassland is home to five carnivores consumers in the ecosystem. Each of the carnivores consumes 20,000 kcal of energy over the course of a day. Assume that the amount of energy available at each level of the food chain is 10% of the energy available at the next level of the food chain. Show that the primary producers in the grassland use 100,000 kcal during a single day and other producers use 1,000,000 kcal per day.

Think and Explain (Synthesis)

21.1 Organisms and Their Environment

44. Does a community contain multiple populations?
answer.
45. A scientist studies how water cycles through a community and how organisms make use of this water. Is this a population-level study, a community-level study, or an ecosystem-level study? Defend your answer.
46. A scientist studies how the number of coyotes in a National Park, California, has changed over the last 50 years. Is this a population-level study, a community-level study, or an ecosystem-level study? Defend your answer.

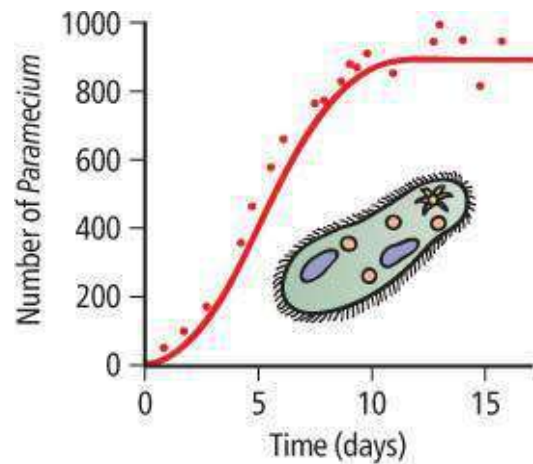


47. A scientist examines how the presence of a non-native species, the starling, affects other species of birds, including the northern flicker, a kind of woodpecker. The scientist compares the northern flicker (left) in the photo below, for example, to the starling woodpecker (right) in the photo below, for example, to see how they compete over food and space. Is this a population-level study, a community-level study, or an ecosystem-level study? Provide your answer.



21.2 Population Ecology

48. How are exponential growth and logistic growth different? Under what real-world circumstances can populations grow exponentially? When will exponential growth in a population stop?
49. What factors could cause population growth to stop? What factors could cause population size to increase?
50. The graph below shows the growth of a population of *Paramecium* in the lab. Did the population grow exponentially or logistically? Can you estimate the carrying capacity of the habitat?



51. Suppose that the carrying capacity of a specific population of songbirds is 1000. Is it possible for this carrying capacity to increase? Under what circumstances could the carrying capacity decrease?

52. What is a survivorship curve? What are some characteristics of a population with a Type I survivorship curve?
53. Why is a baby elephant considered an “expensive” investment?

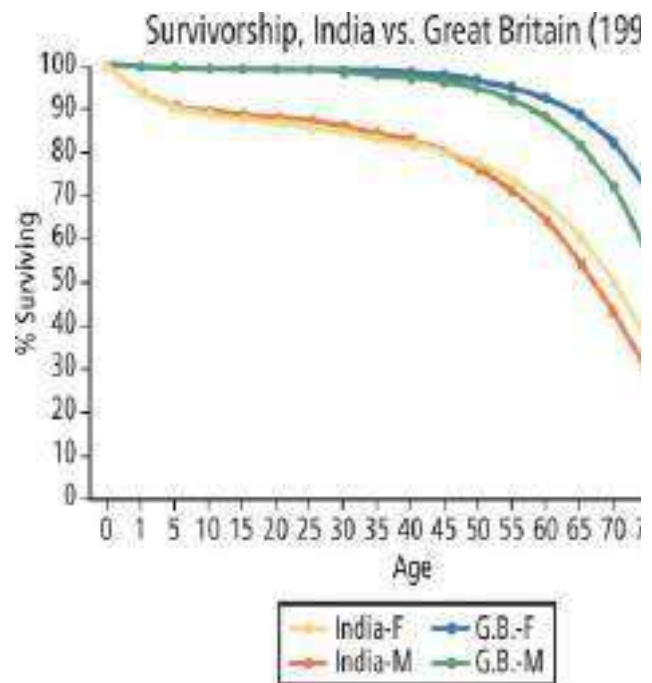


54. Would you expect a tiger to have a Type I, Type II, or Type III survivorship curve?
55. Name an organism that you might see in your local park that has a Type III survivorship curve. Why?

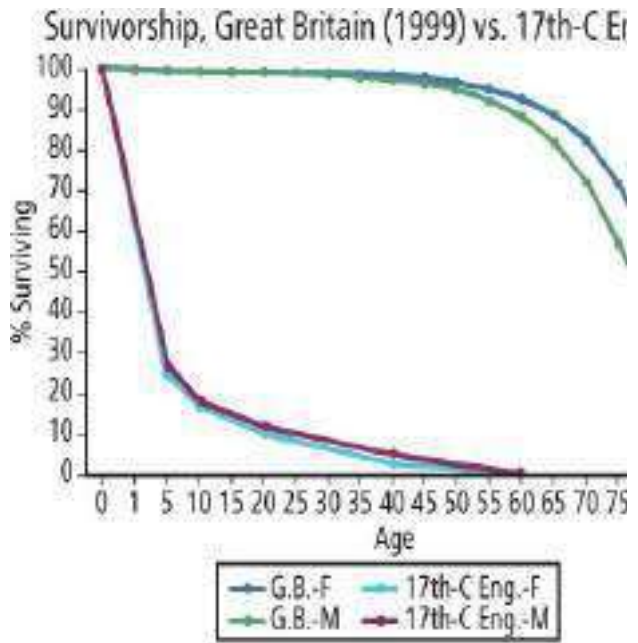
suggests it has a Type III survivorship curve?

21.3 Human Population Growth

57. The graph below shows survivorship curves for females in Great Britain and India in 1999. What do you see between Great Britain and India in 1999? Explain these differences?



58. The graph below shows survivorship curves for females in Great Britain in the 17th century and survivorship in England change from the 17th c



59. All else being equal, will a person who eats a vegetarian diet live longer than a person who eats meat regularly have a larger ecological footprint? Defend your answer.
60. What does it mean that the world human population has reached an “ecological overshoot”?
61. Write a letter to Grandma telling her about how the world population has grown in the past and how it is expected to grow in the next century. Tell her about ecological footprint and how easy it will be for Earth to support this population growth.

21.4 Species Interactions

61. List three producers, three primary consumers, secondary consumers.
62. Think of an example of an organism that eats a a food chain. Is your organism a producer? A c the advantages of eating at multiple levels of a :
63. What is the difference between a food chain an
64. In a habitat, mice eat plant seeds, and owls and the mice. Draw the simple food chain or food w these relationships. Label the producer(s), prim and secondary consumer(s).
65. In a habitat, mice eat plant seeds, and owls and the mice. What term describes the relationship between two species that eat the same prey, as do in this example?
66. Explain how two different populations of plants resources. For what kinds of resources might th
67. What is a niche? Explain the significance of Rol observations of warblers and their niches.
68. How can interspecific competition result in evo natural selection? Use examples in your answer
69. What is an example of a parasite and its host? E relationship in your example benefits the paras

the host.

70. What is an example of mutualism? Explain how in your example benefits the two species involved.
71. Some flowering plants rely on insects to carry pollen from male flowers to female flowers. For example, the bee below is covered with specks of yellow dandelion pollen as they feed on nectar produced by the flowers. Is this an example of parasitism, commensalism, or mutualism?



21A—Kinds of Ecosystems

72. What are the major factors that determine what biome is found in a habitat? Do the activities of organisms affect the type of biome found?
73. Explain why altitude and latitude affect the climate that characterizes a habitat.

74. The map in **Figure 21.15** shows the distribution of tundra on Earth. Strips of tundra are seen in both Alaska and the U.S. mainland. Is this an error? Explain.
75. Do tropical forests tend to provide good soil when they are cleared? Why or why not?
76. Describe the tundra. Why are there no trees in the tundra?
77. Name a biome where regular fires occur. How do fire play in this biome?
78. What is an estuary? What adaptations characterize organisms that live in estuaries?
79. What is an example of plankton? Of nekton?
80. This photo shows a bobbit worm living in Indonesia. Does it live in the pelagic zone or the benthic zone? How can you tell?



21B—Materials Cycling in Ecosystems

81. Describe the water cycle. What are some of the reservoirs for water on Earth?
82. Was every carbon atom in your body once part of another producer? Why or why not?
83. Name at least two different processes that return carbon to the atmosphere.

84. How is the carbon cycle relevant to global warming change?
85. Why do legumes grow better in nutrient-poor soils than other plants?
86. How has human technology affected the nitrogen cycle?

21C—Energy Flow in Ecosystems

87. What is primary productivity? What factors control primary productivity in a habitat?
88. If you eat a pound of pasta, will you gain a pound of weight? Why or why not?
89. Why are there more zebras than lions in the African savanna?

21D—Energy Leaks When Organisms Eat

90. How does the Second Law of Thermodynamics explain why only 10% of the energy at one level of the food chain is available to the next level?
91. How does the energy lost during cellular respiration allow mammals to maintain a stable, high body temperature?
92. What is the eventual fate of all energy that enters Earth's ecosystem from the Sun? Why?

21.5 Change in an Ecosystem

93. Why do you think most of the early animal colonizers were flying insects and birds?
94. Once a habitat is occupied by its climax community, do species composition continue to change? Why or why not?
95. Could a habitat that received regular mild disturbances be more diverse than one that received no disturbances? Compare biodiversity in a habitat that received disturbances to a habitat that received no disturbances?

Think and Discuss (Evaluation)

96. Two populations of rabbits are growing exponentially. One population has rate of increase $r = 1$, and the other has rate of increase $r = 2$. Describe how their population growth curves differ. What factors could cause one population to have a higher rate of increase than the other?
97. Two populations of monkeys are growing logistically. One population has carrying capacity $K = 1000$, and the other population has carrying capacity $K = 5000$. Describe how their population growth curves differ. What factors could cause one population to have a higher carrying capacity than the other?
98. A habitat's carrying capacity for a population can change over time. For example, a forest may be able to support a large number of bears, but when the trees are cut down and the area is paved over, the carrying capacity drops (probably for bears). What other factors could cause the carrying capacity of a habitat to change? How has Earth's carrying capacity for humans changed over time? Does technology influence how many humans a habitat can support?

99. What type of survivorship curve characterizes humans? What other characteristics are associated with this type of curve? Do humans show many of these other characteristics?
100. Two species of salamanders, *Plethodon cinereus* and *Plethodon hoffmani*, overlap in parts of their range in the eastern United States. The two species are very similar in size and diet in places where both species are found. In places where only *Plethodon cinereus* is found, *Plethodon cinereus* is smaller than it usually is. In places where only *Plethodon hoffmani* is found, *Plethodon hoffmani* is larger than it usually is. This is related to what the salamanders eat: *Plethodon cinereus* eats smaller prey than it eats in other parts of its range, and *Plethodon hoffmani* eats larger prey than it eats in other parts of its range. How can natural selection due to interspecific competition explain the evolution of size and diet in these species?
101. Some acacia trees have evolved a special relationship with a species of ants. The trees provide food and nesting sites for the ants in the form of hollow thorns, as shown in the photo) and the ants attack insects and other species that try to eat the trees; they may also kill plants that grow in the immediate vicinity of the trees. Discuss the species interactions (food chain, coexistence, symbiosis, etc.) among the species in this community.



102. Why can't an ecosystem's energy pyramid be inverted (upside down)?
103. A single tree can sometimes support many insect species. Does this contradict the idea that all ecosystems are structured by energy *pyramids*?
104. Different consumers vary in how efficiently they use energy (i.e., energy not lost in feces) to build biomass. The efficiency of insects is 10% to 40%, while mammals and birds use only 1% to 3% of their absorbed energy to build biomass. What accounts for this difference?
105. Would you expect to find more Type I or Type II species among the early colonizers of a habitat? Would you expect

Type I or Type III species in the climax commu

Readiness Assurance Test (1)

Readiness Assurance Test

Interactive

If you have a good handle on this chapter, if you really do, then to score 7 out of 10 on this RAT. If you score less than 7, you need to review before moving on.

Choose the BEST answer to each of the following:
10 questions

1. 1.

All the organisms that live in a specific area make up a(n)

population.

Incorrect.

Press enter after select an option to check the answer

community.

Correct.

Press enter after select an option to check the answer

ecosystem.

Incorrect.

Press enter after select an option to check the answer

Part 3 Summary: Biology

The Integrated Nature of Science

The Science of Autumn Leaves

Every fall, tens of thousands of people travel through New England and the Midwest to watch the trees take on their glorious reds, oranges, and yellows. In New England alone, these tourists—known as “leaf peepers”—contribute several billion dollars to the local economy each year. How do the leaves of deciduous trees change color in the fall? What is this process, and why did natural selection select for it?

Figure 1



Brilliant colors are an unmistakable feature of autumn in forests. But what causes the leaves to change colors?

Scientists call the changes that occur in autumn leaves *leaf senescence*. As a leaf goes through senescence, it deteriorates in a specific way and eventually falls from the tree. Scientists have observed that, for many species, leaf senescence begins on the same day every year, whatever the weather. This suggests that trees use photoperiod—the number of hours of light and darkness during a 24-hour day—as a cue to begin senescence. Because Earth rotates with an axis that is tilted relative to the Sun, days get shorter and nights get longer as autumn progresses. At a critical point, when nights are long enough

releases hormones that initiate leaf senescence. From the weather and other factors affect how quickly the process

During leaf senescence, trees reclaim important nutrients from leaves. These nutrients are saved in the trunk, branches and used by the tree during winter. The most important nutrient that trees reclaim is nitrogen. Plants normally absorb usable nitrogen but this nutrient is in short supply in many environments. Other important nutrients that trees reclaim include phosphorus and other elements. One study showed that trees reclaim as much as 90% of the nitrogen and phosphorus in their leaves during leaf

In order for a tree to reclaim nutrients for the winter, leaf chlorophyll is broken down and then transported from the leaves to the trunk of the tree. One of the molecules that leaves break down is chlorophyll. Chlorophyll is the pigment that plants use for photosynthesis to capture light energy from the Sun. Chlorophyll gives plants their green color. As chlorophyll is broken down, other pigments hidden by the chlorophyll, such as carotenoids, become visible. Carotenoids break down as well, just not as quickly as chlorophyll. Carotenoids are yellow to orange in color,

autumn leaves yellow and orange. The word *carotenoid* Latin word for "carrot."

The red colors in autumn leaves, though, are a complete
The red pigments in leaves come from a class of molecules
anthocyanins. Anthocyanins are also the molecules that
cherry skins, and red cabbages their red colors. Unlike
were present in leaves all along before becoming unma
leaves actually build anthocyanins as they senesce.

Figure 2



In a single autumn leaf, you may see areas where green dominates, areas where yellow and orange carotenoids are dominant, and areas where red anthocyanins have been newly made. Why do leaves make new pigments as they are about to die?

Why does a dying leaf put energy into building anthocyanins? Early hypotheses focused on a tree's interaction with fruit dispersers or herbivores. Maybe the red color attracts fruit dispersers, helping the tree disperse its seeds. Maybe it deters pests, such as aphids or other insects, keeping them away from a tree that was vulnerable.

One clue scientists had was the observation that leaves turn red in autumns that are cold and sunny. Scientists also knew that both cold temperatures and excessive sunlight harm plants. Anthocyanins help protect plants from photoinhibition, a phenomenon known as *photoinhibition*. High-energy blue and ultraviolet light triggers it. Especially in autumn, anthocyanins function like a sunscreen that protects the photosynthetic apparatus in plants. In fact, anthocyanins are produced in light-sensitive plant tissues, including leaf buds, young leaves, and developing fruits.

But, you might wonder, why would leaves need anthocyanins in the fall? After all, sunlight is far more intense in the summer than in the fall. The answer is that summer leaves aren't red. The answer is that a senescing

already partly broken down, is more vulnerable than a summer leaf. In addition, temperatures are higher in the fall than in the summer, which is more favorable to photosynthesis.

Anthocyanins protect fragile autumn leaves, allowing them to continue photosynthesis in the colder autumn months. Photosynthesis provides the energy that leaves need to continue breaking down chlorophyll molecules and transporting nutrients into the branches of the tree. In other words, leaves produce anthocyanins so that they can be recovered from them before they die.

So, which trees should invest the most in anthocyanins? The trees with the reddest leaves? They are the ones that most need to reclaim nitrogen from their leaves. In fact, scientists have observed that trees growing in poorer soil turn more red than trees growing in richer soil. Trees that do not have as great a need to reclaim nitrogen lose their leaves more quickly and are still yellow or even green—for example, some trees that have nitrogen-fixing bacteria in their roots lose their leaves while they are still green.

Experimental evidence supports the idea that anthocyanins are produced mainly as sunscreens. One group of scientists produced a mutant tree that was unable to make anthocyanins. When these trees were exposed to bright light, they turned yellow and lost their leaves more quickly than the wild-type trees.

bright sunlight and cold temperatures, their leaves quickly result, the trees recovered much less nitrogen from the they were lost. Another research group used antifreeze of only some branches of trees. Interestingly, they found chilled branches turned red, while the rest of the tree re

Figure 3



Why are these trees different colors? What can you say trees versus the yellow trees versus the red trees in this

But if cold temperatures make for redder autumn leaves, warming affect fall colors? Will the trees turn less red and less beautiful? And will this affect leaf peepers and the tourism industry built around them? In Vermont, maple syrup is a product of fall colors that bring in the tourists who buy it.

Figure 4



Maple syrup is a big enterprise in Vermont, but it's Vermont's maple leaves that draw in tourists and customers from all over

Check Yourself

Interactive

Question 1

Check Answer

Question 2

Check Answer

Question 1

Gardeners know that if you add nitrogen fertilizer to a tree, its l color later. Why?

Check Answer

Gardeners know that if you add nitrogen fertilizer to a tree, its l color later. Why?

Answer: A tree that has been fertilized has plenty of nitrogen a great a need to reclaim nutrients from its leaves as a tree that ha