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CHAPTER 1 Human Systems: Feedback and Homeostasis

Chapter Outline

1.1 Cell Membrane

Learning Objectives

- Describe the roles of the plasma membrane and cytosol.
- Explain the concept of semipermeability.
- Summarize how the plasma membrane separates the cytosol from the outside environment.

Who guards your cells?

Not everything can make it into your cells. Your cells have a plasma membrane that helps to guard your cells from unwanted intruders.

The Plasma Membrane and Cytosol

If the outside environment of a cell is water-based, and the inside of the cell is also mostly water, something has to make sure the cell stays intact in this environment. What would happen if a cell dissolved in water, like sugar does? Obviously, the cell could not survive in such an environment. So something must protect the cell and allow it to survive in its water-based environment. All cells have a barrier around them that separates them from the environment and from other cells. This barrier is called the **plasma membrane**, or cell membrane.

The Plasma Membrane

The plasma membrane (**Figure** 1.1) is made of a double layer of special lipids, known as **phospholipids**. The phospholipid is a lipid molecule with a hydrophilic ("water-loving") head and two hydrophobic ("water-hating") tails. Because of the hydrophilic and hydrophobic nature of the phospholipid, the molecule must be arranged in a specific pattern as only certain parts of the molecule can physically be in contact with water. Remember that there is water outside the cell, and the **cytoplasm** inside the cell is mostly water as well. So the phospholipids are arranged in a double layer (a bilayer) to keep the cell separate from its environment. Lipids do not mix with water (recall that oil is a lipid), so the phospholipid bilayer of the cell membrane acts as a barrier, keeping water out of the cell, and keeping the cytoplasm inside the cell. The cell membrane allows the cell to stay structurally intact in its water-based environment.

The function of the plasma membrane is to control what goes in and out of the cell. Some molecules can go through the cell membrane to enter and leave the cell, but some cannot. The cell is therefore not completely permeable. "Permeable" means that anything can cross a barrier. An open door is completely permeable to anything that wants to enter or exit through the door. The plasma membrane is **semipermeable**, meaning that some things can enter the cell, and some things cannot.

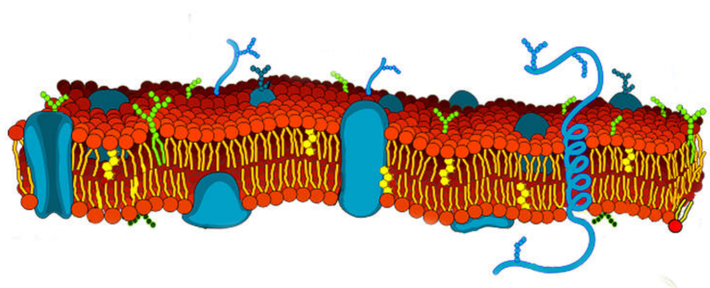


FIGURE 1.1

Plasma membranes are primarily made up of phospholipids (orange). The hydrophilic ("water-loving") head and two hydrophobic ("water-hating") tails are shown. The phospholipids form a bilayer (two layers). The middle of the bilayer is an area without water. There can be water on either side of the bilayer. There are many proteins throughout the membrane.

Cytosol

The inside of all cells also contain a jelly-like substance called **cytosol**. Cytosol is composed of water and other molecules, including **enzymes**, which are proteins that speed up the cell's chemical reactions. Everything in the cell sits in the cytosol, like fruit in a jello mold. The term cytoplasm refers to the cytosol and all of the organelles, the specialized compartments of the cell. The cytoplasm does not include the nucleus. As a prokaryotic cell does not have a nucleus, the DNA is in the cytoplasm.

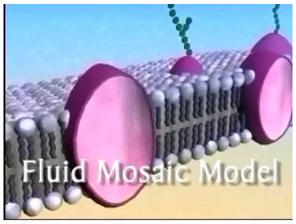
Summary

- The plasma membrane is formed by a phospholipid bilayer.
- The plasma membrane controls what moves inside and outside the cell.
- The cytosol is the jelly-like material in which the contents of the cell are suspended.

Explore More

Use the resource below to answer the following questions.

- **The Plasma Membrane** at http://www.youtube.com/watch?v=moPJkCbKjBs (5:16)



MEDIA

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1. What makes up the "head" region of a phospholipid? Is it hydrophobic or hyrdrophilic?
2. What makes up the "tail" region of a phospholipid? Is it hydrophobic or hyrdrophilic?
3. What happens when you drop a phospholipid in water?
4. How are phospholipids arranged in a plasma membrane?
5. What is a glycoprotein? What is one of the uses of glycoproteins?
6. What is "Brownian movement"? How is this movement related to the cell membrane?

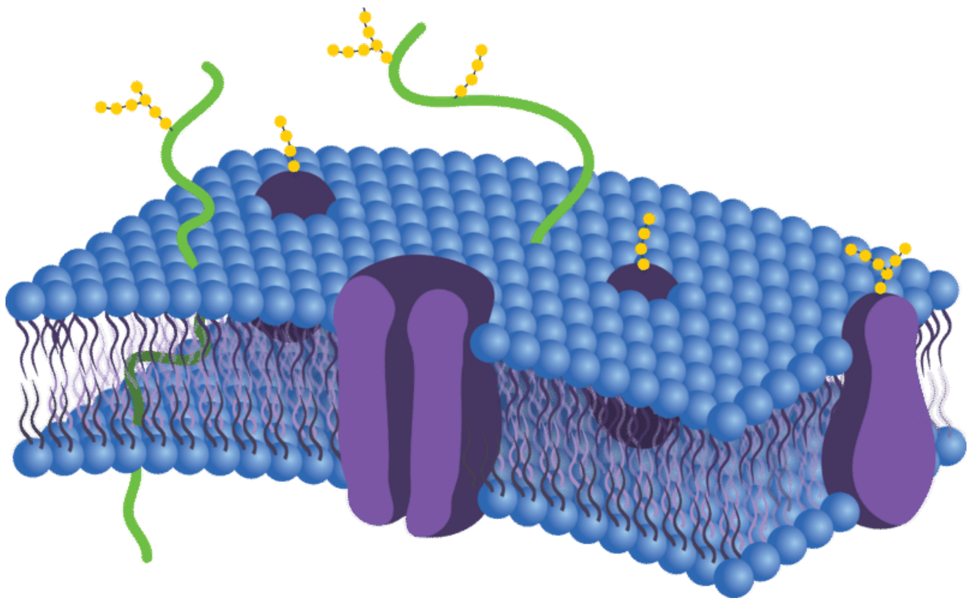
Review

1. What is the plasma membrane?
2. Describe a phospholipid.
3. What are the components of the cytosol?
4. What is meant by the description of the plasma membrane as “semipermeable”?
5. What is the difference between the cytosol and the cytoplasm?

1.2 Phospholipid Bilayer

Learning Objectives

- Explain semipermeability.
- Summarize the structure of a phospholipid.
- Describe the structure and function of the plasma membrane.



All cells have a plasma membrane. This membrane surrounds the cell. So what is its role?

Can molecules enter and leave the cell? Yes. Can anything or everything enter or leave? No. So, what determines what can go in or out? Is it the nucleus? The DNA? Or the plasma membrane?

The Plasma Membrane

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

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A Phospholipid Bilayer

The plasma membrane is composed mainly of phospholipids, which consist of fatty acids and alcohol. The phospholipids in the plasma membrane are arranged in two layers, called a **phospholipid bilayer**. As shown in **Figure** 1.2, each phospholipid molecule has a head and two tails. The head “loves” water (**hydrophilic**) and the tails “hate” water (**hydrophobic**). The water-hating tails are on the interior of the membrane, whereas the water-loving heads point outwards, toward either the cytoplasm or the fluid that surrounds the cell.

Molecules that are hydrophobic can easily pass through the plasma membrane, if they are small enough, because they are water-hating like the interior of the membrane. Molecules that are hydrophilic, on the other hand, cannot pass through the plasma membrane—at least not without help—because they are water-loving like the exterior of the membrane, and are therefore excluded from the interior of the membrane.

Science Friday: Candy Corn in Space

Candy corn is a very tasty treat. In this video by Science Friday, astronaut Don Pettit uses Candy Corn to demonstrate the effects of hydrophobic and hydrophilic interactions.

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Summary

- The plasma membrane forms a barrier between the cytoplasm and the environment outside the cell. The plasma membrane has selective permeability.
- The plasma membrane is primarily composed of phospholipids arranged in a bilayer, with the hydrophobic tails on the interior of the membrane, and the hydrophilic heads pointing outwards.

Review

1. Describe the role of the plasma membrane.
2. What is meant by semipermeability?
3. Describe the composition of the plasma membrane.
4. Explain why hydrophobic molecules can easily cross the plasma membrane, while hydrophilic molecules cannot.

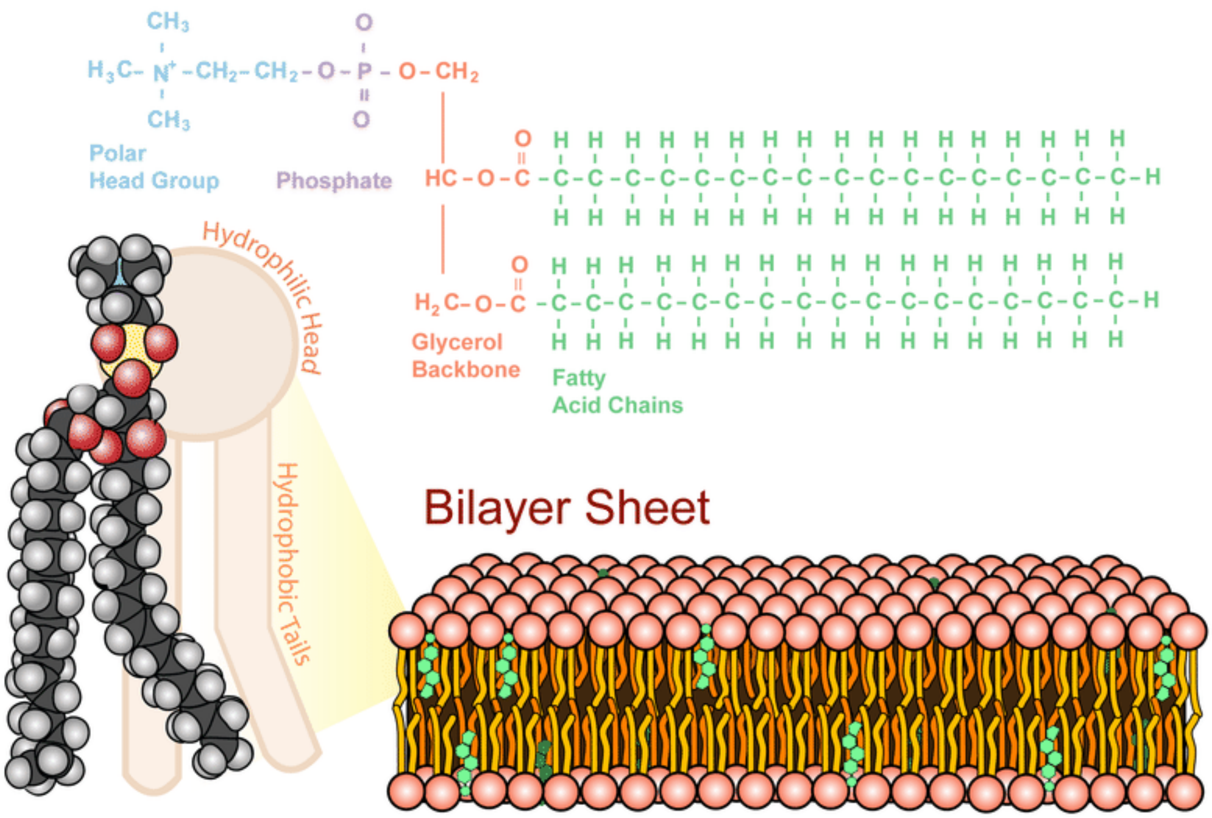


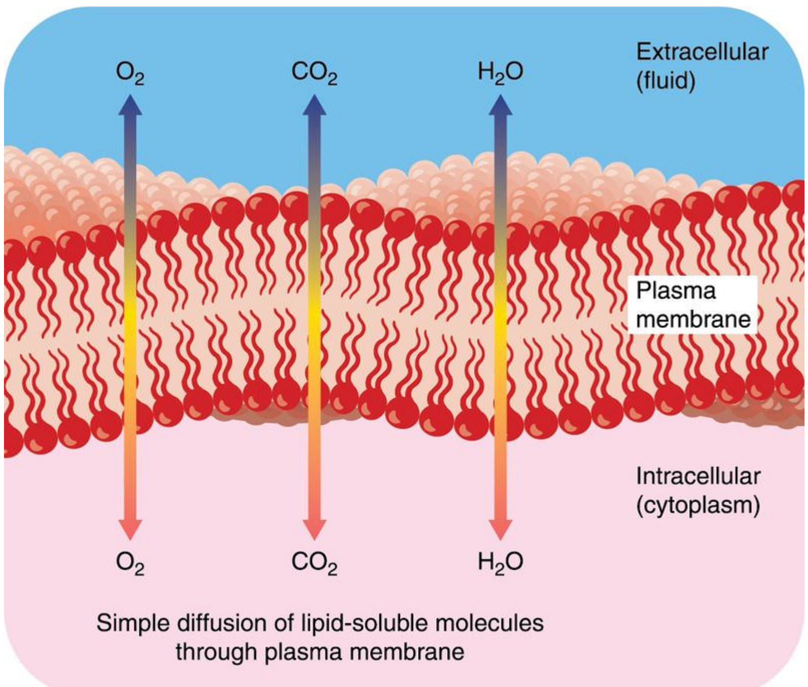
FIGURE 1.2

Phospholipid Bilayer. The phospholipid bilayer consists of two layers of phospholipids, with a hydrophobic, or water-hating, interior and a hydrophilic, or water-loving, exterior. The hydrophilic (polar) head group and hydrophobic tails (fatty acid chains) are depicted in the single phospholipid molecule. The polar head group and fatty acid chains are attached by a 3-carbon glycerol unit.

1.3 Passive Transport

Learning Objectives

- Define passive transport and facilitative diffusion.
- Explain the process of passive transport.
- Distinguish between a channel protein and a carrier protein.
- Summarize the functions of channel proteins and carrier proteins.



Can any molecule move freely through your cell membranes?

The cell regulates most molecules that pass through the cell membrane. If a molecule is charged or very big, it won't make it through the cell membrane on its own. However, small, non-charged molecules like oxygen, carbon dioxide, and water, can pass through the cell membrane freely.

Passive Transport

Recall that the cell membrane is semipermeable. It does not allow everything to pass through. Some molecules can pass easily through your cell membranes, while others have more difficulty. Sometimes molecules need the help of special transport proteins to move across the cell membrane. Some molecules even need an input of energy to help get them across the cell membrane. The movement of molecules across a membrane without the input of energy is known as **passive transport**. When energy (ATP) is needed, the movement is known as **active transport**. Active transport moves molecules against their concentration gradient, from an area of low concentration to an area of high concentration.

Simple Diffusion

One example of passive transport is **diffusion**, when molecules move from an area of high concentration (large amount) to an area of low concentration (low amount). Molecules are said to naturally flow down their concentration gradient. This type of diffusion proceeds without an input of energy. In **simple diffusion**, molecules that are small and uncharged can freely diffuse across a cell membrane. They simply flow through the cell membrane. Simple diffusion does not require energy or need the assistance of a transport protein. Other larger or charged molecules that diffuse across a membrane may need assistance from a protein.

Oxygen is a molecule that can freely diffuse across a cell membrane. For example, oxygen diffuses out of the air sacs in your lungs into your bloodstream because oxygen is more concentrated in your lungs than in your blood. Oxygen moves from the high concentration of oxygen in your lungs to the low concentration of oxygen in your bloodstream. Carbon dioxide, which is exhaled, moves in the opposite direction - from a high concentration in your bloodstream to a low concentration in your lungs.

Passive Transport using Membrane Proteins

Sometimes, molecules cannot move through the cell membrane on their own. These molecules need special transport proteins to help them move across the membrane, a process known as **facilitative diffusion**. These special proteins are called **channel proteins** or **carrier proteins** (**Figure** 1.3), and they are attached to the cell membrane. In fact, they go through the cell membrane, from the inside of the cell to the outside.

Channel proteins provide an open channel or passageway through the cell membrane for molecules to move across. Many channel proteins allow the diffusion of **ions.** Ions are charged atoms. The charge makes it difficult to cross the cell membrane without assistance. Channel proteins are specific for the molecule they transport. For example a sodium ion crosses the membrane through a channel protein specific for sodium ions.

Carrier proteins bind and carry the molecules across the cell membrane. These proteins bind a molecule on one side of the membrane, change shape as they carry the molecule across the membrane, and deposit the molecule on the other side of the membrane. Even though a protein is involved in both these methods of transport, neither method requires energy. Therefore these are still types of passive transport.

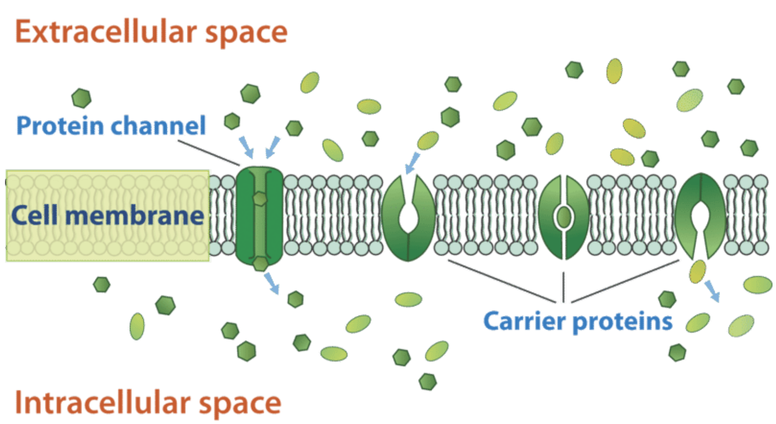


FIGURE 1.3
Protein channels and carrier proteins are involved in passive transport.

Summary

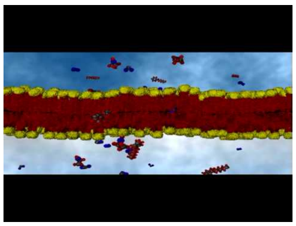
- Passive transport does not require energy input.
- An example of passive transport is diffusion, the movement of molecules from an area of high concentration to an area of low concentration.

- Carrier proteins and channel proteins are involved in facilitated diffusion.

Explore More

Use the resource below to answer the questions that follow.

- **Cell Membrane Passive Transport** at http://www.youtube.com/watch?v=JShwXBWGMyY (4:41)



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1. What does selectively permeable mean?
2. Can a membrane control the direction of diffusion? Explain your reasoning fully.
3. Give two examples of phospholipid soluble molecules? How can these molecules move across a cell membrane? What affects the direction of their movement?
4. What is the difference between simple and facilitated diffusion? What are two types of facilitated diffusion?

Review

1. Explain two ways materials can enter the cell through passive transport.
2. Does passive transport involve an expenditure of much energy? Why or why not?
3. How does oxygen move across the membrane?

1.4 Active Transport

Learning Objectives

- Define active transport.
- Describe the process of active transport.
- Summarize the role of the sodium-potassium pump.

What does it take to roll a stone uphill?

This round stone tends to roll downhill due to the force of gravity. It takes an input of energy to push it uphill. Due to diffusion, molecules tend to move from an area of a large amount to an area of a small amount. So guess what it takes to move molecules the opposite way, from an area of low concentration to an area of high concentration? Energy, of course!

Active Transport

During **active transport,** molecules move from an area of low concentration to an area of high concentration. This is the opposite of **diffusion**, and these molecules are said to flow *against their concentration gradient.* Active transport is called "active" because this type of transport requires energy to move molecules. **ATP** is the most common source of energy for active transport.

As molecules are moving against their concentration gradients, active transport cannot occur without assistance. A **carrier protein** is always required in this process. Like facilitated diffusion, a protein in the membrane carries the molecules across the membrane, except this protein moves the molecules from a low concentration to a high concentration. These proteins are often called "pumps" because they use energy to pump the molecules across the membrane. There are many cells in your body that use pumps to move molecules. For example, your nerve cells (neurons) would not send messages to your brain unless you had protein pumps moving molecules by active transport.

The **sodium-potassium pump** (**Figure** 1.4) is an example of an active transport pump. The sodium-potassium pump uses ATP to move three sodium (Na^+) ions and two potassium (K^+) ions to where they are already highly concentrated. Sodium ions move out of the cell, and potassium ions move into the cell. How do these ions then return to their original positions? As the ions now can flow down their concentration gradients, facilitated diffusion returns the ions to their original positions either inside or outside the cell.

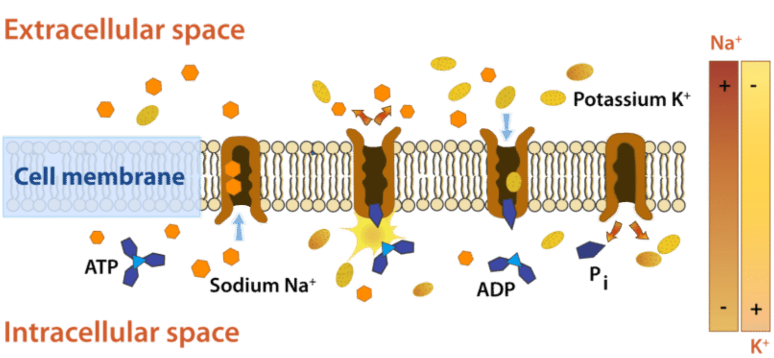

FIGURE 1.4
The sodium-potassium pump moves sodium ions to the outside of the cell and potassium ions to the inside of the cell, areas where these ions are already highly concentrated. ATP is required for the protein to change shape. ATP is converted into ADP (adenosine diphosphate) during active transport.

Summary

- During active transport, a protein pump uses energy, in the form of ATP, to move molecules from an area of low concentration to an area of high concentration.
- An example of active transport is the sodium-potassium pump, which moves sodium ions to the outside of the cell and potassium ions to the inside of the cell.

Explore More

Use the resource below to answer the questions that follow.

- **Osmosis and Active Transport** at http://www.youtube.com/watch?v=6tVc5gyOzO4 (8:40)

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1. What is active transport?
2. Where does a cell obtain the energy for active transport?
3. How does the body prevent the loss of sugar in urine?
4. List three factors that affect the movement of materials across a membrane. Explain how these factors affect the movement of matter.

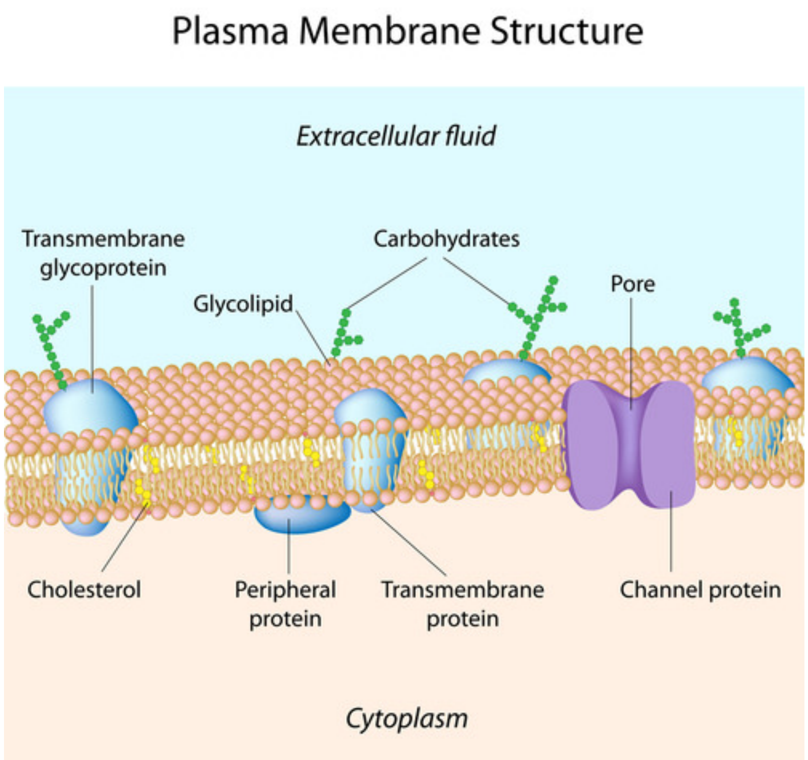
Review

1. How is active transport different from passive transport?
2. What form of energy is usually used in active transport?
3. Give an example of active transport. Explain what occurs during this process.

1.5 Cell Transport - Advanced

Learning Objectives

- Describe the importance of cell transport.



What is cell transport?

It is the movement of substances across the cell membrane either into or out of the cell. Sometimes things just move through the phospholipid bilayer. Other times, substances need the assistance of a protein, like a channel protein or some other transmembrane protein, to cross the cell membrane.

Cell Transport

Cell transport refers to the movement of substances across the cell membrane. Probably the most important feature of a cell's phospholipid membranes is that they are selectively permeable. A membrane that is **selectively permeable**, or semipermeable, has control over what molecules or ions can enter or leave the cell, as shown in **Figure** 1.5. This feature allows a cell to control the transport of materials, as dictated by the cell's function. The permeability of a membrane is dependent on the organization and characteristics of the membrane lipids and proteins. In this way, cell membranes help maintain a state of homeostasis within cells (and tissues, organs, and organ systems) so that an organism can stay alive and healthy.

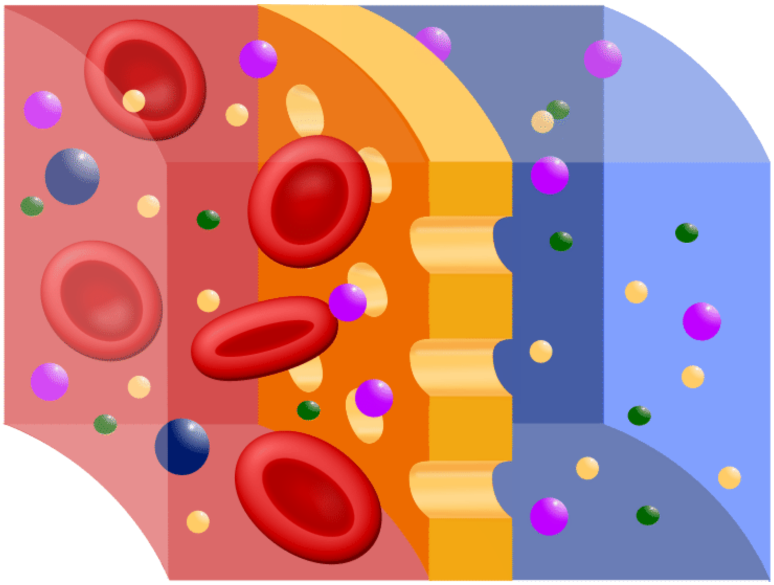


FIGURE 1.5
A selectively permeable, or semipermeable, membrane allows certain molecules through, but not others.

Transport Across Membranes

The molecular make-up of the phospholipid bilayer limits the types of molecules that can pass through it. For example, hydrophobic (water-hating) molecules, such as carbon dioxide (CO_2) and oxygen (O_2), can easily pass through the lipid bilayer, but ions such as calcium (Ca^{2+}) and polar molecules such as water (H_2O) cannot. The hydrophobic interior of the phospholipid bilayer does not allow ions or polar molecules through because they are hydrophilic, or water loving. In addition, large molecules such as sugars and proteins are too big to pass through the phospholipid bilayer. Transport proteins within the membrane allow these molecules to cross the membrane into or out of the cell. This way, polar molecules avoid contact with the nonpolar interior of the membrane, and large molecules are moved through large pores.

Every cell is contained within a membrane punctuated with transport proteins that act as channels or pumps to let in or force out certain molecules. The purpose of the transport proteins is to protect the cell's internal environment and to keep its balance of salts, nutrients, and proteins within a range that keeps the cell and the organism alive.

There are four main ways that molecules can pass through a phospholipid membrane. The first way requires no energy input by the cell and is called simple diffusion. This type of transport includes passive **diffusion** and **osmosis.** No assistance by a transport is necessary in simple diffusion. **Facilitated diffusion,** does involve the assistance of transport proteins. The third way, called **active transport**, requires that the cell uses energy to pull in or pump out certain molecules and ions. Active transport involves proteins known as *pumps.* The fourth way is through **vesicle transport**, in which large molecules are moved across the membrane in bubble-like sacks that are made from pieces of the membrane. Vesicular transport includes **exocytosis** and **endocytosis.**

Homeostasis and Cell Transport

Homeostasis refers to the balance, or equilibrium, within the cell or a body. It is an organism's ability to keep a constant internal environment. Keeping a stable internal environment requires constant adjustments as conditions change inside and outside the cell. The adjusting of systems within a cell is referred to as homeostatic regulation. Because the internal and external environments of a cell are constantly changing, adjustments must be made continuously to stay at or near the normal proportions of all internal substances. This involves continual adjustments in transport of substances across the cell membrane. Homeostasis is a dynamic equilibrium rather than an unchanging state. The cellular processes discussed in the cell transport (passive and active transport) concepts all play an important role in homeostatic regulation.

Summary

- The cell membrane is selectively permeable, allowing only certain substances to pass through.
- Cell transport may require assistance by a protein/pump.
- Cell transport may require energy.
- Some transport involves vesicles.

Review

1. What is meant by cell transport? Why is cell transport important?
2. List types of cell transport.
3. Explain how cell transport helps an organism maintain homeostasis.

1.6 Homeostasis

Learning Objectives

- Define homeostasis.
- Describe the importance of maintaining homeostasis.
- Discuss the roles of the endocrine and nervous systems in maintaining homeostasis.

What happens if stability is disrupted?

Remove one stone and the whole arch collapses. The same is true for the human body. All the systems work together to maintain stability or homeostasis. Disrupt one system, and the whole body may be affected.

Homeostasis

All of the organs and organ systems of the human body work together like a well-oiled machine. This is because they are closely regulated by the nervous and endocrine systems. The **nervous system** controls virtually all body activities, and the **endocrine system** secretes **hormones** that regulate these activities. Functioning together, the organ systems supply body cells with all the substances they need and eliminate their wastes. They also keep temperature, pH, and other conditions at just the right levels to support life processes.

Maintaining Homeostasis

The process in which organ systems work to maintain a stable internal environment is called **homeostasis**. Keeping a stable internal environment requires constant adjustments. Here are just three of the many ways that human organ systems help the body maintain homeostasis:

- Respiratory system: A high concentration of carbon dioxide in the blood triggers faster breathing. The lungs exhale more frequently, which removes carbon dioxide from the body more quickly.
- Excretory system: A low level of water in the blood triggers retention of water by the kidneys. The kidneys produce more concentrated urine, so less water is lost from the body.
- Endocrine system: A high concentration of sugar in the blood triggers secretion of insulin by an endocrine gland called the pancreas. Insulin is a hormone that helps cells absorb sugar from the blood.

So how does your body maintain homeostasis? The regulation of your internal environment is done primarily through negative feedback. **Negative feedback** is a response to a stimulus that keeps a variable close to a set value (**Figure** 1.7). Essentially, it "shuts off" or "turns on" a system when it varies from a set value.

For example, your body has an internal thermostat. During a winter day, in your house a thermostat senses the temperature in a room and responds by turning on or off the heater. Your body acts in much the same way. When body temperature rises, receptors in the skin and the brain sense the temperature change. The temperature change triggers a command from the brain. This command can cause several responses. If you are too hot, the skin makes sweat and blood vessels near the skin surface dilate. This response helps decrease body temperature.

Another example of negative feedback has to do with blood glucose levels. When glucose (sugar) levels in the blood are too high, the pancreas secretes insulin to stimulate the absorption of glucose and the conversion of glucose into glycogen, which is stored in the liver. As blood glucose levels decrease, less insulin is produced. When glucose levels are too low, another **hormone** called glucagon is produced, which causes the liver to convert glycogen back to glucose.

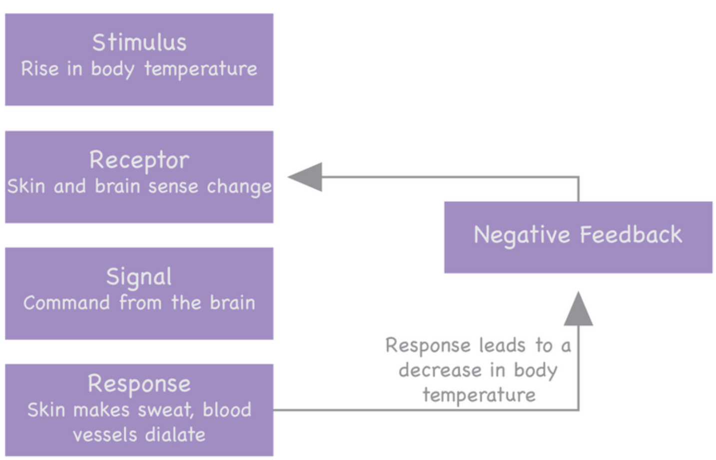


FIGURE 1.6

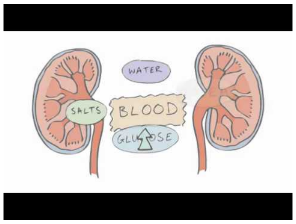
Feedback Regulation. If a raise in body temperature (stimulus) is detected (receptor), a signal will cause the brain to maintain homeostasis (response). Once the body temperature returns to normal, negative feedback will cause the response to end. This sequence of stimulus-receptor-signal-response is used throughout the body to maintain homeostasis.

Positive Feedback

Some processes in the body are regulated by positive feedback. **Positive feedback** is when a response to an event increases the likelihood of the event to continue. An example of positive feedback is milk production in nursing mothers. As the baby drinks her mother's milk, the hormone prolactin, a chemical signal, is released. The more the baby suckles, the more prolactin is released, which causes more milk to be produced. Other examples of positive feedback include contractions during childbirth. When constrictions in the uterus push a baby into the birth canal, additional contractions occur.

Failure of Homeostasis

Many homeostatic mechanisms such as these work continuously to maintain stable conditions in the human body. Sometimes, however, the mechanisms fail. When they do, cells may not get everything they need, or toxic wastes may accumulate in the body. If homeostasis is not restored, the imbalance may lead to disease or even death.



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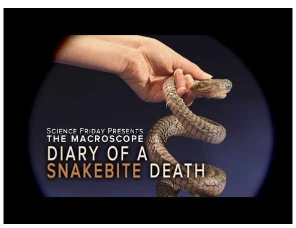
Science Friday: Diary of A Snakebite Death

What does it feel like to be bitten by a venomous snake? In this video by Science Friday, learn about how Dr. Karl P. Schmidt wrote about the effects of snake bite venom while he was dying.



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Summary

- All of the organ systems of the body work together to maintain homeostasis of the organism.
- If homeostasis fails, death or disease may result.

Review

1. What is homeostasis?
2. Describe how one of the human organ systems helps maintain homeostasis.
3. A house has several systems, such as the electrical system, plumbing system, and heating and cooling system. In what ways are the systems of a house similar to human body systems?

1.7 Homeostasis

- Define homeostasis.
- Describe homeostasis and how it is maintained.
- Distinguish negative feedback from positive feedback.

How does your body react to cold?

These people may be having fun in the icy water, but their bodies are struggling to react to the cold. For example, they may begin to shiver. Shivering helps the body return to a stable temperature. The body is always working to achieve stability, or homeostasis.

Homeostasis and Feedback Regulation

When you walk outside on a cool day, does your body temperature drop? No, your body temperature stays stable at around 98.6 degrees Fahrenheit. Even when the temperature around you changes, your internal temperature stays the same.

This ability of the body to maintain a stable internal environment despite a changing environment is called **homeostasis**. Homeostasis doesn't just protect against temperature changes. Other aspects of your internal environment also stay stable. For example, your body closely regulates your fluid balance. You may have noticed that if you are slightly dehydrated, your urine is darker. That's because the urine is more concentrated and less water is mixed in with it.

Maintaining Homeostasis

So how does your body maintain homeostasis? The regulation of your internal environment is done primarily through **negative feedback.** Negative feedback is a response to a stimulus that keeps a variable close to a set value (**Figure** 1.7). Essentially, it "shuts off" or "turns on" a system when it varies from a set value.

For example, your body has an internal thermostat. During a winter day, in your house a thermostat senses the temperature in a room and responds by turning on or off the heater. Your body acts in much the same way. When body temperature rises, receptors in the skin and the brain sense the temperature change. The temperature change triggers a command from the brain. This command can cause several responses. If you are too hot, the skin makes sweat and blood vessels near the skin surface dilate. This response helps decrease body temperature.

Another example of negative feedback has to do with blood glucose levels. When glucose (sugar) levels in the blood are too high, the pancreas secretes insulin to stimulate the absorption of glucose and the conversion of glucose into glycogen, which is stored in the liver. As blood glucose levels decrease, less insulin is produced. When glucose levels are too low, another **hormone** called glucagon is produced, which causes the liver to convert glycogen back to glucose.

For additional information, see *Homeostasis* at https://www.youtube.com/watch?v=rSBbnHLR_cg .

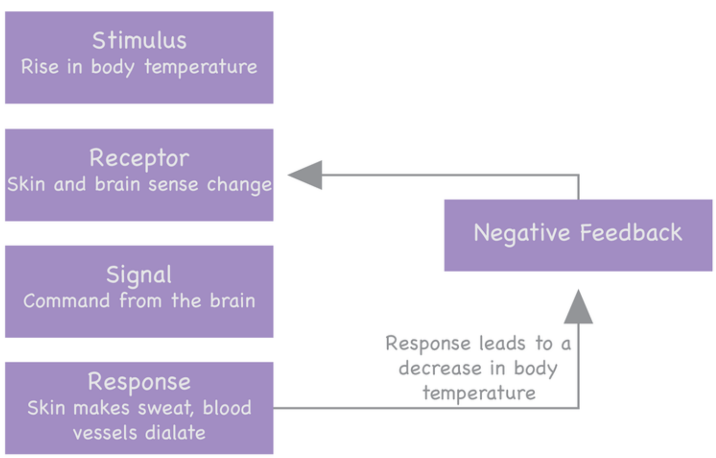


FIGURE 1.7

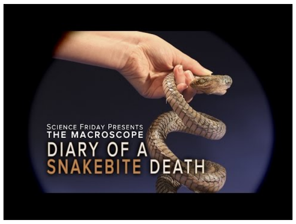
Feedback Regulation. If a raise in body temperature (stimulus) is detected (receptor), a signal will cause the brain to maintain homeostasis (response). Once the body temperature returns to normal, negative feedback will cause the response to end. This sequence of stimulus-receptor-signal-response is used throughout the body to maintain homeostasis.

Positive Feedback

Some processes in the body are regulated by positive feedback. **Positive feedback** is when a response to an event increases the likelihood of the event to continue. An example of positive feedback is milk production in nursing mothers. As the baby drinks her mother's milk, the hormone prolactin, a chemical signal, is released. The more the baby suckles, the more prolactin is released, which causes more milk to be produced. Other examples of positive feedback include contractions during childbirth. When constrictions in the uterus push a baby into the birth canal, additional contractions occur.

Science Friday: Diary of A Snakebite Death

What does it feel like to be bitten by a venomous snake? In this video by Science Friday, learn about how Dr. Karl P. Schmidt wrote about the effects of snake bite venom while he was dying.



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Summary

- Homeostasis is the ability of the body to maintain a stable internal environment despite a changing external environment.
- Homeostasis is maintained primarily through negative feedback, when a response to a stimulus keeps a variable close to a set value.

Explore More

Use the resources below to answer the questions that follow.

Explore More I

1. What are three variables affected by homeostasis? What is the normal human range for these variables?
2. What is negative feedback? What is a sensor and an effector? How does this relate to homeostasis?
3. How does temperature affect enzymes? Why is this important to organisms?
4. How is the body temperature of ectotherms related to environmental temperatures? How does this differ from endotherms?
5. What happens if a fish is exposed to a rapid change in water temperature? What mechanism is involved in this response?

Explore More II

- **Homeostasis** at http://www.think-bank.com/iwb/flash/homeostasis.html

1. List four internal conditions that humans regulate?
2. What happens to blood flow in your body when your internal temperature increases?
3. What happens to blood flow in your body when your internal temperature decreases?
4. What is ADH? What is its function?
5. What are the roles of insulin and glucagon? What do they help the body regulate?

Review

1. What is homeostasis?
2. What is the difference between negative feedback and positive feedback?
3. What is a hormone?

1.8 Hormone Regulation

Learning Objectives

- Describe feedback mechanisms that regulate hormone secretion.
- Explain a negative feedback loop.
- Distinguish between a negative feedback loop and a positive feedback loop.

On or off?

Hormones alter conditions inside the cell, usually in response to a stimulus. That means they are activated at specific times. So they must be turned on and then turned back off. What turns these hormones and their responses on or off?

Hormone Regulation: Feedback Mechanisms

Hormones control many cell activities, so they are very important for homeostasis. But what controls the hormones themselves? Most hormones are regulated by feedback mechanisms. A **feedback mechanism** is a loop in which a product feeds back to control its own production. Most hormone feedback mechanisms involve **negative feedback loops**. Negative feedback keeps the concentration of a hormone within a narrow range.

Negative Feedback

Negative feedback occurs when a product feeds back to decrease its own production. This type of feedback brings things back to normal whenever they start to become too extreme. The thyroid gland is a good example of this type of regulation. It is controlled by the negative feedback loop shown in **Figure** 1.8.

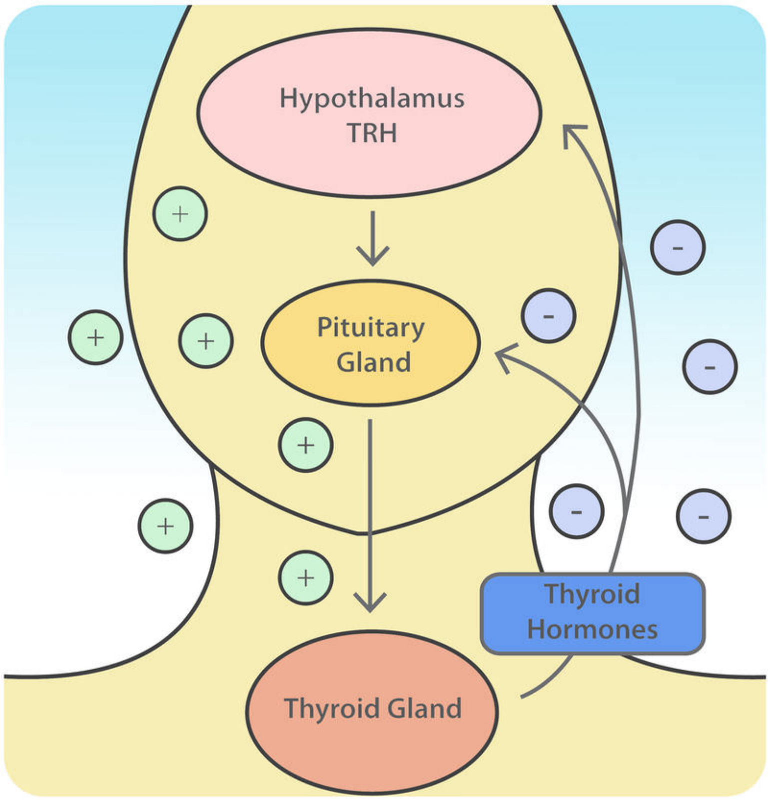
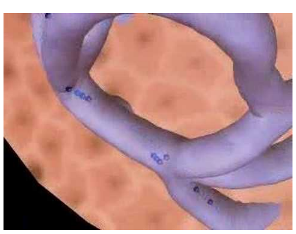


FIGURE 1.8
The thyroid gland is regulated by a negative feedback loop. The loop includes the hypothalamus and pituitary gland in addition to the thyroid.

Here's how thyroid regulation works. The hypothalamus secretes thyrotropin-releasing hormone, or TRH. TRH stimulates the pituitary gland to produce thyroid-stimulating hormone, or TSH. TSH, in turn, stimulates the thyroid gland to secrete its hormones. When the level of thyroid hormones is high enough, the hormones feedback to stop the hypothalamus from secreting TRH and the pituitary from secreting TSH. Without the stimulation of TSH, the thyroid gland stops secreting its hormones. Soon, the level of thyroid hormone starts to fall too low. What do you think happens next?



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Negative feedback also controls insulin secretion by the pancreas.

Positive feedback

Positive feedback occurs when a product feeds back to increase its own production. This causes conditions to become increasingly extreme. An example of positive feedback is milk production by a mother for her baby. As the baby suckles, nerve messages from the nipple cause the pituitary gland to secrete prolactin. Prolactin, in turn, stimulates the mammary glands to produce milk, so the baby suckles more. This causes more prolactin to be secreted and more milk to be produced. This example is one of the few positive feedback mechanisms in the human body. What do you think would happen if milk production by the mammary glands was controlled by negative feedback instead?

Summary

- Most hormones are controlled by negative feedback, in which the hormone feeds back to decrease its own production. This type of feedback brings things back to normal whenever they start to become too extreme.
- Positive feedback is much less common because it causes conditions to become increasingly extreme.

Review

1. What is negative feedback?
2. Why are negative feedback mechanisms more common than positive feedback mechanisms in the human body?
3. What might happen if an endocrine hormone such as thyroid hormone was controlled by positive instead of negative feedback?
4. Tasha had a thyroid test. Her doctor gave her an injection of TSH and 15 minutes later measured the level of thyroid hormone in her blood. What is TSH? Why do you think Tasha's doctor gave her an injection of TSH? How would this affect the level of thyroid hormones in her blood if her thyroid is normal?

1.9 Diabetes

Learning Objectives

- Define diabetes.
- Explain causes of diabetes.
- Distinguish type 1 diabetes from type 2 diabetes.
- List common symptoms and complications of diabetes.

What do these foods have in common?

These foods are all high in sugar. A person with diabetes has to avoid these types of foods.

Diabetes

Diabetes is a non-infectious disease in which the body is unable to control the amount of sugar in the blood. People with diabetes have high blood sugar, either because their bodies do not produce enough insulin, or because their cells do not respond to insulin. **Insulin** is a hormone that helps cells take up sugar from the blood. Without enough insulin, the blood contains too much sugar. This can damage blood vessels and other cells throughout the body. The kidneys work hard to filter out and remove some of the extra sugar. This leads to frequent urination and excessive thirst.

There are two main types of diabetes, type 1 diabetes and type 2 diabetes. Type 1 diabetes makes up about 5-10% of all cases of diabetes in the United States. Type 2 diabetes accounts for most of the other cases. Both types of diabetes are more likely in people that have certain genes. Having a family member with diabetes increases the risk of developing the disease.

Either type of diabetes can increase the chances of having other health problems. For example, people with diabetes are more likely to develop heart disease and kidney disease. Type 1 and type 2 diabetes are similar in these ways. However, the two types of diabetes have different causes.

Type 1 Diabetes

Type 1 diabetes occurs when the immune system attacks normal cells of the pancreas. Since the cells in the pancreas are damaged, the pancreas cannot make insulin. Type 1 diabetes usually develops in childhood or adolescence.

People with type 1 diabetes must frequently check the sugar in their blood. They use a meter to monitor their blood sugar (**Figure** 1.9). Whenever their blood sugar starts to get too high, they need a shot of insulin. The insulin brings their blood sugar back to normal. There is no cure for type 1 diabetes. Therefore, insulin shots must be taken for life. Most people with this type of diabetes learn how to give themselves insulin shots.

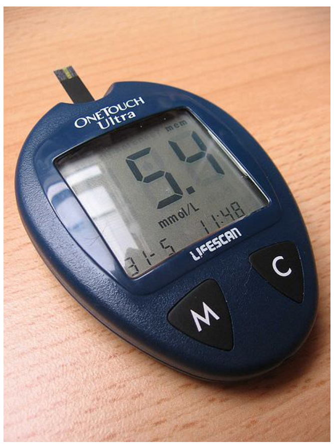


FIGURE 1.9
This is one type of meter used by people with diabetes to measure their blood sugar. Modern meters like this one need only a drop of blood and take less than a minute to use.

Type 2 Diabetes

Type 2 diabetes occurs when body cells are no longer sensitive to insulin. The pancreas may still make insulin, but the cells of the body cannot use it efficiently. Being overweight and having high blood pressure increase the chances of developing type 2 diabetes. Type 2 diabetes usually develops in adulthood, but it is becoming more common in teens and children. This is because more young people are overweight, due to a high sugar and fat diet, now than ever before.

Some cases of type 2 diabetes can be cured with weight loss. However, most people with the disease need to take medicine to control their blood sugar. Regular exercise and balanced eating also help, and should be a regular part of the treatment for these people. Like people with type 1 diabetes, people with type 2 diabetes must frequently check their blood sugar.

Symptoms

Common symptoms of diabetes include the following:

- frequent urination
- feeling very thirsty
- feeling very hungry, even though you are eating
- extreme fatigue

- blurry vision
- cuts or bruises that are slow to heal
- weight loss, even though you are eating more (type 1)
- tingling, pain, or numbness in the hands or feet (type 2)

Complications

Complications of diabetes can include the following:

- eye complications
- foot complications
- skin complications
- high blood pressure
- hearing issues
- nerve damage
- kidney disease
- artery disease
- stroke
- stress

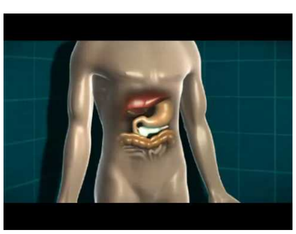
Summary

- In type 1 diabetes, the pancreas cannot make enough insulin, the hormone that helps take up sugar from the blood.
- In type 2 diabetes, the body cells cannot use insulin properly.

Explore More

Use the resource below to answer the questions that follow.

- **Diabetes and the Body** at http://www.youtube.com/watch?v=jHRfDTqPzj4 (8:42)



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1. How does a "normal" body respond when it senses that glucose levels in the blood stream are increasing?
2. How does insulin affect blood glucose levels? What mechanism does it act by?
3. What causes type 1 diabetes? How does this affect the body?
4. What causes type 2 diabetes? What are three symptoms of type 2 diabetes?
5. How can the liver make the situation worse with type 2 diabetes? Why does the liver respond this way?
6. Which type of diabetes is most likely to be influenced by dietary changes?

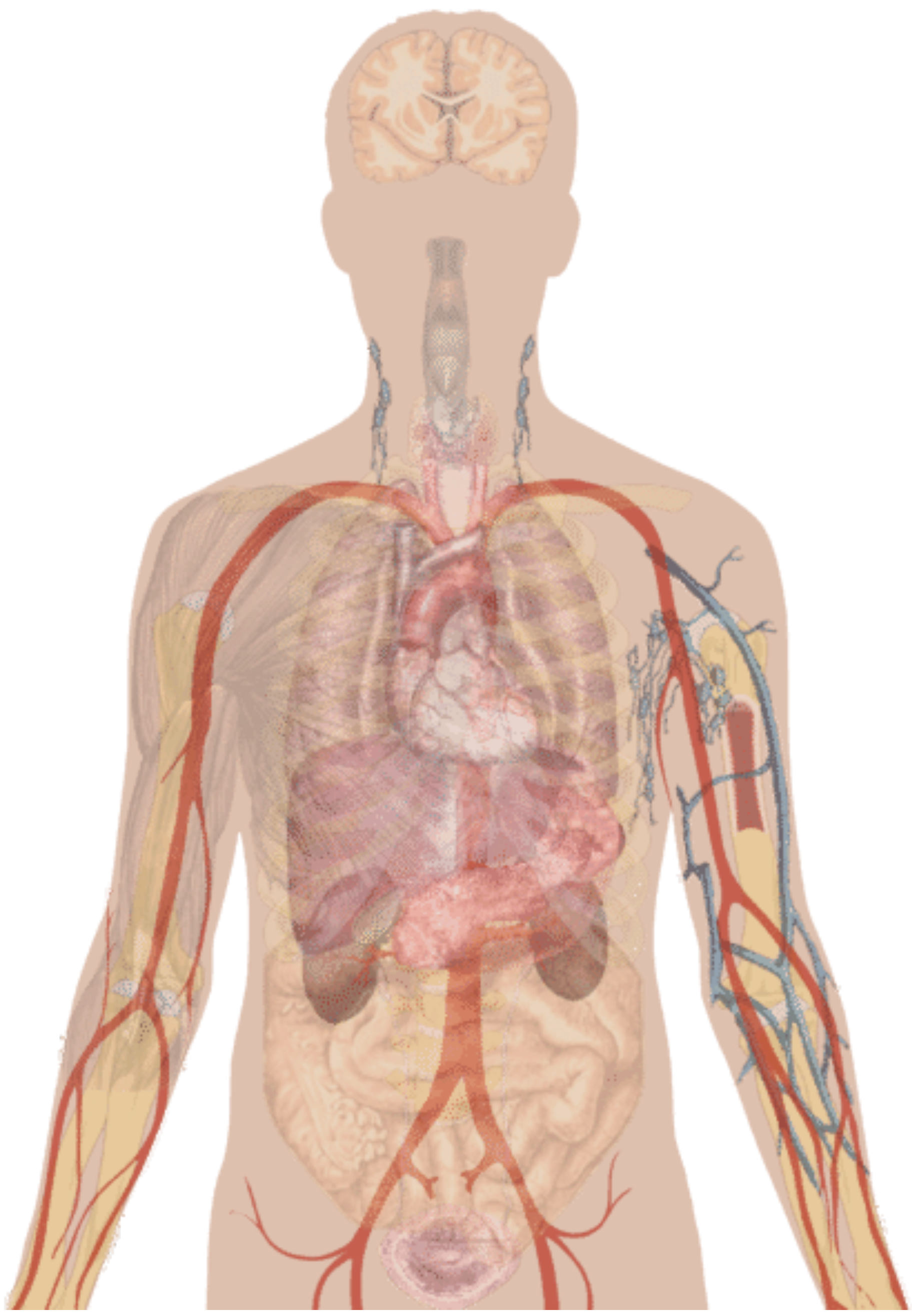
Review

1. What is diabetes?
2. Compare and contrast type 1 and type 2 diabetes.
3. What can increase your risk of developing type 2 diabetes?
4. List three common symptoms of diabetes.

1.10 Human Organs and Organ Systems - Advanced

Learning Objectives

- Summarize how tissues and organs relate to each other.
- Identify the defining features of organs and organ systems.
- Understand the relationship between organs and organ systems.



Organs and Organ Systems

Organs are the next level of organization in the body. An **organ** is a structure made of two or more tissues that work together for a common purpose. Skin, the largest organ in the body, is shown in **Figure** 2.19. Organs can be as primitive as the brain of a flatworm (a group of nerve cells), as large as the stem of a sequoia (up to 90 meters (300 feet) in height), or as complex as a human liver. The human body has many different organs including the heart, the kidneys, the pancreas, and the skin. Two or all of the tissue types can be found in each organ. Organs inside the body are called internal organs. The internal organs collectively are often called **viscera.**

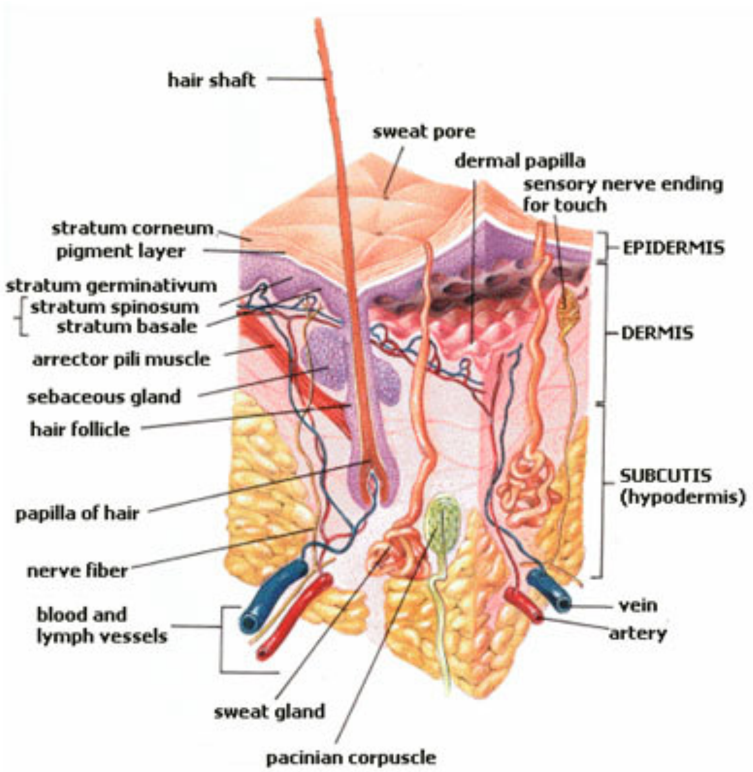


FIGURE 1.10

Your skin is the largest organ in your body. In this cross section image of skin, the four different tissue types (epithelial, connective, nervous, and muscle tissues) can be seen working together.

The most complex organisms have organ systems. An **organ system** is a group of organs that act together to carry out complex, interrelated functions, with each organ focusing on a subset of the task. For example, the human digestive system is an organ system in which the mouth and esophagus ingest food, the stomach crushes and liquefies it, the pancreas and gall bladder make and release digestive enzymes, and the intestines absorb nutrients into the blood. An organ can be part of more than one organ system. For example, the ovaries produce hormones, which makes them a part of the endocrine system; the ovaries also make eggs, which makes them a part of the reproductive system as well. One of the most important functions of organ systems is to provide cells with oxygen and nutrients and to remove toxic waste products such as carbon dioxide. A number of organ systems, including the cardiovascular and respiratory systems, work together to do this.

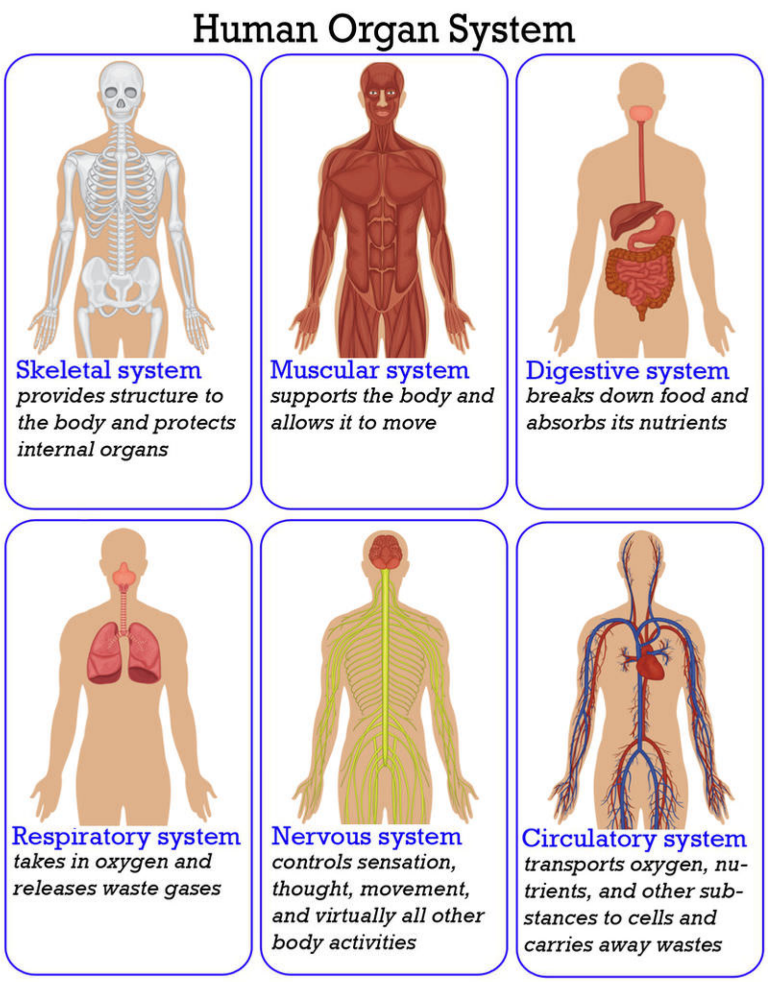


FIGURE 1.11
Many of the organ systems that make up the human body are represented here. What is the overall function of each organ system?

The different organ systems of the body are shown in **Table** 2.3. Sometimes the cardiovascular system and the lymphatic system are grouped together into one single system called the circulatory system.

TABLE 1.1: Major Organ Systems of the Human Body

Organ System	Function	Organs, Tissues, and Structures Involved
Cardiovascular	Transports oxygen, nutrients, and other substances to the cells, and transports wastes, carbon dioxide, and other substances away from the cells; it can also help stabilize body temperature and pH.	Heart, blood, and blood vessels.
Lymphatic	Defends against infection and disease. Transfers lymph between tissues and the blood stream.	Lymph, lymph nodes, and lymph vessels.
Digestive	Processes foods and absorbs nutrients, minerals, vitamins, and water.	Salivary glands, esophagus, stomach, liver, gallbladder, pancreas, small intestine, and large intestine.

TABLE 1.1: (continued)

Organ System	Function	Organs, Tissues, and Structures Involved
Endocrine	Provides communication within the body via hormones. Directs long-term change over other organ systems to maintain homeostasis.	Pituitary gland, pineal gland, thyroid, parathyroid gland, adrenal glands, testes, and ovaries.
Integumentary	Provides protection from both injury and fluid loss and provides physical defense against infection by microorganisms. Controls temperature.	Skin, hair, and nails.
Muscular	Provides movement, support, and heat production.	Tendons, skeletal, cardiac, and smooth muscles.
Nervous	Collects, transfers, and processes information. Directs short-term change over other organ systems in order to maintain homeostasis.	Brain, spinal cord, nerves, and sensory organs (eyes, ears, tongue, skin, and nose).
Reproductive	Produces gametes (sex cells) and sex hormones; ultimately produces offspring.	Fallopian tubes, uterus, vagina, ovaries, mammary glands, testes, vas deferens, seminal vesicles, prostate, and penis.
Respiratory	Delivers air to sites where gas exchange can occur between the blood and cells (around body) or blood and air (lungs).	Mouth, nose, pharynx, larynx, trachea, bronchi, lungs, and diaphragm.
Skeletal	Supports and protects soft tissues of the body. Provides movement at joints, produces blood cells, and stores minerals.	Bones, cartilage, and ligaments.
Urinary	Removes excess water, salts, and waste products from the blood and body. Controls pH.	Kidneys, ureters, urinary bladder, and urethra.
Immune	Defends against microbial pathogens (disease-causing agents) and other diseases.	Leukocytes, tonsils, adenoids, thymus, and spleen.

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Summary

- Organs are structures composed of two or more tissues; organ systems are systems composed of two or more organs.
- Organ systems carry out complex tasks, with each organ completing one aspect of the task.

Review

1. What is the difference between an organ and an organ system?
2. How many major organ systems are there? What are they?

1.11 References

1. Mariana Ruiz Villarreal (LadyofHats). http://commons.wikimedia.org/wiki/File:Cell_membrane_detailed_diagram_en.svg . Public Domain
2. Mariana Ruiz Villarreal (LadyofHats). http://commons.wikimedia.org/wiki/File:Cell_membrane_detailed_diagram_en.svg . Public Domain
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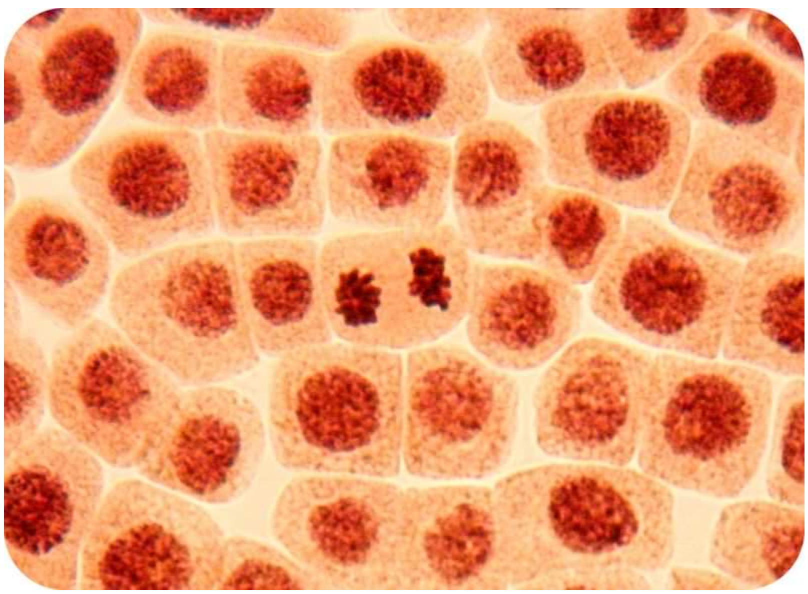
CHAPTER 2 Human Systems: System Interactions

Chapter Outline

2.1 Cell Theory

- Explain how cells are observed.
- Define cell. Describe the general role of a cell.
- State the three main parts of the cell theory.
- Summarize the structure-function relationship of a cell.
- Explain the levels of organization in an organism.



What are you made of?

Cells make up all living things, including your own body. This picture shows a typical group of cells. But not all cells look alike. Cells can differ in shape and sizes. And the different shapes usually means different functions.

Introduction to Cells

A **cell** is the smallest structural and functional unit of an organism. Some organisms, like bacteria, consist of only one cell. Big organisms, like humans, consist of trillions of cells. Compare a human to a banana. On the outside, they look very different, but if you look close enough you'll see that their cells are actually very similar.

Observing Cells

Most cells are so small that you cannot see them without the help of a **microscope**. It was not until 1665 that English scientist Robert Hooke invented a basic light microscope and observed cells for the first time, by looking at a piece of cork. You may use light microscopes in the classroom. You can use a light microscope to see cells (**Figure** 2.1). But many structures in the cell are too small to see with a light microscope. So, what do you do if you want to see the tiny structures inside of cells?

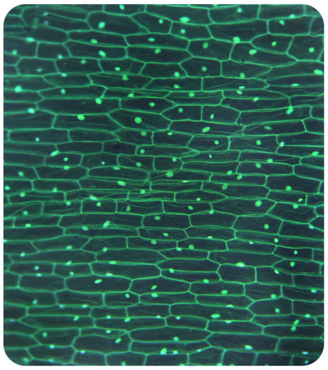


FIGURE 2.1
The outline of onion cells are visible under a light microscope.

In the 1950s, scientists developed more powerful microscopes. A light microscope sends a beam of light through a specimen, or the object you are studying. A more powerful microscope, called an **electron microscope**, passes a beam of electrons through the specimen. Sending electrons through a cell allows us to see its smallest parts, even the parts inside the cell (**Figure** 2.2). Without electron microscopes, we would not know what the inside of a cell looked like.

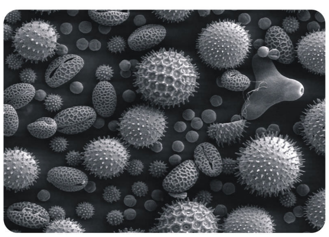


FIGURE 2.2
An electron microscope allows scientists to see much more detail than a light microscope, as with this sample of pollen.

Cell Theory

In 1858, after using microscopes much better than Hooke's first microscope, Rudolf Virchow developed the hypothesis that cells only come from other cells. For example, bacteria, which are single-celled organisms, divide in half (after they grow some) to make new bacteria. In the same way, your body makes new cells by dividing the cells you already have. In all cases, cells only come from cells that have existed before. This idea led to the development of one of the most important theories in biology, the **cell theory**.

Cell theory states that:

1. All organisms are composed of cells.
2. Cells are alive and the basic living units of organization in all organisms.
3. All cells come from other cells.

As with other scientific theories, many hundreds, if not thousands, of experiments support the cell theory. Since Virchow created the theory, no evidence has ever been identified to contradict it.

Specialized Cells

Although cells share many of the same features and structures, they also can be very different (**Figure** 2.3). Each cell in your body is designed for a specific task. In other words, the cell's function is partly based on the cell's structure. For example:

- Red blood cells are shaped with a pocket that traps oxygen and brings it to other body cells.
- Nerve cells are long and stringy in order to form a line of communication with other nerve cells, like a wire. Because of this shape, they can quickly send signals, such as the feeling of touching a hot stove, to your brain.
- Skin cells are flat and fit tightly together to protect your body.

As you can see, cells are shaped in ways that help them do their jobs. Multicellular (many-celled) organisms have many types of specialized cells in their bodies.

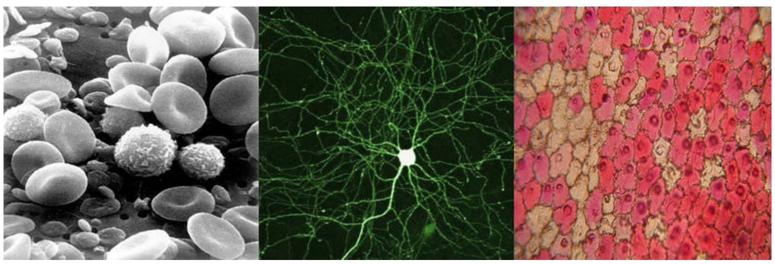


FIGURE 2.3

Red blood cells (*left*) are specialized to carry oxygen in the blood. Neurons (*center*) are shaped to conduct electrical impulses to many other nerve cells. These epidermal cells (*right*) make up the "skin" of plants. Note how the cells fit tightly together.

Levels of Organization

While cells are the basic units of an organism, groups of cells can perform a job together. These cells are called specialized because they have a special job. Specialized cells can be organized into **tissues**. For example, your liver cells are organized into liver tissue. Your liver tissue is further organized into an organ, your liver. **Organs** are formed from two or more specialized tissues working together to perform a job. All organs, from your heart to your liver, are made up of an organized group of tissues.

These organs are part of a larger system, the **organ systems**. For example, your brain works together with your spinal cord and other nerves to form the nervous system. This organ system must be organized with other organ systems, such as the circulatory system and the digestive system, for your body to work. Organ systems work together to form the entire organism. There are many levels of organization in living things (**Figure** 2.4).

Summary

- Cells were first observed under a light microscope, but today's electron microscopes allow scientists to take a closer look at the inside of cells.
- Cell theory says that:
  - All organisms are composed of cells.
  - Cells are alive and the basic living units of organization in all organisms.
  - All cells come from other cells.
- Cells are organized into tissues, which are organized into organs, which are organized into organ systems, which are organized to create the whole organism.

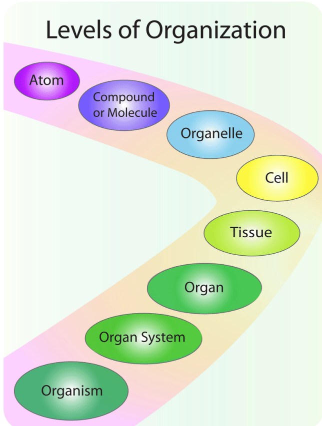


FIGURE 2.4

Levels of organization, from the atom (smallest) to the organism (largest). Notice that organelles are inside a cell, and organs are inside an organism.

Explore More

1. What is the average size of a grain of salt?
2. How big is an amoeba proteus? How big is a paramecium? (Remember this relationship for when you study amoeba.)
3. How big is a skin cell? How big is a red blood cell? Can you think of any problems that might exist if this relationship was reversed? Explain your thinking fully.
4. How big is an *E. coli* bacterium? How big is a mitochondrion? (Remember this relationship for when you study endosymbiosis.)
5. Are all cells the same size?

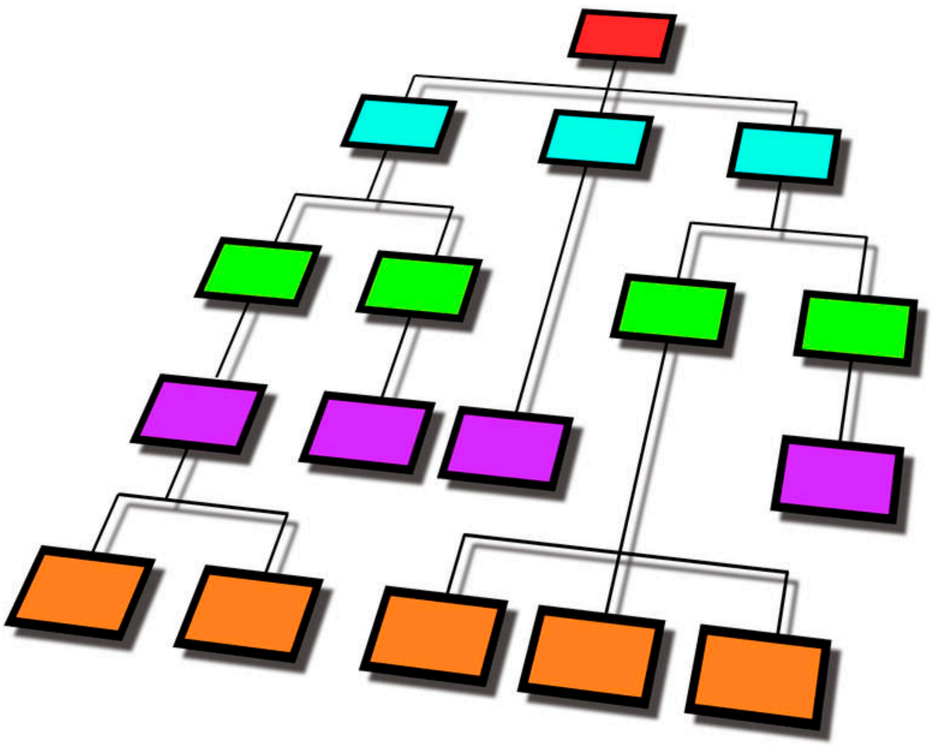
Review

1. What type of microscope would be best for studying the structures found inside of cells?
2. What are the three basic parts of the cell theory?
3. According the cell theory, can you create a cell by combining molecules in a laboratory? Why or why not?
4. Give an example of a specialized cell.
5. What is a tissue?
6. What is the relationship between tissues and organs?

2.2 Cell Organization

Learning Objectives

- Explain how cells are organized in living things.
- Explain the significance of colonial organisms.
- Describe the origin of multicellular organisms.
- Distinguish a tissue from an organ from an organ system.



Why be organized?

It can be said organization leads to efficiency. And in you, cells are organized into tissues, which are organized into organs, which are organized into organ systems, which form you. And it can be said that the human body is a very organized and efficient system.

Organization of Cells

Biological organization exists at all levels in organisms. It can be seen at the smallest level, in the molecules that made up such things as DNA and proteins, to the largest level, in an organism such as a blue whale, the largest mammal on Earth. Similarly, single celled prokaryotes and eukaryotes show order in the way their cells are arranged. Single-celled organisms such as an amoeba are free-floating and independent-living. Their single-celled "bodies" are able to carry out all the processes of life, such as metabolism and respiration, without help from other cells. Some single-celled organisms, such as bacteria, can group together and form a biofilm. A **biofilm** is a large grouping of many bacteria that sticks to a surface and makes a protective coating over itself. Biofilms can show similarities to multicellular organisms. Division of labor is the process in which one group of cells does one job (such as making the "glue" that sticks the biofilm to the surface), while another group of cells does another job (such as taking in nutrients). Multicellular organisms carry out their life processes through division of labor. They have specialized cells that do specific jobs. However, biofilms are not considered multicellular organisms and are instead called colonial organisms. The difference between a multicellular organism and a colonial organism is that individual organisms from a colony or biofilm can, if separated, survive on their own, while cells from a multicellular organism (e.g., liver cells) cannot.

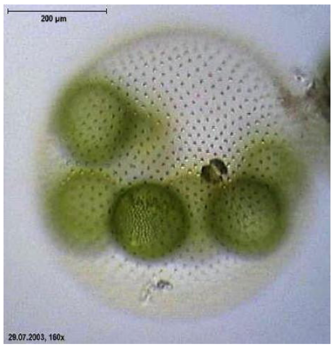


FIGURE 2.5

Colonial algae of the genus *Volvox*.

Colonial Organisms

Colonial organisms were probably one of the first evolutionary steps towards multicellular organisms. Algae of the genus *Volvox* are an example of the border between colonial organisms and multicellular organisms.

Each *Volvox*, shown in **Figure** 2.5, is a colonial organism. It is made up of between 1,000 to 3,000 photosynthetic algae that are grouped together into a hollow sphere. The sphere has a distinct front and back end. The cells have eyespots, which are more developed in the cells near the front. This enables the colony to swim towards light.

Origin of Multicellularity

The oldest known multicellular organism is a red algae *Bangiomorpha pubescens*, fossils of which were found in 1.2 billion-year-old rock. As the first organisms were single-celled, these organisms had to evolve into multicellular organisms.

Scientists think that multicellularity arose from cooperation between many organisms of the same species. The **Colonial Theory** proposes that this cooperation led to the development of a multicellular organism. Many examples of cooperation between organisms in nature have been observed. For example, a certain species of amoeba (a single-celled protist) groups together during times of food shortage and forms a colony that moves as one to a new location. Some of these amoebas then become slightly differentiated from each other. *Volvox*, shown in **Figure** 2.5, is another example of a colonial organism. Most scientists accept that the Colonial Theory explains how multicellular organisms evolved.

Multicellular organisms are organisms that are made up of more than one type of cell and have specialized cells that are grouped together to carry out specialized functions. Most life that you can see without a microscope is multicellular. As discussed earlier, the cells of a multicellular organism would not survive as independent cells. The body of a multicellular organism, such as a tree or a cat, exhibits organization at several levels: tissues, organs, and organ systems. Similar cells are grouped into tissues, groups of tissues make up organs, and organs with a similar function are grouped into an organ system.

Levels of Organization in Multicellular Organisms

The simplest living multicellular organisms, sponges, are made of many specialized types of cells that work together for a common goal. Such cell types include digestive cells, tubular pore cells, and epidermal cells. Though the different cell types create a large, organized, multicellular structure — the visible sponge — they are not organized into true interconnected tissues. If a sponge is broken up by passing it through a sieve, the sponge will reform on the other side. However, if the sponge's cells are separated from each other, the individual cell types cannot survive alone. Simpler colonial organisms, such as members of the genus *Volvox*, as shown in **Figure** 2.5, differ in that their individual cells are free-living and can survive on their own if separated from the colony.

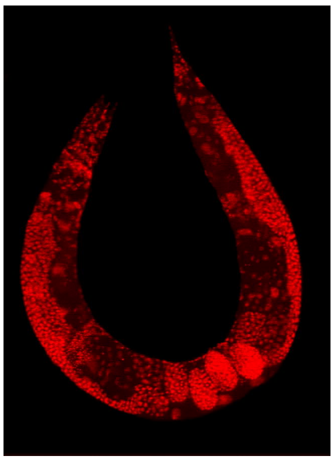
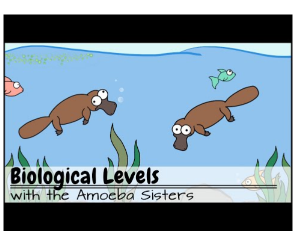


FIGURE 2.6
This roundworm, a multicellular organism, was stained to highlight the nuclei of all the cells in its body (red dots).

A **tissue** is a group of connected cells that have a similar function within an organism. More complex organisms such as jellyfish, coral, and sea anemones have a tissue level of organization. For example, jellyfish have tissues that have separate protective, digestive, and sensory functions.

Even more complex organisms, such as the roundworm shown in **Figure** 2.6, while also having differentiated cells and tissues, have an organ level of development. An **organ** is a group of tissues that has a specific function or group of functions. Organs can be as primitive as the brain of a flatworm (a group of nerve cells), as large as the stem of a sequoia (up to 90 meters, or 300 feet, in height), or as complex as a human liver.

The most complex organisms (such as mammals, trees, and flowers) have organ systems. An **organ system** is a group of organs that act together to carry out complex related functions, with each organ focusing on a part of the task. An example is the human digestive system, in which the mouth ingests food, the stomach crushes and liquifies it, the pancreas and gall bladder make and release digestive enzymes, and the intestines absorb nutrients into the blood.



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Summary

- Single-celled organisms are able to carry out all the processes of life without help from other cells.
- Multicellular organisms carry out their life processes through division of labor. They have specialized cells that do specific jobs.
- The Colonial Theory proposes that cooperation among cells of the same species led to the development of a multicellular organism.
- Multicellular organisms, depending on their complexity, may be organized from cells to tissues, organs, and organ systems.

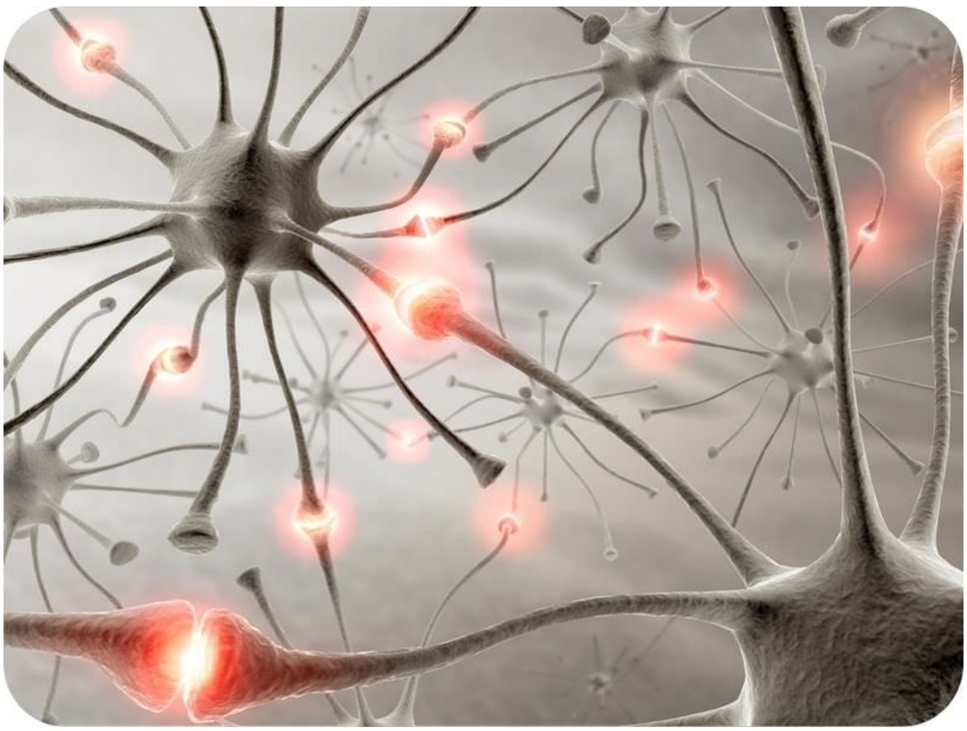
Review

1. What is a multicellular organism?
2. What is a cell feature that distinguishes a colonial organism from a multicellular organism?
3. What is the difference between a cell and a tissue?
4. Describe the top two levels of organization of an organism.

2.3 Organelles

Learning Objectives

- List the main organelles found in an eukaryotic cell.
- Define the role of a ribosome.
- Describe the functions of the mitochondria, endoplasmic reticulum, and Golgi apparatus.
- Explain the function of a vesicle, a vacuole, and a lysosome.



Do brain cells have the same internal structures as your other cells?

Yes. Although brain cells look quite different from your other cells, they have the same internal structures as other cells. They need the same structures because they need to perform the same tasks, such as making proteins and obtaining energy.

Organelles

Eukaryotic cells have many specific functions, so it can be said that a cell is like a factory. A factory has many machines and people, and each has a specific role. Just like a factory, the cell is made up of many different parts. Each part has a special role. The different parts of the cell are called **organelles**, which means "small organs." All organelles are found in eukaryotic cells. Prokaryotic cells are "simpler" than eukaryotic cells. Though prokaryotic cells still have many functions, they are not as specialized as eukaryotic cells, lacking membrane-bound organelles. Thus, most organelles are not found in prokaryotic cells.

Below are the main organelles found in eukaryotic cells (**Figure** 2.7):

1. The **nucleus** of a cell is like a safe containing the factory's trade secrets. The nucleus contains the genetic material (DNA), the information needed to build thousands of proteins.
2. The **mitochondria** are the powerhouses of the cell. Mitochondria are the organelles where cellular energy is produced, providing the energy needed to power chemical reactions. This process, known as **cellular respiration**, produces energy is in the form of **ATP** (adenosine triphosphate). Cells that use a lot of energy may have thousands of mitochondria.
3. **Vesicles** are small membrane bound sacs that transport materials around the cell and to the cell membrane.
4. The **vacuoles** are like storage centers. Plant cells have larger vacuoles than animal cells. Plants store water and nutrients in their large central vacuoles.
5. **Lysosomes** are like the recycling trucks that carry waste away from the factory. Lysosomes have digestive enzymes that break down old molecules into parts that can be recycled.
6. In both eukaryotes and prokaryotes, **ribosomes** are the non-membrane bound organelles where proteins are made. Ribosomes are like the machines in the factory that produce the factory's main product. Proteins are the main product of the cell.
7. Some ribosomes can be found on folded membranes called the **endoplasmic reticulum** (ER), others float freely in the cytoplasm. If the ER is covered with ribosomes, it looks bumpy like sandpaper, and is called the rough endoplasmic reticulum. If the ER does not contain ribosomes, it is smooth and called the smooth endoplasmic reticulum. Many proteins are made on the ribosomes on the rough ER. These proteins immediately enter the ER, where they are modified, packaged into vesicles and sent to the Golgi apparatus. Lipids are made in the smooth ER.
8. The **Golgi apparatus** works like a mail room. The Golgi apparatus receives proteins from the rough ER and puts "shipping addresses" on them. The Golgi then packages the proteins into vesicles and sends them to the right place in the cell or to the cell membrane. Some of these proteins are secreted from the cell (they exit the cell); others are placed into the cell membrane.

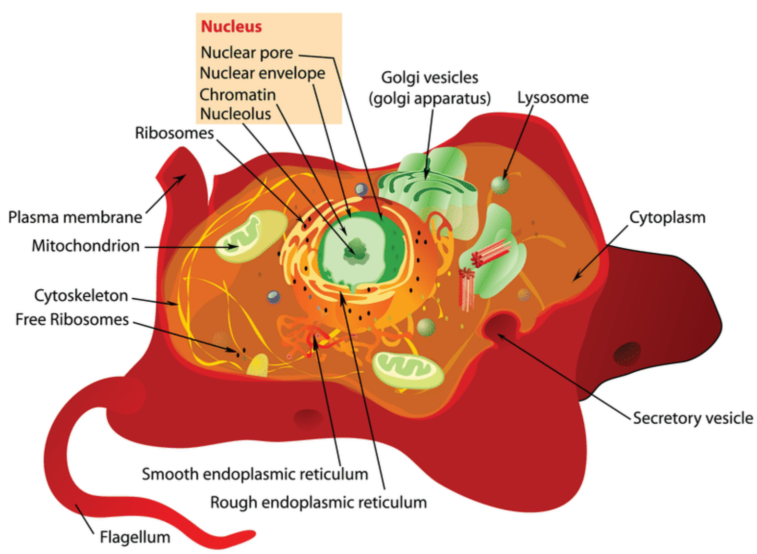


FIGURE 2.7

Eukaryotic cells contain special compartments surrounded by membranes, called organelles. For example, notice in this image the mitochondria, lysosomes, and Golgi apparatus.

Also, the **cytoskeleton** gives the cell its shape, and the **flagella** helps the cell to move. Prokaryotic cells may also have flagella.

Summary

- The nucleus stores the genetic information.

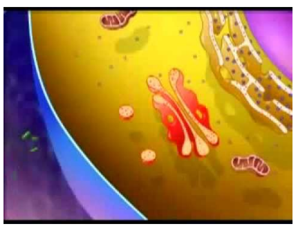
- The vacuoles are needed for storage.
- The lysosomes recycle waste.
- The cytoskeleton provides the shape of the cell.
- The ribosomes produce proteins.
- The rough ER is covered with ribosomes and makes proteins, while the smooth ER makes lipids.
- The Golgi apparatus packages proteins.

Explore More

Use the resources below to answer the following questions.

Explore More I

- **Cell Organelles and Their Function** at http://www.youtube.com/watch?v=fKEaTt9heNM (6:25)



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1. What are the functions of the endoplasmic reticulum? What gives the rough endoplasmic reticulum its "rough" appearance?
2. What are the most abundant organelles in a cell? Where do they occur? What is there function?
3. What is the appearance of the Golgi apparatus? What is the function of the Golgi apparatus?
4. What are lysosomes? What are their functions?
5. What is the function of mitochondria? Do all cells have the same number of mitochondria? How can this situation be explained?

Explore More II

- **Plant and Animal Cell Organelles** at http://www.cellsalive.com/cells/cell_model.htm .

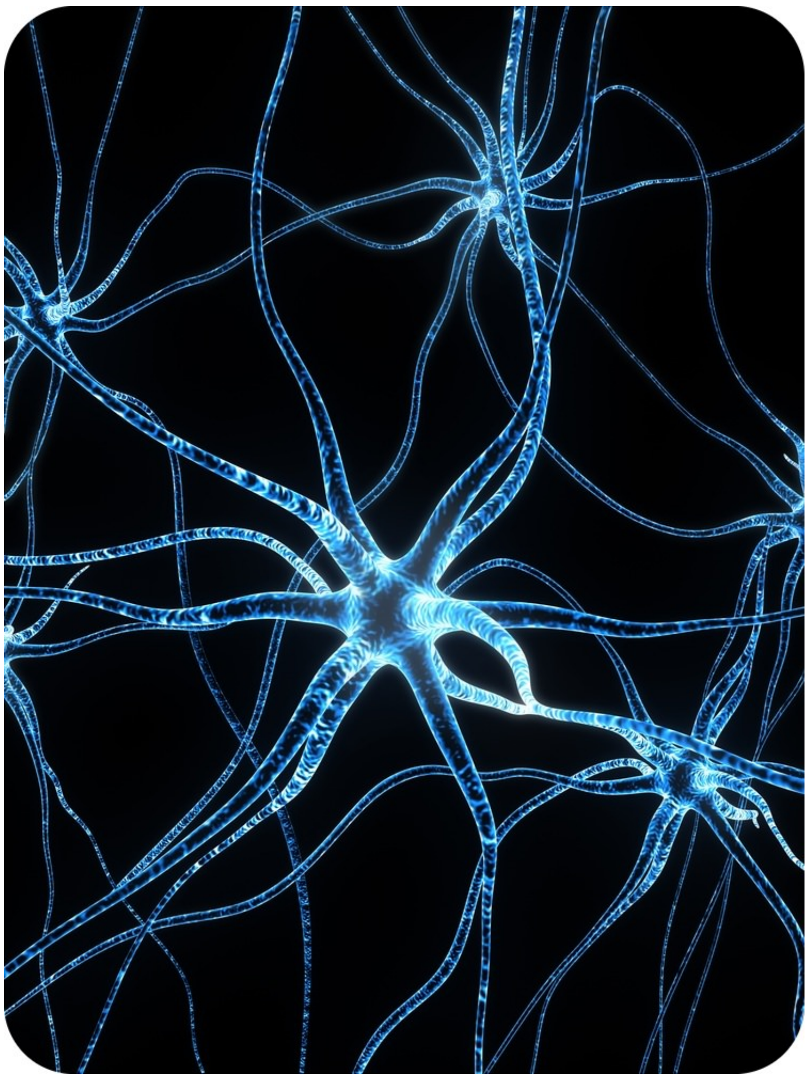
1. What is cytosol? How does this differ from cytoplasm?
2. What are the primary types of protein filaments that make up the cytoskeleton?
3. What is the function of a peroxisome?
4. What is a secretory vesicle? Where are they made? What is their function?

Review

1. What is the purpose of the Golgi apparatus?
2. What is the purpose of the mitochondria?
3. How is the smooth ER different from the rough ER?
4. What is a lysosome?

2.4 Human Body

- List the levels of organization in the human body.
- Define cell, tissue, organ, and organ system.
- Identify the four types of tissues that make up the body.
- Give examples of organ systems and their functions.



Do cells work together?

Cells, like these nerve cells, do not work in isolation. To send orders from your brain to your legs, for example, signals pass through many nerve cells. These cells work together to perform a similar function. Just as muscle cells work together, bone cells and many other cells do as well. A group of similar cells that work together is known as a tissue.

Organization of Your Body: Cells, Tissues, Organs

Cells are grouped together to carry out specific functions. A group of cells that work together form a **tissue**. Your body has four main types of tissues, as do the bodies of other animals. These tissues make up all structures and contents of your body. An example of each tissue type is pictured in the **Figure** 2.8.

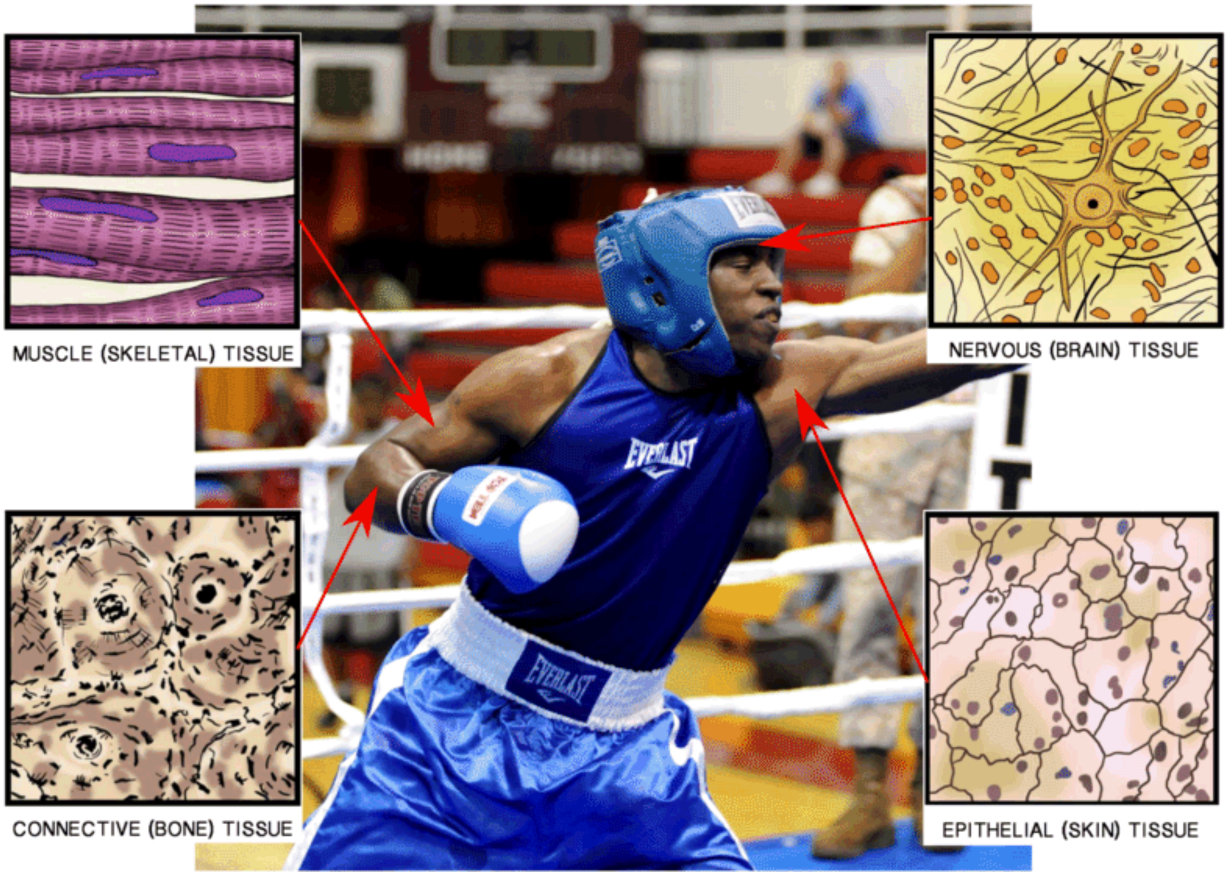


FIGURE 2.8
Your body has four main types of tissue: nervous tissue, epithelial tissue, connective tissue, and muscle tissue. They are found throughout your body.

1. **Epithelial tissue** is made up of layers of tightly packed cells that line the surfaces of the body. Examples of epithelial tissue include the skin, the lining of the mouth and nose, and the lining of the digestive system.
2. **Connective tissue** is made up of many different types of cells that are all involved in supporting and binding other tissues of the body. Examples include tendon, cartilage, and bone. Blood is also classified as a specialized connective tissue.
3. **Muscle tissue** is made up of bands of cells that contract and allow movement.
4. **Nervous tissue** is made up of nerve cells that sense stimuli and transmit signals. Nervous tissue is found in nerves, the spinal cord, and the brain.

Groups of Tissues Form Organs

A single tissue alone cannot do all the jobs that are needed to keep you alive and healthy. Two or more tissues working together can do a lot more. An **organ** is a structure made of two or more tissues that work together. The heart (**Figure** 2.9) is made up of the four types of tissues.

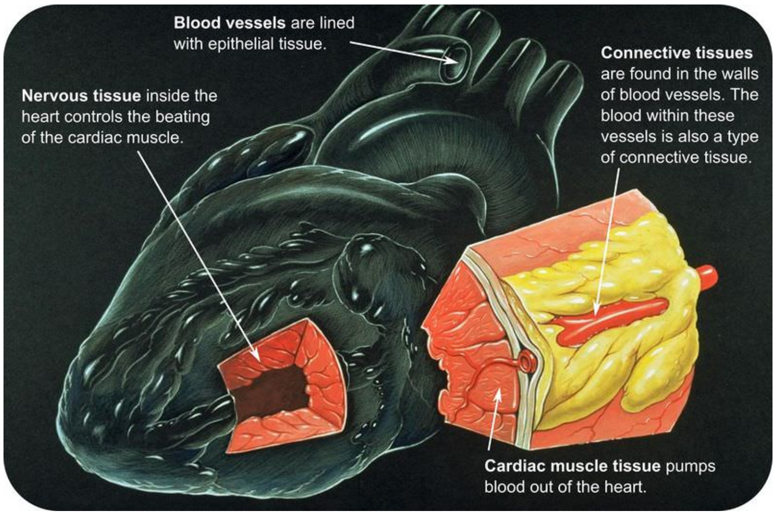


FIGURE 2.9
The four different tissue types work together in the heart as they do in the other organs.

Groups of Organs Form Organ Systems

Your heart pumps blood around your body. But how does your heart get blood to and from every cell in your body? Your heart is connected to blood vessels such as veins and arteries. Organs that work together form an **organ system**. Together, your heart, blood, and blood vessels form your **cardiovascular system**.

What other organ systems can you think of?

Organ Systems Work Together

Your body's 12 organ systems are shown below (**Table** 2.2). Your organ systems do not work alone in your body. They must all be able to work together.

For example, one of the most important functions of organ systems is to provide cells with oxygen and nutrients and to remove toxic waste products such as carbon dioxide. A number of organ systems, including the cardiovascular and respiratory systems, all work together to do this.

TABLE 2.1: Major Organ Systems of the Human Body

Organ System	Major Tissues and Organs	Function
Cardiovascular	Heart; blood vessels; blood	Transports oxygen, hormones, and nutrients to the body cells. Moves wastes and carbon dioxide away from cells.
Lymphatic	Lymph nodes; lymph vessels	Defend against infection and disease, moves lymph between tissues and the blood stream.

TABLE 2.1: (continued)

Organ System	Major Tissues and Organs	Function
Digestive	Esophagus; stomach; small intestine; large intestine	Digests foods and absorbs nutrients, minerals, vitamins, and water.
Endocrine	Pituitary gland, hypothalamus; adrenal glands; ovaries; testes	Produces **hormones** that communicate between cells.
Integumentary	Skin, hair, nails	Provides protection from injury and water loss, physical defense against infection by microorganisms, and temperature control.
Muscular	Cardiac (heart) muscle; skeletal muscle; smooth muscle; tendons	Involved in movement and heat production.
Nervous	Brain, spinal cord; nerves	Collects, transfers, and processes information.
Reproductive	Female: uterus; vagina; fallopian tubes; ovaries Male: penis; testes; seminal vesicles	Produces gametes (sex cells) and sex hormones.
Respiratory	Trachea, larynx, pharynx, lungs	Brings air to sites where gas exchange can occur between the blood and cells (around body) or blood and air (lungs).
Skeletal	Bones, cartilage; ligaments	Supports and protects soft tissues of body; produces blood cells; stores minerals.
Urinary	Kidneys; urinary bladder	Removes extra water, salts, and waste products from blood and body; controls pH; controls water and salt balance.
Immune	Bone marrow; spleen; white blood cells	Defends against diseases.

Summary

- The levels of organization in the human body include: cells, tissues, organs, and organ systems.
- There are four tissue types in the body: epithelial tissue, connective tissue, muscle tissue, and nervous tissue.

Explore More

Use the resources below to answer the following questions.

- **Human Body Plan** at http://vimeo.com/37349968 (2:28)

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/57507

1. What kind of symmetry does the human body plan show? Explain what this means.
2. How does this symmetry extend to our senses?
3. How much of our body is made of muscle? What does this muscle do?
4. How are oxygen and nutrients delivered to the cells of the body?
5. What controls all the activity on the body? How much energy does this organ use?

Go here to see the placement of some organs and body parts. See how fast you can assemble the systems.

- **All Systems Go** at http://sciencenetlinks.com/interactives/systems.html

Review

1. What are the four levels of organization in an organism?
2. List the four types of tissues that make up the human body.
3. Describe epithelial tissue.
4. Give two examples of connective tissue.
5. What is the role of the nervous system?
6. What is the role of the cardiovascular system?

2.5 Human Body

Learning Objectives

- Outline the levels of organization of the human body.
- Distinguish between cells, tissues, organs, and organ systems.
- List the types of tissues in the human body.
- Give examples of the roles of organ systems.

How is the human body similar to a well-tuned machine?

Many people have compared the human body to a machine. Think about some common machines, such as drills and washing machines. Each machine consists of many parts, and each part does a specific job, yet all the parts work together to perform an overall function. The human body is like a machine in all these ways. In fact, it may be the most fantastic machine on Earth.

The human machine is organized at different levels, starting with the cell and ending with the entire organism (see **Figure** 2.10). At each higher level of organization, there is a greater degree of complexity.

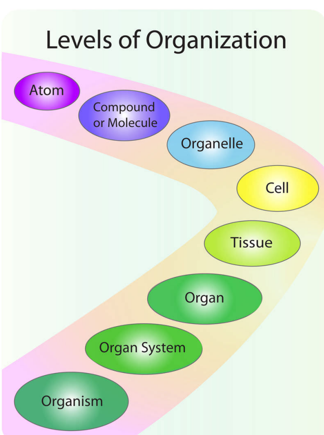
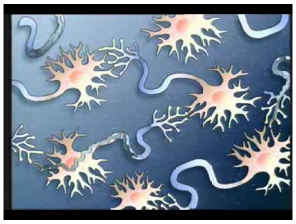


FIGURE 2.10
The human organism has several levels of organization.

Cells

The most basic parts of the human machine are cells—an amazing 100 trillion of them by the time the average person reaches adulthood! **Cells** are the basic units of structure and function in the human body, as they are in all living things. Each cell carries out basic life processes that allow the body to survive. Many human cells are specialized in form and function, as shown in **Figure** 2.14. Each type of cell in the figure plays a specific role. For example, nerve cells have long projections that help them carry electrical messages to other cells. Muscle cells have many mitochondria that provide the energy they need to move the body.



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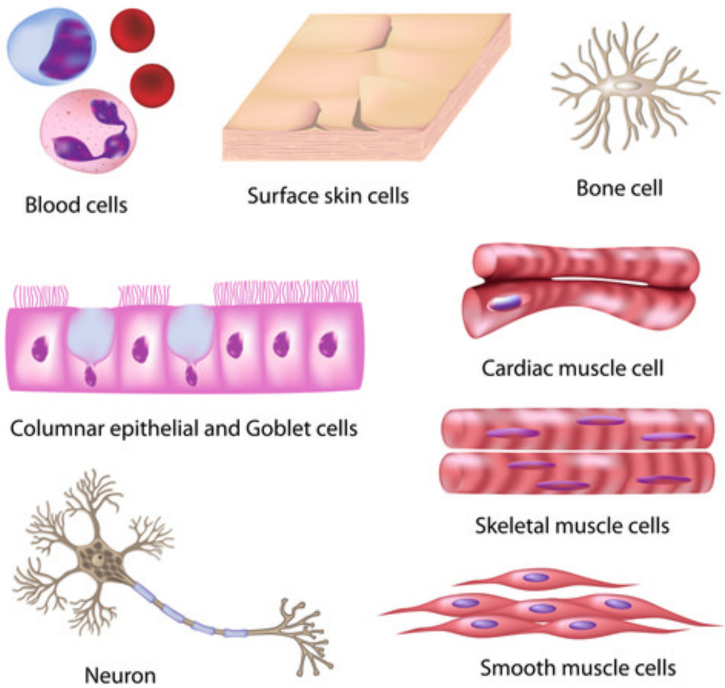


FIGURE 2.11

Different types of cells in the human body are specialized for specific jobs. Do you know the functions of any of the cell types shown here?

Tissues

After the cell, the tissue is the next level of organization in the human body. A **tissue** is a group of connected cells that have a similar function. There are four basic types of human tissues: epithelial, muscle, nervous, and connective tissues. These four tissue types, which are shown in **Figure** 2.17, make up all the organs of the human body.

- **Connective tissue** is made up of cells that form the body's structure. Examples include bone and cartilage.
- **Epithelial tissue** is made up of cells that line inner and outer body surfaces, such as the skin and the lining of the digestive tract. Epithelial tissue protects the body and its internal organs, secretes substances such as hormones, and absorbs substances such as nutrients.
- **Muscle tissue** is made up of cells that have the unique ability to contract, or become shorter. Muscles attached to bones enable the body to move.
- **Nervous tissue** is made up of **neurons**, or nerve cells, that carry electrical messages. Nervous tissue makes up the brain and the nerves that connect the brain to all parts of the body.

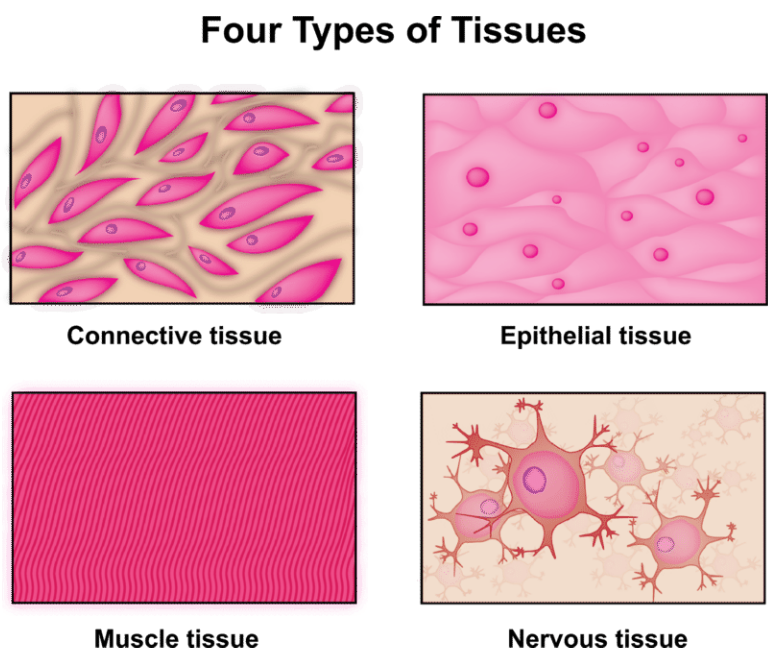


FIGURE 2.12
The human body consists of these four tissue types.

Organs and Organ Systems

After tissues, organs are the next level of organization of the human body. An **organ** is a structure that consists of two or more types of tissues that work together to do the same job. Examples of human organs include the brain, heart, lungs, skin, and kidneys. Human organs are organized into organ systems, many of which are shown in **Figure** 2.13. An **organ system** is a group of organs that work together to carry out a complex overall function. Each organ of the system does part of the larger job.

Your body's 12 organ systems are shown below (**Table** 2.2). Your organ systems do not work alone in your body. They must all be able to work together. For example, one of the most important functions of organ systems is to provide cells with oxygen and nutrients and to remove toxic waste products such as carbon dioxide. A number of organ systems, including the cardiovascular and respiratory systems, all work together to do this.

TABLE 2.2: Major Organ Systems of the Human Body

Organ System	Major Tissues and Organs	Function
Cardiovascular	Heart; blood vessels; blood	Transports oxygen, hormones, and nutrients to the body cells. Moves wastes and carbon dioxide away from cells.
Lymphatic	Lymph nodes; lymph vessels	Defend against infection and disease, moves lymph between tissues and the blood stream.
Digestive	Esophagus; stomach; small intestine; large intestine	Digests foods and absorbs nutrients, minerals, vitamins, and water.
Endocrine	Pituitary gland, hypothalamus; adrenal glands; ovaries; testes	Produces **hormones** that communicate between cells.

TABLE 2.2: (continued)

Organ System	Major Tissues and Organs	Function
Integumentary	Skin, hair, nails	Provides protection from injury and water loss, physical defense against infection by microorganisms, and temperature control.
Muscular	Cardiac (heart) muscle; skeletal muscle; smooth muscle; tendons	Involved in movement and heat production.
Nervous	Brain, spinal cord; nerves	Collects, transfers, and processes information.
Reproductive	Female: uterus; vagina; fallopian tubes; ovaries Male: penis; testes; seminal vesicles	Produces gametes (sex cells) and sex hormones.
Respiratory	Trachea, larynx, pharynx, lungs	Brings air to sites where gas exchange can occur between the blood and cells (around body) or blood and air (lungs).
Skeletal	Bones, cartilage; ligaments	Supports and protects soft tissues of body; produces blood cells; stores minerals.
Urinary	Kidneys; urinary bladder	Removes extra water, salts, and waste products from blood and body; controls pH; controls water and salt balance.
Immune	Bone marrow; spleen; white blood cells	Defends against diseases.

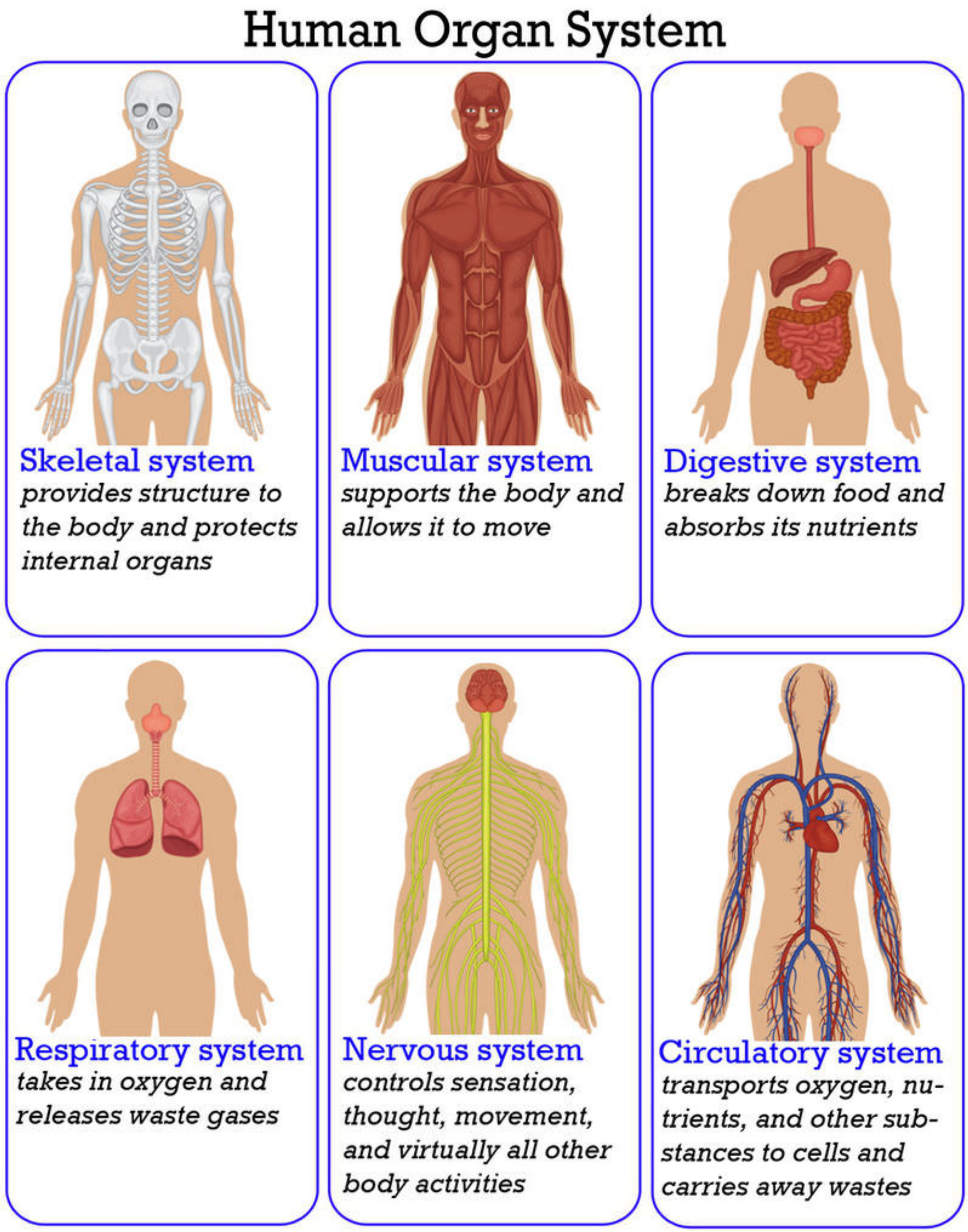


FIGURE 2.13

Many of the organ systems that make up the human body are represented here. What is the overall function of each organ system?

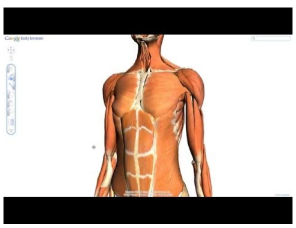
Summary

- The human body is organized at different levels, starting with the cell.
- Cells are organized into tissues, and tissues form organs.
- Organs are organized into organ systems such as the skeletal and muscular systems.

Review

1. What are the levels of organization of the human body?
2. Which type of tissue covers the surface of the body?
3. What are the functions of the skeletal system?
4. Which organ system supports the body and allows it to move?
5. Explain how form and function are related in human cells. Include examples.
6. Compare and contrast epithelial and muscle tissues.

Resources



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2.6 Cells of the Human Body - Advanced

Learning Objectives

- Outline the role of a specialized cell.
- Understand the difference between cells and stem cells.
- Understand the process of cell differentiation, and determine which types of cells undergo differentiation.
- List three types of stem cells.

How is the human body similar to a well-tuned machine?

Over and over, the human body is compared to a complex piece of machinery. Like any common machine, the human body is composed of a variety of parts, each working separately, but also working together.

Cells

Cells are the most basic units of life in your body, and each cell is specialized, with a specific function. Nerve cells transmit electrical messages around the body, and white blood cells attack invading bacteria throughout the body. Other cells include specialized cells in the kidney (such as kidney glomerulus parietal cells), brain (such as astrocytes), stomach (such as parietal cells), and muscles (such as red and white skeletal muscle fibers). Cells group together to form tissues; different tissues work together to form organs. This grouping of cells and tissues is referred to as levels of organization. Complex multicellular organisms, which include flatworms and humans, have different levels of organization. The human body's levels begin with cells and conclude with the entire organism. Flatworms, though they lack specialized circulatory and respiratory systems, also have levels of organization ranging from cells to the entire organism.

Differentiation

Every cell in the body originates from a single fertilized egg called a zygote. The zygote divides repeatedly to produce an embryo. These embryonic cells continue to divide, differentiating into all the cell types present in the body of all humans (and other mammals), from a new-born baby to an elderly adult. **Differentiation** is the process by which an unspecialized cell, such as a fertilized egg cell, divides many times to produce specialized cells. During differentiation, certain genes are turned on, or become activated, while other genes are switched off, becoming inactivated. This process is regulated by the cell. A differentiated cell will develop specific structures and perform certain functions.

A cell that is able to differentiate into all cell types within a body is called **totipotent.** They have "total potential" to differentiate into any cell type. In mammals, only the zygote and early embryonic cells are totipotent. A cell that is able to differentiate into many, but not all, cell types is called **pluripotent.** Such cells have "plural potential" (but not "total potential") to differentiate into *most* cell types. **Figure** 2.15 gives a visual representation of cell differentiation.

Stem Cells

An unspecialized cell that can divide and give rise to different specialized cells is called a **stem cell** (**Figure** 2.15). Zygotes and embryonic cells are both types of stem cells. These stem cells, called **embryonic stem cells,** can divide indefinitely and can specialize into any cell type. They are totipotent. In contrast, **adult stem cells,** also known as

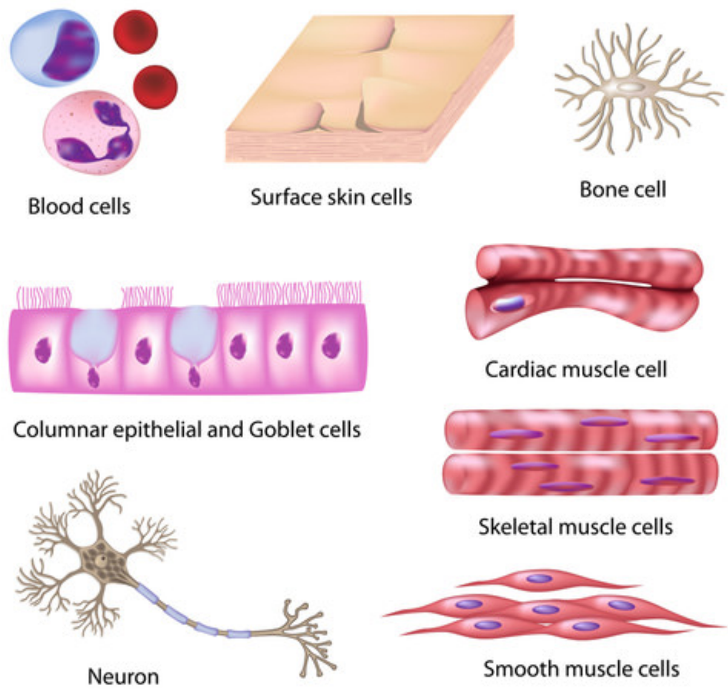

FIGURE 2.14
Different types of cells in the human body are specialized for specific jobs. Do you know the functions of any of the cell types shown here?

somatic stem cells, are undifferentiated cells found within the body that divide to replace dying cells and damaged tissues. Adult stem cells can divide indefinitely and generate all the cell types of the organ from which they originate. They can potentially re-grow the entire organ from just a few cells. A third type of stem cell is found in both the blood from the umbilical cord of a new-born baby and the placenta. These "cord blood stem cells" are considered to be adult stem cells because they cannot generate all body cell types, just different types of blood cells. Adult stem cells and cord blood stem cells are pluripotent.

Stem Cells in Medicine

Stem cells are of great interest to researchers because of their ability to both divide indefinitely and differentiate into many cell types. Stem cells have many existing and even more potential therapeutic applications. Such therapies include treatments for cancer, blood disorders, brain or spinal cord injuries, and blindness.

Embryonic stem cells, shown in **Figure** 2.16, are taken from eggs that were donated to research and fertilized in the laboratory. These stem cells may have the greatest potential because they are totipotent and thus have the most potential medical applications. However, embryonic stem cells are relatively controversial. Some individuals and groups have objections to the harvesting of embryonic stem cells because harvesting the stem cells involves the destruction of the embryo. Some researchers are looking into methods of extracting embryonic stem cells without destroying the actual embryo. Other researchers have claimed success in harvesting embryonic stem cells from the embryonic fluid that surrounds a growing fetus. Additionally, stem cells harvested from a donated embryo differ from a potential patient's tissue type. Therefore, just as in organ transplantation, there is a risk that the patient's body may reject the transplanted embryonic stem cells.

Adult stem cells, including cord blood stem cells, have already been used to treat diseases of the blood such as sickle-cell anemia and certain types of cancer. Unlike embryonic stem cells, the use of adult stem cells in research and therapy is not controversial because the production of adult stem cells does not require the destruction of an embryo. Adult stem cells can be isolated from tissue samples, such as bone marrow, of a patient. Scientists have

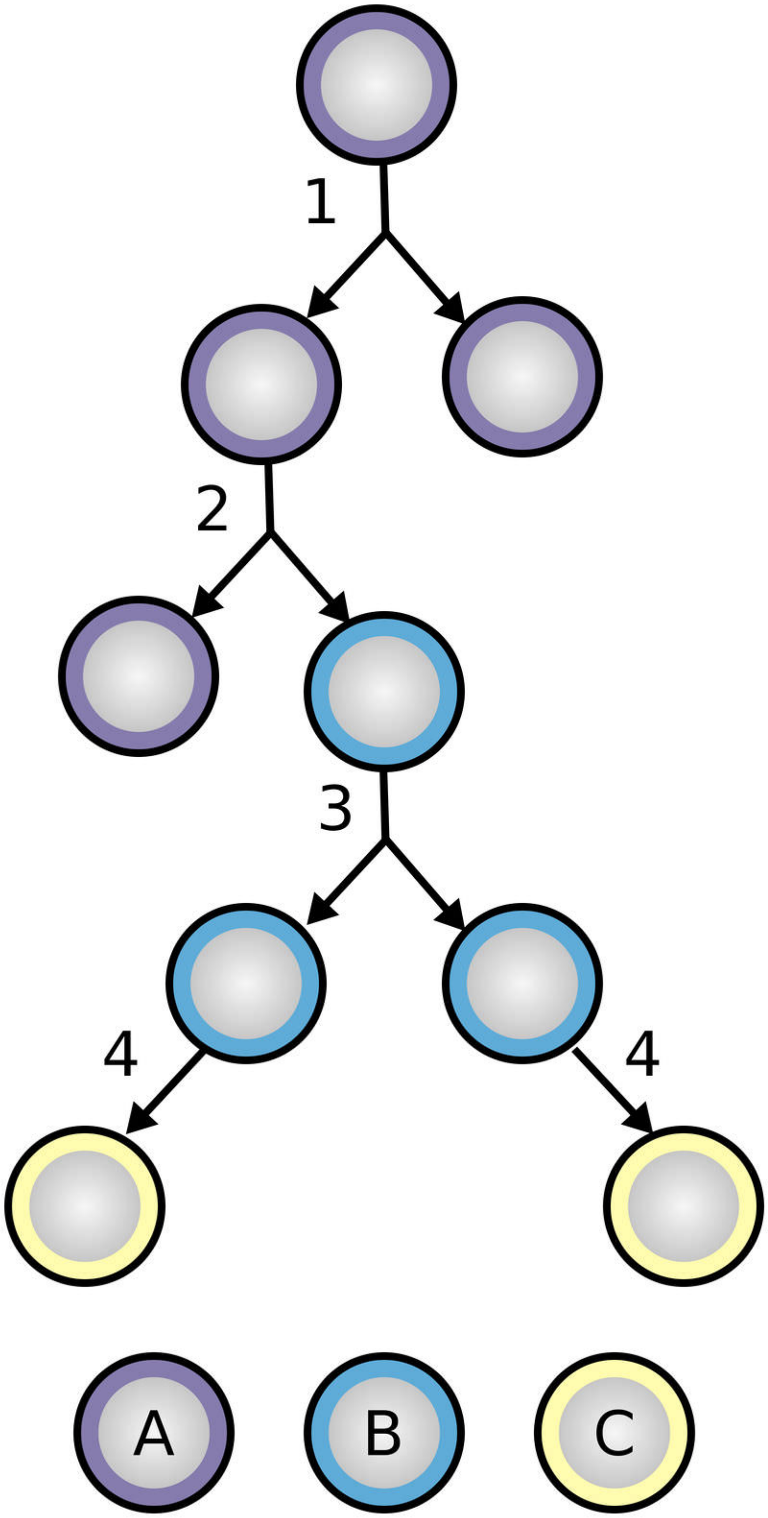

FIGURE 2.15
Division and differentiation of stem cells into specialized cells.

recently discovered more sources of adult stem cells in the body including in body fat, the inside lining of the nose, and the brain. Some researchers are investigating ways to revert adult stem cells back to a totipotent stage.

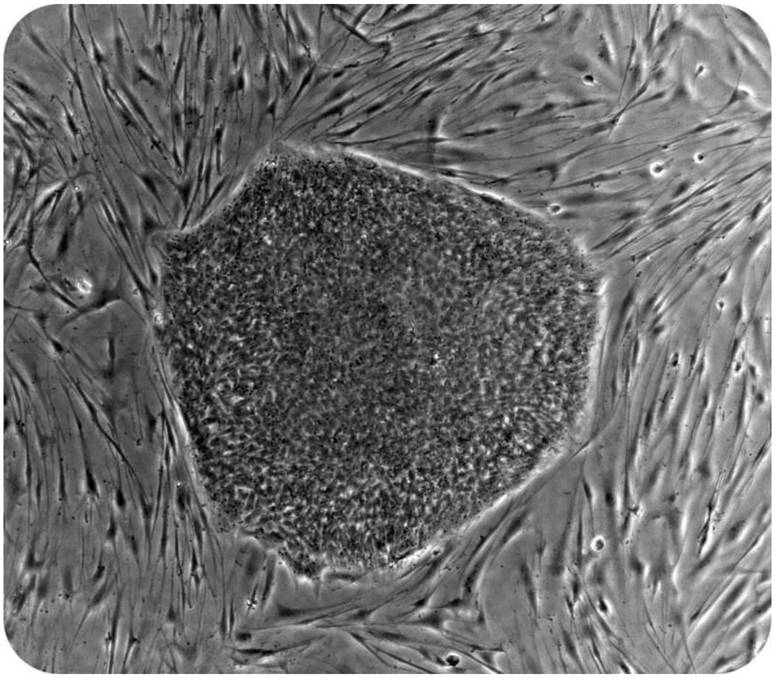

FIGURE 2.16
A human embryonic stem cell colony, which was grown in a laboratory on a feeder layer of mouse cells.

Summary

- Cells are the most basic units of life found in the human body and any living organism.
- Stem cells undergo the process of differentiation to become specialized cells.

Review

1. What are totipotent and pluripotent cells?
2. What are stem cells? Where do they come from?

Explore More

MEDIA
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Use the video above to answer the following questions:

1. When did scientists first understand the idea of differentiation?
2. What changes in a totipotent cell to make it specialize?
3. Can a blood stem cell become a muscle, brain, and/or liver cell?

2.7 Tissues of the Human Body - Advanced

Learning Objectives

- Identify the four tissue types found in the human body.

Muscle, connective, skeletal, and epithelial. What do these have in common?

Tissues

A **tissue** is a group of connected cells that have a similar function within an organism. The simplest living, multicellular organisms, sponges, are made of many specialized types of cells that work together for a common goal. Such cell types include digestive cells, tubular pore cells, and epidermal cells. Though the different cell types create a large organized, multicellular structure—the visible sponge—they are not organized into true tissues. If a sponge is broken up by passing it through a sieve, the sponge will reform on the other side.

More complex organisms, such as jellyfish, coral, and sea anemones, have a tissue level of organization. For example, jellyfish have tissues that have separate protective, digestive, and sensory functions. There are four basic types of tissues in the bodies of all animals including the human body. These make up all the organs, structures, and other contents of the body. **Figure** 2.18 shows an example of each tissue type. The four basic types of tissues are epithelial, muscle, nervous, and connective.

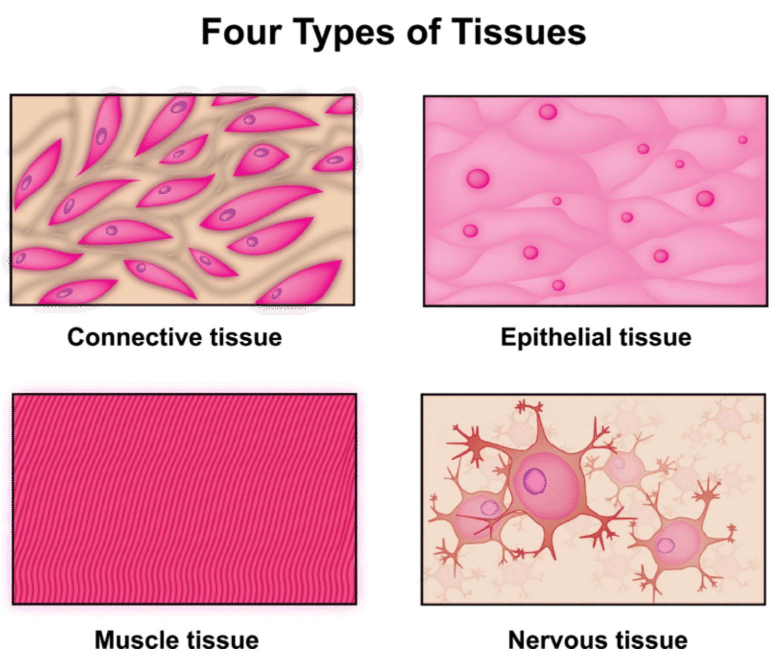


FIGURE 2.17
The human body consists of these four tissue types.

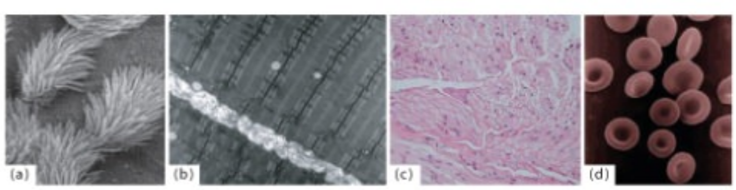


FIGURE 2.18
(a) A scanning electron micrograph (SEM) image of lung trachea epithelial tissue. (b) A transmission electron micrograph (TEM) image of skeletal muscle tissue. (c) A light microscope image of neurons of nervous tissue. (d) Red blood cells, a connective tissue.

Epithelial tissue is made up of a layer or layers of tightly packed cells that line the surfaces of the body. The largest example of epithelial tissue (also the largest organ in the human body) is the skin. Mammalian skin consists of stratified epithelium, which has several layers of cells. The outermost layers of cells, called squamous cells, are flat plate-like cells, while the deeper layers are roughly cube shaped and called cuboidal cells. Epithelial tissue has multiple functions, but it serves primarily to protect, absorb, and secrete. As you probably already know, our skin organ covers our entire body and protects underlying tissues from bacteria, chemicals, and other injury. Epithelial cells also line the small intestine where they absorb nutrients, and similar cells in the glands secrete enzymes and hormones.

Muscle tissue encompasses not only the muscles, such as those in our legs or fingers, that we actively control, but also the tissue that forms most of our internal organs. There are three types of muscle tissue: skeletal, cardiac, and smooth. Skeletal muscle tissue forms what we think of as our muscles; it is attached to our bones by our tendons and can be relaxed or contracted voluntarily. Similar in structure to skeletal muscle, cardiac muscle is found exclusively in the walls of the heart. The major difference, however, is that cardiac muscle is involuntary and cannot be actively controlled. Similarly, smooth muscle, which forms the muscle layers in internal organs such as the digestive tract and bladder, is an involuntary tissue. Smooth muscle tissue controls slow involuntary movements such as stomach wall contractions and the contractions of arteries to regulate blood flow.

Nervous tissue is made up of the nerve cells (neurons) that form the nervous system, including the brain and spinal cord. These cells are especially responsive to stimuli, allowing nervous tissue to transmit stimuli from the brain to the body extremely rapidly.

Connective tissue connects, supports, or separates other tissues and organs. Connective tissue proper, a form of connective tissue, can be either loose or dense. Adipose tissue, or fat, is loose connective tissue, while tendons and ligaments, composed of collagen, are examples of dense connective tissue. Other forms of connective tissue include blood (fluid connective tissue) and cartilage and bone (both forms of supporting connective tissue).

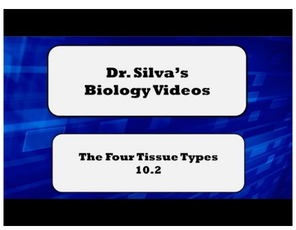
Summary

- Tissues are composed of cells, and multiple tissues together constitute an organ.
- The human body has four types of tissues: nervous, muscle, connective, and epithelial

Review

1. What are the four types of tissues? Give an example of each.
2. What is the difference between tissue and cellular level organization?
3. Are there any organisms that do not have tissue structures? If yes, what organism(s)?

Explore More



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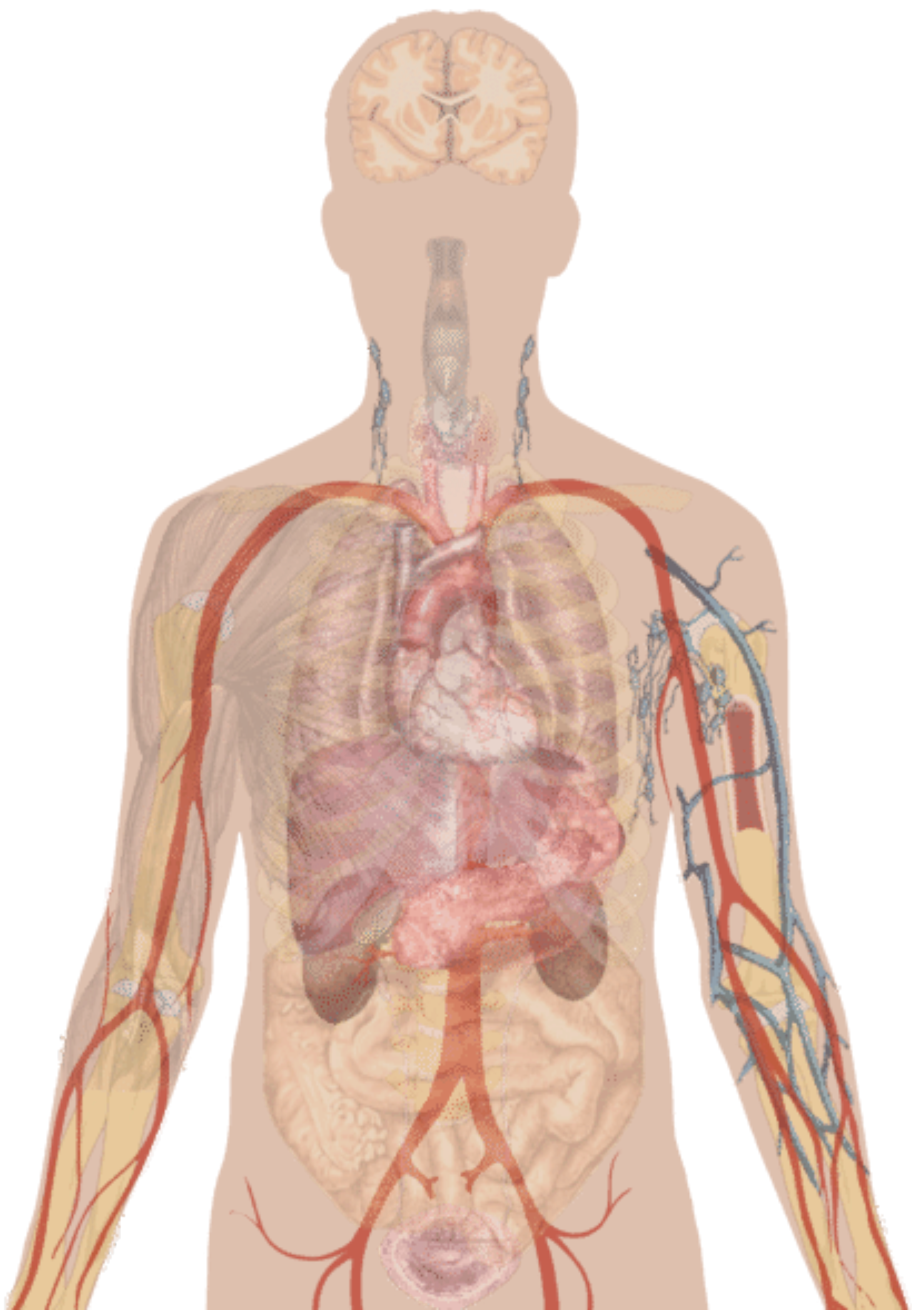
Use the video above to answer the following questions:

1. What are some different types of connective tissue?
2. What is the extracellular matrix?
3. What are the differences between skeletal, cardiac, and smooth muscle tissue?

2.8 Human Organs and Organ Systems - Advanced

Learning Objectives

- Summarize how tissues and organs relate to each other.
- Identify the defining features of organs and organ systems.
- Understand the relationship between organs and organ systems.



Organs and Organ Systems

Organs are the next level of organization in the body. An **organ** is a structure made of two or more tissues that work together for a common purpose. Skin, the largest organ in the body, is shown in **Figure** 2.19. Organs can be as primitive as the brain of a flatworm (a group of nerve cells), as large as the stem of a sequoia (up to 90 meters (300 feet) in height), or as complex as a human liver. The human body has many different organs including the heart, the kidneys, the pancreas, and the skin. Two or all of the tissue types can be found in each organ. Organs inside the body are called internal organs. The internal organs collectively are often called **viscera.**

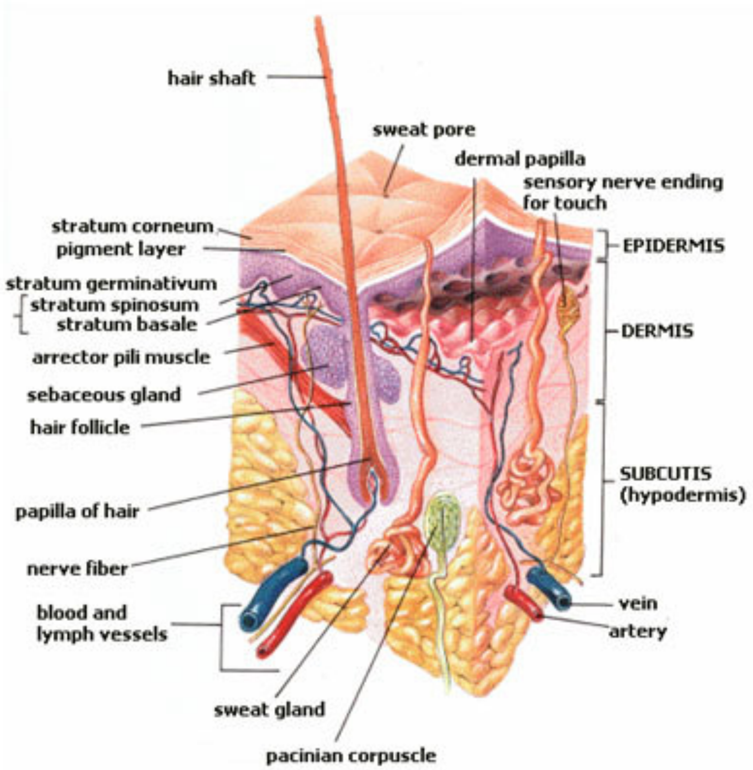


FIGURE 2.19
Your skin is the largest organ in your body. In this cross section image of skin, the four different tissue types (epithelial, connective, nervous, and muscle tissues) can be seen working together.

The most complex organisms have organ systems. An **organ system** is a group of organs that act together to carry out complex, interrelated functions, with each organ focusing on a subset of the task. For example, the human digestive system is an organ system in which the mouth and esophagus ingest food, the stomach crushes and liquefies it, the pancreas and gall bladder make and release digestive enzymes, and the intestines absorb nutrients into the blood. An organ can be part of more than one organ system. For example, the ovaries produce hormones, which makes them a part of the endocrine system; the ovaries also make eggs, which makes them a part of the reproductive system as well. One of the most important functions of organ systems is to provide cells with oxygen and nutrients and to remove toxic waste products such as carbon dioxide. A number of organ systems, including the cardiovascular and respiratory systems, work together to do this.

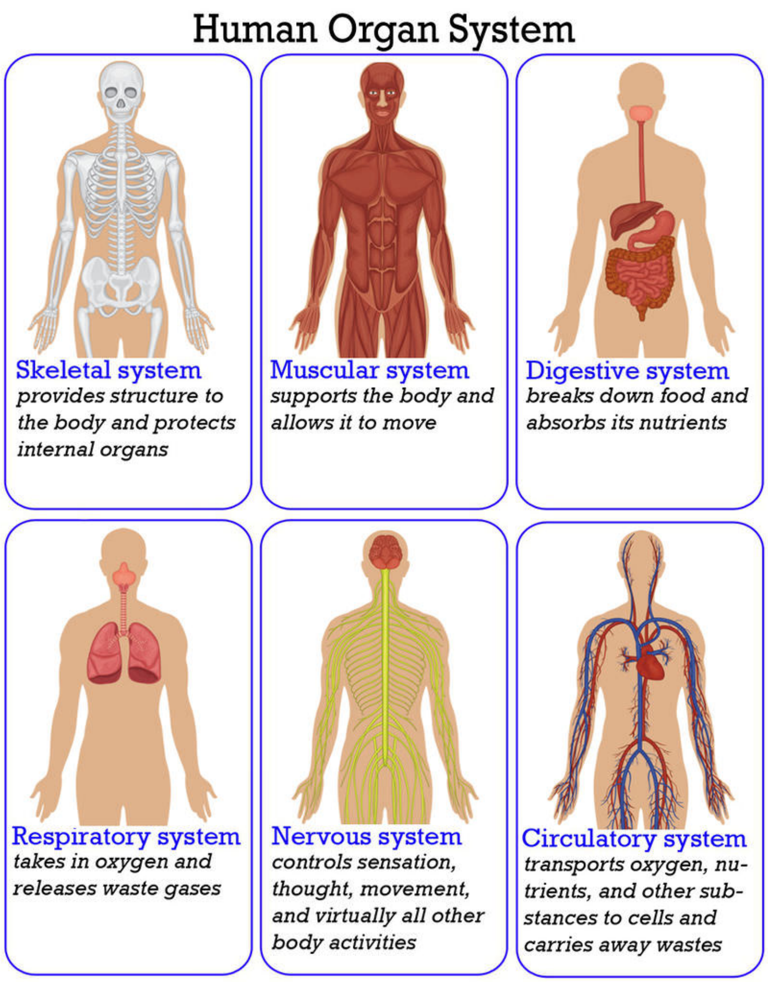


FIGURE 2.20
Many of the organ systems that make up the human body are represented here. What is the overall function of each organ system?

The different organ systems of the body are shown in **Table** 2.3. Sometimes the cardiovascular system and the lymphatic system are grouped together into one single system called the circulatory system.

TABLE 2.3: Major Organ Systems of the Human Body

Organ System	Function	Organs, Tissues, and Structures Involved
Cardiovascular	Transports oxygen, nutrients, and other substances to the cells, and transports wastes, carbon dioxide, and other substances away from the cells; it can also help stabilize body temperature and pH.	Heart, blood, and blood vessels.
Lymphatic	Defends against infection and disease. Transfers lymph between tissues and the blood stream.	Lymph, lymph nodes, and lymph vessels.
Digestive	Processes foods and absorbs nutrients, minerals, vitamins, and water.	Salivary glands, esophagus, stomach, liver, gallbladder, pancreas, small intestine, and large intestine.

TABLE 2.3: (continued)

Organ System	Function	Organs, Tissues, and Structures Involved
Endocrine	Provides communication within the body via hormones. Directs long-term change over other organ systems to maintain homeostasis.	Pituitary gland, pineal gland, thyroid, parathyroid gland, adrenal glands, testes, and ovaries.
Integumentary	Provides protection from both injury and fluid loss and provides physical defense against infection by microorganisms. Controls temperature.	Skin, hair, and nails.
Muscular	Provides movement, support, and heat production.	Tendons, skeletal, cardiac, and smooth muscles.
Nervous	Collects, transfers, and processes information. Directs short-term change over other organ systems in order to maintain homeostasis.	Brain, spinal cord, nerves, and sensory organs (eyes, ears, tongue, skin, and nose).
Reproductive	Produces gametes (sex cells) and sex hormones; ultimately produces offspring.	Fallopian tubes, uterus, vagina, ovaries, mammary glands, testes, vas deferens, seminal vesicles, prostate, and penis.
Respiratory	Delivers air to sites where gas exchange can occur between the blood and cells (around body) or blood and air (lungs).	Mouth, nose, pharynx, larynx, trachea, bronchi, lungs, and diaphragm.
Skeletal	Supports and protects soft tissues of the body. Provides movement at joints, produces blood cells, and stores minerals.	Bones, cartilage, and ligaments.
Urinary	Removes excess water, salts, and waste products from the blood and body. Controls pH.	Kidneys, ureters, urinary bladder, and urethra.
Immune	Defends against microbial pathogens (disease-causing agents) and other diseases.	Leukocytes, tonsils, adenoids, thymus, and spleen.

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Summary

- Organs are structures composed of two or more tissues; organ systems are systems composed of two or more organs.
- Organ systems carry out complex tasks, with each organ completing one aspect of the task.

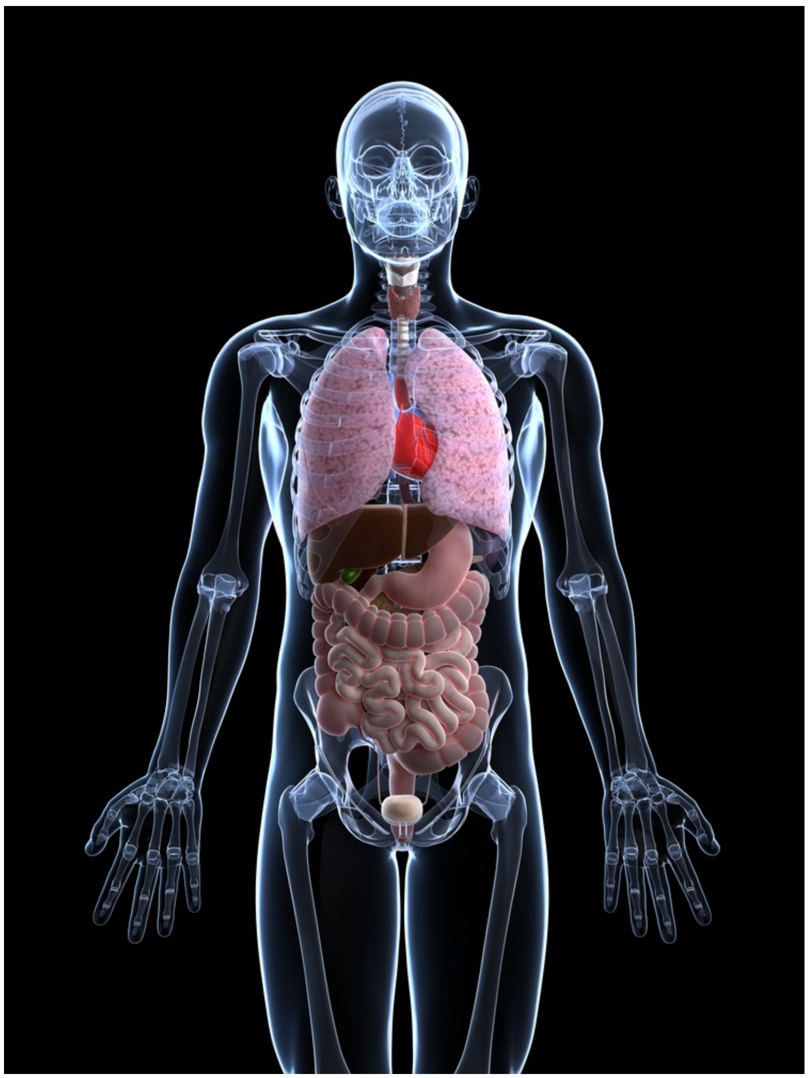
Review

1. What is the difference between an organ and an organ system?
2. How many major organ systems are there? What are they?

2.9 System Interactions in the Human Body - Advanced

Learning Objectives

- Name and describe two body systems that work together for a common purpose.
- Summarize the role of the endocrine system in homeostasis.
- Outline the result of a disturbance in the homeostasis of a body system.



What do you get when the body systems interact?

You get an organism. Here we easily recognize parts of the respiratory, circulatory, digestive, and skeletal systems. Though these can function alone, they need to work together to make a living organism. They also need to work with the the endocrine and nervous systems, as well as the other systems.

System Interactions

Each body system contributes to the **homeostasis** of other systems and of the entire organism. No system of the body works in isolation, and the well-being of the person depends upon the well-being of all the interacting body systems. A disruption within one system generally has consequences for several other body systems. Most of these organ systems are controlled by **hormones** secreted from the pituitary gland, a part of the endocrine system. **Table** 2.4 summarizes how various body systems work together to maintain homeostasis.

Main examples of homeostasis in mammals are as follows:

- The regulation of the amounts of water and minerals in the body. This is known as **osmoregulation.** This happens primarily in the kidneys.
- The removal of metabolic waste. This is known as **excretion.** This is done by the excretory organs such as the kidneys and lungs.
- The regulation of body temperature. This is mainly done by the skin.
- The regulation of blood glucose levels. This is mainly done by the liver and the insulin and glucagon secreted by the pancreas.

TABLE 2.4: Types of Homeostatic Regulation in the Body

	Homeostatic Processes	Hormones and Other Messengers	Tissues, Organs, and Organ Systems Involved
Osmoregulation (also called excretion)	Excess water, salts, and urea expelled from the body.	Antidiuretic hormone (ADH), aldosterone, angiotensin II, and carbon dioxide.	Kidneys, urinary bladder, ureters, urethra (urinary system), pituitary gland (endocrine system), and lungs (respiratory system).
Thermoregulation	Sweating, shivering, dilation/constriction of blood vessels at the skin surface, insulation by adipose tissue, and breakdown of adipose tissue to produce heat.	Nerve impulses.	Skeletal muscle (muscular system), nerves (nervous system), blood vessels (cardiovascular system), skin and adipose tissue (integumentary system), and hypothalamus (endocrine system).
Chemical Regulation (including glucoregulation)	Release of insulin and glucagon into the blood in response to rising and falling blood glucose levels respectively. Increase in breathing rate in response to increased carbon dioxide levels in the blood, release of carbon dioxide into exhaled air from the lungs, and secretion of erythropoietin by kidneys to stimulate formation of red blood cells.	Insulin, glucagon, cortisol, carbon dioxide, nerve impulses, and erythropoietin (EPO).	Pancreas (endocrine system), liver (digestive system), adrenal glands (endocrine system), lungs (respiratory system), brain (nervous system), and kidneys (urinary system).

Endocrine System

The endocrine system, shown in **Figure** 2.21, includes glands that secrete hormones into the bloodstream. Hormones are chemical messenger molecules that are made by cells in one part of the body and cause changes in cells in another part of the body. The endocrine system regulates the metabolism and development of most body cells and body systems through feedback mechanisms. For example, Thyrotropin-Releasing Hormone (TRH) and Thyroid Stimulating Hormone (TSH) are controlled by a number of negative feedback mechanisms. The endocrine glands also release hormones that affect skin and hair color, appetite, and secondary sex characteristics of both males and females.

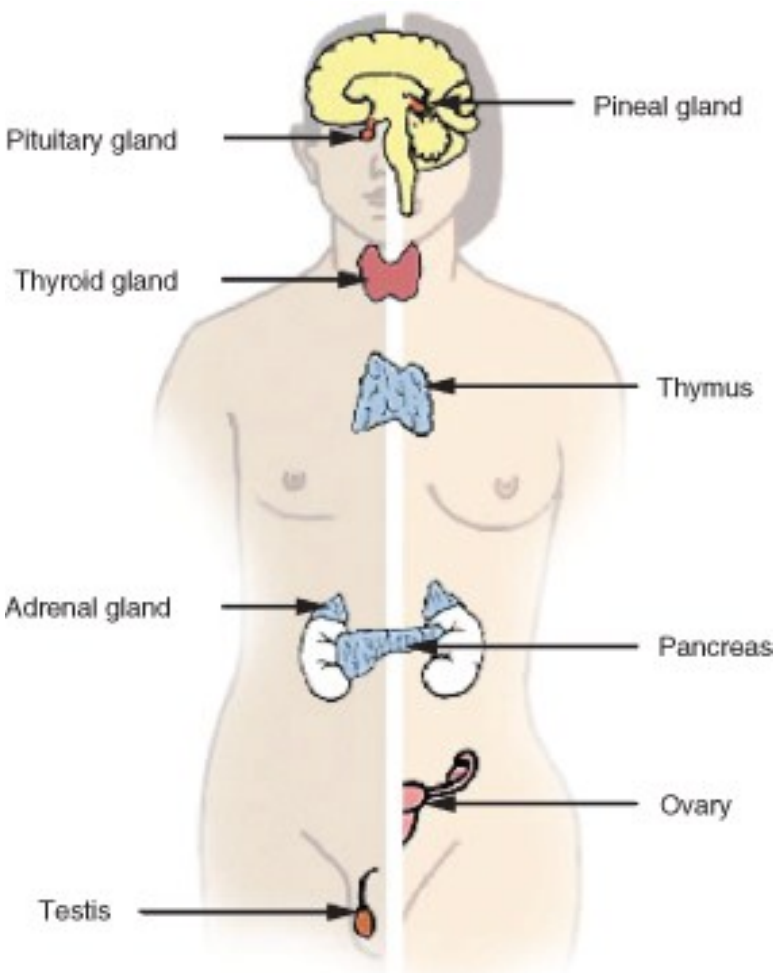


FIGURE 2.21
The endocrine system controls almost every other body system through feedback mechanisms. Most of the mechanisms of the endocrine system are negative feedback loops.

The endocrine system has a regulatory effect on other organ systems in the human body. In the muscular system, hormones adjust muscle metabolism, energy production, and growth. In the nervous system, hormones affect neural metabolism, regulate fluid and ion concentrations, and help with reproductive hormones that influence brain development.

Urinary System

Toxic wastes build up in the blood as proteins and nucleic acids are broken down and used by the body. The urinary system rids the body of these wastes. The urinary system is also directly involved in maintaining proper blood volume. The kidneys also play an important role in maintaining the correct salt and water contents of the body.

External changes, such as warm weather, that lead to excess fluid loss trigger feedback mechanisms that act to maintain the body's fluid content by inhibiting fluid loss. The kidneys also produce a hormone called erythropoietin, also known as EPO, which stimulates red blood cell production.

Reproductive System

The reproductive system does little for the homeostasis of the organism. The reproductive system relates instead to the maintenance of the species. However, sex hormones do have an effect on other body systems, and an imbalance in sex hormones can lead to various disorders. For example, a woman whose ovaries are removed early in life is at higher risk of developing osteoporosis, a disorder in which bones are thin and break easily. The hormone estrogen, produced by the ovaries, is important for bone growth. Therefore, a woman who does not produce estrogen will have impaired bone development.

Summary

- The body systems constantly interact with each other to maintain homeostasis.

Review

1. Define homeostasis.
2. What is meant by body system interactions?
3. Give an example of a body system interaction.

2.10 Respiratory System

- Describe how breathing works.
- Define respiration, inhalation, and exhalation.
- Summarize how the lungs allow air in, and how inhaled oxygen enters the bloodstream.

Why do you breathe?

We breathe because we need oxygen. Breathing also releases carbon dioxide from our bodies into the air. The respiratory system is the body system that brings air containing oxygen into the body and releases carbon dioxide into the atmosphere. Recall that oxygen is needed to make ATP.

How We Breathe

Most of the time, you breathe without thinking about it. Breathing is mostly an involuntary action that is controlled by a part of your brain that also controls your heart beat. If you swim, do yoga, or sing, you know you can control your breathing, however. Taking air into the body through the nose and mouth is called **inhalation**. Pushing air out of the body through the nose or mouth is called **exhalation**. The woman pictured below is exhaling before she surfaces from the pool water (**Figure** 2.22).

FIGURE 2.22
Being able to control breathing is important for many activities, such as swimming. The woman in the photograph is exhaling as she exits the water.

How do lungs allow air in? Air moves into and out of the lungs by the movement of muscles. The most important muscle in the process of breathing is the **diaphragm**, a sheet of muscle that spreads across the bottom of the rib cage. The diaphragm and rib muscles contract and relax to move air into and out of the lungs. During inhalation, the diaphragm contracts and moves downward. The rib muscles contract and cause the ribs to move outward. This causes the chest volume to increase. Because the chest volume is larger, the air pressure inside the lungs is lower than the air pressure outside. This difference in air pressures causes air to be sucked into the lungs. When the diaphragm and rib muscles relax, air is pushed out of the lungs. Exhalation is similar to letting the air out of a balloon.

How does the inhaled oxygen get into the bloodstream? The exchange of gasses between the lungs and the blood happens in tiny sacs called **alveoli**. The walls of the alveoli are very thin and allow gases to pass though them. The alveoli are lined with capillaries (**Figure** 2.23). Oxygen moves from the alveoli to the blood in the capillaries that surround the alveoli. At the same time, carbon dioxide moves in the opposite direction, from capillary blood to the alveoli. The gases move by simple diffusion, passing from an area of high concentration to an area of low concentration. For example, initially there is more oxygen in the alveoli than in the blood, so oxygen moves by diffusion from the alveoli into the blood.

Breathing and Respiration

The process of getting oxygen into the body and releasing carbon dioxide is called **respiration**. Sometimes breathing is called respiration, but there is much more to respiration than just breathing. Breathing is only the movement of oxygen into the body and carbon dioxide out of the body. The process of respiration also includes the exchange of oxygen and carbon dioxide between the blood and the cells of the body.

Summary

- The diaphragm and rib muscles contract when you inhale and relax when you exhale.

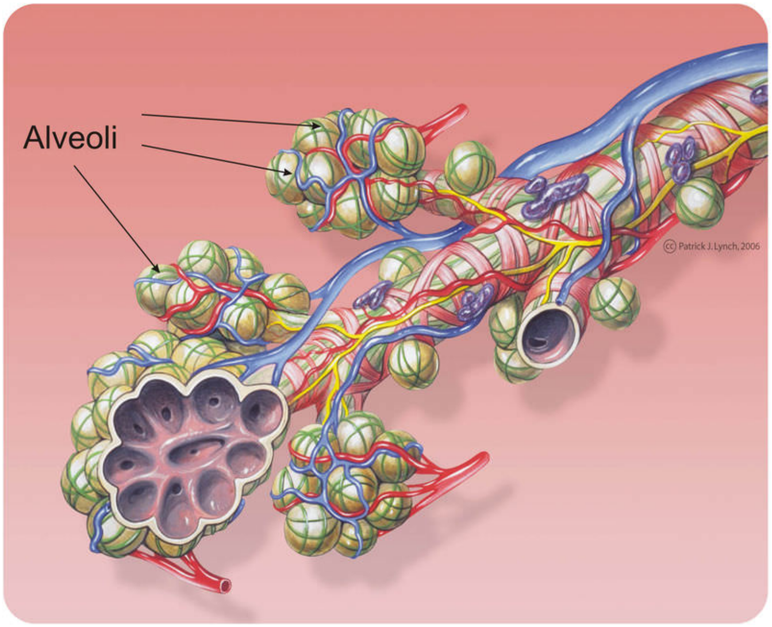


FIGURE 2.23
During respiration, oxygen gets pulled into the lungs and enters the blood by passing across the thin alveoli membranes and into the capillaries. The alveoli are at the end of the long air passages.

- The process of getting oxygen into the body and releasing carbon dioxide is called respiration.

Explore More

1. What happens to air as it enters the respiratory system? List three things.
2. What happens at the alveolar sacs? How does this occur?
3. What is the function of the epiglottis?

Review

1. In what part of the lung does gas exchange occur?
2. What causes the gases to move in the lungs during gas exchange?
3. What is the difference between breathing and respiration?

2.11 Cardiovascular System

Learning Objectives

- List the components of the cardiovascular system.
- Explain the main function of the cardiovascular system.
- Describe additional functions of the cardiovascular system.

What do you do for "cardio"?

"Cardio" has become slang for aerobic exercise that raises your heart rate for an extended amount of time. Cardio can include biking, running, or swimming. Can you guess one of the main organs of the cardiovascular system? Yes, your heart.

Functions of the Cardiovascular System

Your cardiovascular system has many jobs. At times the cardiovascular system can work like a pump, a heating system, or even a postal carrier. To do these tasks, your cardiovascular system works with other organ systems, such as the respiratory, endocrine, and nervous systems.

The **cardiovascular system** (**Figure** 2.24) is made up of the heart, the blood vessels, and the blood. It moves nutrients, gases (like oxygen), and wastes to and from your cells. Every cell in your body depends on your cardiovascular system. If your cells don't receive nutrients, they cannot survive. The main function of the cardiovascular system is to deliver oxygen to each of your cells. Blood receives oxygen in your lungs (the main organs of the respiratory system) and then is pumped, by your heart, throughout your body. The oxygen then diffuses into your cells, and carbon dioxide, a waste product of cellular respiration, moves from your cells into your blood to be delivered back to your lungs and exhaled. Each cell in your body needs oxygen, as oxygen is used in cellular respiration to produce energy in the form of ATP. Without oxygen, lactic acid fermentation would occur in your cells, which can only be maintained for a brief period of time. Arteries carry blood full of oxygen ("oxygen-rich") away from the heart and veins return oxygen-poor blood back to the heart.

The cardiovascular system also plays a role in maintaining body temperature. It helps to keep you warm by moving warm blood around your body. Your blood vessels also control your body temperature to keep you from getting too hot or too cold. When your brain senses that your body temperature is increasing, it sends messages to the blood vessels in the skin to increase in diameter. Increasing the diameter of the blood vessels increases the amount of blood and heat that moves near the skin's surface. The heat is then released from the skin. This helps you cool down. What do you think your blood vessels do when your body temperature is decreasing?

The blood also carries hormones, which are chemical messenger molecules produced by organs of the endocrine system, through your body. Hormones are produced in one area of your body and have an effect on another area. To get to that other area, they must travel through your blood. An example is the hormone adrenaline, produced by the adrenal glands on top of the kidneys. Adrenaline has multiple effects on the heart (it quickens the heart rate), on muscles and on the airway.

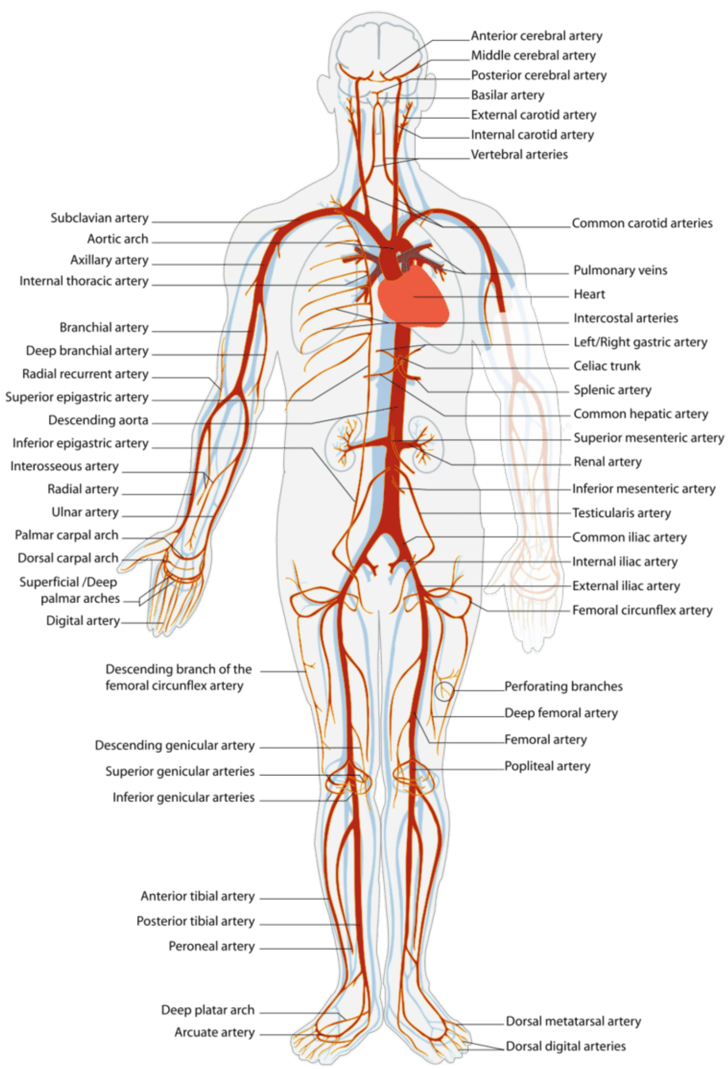


FIGURE 2.24

The cardiovascular system moves nutrients and other substances throughout the body.

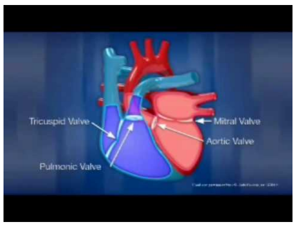
Summary

- The cardiovascular system is made up of the heart, the blood vessels, and the blood.
- The cardiovascular system moves nutrients, hormones, gases, and wastes to and from your cells.

Explore More

Use the resource below to answer the questions that follow.

- **Intro To The Cardiovascular System**



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1. Where does blood enter the heart? Where does it exit the heart?
2. How does blood entering the right side of the heart differ from blood entering the left side of the heart?
3. Why is it important for the heart to have one-way valves? How do you think a leaky valve affects the functioning of the heart?
4. What are coronary arteries? What are their function? How are they involved in heart disease?

Review

1. List three components of the cardiovascular system.
2. List the main functions of the cardiovascular system.
3. Why does each cell in your body need oxygen?
4. Complete this sentence: _______ carry blood full of oxygen _______ from the heart and _______ return oxygen-poor blood back to the heart.

2.12 Blood

Learning Objectives

- List the components of the blood.
- Describe the main roles of red blood cells and white blood cells.
- List the types of white blood cells and explain their functions.
- Summarize the importance of platelets.

What's in your blood?

These bags of blood will be stored until they are needed for a transfusion. But what exactly is blood? What makes up the blood? Most of your blood is water. However, there are also many other important components of your blood.

Components of Blood

Did you know that blood is a tissue? Blood is a fluid connective tissue that is made up of red blood cells, white blood cells, platelets, and plasma. The cells that make up blood are pictured below (**Figure** 2.25). The different parts of blood have different roles.

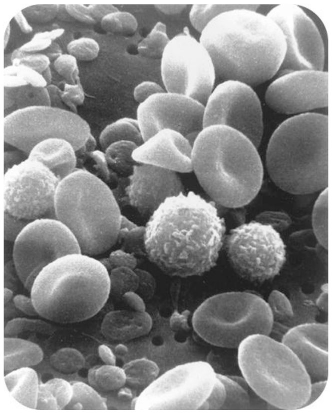


FIGURE 2.25
A scanning electron microscope (SEM) image of human blood cells. Red blood cells are the flat, bowl-shaped cells, the tiny disc-shaped pieces are platelets, and white blood cells are the round cells shown in the center.

Plasma

If you were to filter out all the cells in blood, a golden-yellow liquid would be left behind. **Plasma** is this fluid part of the blood. Plasma is about 90% water and about 10% dissolved proteins, glucose, ions, hormones, and gases. Blood is made up mostly of plasma.

Red Blood Cells

Red blood cells (RBCs) are flattened, disk-shaped cells that carry oxygen. They are the most common blood cell in the blood. There are about 4 to 6 million RBCs per cubic millimeter of blood. Each RBC has about 200 million molecules of hemoglobin. **Hemoglobin** is the protein that carries oxygen. Hemoglobin also gives the red blood cells their red color.

Red blood cells (**Figure** 2.26) are made in the red marrow of long bones, rib bones, the skull, and vertebrae. Each red blood cell lives for only 120 days (about four months). After this time, they are destroyed in the liver and spleen. Mature red blood cells do not have a nucleus or other organelles. Lacking these components allows the cells to have more hemoglobin and carry more oxygen.

FIGURE 2.26
The flattened shape of red blood cells helps them carry more oxygen than if they were rounded.

White Blood Cells

White blood cells (WBCs) are usually larger than red blood cells. They do not have hemoglobin and do not carry oxygen. White blood cells make up less than one percent of the blood's volume. Most WBCs are made in the bone marrow, and some mature in the lymphatic system. There are different WBCs with different jobs. WBCs defend the body against infection by bacteria, viruses, and other **pathogens**. WBCs do have a nucleus and other organelles.

- Neutrophils are WBCs that can squeeze through capillary walls and swallow particles such as bacteria and parasites.
- Macrophages are large WBCs that can also swallow and destroy old and dying cells, bacteria, or viruses. Below, a macrophage is attacking and swallowing two particles, possibly disease-causing pathogens (**Figure** 2.27). Macrophages also release chemical messages that cause the number of WBCs to increase.
- Lymphocytes are WBCs that fight infections caused by viruses and bacteria. Some lymphocytes attack and kill cancer cells. Lymphocytes called B-cells make antibodies.

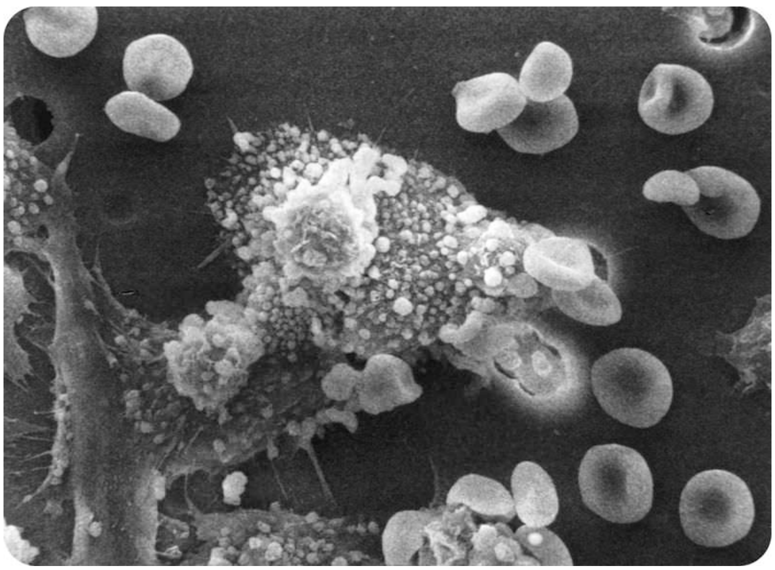


FIGURE 2.27
A type of white blood cell, called a macrophage, is attacking a cancer cell.

Platelets

Platelets (**Figure** 2.28) are very small, but they are very important in blood clotting. Platelets are not cells. They are sticky little pieces of larger cells. Platelets bud off large cells that stay in the bone marrow. When a blood vessel gets cut, platelets stick to the injured areas. They release chemicals called clotting factors, which cause proteins to form over the wound. This web of proteins catches red blood cells and forms a clot. This clot stops more blood from leaving the body through the cut blood vessel. The clot also stops bacteria from entering the body. Platelets survive in the blood for ten days before they are removed by the liver and spleen.

Science Friday: True BloodSuckers - Leeches

Leeches seem like disgusting creatures with little intelligence. But, in this video by Science Friday, Dr. Mark Siddall discusses his research on leeches and some of their interesting properties.

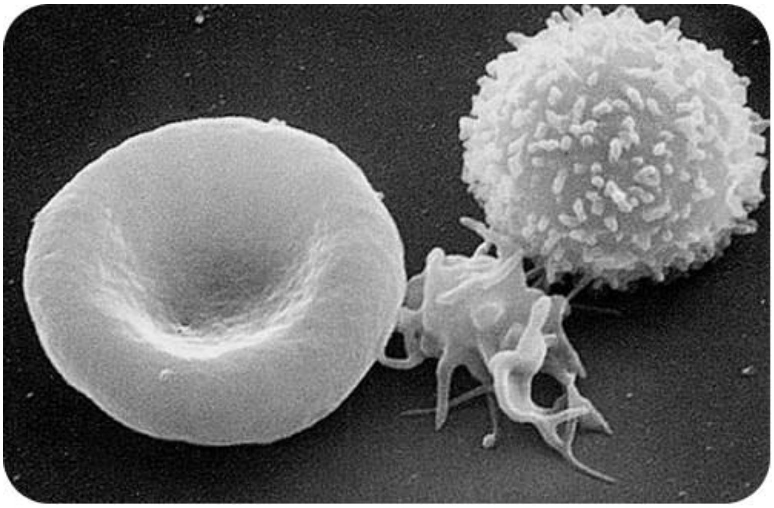
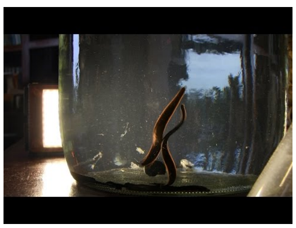


FIGURE 2.28
A platelet lies between a red blood cell, at left, and a white blood cell at right. Platelets are little pieces of larger cells that are found in the bone marrow.



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Summary

- Plasma, the fluid part of the blood, is mostly made up of water but also contains dissolved proteins, glucose, ions, hormones, and gases.
- Red blood cells carry oxygen, while white blood cells defend the body against infection by bacteria, viruses, and other diseases.

Explore More

Use the resource below to answer the questions that follow.

- **The Components of Blood** at http://www.youtube.com/watch?v=C5qmKirdiic (2:01)

MEDIA
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URL: http://www.ck12.org/flx/render/embeddedobject/57526

1. What is another name for red blood cells? What is the function of red blood cells?
2. Why are red blood cells red?
3. What is another name for white bloods cells? What is the function of white blood cells?
4. What is another name for platelets? What is the function of platelets?

Review

1. Is blood a tissue? Explain your answer.
2. What is the purpose of the white blood cells?
3. What is the purpose of the red blood cells?
4. What are macrophages?
5. What are platelets? What is the primary role of platelets?

2.13 Heart

Learning Objectives

- Describe the structure of the heart.
- Explain the function of each heart chamber.
- Summarize how blood moves through the heart.

Where is your heart?

Place your hand on your heart. Did you put your hand on the left side of your chest? Most people do, but the heart is actually located closer to the center of the chest.

The Heart

What does the heart look like? How does it pump blood? The heart is divided into four chambers (**Figure** 2.29), or spaces: the left and right atria, and the left and right ventricles. An **atrium** (singular for atria) is one of the two small, thin-walled chambers on the top of the heart where the blood first enters. A **ventricle** is one of the two muscular V-shaped chambers that pump blood out of the heart. You can remember they are called ventricles because they are shaped like a "V."

The atria receive the blood, and the ventricles pump the blood out of the heart. Each of the four chambers of the heart has a specific job.

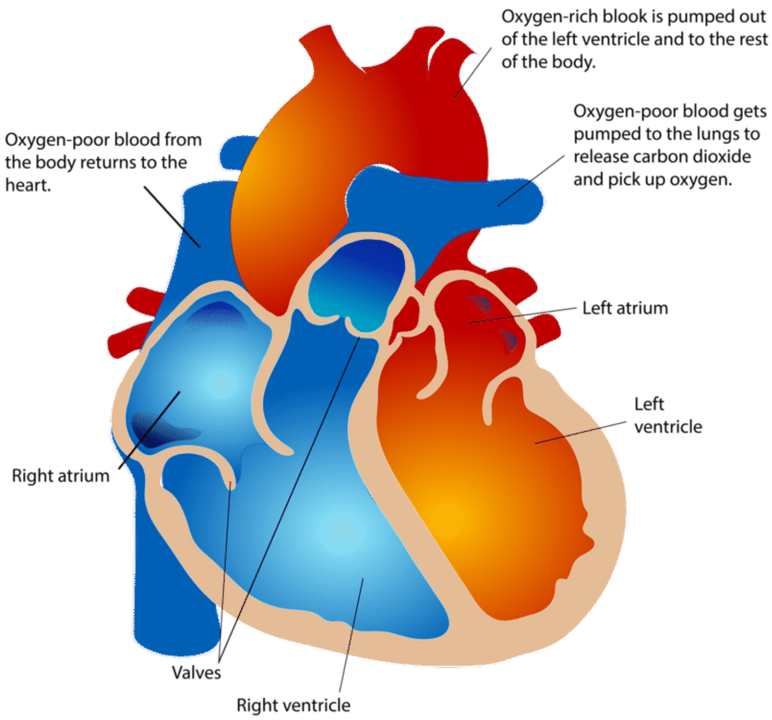

FIGURE 2.29
The atria receive blood and the ventricles pump blood out of the heart.

- The right atrium receives oxygen-poor blood from the body.
- The right ventricle pumps oxygen-poor blood toward the lungs, where it receives oxygen.
- The left atrium receives oxygen-rich blood from the lungs.
- The left ventricle pumps oxygen-rich blood out of the heart to the rest of the body.

Blood Flow Through the Heart

Blood flows through the heart in two separate loops. You can think of them as a "left side loop" and a "right side loop." The right side of the heart collects oxygen-poor blood from the body and pumps it into the lungs, where it releases carbon dioxide and picks up oxygen. (Recall that carbon dioxide is a waste product that must be removed. It is removed when we exhale.) The left side carries the oxygen-rich blood back from the lungs into the left side of the heart, which then pumps the oxygen-rich blood to the rest of the body. The blood delivers oxygen to the cells of the body, where it is needed for cellular respiration, and returns to the heart oxygen-poor.

To move blood through the heart, the cardiac muscle needs to contract in an organized way. Blood first enters the atria (**Figure** 2.30). When the atria contract, blood is pushed into the ventricles. After the ventricles fill with blood, they contract, and blood is pushed out of the heart. The heart is mainly composed of cardiac muscle. These muscle cells contract in unison, causing the heart itself to contract and generating enough force to push the blood out.

So how is the blood kept from flowing back on itself? **Valves** (**Figure** 2.30) in the heart keep the blood flowing in one direction. The valves do this by opening and closing in one direction only. Blood only moves forward through the heart. The valves stop the blood from flowing backward. There are four valves of the heart.

- The two atrioventricular (AV) valves stop blood from moving from the ventricles to the atria.
- The two semilunar (SL) valves are found in the arteries leaving the heart, and they prevent blood from flowing back from the arteries into the ventricles.

Why does a heart beat? The "lub-dub" sound of the heartbeat is caused by the closing of the AV valves ("lub") and SL valves ("dub") after blood has passed through them.

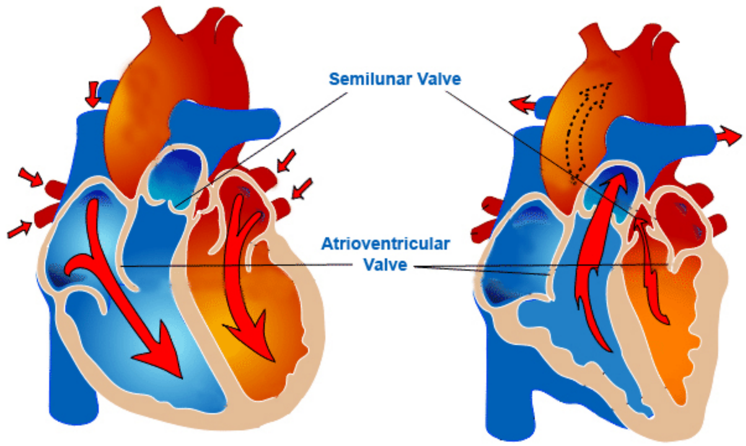

FIGURE 2.30
Blood flows in only one direction in the heart. Blood enters the atria, which contract and push blood into the ventricles. The atria relax and the ventricles fill with blood. Finally, the ventricles contract and push blood around the body.

Summary

- Blood enters the heart at the atria and then flows into the ventricles, which contract and push blood around the body.
- Valves in the heart keep the blood flowing in one direction.

Explore More

Use the resource below to answer the questions that follow.

- **Working of the Heart** at http://www.youtube.com/watch?v=NF68qhyfcoM (1:36)

MEDIA
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1. How many chambers does a mammalian heart have? What are these chambers called?
2. What are the smallest blood vessels in the body?
3. What is the function of the circulatory system? What role does the heart play?
4. What passes from the cells into the capillaries? What passes into the cells from the capillaries?

Review

1. What are the ventricles?
2. Where does oxygen-poor blood first enter the heart?
3. What part of the heart pumps blood to the rest of the body?
4. What is the purpose of the valves in the heart?

2.14 Nervous System

Learning Objectives

- Define nerve.
- Describe the role of a nerve.
- Explain the functions of the nervous system.

What body system helps you learn?

As these girls are studying, many processes are taking place. Their eyes have to take in the words on the page, and their brains have to process the meaning of the words. The brain also has to assimilate the knowledge so it can be retrieved at a later time. All these processes are controlled by the nervous system.

Introduction to the Nervous System

Michelle was riding her scooter when she hit a hole in the street and started to lose control. She thought she would fall, but, in the blink of an eye, she shifted her weight and kept her balance. Her heart was pounding, but at least she didn't get hurt. How was she able to react so quickly? Michelle can thank her nervous system for that (**Figure** 2.31).

The **nervous system,** together with the **endocrine system,** controls all the other **organ systems.** The nervous system sends one type of signal around the body, and the endocrine system sends another type of signal around the body. The endocrine system makes and releases chemical messenger molecules, or hormones, which tell other body parts that a change or a reaction is necessary. So what type of signal does the nervous system send?

Controlling muscles and maintaining balance are just two of the roles of the nervous system. The nervous system also lets you:

- Sense your surroundings with your eyes and other sense organs.

FIGURE 2.31
Staying balanced when riding a scooter requires control over the body's muscles. The nervous system controls the muscles and maintains balance.

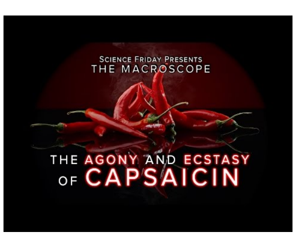
- Sense the environment inside of your body, including temperature.
- Control your internal body systems and keep them in balance.
- Prepare your body to fight or flee in an emergency.
- Use language, think, learn, and remember.

The nervous system works by sending and receiving electrical signals. The main organs of the nervous system are the brain and the spinal cord. The signals are carried by **nerves** in the body, similar to the wires that carry electricity all over a house. The signals travel from all over the body to the spinal cord and up to the brain, as well as moving in the other direction. For example, when Michelle started to fall off her scooter, her nervous system sensed that she was losing her balance. It responded by sending messages from her brain to muscles in her body. Some muscles tightened while others relaxed. Maybe these actions moved her hips or her arms. The nervous system, working together with the muscular and skeletal systems, allowed Michelle to react to the situation. As a result, Michelle's body became balanced again. The messages released by the nervous system traveled through nerves. Just like the electricity that travels through wires, nerve quickly carry the electrical messages around the body.

Think about how quickly all this happens. It has to be really fast, otherwise Michelle would not have been able to react. What would happen if a car pulled out unexpectedly in front of Michelle? A signal would have to go from her eyes to her brain and then to her muscles. What allows the nervous system to react so fast. It starts with the special cell of the nervous system, the neuron.

Science Friday: The Agony and Ecstasy of Capsaicin

Have you ever tasted something spicy? In this video by Science Friday, Dr. Marco Tizzano discusses how capsaicin creates the burning sensation that some people enjoy.



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Summary

- The nervous system sends electrical messages throughout the body and controls all other body systems.
- The nervous system allows you to think, learn, sense your surroundings, and control your internal body systems.

Explore More

Use the resource below to answer the questions that follow.

- **Nervous System** at http://www.getbodysmart.com/ap/nervoussystem/menu/menu.html

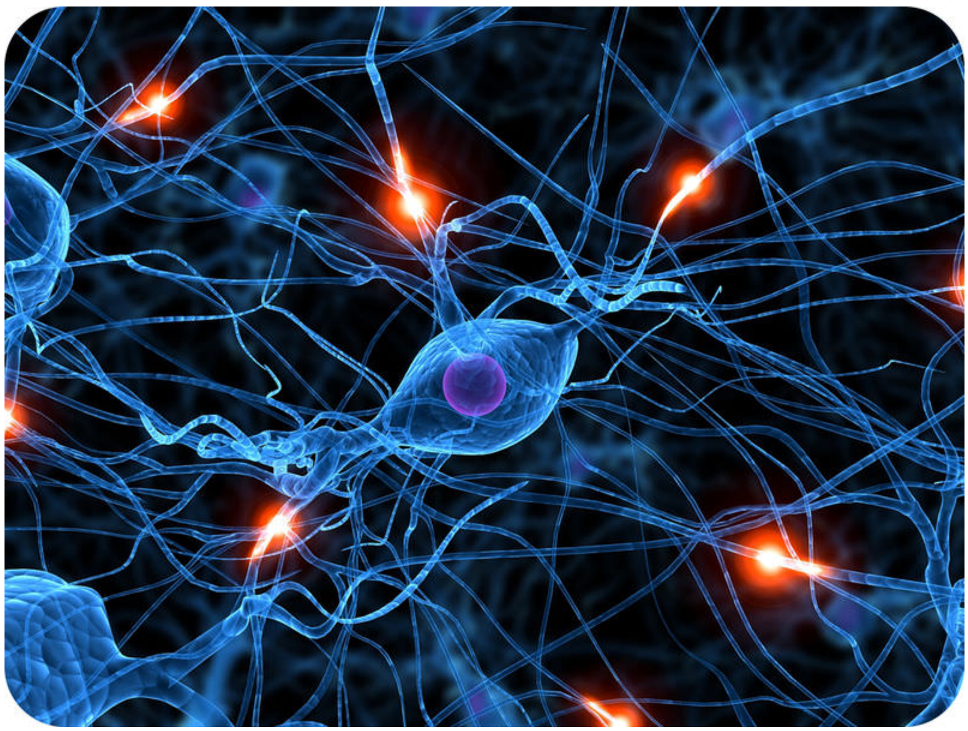
1. What are the major organs of the nervous system?
2. What does the somatic nervous system do? Why is a system like this useful to organisms?
3. What does the autonomic nervous system do? How does it differ from the somatic nervous system?

Review

1. What are three functions of the nervous system?
2. What type of signals does the nervous system send? What carries these signals?
3. What are the main organs of the nervous system?

2.15 Nerve Impulse

- Define neuron and synapse.
- Describe neuron structure.
- Explain the role of the dendrites and axon.
- Distinguish sensory neurons from motor neurons.
- Summarize what happens when a nerve impulse reaches the end of an axon.



What do nerve cells look like?

Note that like most other cells, these nerve cells have a nucleus. They also have other organelles. However, the long, threadlike extensions of the nerve cells are unique. This is where the nerve impulses are transmitted.

Neurons and Nerve Impulses

The nervous system is made up of nerves. A **nerve** is a bundle of nerve cells. A nerve cell that carries messages is called a **neuron** (**Figure** 2.32). The messages carried by neurons are called **nerve impulses**. Nerve impulses can travel very quickly because they are electrical impulses.

Think about flipping on a light switch when you enter a room. When you flip the switch, the electricity flows to the light through wires inside the walls. The electricity may have to travel many meters to reach the light, but the light still comes on as soon as you flip the switch. Nerve impulses travel just as fast through the network of nerves inside the body.

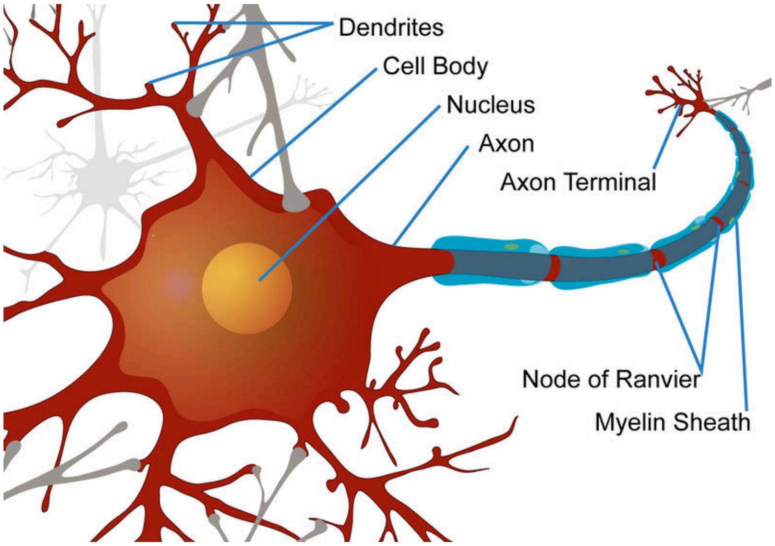


FIGURE 2.32
The axons of many neurons, like the one shown here, are covered with a fatty layer called myelin sheath. The sheath covers the axon, like the plastic covering on an electrical wire, and allows nerve impulses to travel faster along the axon. The node of Ranvier, shown in this diagram, is any gap in the myelin sheath; it allows faster transmission of a signal.

What Does a Neuron Look Like?

A neuron has a special shape that lets it pass signals from one cell to another. A neuron has three main parts (**Figure** 2.32):

1. The cell body.
2. Many dendrites.
3. One axon.

The **cell body** contains the nucleus and other organelles. Dendrites and axons connect to the cell body, similar to rays coming off of the sun. **Dendrites** receive nerve impulses from other cells. **Axons** pass the nerve impulses on to other cells. A single neuron may have thousands of dendrites, so it can communicate with thousands of other cells but only one axon. The axon is covered with a **myelin sheath**, a fatty layer that insulates the axon and allows the electrical signal to travel much more quickly. The **node of Ranvier** is any gap within the myelin sheath exposing the axon, and it allows even faster transmission of a signal.

Types of Neurons

Neurons are usually classified based on the role they play in the body. Two main types of neurons are sensory neurons and motor neurons.

- **Sensory neurons** carry nerve impulses from sense organs and internal organs to the central nervous system.
- **Motor neurons** carry nerve impulses from the central nervous system to organs, glands, and muscles—the opposite direction.

Both types of neurons work together. Sensory neurons carry information about the environment found inside or outside of the body to the central nervous system. The central nervous system uses the information to send messages through motor neurons to tell the body how to respond to the information.

The Synapse

The place where the axon of one neuron meets the dendrite of another is called a **synapse**. Synapses are also found between neurons and other types of cells, such as muscle cells. The axon of the sending neuron does not actually touch the dendrite of the receiving neuron. There is a tiny gap between them, the synaptic cleft (**Figure** 2.33).

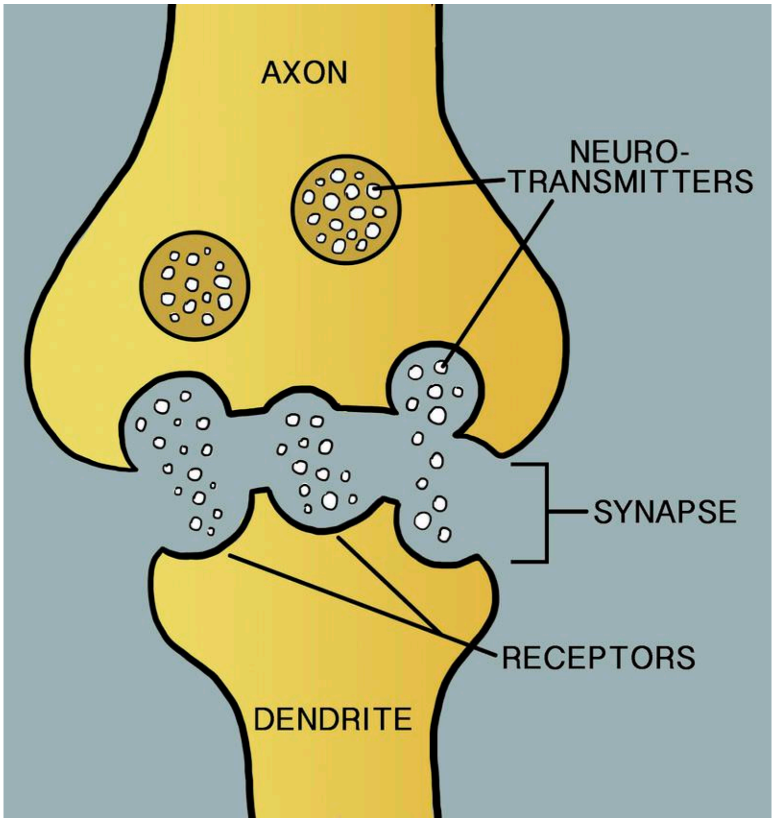


FIGURE 2.33
This diagram shows a synapse between neurons. When a nerve impulse arrives at the end of the axon, neurotransmitters are released and travel to the dendrite of another neuron, carrying the nerve impulse from one neuron to the next.

The following steps describe what happens when a nerve impulse reaches the end of an axon.

1. When a nerve impulse reaches the end of an axon, the axon releases chemicals called **neurotransmitters**.
2. Neurotransmitters travel across the synapse between the axon and the dendrite of the next neuron.
3. Neurotransmitters bind to the membrane of the dendrite.
4. The binding allows the nerve impulse to travel through the receiving neuron.

Did you ever watch a relay race? After the first runner races, he or she passes the baton to the next runner, who takes over. Neurons are a little like relay runners. Instead of a baton, they pass neurotransmitters to the next neuron. Examples of neurotransmitters are chemicals such as serotonin, dopamine, and adrenaline.

You can watch an animation of nerve impulses and neurotransmitters at http://www.mind.ilstu.edu/curriculum/neurons_intro/neurons_intro.php .

Some people have low levels of the neurotransmitter called serotonin in their brain. Scientists think that this is one cause of depression. Medications called antidepressants help bring serotonin levels back to normal. For many people with depression, antidepressants control the symptoms of their depression and help them lead happy, productive lives.

Summary

- Neurons, or nerve cells that carry nerve impulses, are made up of the cell body, the axon, and several dendrites.
- Signals move across the synapse, the place where the axon of one neuron meets the dendrite of another, using chemicals called neurotransmitters.

Explore More

Use the resource below to answer the questions that follow.

- **Neuroscience For Kids** at http://faculty.washington.edu/chudler/cells.html

1. What are the three types of neurons?
2. What neurons are most abundant in the central nervous system?
3. What is the function of sensory neurons?
4. What is the function of motor neurons?
5. What is the role of interneurons?

Review

1. Describe a neuron and identify its three main parts.
2. Distinguish between dendrites and the axon.
3. Distinguish between sensory and motor neurons.
4. Explain how one neuron transmits a nerve impulse to another neuron.

2.16 Innate Immune System

- Describe the body's first line of defense against pathogens.
- Discuss the role of skin and mucous membranes in the first line of defense.

What is your nose good for?

Your nose does a lot of work for you! Obviously, it helps you breathe and provides your sense of smell. But you might not realize that your nose also helps to fight off disease.

The Immune System's First Line of Defense

It is the immune system's job to protect the body. Your body has many ways to protect you from pathogens. Your body's defenses are like a castle. The outside of a castle was protected by a moat and high walls. Inside the castle, soldiers were ready to fight off any enemies that made it across the moat and over the walls. Like a castle, your body has a series of defenses. Only pathogens that get through all the defenses can harm you.

The first line of defence includes both physical and chemical barriers that are always ready and prepared to defend the body from infection. Pathogens must make it past this first line of defense to cause harm. If this defense is broken, the second line of defense within your body is activated.

Your body's first line of defense is like a castle's moat and walls. It keeps most pathogens out of your body. This is a non-specific type of defense, in that it tries to keep all pathogens out. The first line of defense includes different types of barriers. Being the "first line", it starts with the skin. The first line also includes tears, mucus, cilia, stomach acid, urine flow, and friendly bacteria.

Skin and Mucous Membranes

The skin is a very important barrier to pathogens. The skin is the body's largest organ. In adults, it covers an area of about 16 to 22 square feet! The skin is also the body's most important defense against disease. It forms a physical barrier between the body and the outside world. The skin has several layers that stack on top of each other (**Figure** 2.34). The outer layer is tough and waterproof. It is very difficult for pathogens to get through this layer of skin.

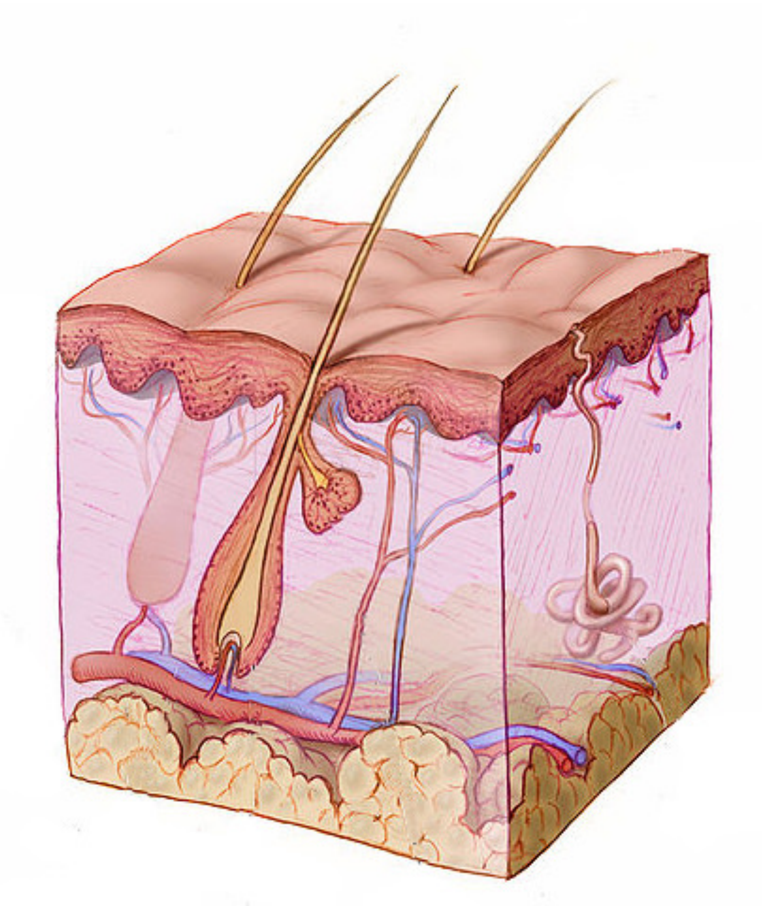


FIGURE 2.34
This drawing shows that the skin has many layers. The outer layer is so tough that it keeps out most pathogens.

The mouth and nose are not lined with skin. Instead, they are lined with **mucous membranes**. Other organs that are exposed to the outside world, including the lungs and stomach, are also lined with mucous membranes. Mucous membranes are not tough like skin, but they have other defenses.

One defense of mucous membranes is the mucus they release. **Mucus** is a sticky, moist substance that covers mucous membranes. Most pathogens get stuck in the mucus before they can do harm to the body. Many mucous membranes also have cilia. Cilia in the lungs are pictured below (**Figure** 2.35). **Cilia** are tiny finger-like projections. They move in waves and sweep mucus and trapped pathogens toward body openings. When you clear your throat or blow your nose, you remove mucus and pathogens from your body.

Chemicals

Most body fluids that you release from your body contain chemicals that kill pathogens. For example, mucus, sweat, tears, and saliva contain enzymes called lysozymes that kill pathogens. These enzymes can break down the cell walls of bacteria to kill them.

FIGURE 2.35
This is what the cilia lining the lungs look like when they are magnified. Their movements constantly sweep mucus and pathogens out of the lungs. Do they remind you of brushes?

The stomach also releases a very strong acid, called hydrochloric acid. This acid kills most pathogens that enter the stomach in food or water. Urine is also acidic, so few pathogens can grow in it.

Helpful Bacteria

You are not aware of them, but your skin is covered by millions (or more!) of bacteria. Millions more live inside your body. Most of these bacteria help defend your body from pathogens. How do they do it? They compete with harmful bacteria for food and space. This prevents the harmful bacteria from multiplying and making you sick.

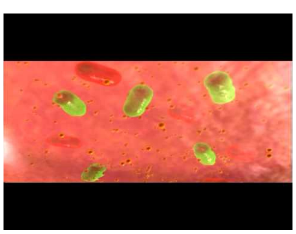
Summary

- Your body's first line of defense includes the skin and other barriers that keep pathogens out of your body.
- Most body fluids that you release from your body contain chemicals that kill pathogens.

Explore More

Use the resource below to answer the questions that follow.

- **Introduction To How The Immune System Works** at http://www.youtube.com/watch?v=IWMJIMzsEMg (3:16)



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1. How do external barriers help our immune system?
2. Where is mucus used as a barrier?
3. How do some bacteria aid our immune system?

Review

1. How does your skin protect you from pathogens?
2. What is mucus? What are mucous membranes?
3. How is mucus helpful?
4. How are lysozymes helpful?
5. How do helpful bacteria defend your body?

2.17 Immunity

- Define immunity and vaccination.
- Describe immunity and how vaccinations work.

Is this child more fortunate than many children?

You may not feel lucky to get a shot. But you are very lucky to be able to get vaccinations. In many parts of the world, children do not get routine vaccinations. In 2008, the World Health Organization (WHO) estimated that 1.5 million children under the age of 5 died from diseases that are preventable with vaccinations.

Immunity and Vaccination

In previous concepts, you learned about B and T cells, special types of white blood cells that help your body to fight off a specific pathogen. They are necessary when the body is fighting off an infection. But what happens to them after the pathogen has been destroyed?

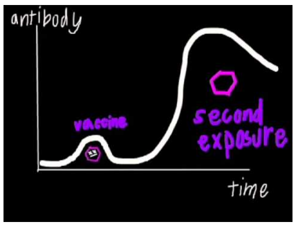
Most B and T cells die after an infection has been brought under control. But some of them survive for many years. They may even survive for a person's lifetime. These long-lasting B and T cells are called memory cells. They allow the immune system to "remember" the pathogen after the infection is over. If the pathogen invades the body again, the memory cells will start dividing in order to fight the pathogen or disease.

These dividing cells will quickly produce a new army of B or T cells to fight the pathogen. They will begin a faster, stronger attack than the first time the pathogen invaded the body. As a result, the immune system will be able to destroy the pathogen before it can cause an infection. Being able to attack the pathogen in this way is called **immunity**.

Immunity can also be caused by vaccination. **Vaccination** is the process of exposing a person to a pathogen on purpose in order to develop immunity. In vaccination, a modified pathogen is usually injected under the skin by a shot. Only part of the pathogen is injected, or a weak or dead pathogen is used. It sounds dangerous, but the shot prepares your body for fighting the pathogen without causing the actual illness. Vaccination triggers an immune response against the injected antigen. The body prepares "memory" cells for use at a later time, in case the antigen is ever encountered again. Essentially, a vaccine imitates an infection, triggering an immune response, without making a person sick.

In many countries, children receive their first vaccination at birth with the Hepatitis B shot, which protects infants from Hepatitis B, a serious liver disease. Before vaccines, many children died from diseases that vaccines now prevent, such as whooping cough, measles, and polio. Those same germs exist today, but because babies are now protected by vaccines, we do not see these diseases nearly as often. Diseases you have probably been vaccinated against include measles, mumps, and chicken pox.

How does a vaccine work? See *How a Vaccine Works* at https://www.youtube.com/watch?v=7MaiT5w5NWQ and *The History of Vaccines* at http://www.historyofvaccines.org/content/articles/top-20-questions-about-vaccination .



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Summary

- Immunity is the ability to resist a particular pathogen.
- Vaccination is deliberate exposure to a pathogen in order to bring about immunity.

Explore More

Use the resource below to answer the questions that follow.

- **What Is Immunity?** at http://www.youtube.com/watch?v=vCBfiQnyiKw (1:23)

MEDIA

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URL: http://www.ck12.org/flx/render/embeddedobject/57552

1. How do vaccines provide immunity? How is the immune response initiated by vaccines similar to the body's natural immune response?
2. Why do some people decide to take vaccines rather than letting the body develop natural immunity?

Review

1. Define immunity.
2. Define vaccination.
3. If you have been vaccinated against measles, you are unlikely to ever have the disease, even if you are exposed to the measles virus. How does this work?

2.18 Inflammatory Response

- Summarize the body's second line of defense against pathogens.
- Define inflammation.
- Explain how inflammation helps protect you from pathogens.
- Describe the roles of white blood cells.

Have you ever sprained your ankle?

Did you notice redness and swelling near the injury? These symptoms indicate that your body is attempting to fight off infection.

The Immune System's Second Line of Defense

The little girl pictured below (**Figure** 2.36) has a scraped knee. A scrape is a break in the skin that may let pathogens enter the body. If bacteria enter through the scrape, they could cause an infection. These bacteria would then face the body's second line of defense. The second line of defense is also nonspecific, fighting many types of pathogens.

Inflammation

The body's second line of defense against pathogens includes the inflammatory response. If bacteria enter the skin through a scrape, the area may become red, warm, and painful. These are signs of inflammation. **Inflammation** is one way the body reacts to infections or injuries. Inflammation is caused by chemicals that are released when skin or other tissues are damaged. The chemicals cause nearby blood vessels to dilate, or expand. This increases blood flow to the damaged area, which makes the area red and slightly warm. The chemicals also attract white blood cells called neutrophils to the wound and cause them to leak out of blood vessels into the damaged tissue.

FIGURE 2.36
This little girl just got her first scraped knee. It doesn't seem to hurt, but the break in her skin could let pathogens enter her body. That's why scrapes should be kept clean and protected until they heal.

White Blood Cells

What do these white blood cells do at the site of inflammation? The main role of white blood cells is to fight pathogens in the body. There are actually several different kinds of white blood cells. Some white blood cells have very specific functions. They attack only certain pathogens. Other white blood cells attack any pathogen they find. These white blood cells travel to areas of the body that are inflamed. They are called **phagocytes**, which means "eating cells." Neutrophils are a type of phagocyte. In addition to pathogens, phagocytes "eat" dead cells. They surround the pathogens and destroy them. Sometimes it is said that the phagocyte engulfs the pathogen, and then destroys it. This process is called **phagocytosis**.

White blood cells also make chemicals that cause a fever. A **fever** is a higher-than-normal body temperature. Normal human body temperature is 98.6°F (37°C). Most bacteria and viruses that infect people reproduce fastest at this temperature. When the temperature is higher, the pathogens cannot reproduce as fast, so the body raises the temperature to kill them. A fever also causes the immune system to make more white blood cells. In these ways, a fever helps the body fight infection.

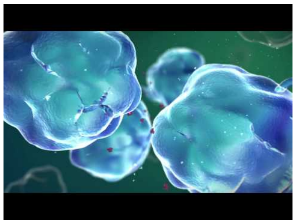
Summary

- If pathogens enter your body, inflammation occurs.
- White blood cells called phagocytes travel to areas of the body that are inflamed.

Explore More

Use the resource below to answer the questions that follow.

- **Our Immune System** at http://www.youtube.com/watch?v=MI-BLaj5nFk (4:53)



MEDIA

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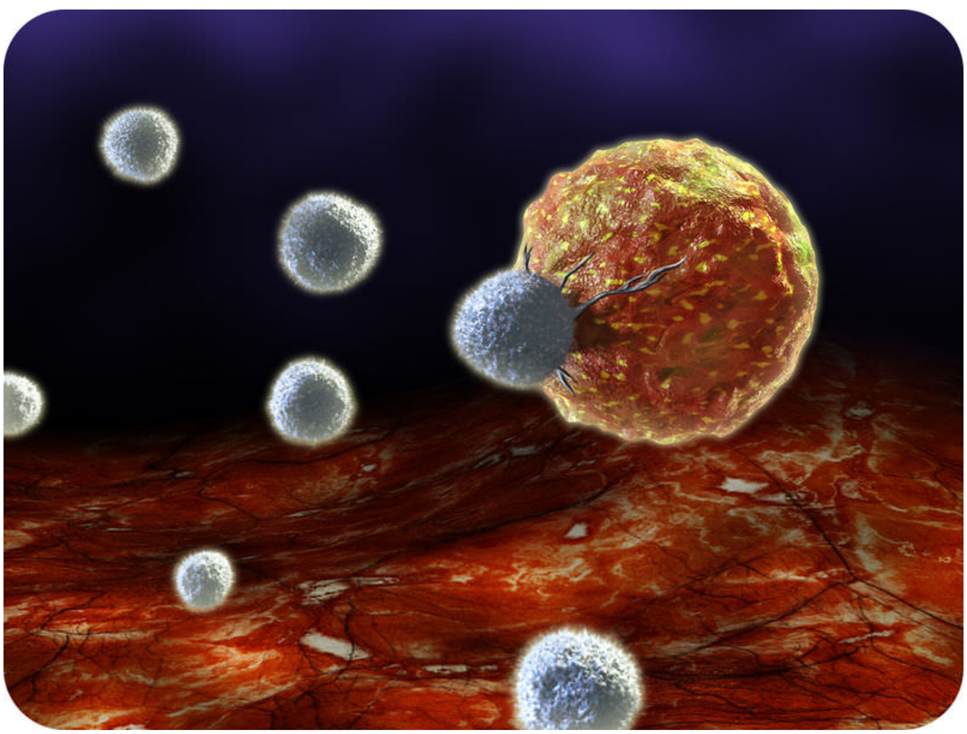
1. What is a macrophage? What does it do when it recognizes a "non-self" substance?
2. What are cytokines? What message do they send to the rest of the body's cells?
3. How do macrophages interact with T-cells? Where does this interaction occur?

Review

1. Describe inflammation.
2. What is the main role of white blood cells?
3. Describe phagocytosis.
4. A fever is a sign of infection. Why might it be considered a good sign?

2.19 Humoral Response

- Distinguish B cells from T cells.
- Define antibody and antigen.
- Explain how B cells and T cells respond to pathogens.
- Summarize the roles of killer T cells and helper T cells.



What happens when your body recognizes an invader?

When your immune system detects an invading pathogen, it goes on the attack! Notice how this T-cell is setting out to destroy a cancer cell.

B and T Cell Response

Some defenses, like your skin and mucous membranes, are not designed to ward off a specific pathogen. They are just general defenders against disease. Your body also has defenses that are more specialized. Through the help of your immune system, your body can generate an army of cells to kill that one specific pathogen.

There are two different types of specific immune responses. One type involves B cells. The other type involves T cells. Recall that **B cells** and **T cells** are types of white blood cells that are key in the immune response. Whereas the immune system's first and second line of defense are more generalized or non-specific, the immune response is specific. It can be described as a specific response to a specific pathogen, meaning it uses methods to target just one pathogen at a time. These methods involve B and T cells.

B Cell Response

B cells respond to pathogens and other cells from outside the body in the blood and lymph. Most B cells fight infections by making antibodies. An **antibody** is a large, Y-shaped protein that binds to an **antigen**, a protein that is recognized as foreign. Antigens are found on the outside of bacteria, viruses and other foreign microorganisms. Each antibody can bind with just one specific type of antigen (**Figure** 2.37). They fit together like a lock and key. Once an antigen and antibody bind together, they signal for a **phagocyte** to destroy them. Phagocytes are white blood cells that engulf targeted antigens by phagocytosis. As the antigen is on the outside of a pathogen, the pathogen is destroyed by this process.

At any one time the average human body contains antibodies that can react with about 100,000,000 different antigens. This means that there can be 100,000,000 different antibody proteins in the body.

T Cell Response

There are different types of T cells, including killer T cells and helper T cells. **Killer T cells** destroy infected, damaged, or cancerous body cells (**Figure** 2.38). When the killer T cell comes into contact with the infected cell, it releases poisons. The poisons make tiny holes in the cell membrane of the infected cell. This causes the cell to burst open. Both the infected cell and the pathogens inside it are destroyed.

Helper T cells do not destroy infected or damaged body cells. But they are still necessary for an immune response. They help by releasing chemicals that control other lymphocytes. The chemicals released by helper T cells "switch on" both B cells and killer T cells so they can recognize and fight specific pathogens.

Summary

- B cells produce antibodies against pathogens in the blood and lymph.
- Killer T cells destroy body cells infected with pathogens.

Explore More

1. What starts an immune response?
2. How do killer T cells fight pathogens?
3. How do B cells fight pathogens?
4. Explain how long-term immunity comes about.

Review

1. Explain how B cells help fight infections.
2. Describe an antibody and its role.
3. How do killer T cells fight pathogens?
4. Describe the role of helper T cells.

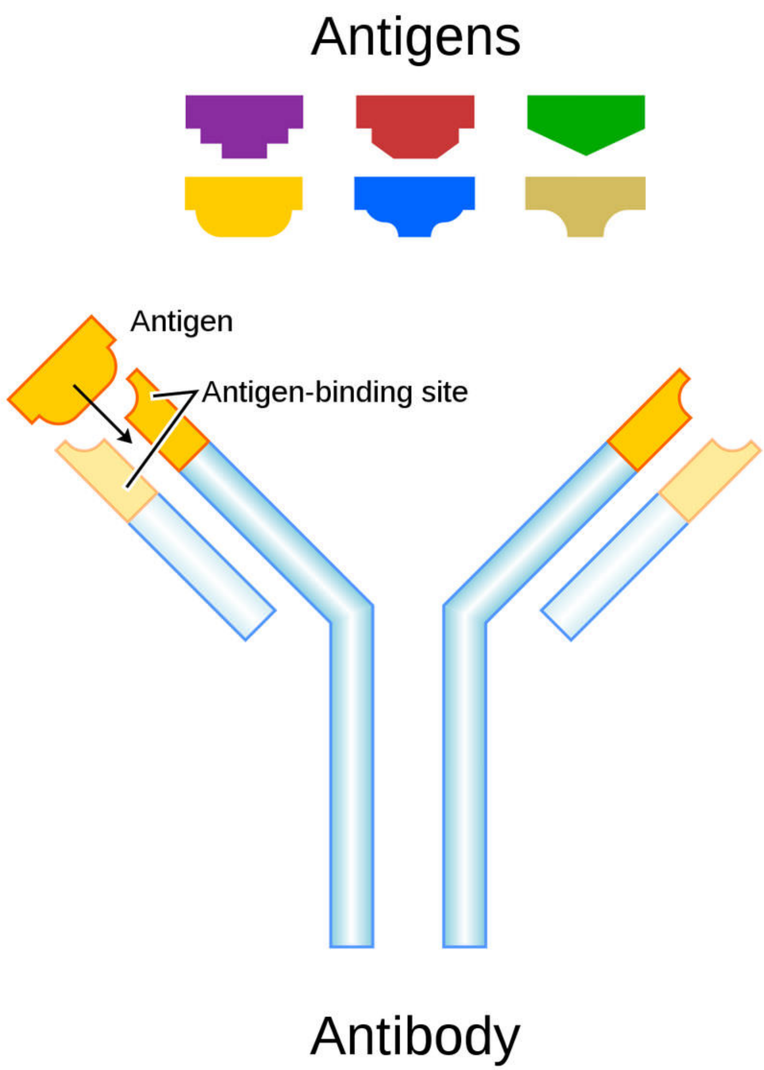


FIGURE 2.37
This diagram shows how an antibody binds with an antigen. The antibody was produced by a B cell. It binds with just one type of antigen. Antibodies produced by different B cells bind with other types of antigens. The antigen-binding sites can vary, such that they are specific for just one antigen.

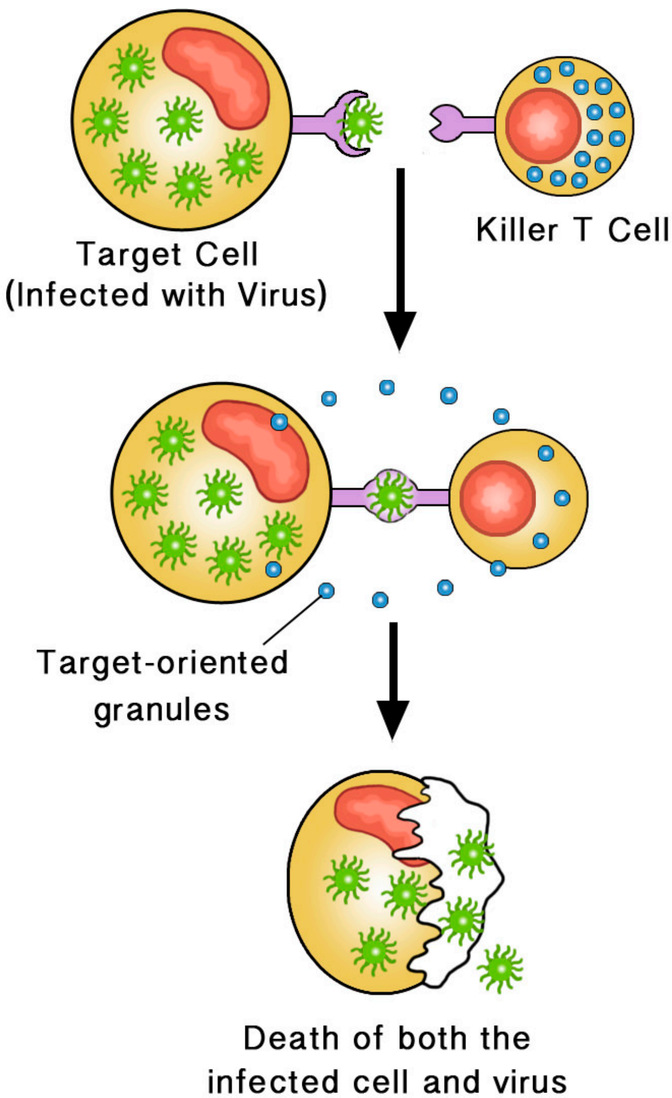


FIGURE 2.38

In this diagram, a killer T cell recognizes a body cell infected with a virus. After the killer T cell makes contact with the infected cell, it releases poisons that cause the infected cell to burst. This kills both the infected cell and the viruses inside it.

2.20 HIV AIDS

Learning Objectives

- Explain how the virus known as HIV causes AIDS.
- Discuss how HIV is spread.
- Summarize the effects of HIV in the immune system.
- Describe AIDS.

What does a red ribbon symbolize?

This red ribbon is a symbol for support of HIV-positive people and those living with AIDS. As of 2010, an estimated 34 million people are living with HIV worldwide.

HIV Infection and AIDS

HIV, or human immunodeficiency virus, causes AIDS. **AIDS** stands for "acquired immune deficiency syndrome." It is a condition that causes death and does not have a known cure. AIDS usually develops 10 to 15 years after a person is first infected with HIV. The development of AIDS can be delayed with proper medicines. The delay can be well over 20 years with the right medicines. Today, individuals who acquire HIV after 50 years of age can expect to reach an average human life span.

How HIV Spreads

HIV spreads through contact between an infected person's body fluids and another person's bloodstream or mucus membranes, which are found in the mouth, nose, and genital areas. Body fluids that may contain HIV are blood, semen, vaginal fluid, and breast milk. The virus can spread through sexual contact or shared drug needles. It can also spread from an infected mother to her baby during childbirth or breastfeeding. Saliva can carry the HIV virus, but it won't spread it, unless the saliva gets into the bloodstream. Other body fluids such as urine and sweat do not contain the virus. HIV does not spread in any fluid in which the host cells cannot survive.

Some people think they can become infected with HIV by donating blood or receiving donated blood. This is not true. The needles used to draw blood for donations are always new. Therefore, they cannot spread the virus. Donated blood is also tested to make sure it is does not contain HIV.

HIV is not transmitted by day-to-day contact in the workplace, schools, or social settings. HIV is not transmitted through shaking hands, hugging, or a casual kiss. You cannot become infected from a toilet seat, a drinking fountain, a door knob, dishes, drinking glasses, food, or pets.

HIV and the Immune System

How does an HIV infection develop into AIDS? HIV destroys white blood cells called **helper T cells**. The cells are produced by the immune system. This is the body system that fights infections and other diseases.

HIV invades helper T cells and uses them to produce more virus particles (**Figure** 2.39). Then, the virus kills the helper T cells. As the number of viruses in the blood rises, the number of helper T cells falls. Without helper T cells, the immune system is unable to protect the body. The infected person cannot fight infections and other diseases because they do not have T cells. This is why people do not die from HIV. Instead, they die from another illness, like the common cold, that they cannot fight because they do not have helper T cells.

Medications can slow down the increase of viruses in the blood. But the medications cannot remove the viruses from the body. At present, there is no cure for HIV infection. A vaccine against HIV could stop this disease, and such a vaccine is in development, though it could take many years before it can be given to prevent this virus.

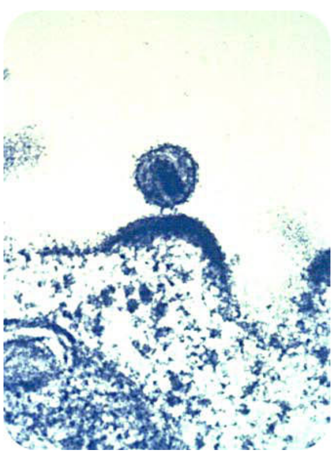


FIGURE 2.39

In this picture, the large structure on the bottom is a human immune cell. It is infected with HIV. A new HIV particle is shown budding out of the immune cell.

AIDS

AIDS is not really a single disease. It is a set of symptoms and other diseases. It results from years of damage to the immune system by HIV. AIDS occurs when helper T cells fall to a very low level, making it difficult for the affected person to fight various diseases and other infections. These people develop infections or cancers that people with a healthy immune systems can easily resist. These diseases are usually the cause of death of people with AIDS.

The first known cases of AIDS occurred in 1981. Since then, AIDS has led to the deaths of more than 35 million people worldwide. Many of them were children. The greatest number of deaths occurred in Africa. It is also where medications to control HIV are least available. There are currently more people infected with HIV in Africa than any other part of the world. Well over 30 million people are living with HIV worldwide.

Summary

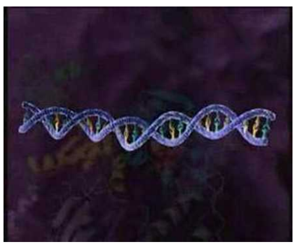
- HIV causes AIDS by destroying disease-fighting cells produced by the immune system.
- HIV spreads through contact between an infected person's body fluids and another person's bloodstream or mucus membranes; body fluids that may contain HIV include blood, semen, vaginal fluid, and breast milk.

Explore More

Use the resources below to answer the questions that follow.

Explore More I

- **HIV Replication** at http://www.youtube.com/watch?v=RO8MP3wMvqg (5:13)



MEDIA
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1. What are the steps of HIV infection and replication?
2. How can understanding all the steps of infection help develop treatments to HIV?
3. What does HIV inject into a cell?
4. What enzymes does HIV supply to the host cell?

Explore More II

- **HIV Immunity** at http://www.pbs.org/wgbh/evolution/library/10/4/quicktime/l_104_06.html

1. Not all people show the same vulnerability to HIV infection. What did scientists do when they first found indications that this was the case?
2. How can studying people with natural resistance to HIV help develop treatments?

Review

1. How does an HIV infection develop into AIDS?
2. Explain why AIDS does not kill people but causes other illnesses to kill people infected with HIV.
3. What body fluids from an infected person may contain HIV?
4. What body fluids from an infected person do not contain HIV?

2.21 References

1. Rupali Raju. CK-12 Foundation . CC BY-NC 3.0;Public Domain; CC BY 2.0; CC BY 2.0
2. Image copyright Jubal Harshaw, 2014;Mariana Ruiz Villarreal (User:LadyofHats/Wikimedia Commons);Bruce Wetzel and Harry Schaefer/National Cancer Institute; Mike Seyfang; Umberto Salvagnin. http://www.shutterstock.com;http://commons.wikimedia.org/wiki/File:Average_prokaryote_cell-_en.svg;http://commons.wikimedia.org/wiki/File:SEM_blood_cells.jpg; http://www.flickr.com/photos/mikeblogs/3101400087/; http://www.flickr.com/photos/kaibara/2865288013/ . Used under license from Shutterstock.com;Public Domain; CC BY 2.0; CC BY 2.0
3. Dartmouth Electron Microscope Facility. http://commons.wikimedia.org/wiki/File:Misc_pollen.jpg . Public Domain
4. Bruce Wetzel and Harry Schaefer/National Cancer Institute; Mike Seyfang; Umberto Salvagnin;Rupali Raju. http://commons.wikimedia.org/wiki/File:SEM_blood_cells.jpg; http://www.flickr.com/photos/mikeblogs/3101400087/; http://www.flickr.com/photos/kaibara/2865288013/;CK-12 Foundation . Public Domain; CC BY 2.0; CC BY 2.0;Public Domain
5. Rupali Raju. CK-12 Foundation . CC BY-NC 3.0
6. The Evolution of Self-Fertile Hermaphroditism: The Fog Is Clearing. PLoS Biol 3(1): e30. doi:10.1371/journal.pbio.00300 http://biology.plosjournals.org/perlserv/?request=slideshow&type=figure&doi=10.1371/journal.pbio.0030030&id=20204 . CC BY 2.5
7. Dr. Ralf Wagner;Patrick J. Lynch, medical illustrator; C. Carl Jaffe, MD, cardiologist. http://commons.wikimedia.org/wiki/File:Volvox_aureus_3_Ansichten.jpg;http://commons.wikimedia.org/wiki/File:Heart_myocardium_diagram.jpg . CC BY 3.0;CC BY 2.5
8. The Evolution of Self-Fertile Hermaphroditism: The Fog Is Clearing. PLoS Biol 3(1): e30. doi:10.1371/journal.pbio.00300 http://biology.plosjournals.org/perlserv/?request=slideshow&type=figure&doi=10.1371/journal.pbio.0030030&id=20204 . CC BY 2.5
9. Mariana Ruiz Villarreal (LadyofHats), modified by CK-12 Foundation;Mariana Ruiz Villarreal (LadyofHats). http://commons.wikimedia.org/wiki/Image:Animal_cell_structure.svg;http://commons.wikimedia.org/wiki/File:Cell_membrane_detailed_diagram_en.svg . Public Domain
10. Mariana Ruiz Villarreal (LadyofHats), modified by CK-12 Foundation;Mariana Ruiz Villarreal (LadyofHats). http://commons.wikimedia.org/wiki/Image:Animal_cell_structure.svg;http://commons.wikimedia.org/wiki/File:Cell_membrane_detailed_diagram_en.svg . Public Domain
11. Patrick J. Lynch, medical illustrator; C. Carl Jaffe, MD, cardiologist. http://commons.wikimedia.org/wiki/File:Heart_myocardium_diagram.jpg . CC BY 2.5
12. Boxer: U.S. Army (Flickr:familymwr); Illustrations: Laura Guerin. Boxer: http://www.flickr.com/photos/familymwr/5085770296/; Illustrations: CK-12 Foundation . Boxer: CC BY 2.0; Illustrations: CC BY-NC 3.0
13. Patrick J. Lynch, medical illustrator; C. Carl Jaffe, MD, cardiologist. http://commons.wikimedia.org/wiki/File:Heart_myocardium_diagram.jpg . CC BY 2.5
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18. Image copyright Alila Sao Mai, 2011. http://www.shutterstock.com . Used under license from Shutterstock.com
19. Wykis. http://en.wikipedia.org/wiki/Image:Stem_cell_division_and_differentiation.svg . Public Domain
20. Original uploader was Id711 at en.wikipedia. http://en.wikipedia.org/wiki/Image:Human_embryonic_stem_

cell_colony_phase.jpg . Public Domain
21. CK-12 Foundation - Zachary Wilson. . CC-BY-NC-SA 3.0
22. Drs. Noguchi, Rodgers, and Schechter of NIDDK. http://remf.dartmouth.edu/images/mammalianLungSEM/source/9.html http://remf.dartmouth.edu/images/humanMuscleTEM/source/2.html http://commons.wikimedia.org/wiki/Image:Redbloodcells.jpg . (a) Public Domain (b) Public Domain (d) Public Domain
23. . http://upload.wikimedia.org/wikipedia/commons/3/34/Skin.jpg . Public Domain
24. Image copyright Matthew Cole, 2014. http://www.shutterstock.com . Used under licenses from Shutterstock.com
25. USFG. http://commons.wikimedia.org/wiki/File:Illu_endocrine_system.png . Public Domain
26. Patrick J. Lynch, medical illustrator, C. Carl Jaffe, MD, cardiologist. http://commons.wikimedia.org/wiki/File:Bronchial_anatomy.jpg . CC BY 2.5;CC BY-NC 3.0
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29. Mariana Ruiz Villarreal (Wikimedia: LadyofHats). http://commons.wikimedia.org/wiki/File:Arterial_System_en.svg . Public Domain
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32. Courtesy of Bruce Wetzel, Harry Schaefer, National Cancer Institute. http://visualsonline.cancer.gov/details.cfm?imageid=2129 . Public Domain
33. Courtesy of Drs. Noguchi, Rodgers, and Schechter of the National Institute of Diabetes and Digestive and Kidney Diseases. http://commons.wikimedia.org/wiki/File:Redbloodcells.jpg . Public Domain
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35. Courtesy of the National Cancer Institute - Frederick. http://commons.wikimedia.org/wiki/File:Red_White_Blood_cells.jpg . Public Domain
36. . . CC BY-NC
37. Mariana Ruiz Villarreal (Wikimedia: LadyofHats), modified by CK-12 Foundation;Mariana Ruiz Villarreal (Wikimedia: LadyofHats). http://commons.wikimedia.org/wiki/File:P_Anatomy.svg;http://commons.wikimedia.org/wiki/File:Arterial_System_en.svg . Public Domain
38. Mariana Ruiz Villarreal (Wikimedia: LadyofHats). http://commons.wikimedia.org/wiki/File:Human_healthy_pumping_heart_en.svg;http://commons.wikimedia.org/wiki/File:Arterial_System_en.svg . Public Domain
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41. . . CC BY-NC
42. Zachary Wilson, modifying image by Mariana Ruiz Villarreal;Flickr:FaceMePLS. CK-12 Foundation (original image: http://commons.wikimedia.org/wiki/File:Complete_neuron_cell_diagram_en.svg);http://www.flickr.com/photos/faceme/5448327286/ . CC BY-NC 3.0 (original image in public domain);CC BY 2.0
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44. . . CC BY-NC
45. Courtesy of Don Bliss, National Cancer Institute. http://commons.wikimedia.org/wiki/File:Anatomy_The_Skin_-_NCI_Visuals_Online.jpg . Public Domain
46. Charles Daghlian. http://commons.wikimedia.org/wiki/File:Bronchiolar_epithelium_3_-_SEM.jpg . Public Domain
47. . . CC BY-NC
48. . . CC BY-NC
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50. . . CC BY-NC
51. User:Fvasconcellos/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Antibody.svg . Public Domain
52. Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
53. . . CC BY-NC
54. Courtesy of the National Institutes of Health. http://commons.wikimedia.org/wiki/File:Hiv_budding.jpg . Public Domain

CHAPTER 3 Matter and Energy: Macromolecules

Chapter Outline

3.1 Elements and Compounds

Learning Objectives

- Define matter, element, atom, molecule, and compound.
- Explain the relationship between an element, an atom, a molecule and a compound.
- Understand the basic structure of the Periodic Table.
- Diagram a chemical reaction and examine the relationship between chemical reactions and atoms, molecules and compounds.
- Explain the role of chemistry and chemicals of life in the life sciences.

What's happening in this beaker?

The bubbles indicate that vapor is being formed, which lets you know that a chemical reaction is taking place. Many chemical reactions are going on constantly inside your body. In fact, there are probably thousands of chemical reactions occurring every second in every one of your cells. And as all living things are comprised of chemicals, understanding how chemicals work is essential to understanding how living things work.

Chemicals of Life

The Elements

If you pull a flower petal from a plant and break it in half, and then take that piece and break it in half again, and take the next piece and break it half, and so on, and so on, until you cannot even see the flower anymore, what do you think you will find? We know that the flower petal is made of **cells**, but what are cells made of? Scientists have broken down **matter**, or anything that takes up space and has mass—like a cell—into the smallest pieces that cannot be broken down anymore. Every physical object, including rocks, animals, flowers, and your body, are all made up of matter.

Matter is made up of a mixture of things called elements. **Elements** are substances that cannot be broken down into simpler substances. There are more than 100 known elements, and 92 occur naturally around us. The others have been made only in the laboratory.

Inside of elements, you will find identical atoms. An **atom** is the simplest and smallest particle of matter that still has chemical properties of the element. Atoms are the building block of all of the elements that make up the matter in your body or any other living or non-living thing. Atoms are so small that only the most powerful microscopes can see them.

Atoms themselves are composed of even smaller particles, including positively charged **protons**, uncharged **neutrons**, and negatively charged **electrons**. Protons and neutrons are located in the center of the atom, or the nucleus, and the electrons move around the nucleus. How many protons an atom has determines what element it is. For example, hydrogen (H) has just one proton, helium (He) always has two protons (**Figure** 3.1), while sodium (Na) always has 11.

All the atoms of a particular element have the exact same number of protons, and the number of protons is that element's **atomic number**. An atom usually has the same number of protons and electrons, but sometimes an atom may gain or lose an electron, giving the atom a positive or negative charge. These atoms are known as **ions** and are depicted with a "+" or "-" sign. Ions, such as H^+, Na^+, K^+, or Cl^- have significant biological roles.

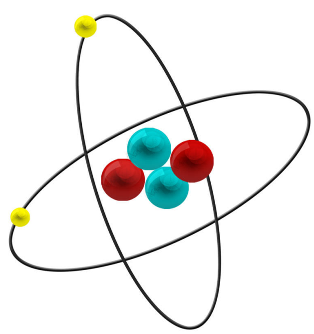

FIGURE 3.1

An atom of Helium (He) contains two positively charged protons (red), two uncharged neutrons (blue), and two negatively charged electrons (yellow).

The Periodic Table

In 1869, a Russian scientist named Dmitri Mendeleev created the **periodic table**, which is a way of organizing elements according to their unique characteristics, like atomic number, density, boiling point, and other values (**Figure** 3.2). Each element is represented by a one or two letter symbol. For example, H stands for hydrogen, and Au stands for gold. The vertical columns in the periodic table are known as groups, and elements in groups tend to have very similar properties. The table is also divided into rows, known as periods.

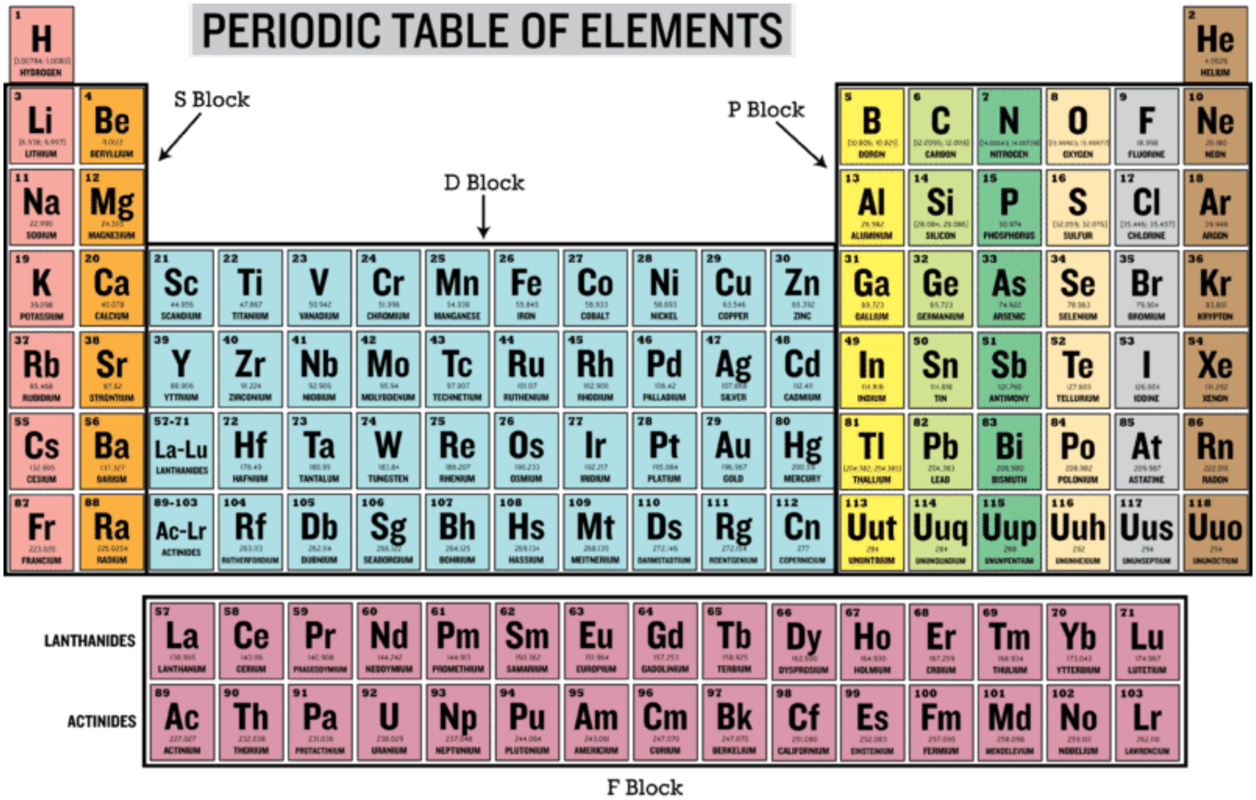

FIGURE 3.2

The periodic table groups the elements based on their properties. The table begins with Hydrogen, atomic number 1.

Chemical Reactions

A **molecule** is any combination of two or more atoms. The oxygen in the air we breathe is two oxygen atoms connected by a chemical bond to form O_2, or molecular oxygen. A carbon dioxide molecule is a combination of one carbon atom and two oxygen atoms, CO_2. Because carbon dioxide includes two different elements, it is a compound as well as a molecule.

A **compound** is any combination of two or more different elements. A compound has different properties from the elements that it contains. Elements and combinations of elements (compounds) make up all the many types of matter in the Universe. A **chemical reaction** is a process that breaks or forms the bonds between atoms of molecules and compounds. For example, two hydrogens and one oxygen bind together to form water, H_2O. The molecules that come together to start a chemical reaction are the **reactants**. So hydrogen and oxygen are the reactants. The **product** is the end result of a reaction. In this example, water is the product.

Atoms also come together to form compounds much larger than water. It is some of these large compounds that come together to form the basis of the cell. So essentially, your cells are made out of compounds, which are made out of atoms.

Summary

- Elements are substances that cannot be broken down into simpler substances with different properties.
- Elements have been organized by their properties to form the periodic table.
- Two or more atoms can combine to form a molecule.
- Molecules consisting of more than one element are called compounds.
- Reactants can combine through chemical reactions to form products.

Explore More

Use the resource below to answer the following questions.

- **Periodic table** at http://www.webelements.com/

1. What is the atomic number of nitrogen? When and where was it identified? In what state of matter does nitrogen exist at room temperature?
2. What is the atomic number of oxygen? When and where was it identified? In what state of matter does oxygen exist at room temperature?
3. What is the atomic number of carbon? When and where was it identified? In what state of matter does it exist at room temperature?
4. What is the atomic number of phosphorus? From what was phosphorus originally isolated? In what state of matter does it exist at room temperature?

Review

1. What is an element?
2. What is the difference between the terms molecule and compound?
3. Describe the composition of an atom.
4. Who is credited with developing the periodic table?

3.2 Organic Compounds

Learning Objectives

- Define proteins, carbohydrates, lipids, nucleic acids.
- Recognize the basic structure of organic compounds and explain their basic functions.
- Distinguish the categories of organic compounds, compare and contrast their roles, and analyze the components of each category.
- Summarize in detail the structure and function of the organic compounds, emphasizing the relationship between structure and function.

What makes up a healthy diet?

A healthy diet includes protein, fats, and carbohydrates. Why? Because these compounds are three of the main building blocks that make up your body. You obtain these building blocks from the food that you eat, and you use these building blocks to make the organic compounds necessary for life.

Organic Compounds

The main chemical components of living organisms are known as **organic compounds**. Organic compounds are molecules built around the element carbon (C). Living things are made up of very large molecules. These large molecules are called **macromolecules** because “macro” means large; they are made by smaller molecules bonding together. Our body gets these smaller molecules, the "building blocks" or **monomers**, of organic molecules from the food we eat. Which organic molecules do you recognize from the list below?

The four main types of macromolecules found in living organisms, shown in **Table** 3.1, are:

1. Proteins.
2. Carbohydrates.
3. Lipids.

4. Nucleic Acids.

TABLE 3.1: The Four Main Classes of Organic Molecules

	Proteins	Carbohydrates	Lipids	Nucleic Acids
Elements	C, H, O, N, S	C, H, O	C, H, O, P	C, H, O, P, N
Examples	Enzymes, muscle fibers, antibodies	Sugar, glucose, starch, glycogen, cellulose	Fats, oils, waxes, steroids, phospholipids in membranes	DNA, RNA, ATP
Monomer (small building block molecule)	Amino acids	Monosaccharides (simple sugars)	Often include fatty acids	Nucleotides

Carbohydrates

Carbohydrates are sugars, or long chains of sugars. An important role of carbohydrates is to store energy. **Glucose** (**Figure** 3.3) is an important simple sugar molecule with the chemical formula $C_6H_{12}O_6$. Simple sugars are known as **monosaccharides**. Carbohydrates also include long chains of connected sugar molecules. These long chains often consist of hundreds or thousands of monosaccharides bonded together to form **polysaccharides**. Plants store sugar in polysaccharides called **starch**. Animals store sugar in polysaccharides called **glycogen**. You get the carbohydrates you need for energy from eating carbohydrate-rich foods, including fruits and vegetables, as well as grains, such as bread, rice, or corn.

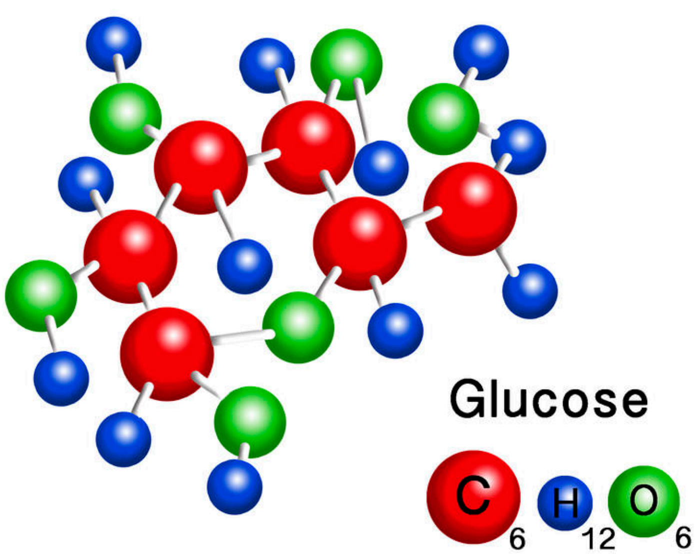

FIGURE 3.3
A molecule of glucose, a type of carbohydrate.

Proteins

Proteins are molecules that have many different functions in living things. All proteins are made of monomers called **amino acids** (**Figure** 3.4) that connect together like beads on a necklace (**Figure** 3.5). There are only 20 common amino acids needed to build proteins. These amino acids form in thousands of different combinations, making about 100,000 or more unique proteins in humans. Proteins can differ in both the number and order of amino acids. It is the number and order of amino acids that determines the shape of the protein, and it is the shape (structure) of the protein that determines the unique function of the protein. Small proteins have just a few hundred amino acids. The largest proteins have more than 25,000 amino acids.

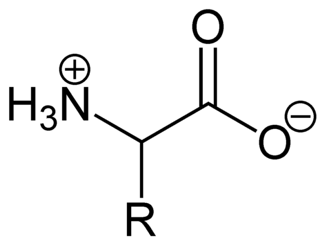

FIGURE 3.4
This model shows the general structure of all amino acids. Only the side chain, R, varies from one amino acid to another. KEY: H = hydrogen, N = nitrogen, C = carbon, O = oxygen, R = variable side chain.

FIGURE 3.5
Amino acids connect together like beads on a necklace. MET, ASN, TRP, and GLN refer to four different amino acids.

Many important molecules in your body are proteins. Examples include enzymes, antibodies, and muscle fiber. **Enzymes** are a type of protein that speed up chemical reactions. They are known as "biological catalysts." For example, your stomach would not be able to break down food if it did not have special enzymes to speed up the rate of digestion. **Antibodies** that protect you against disease are proteins. Muscle fiber is mostly protein (**Figure** 3.6).

FIGURE 3.6
Muscle fibers are made mostly of protein.

It's important for you and other animals to eat food with protein, because we cannot make certain amino acids on our own. You can get proteins from plant sources, such as beans, and from animal sources, like milk or meat. When you eat food with protein, your body breaks the proteins down into individual amino acids and uses them to build new proteins. You really are what you eat!

Lipids

Have you ever tried to put oil in water? They don't mix. Oil is a type of lipid. **Lipids** are molecules such as fats, oils, and waxes. The most common lipids in your diet are probably fats and oils. Fats are solid at room temperature, whereas oils are fluid. Animals use fats for long-term energy storage and to keep warm. Plants use oils for long-term energy storage. When preparing food, we often use animal fats, such as butter, or plant oils, such as olive oil or canola oil. There are many more type of lipids that are important to life. One of the most important are the **phospholipids** that make up the protective outer membrane of all cells (**Figure** 3.7). These lipid membranes are impermeable to most water soluble compounds.

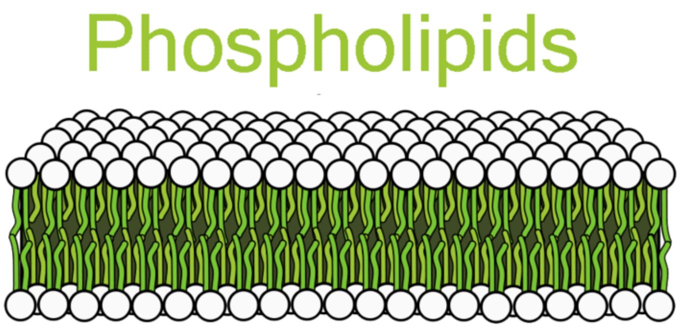

FIGURE 3.7
Phospholipids in a membrane, shown as two layers (a bilayer) of phospholipids facing each other.

Nucleic acids

Nucleic acids are long chains of nucleotides. Nucleotides are made of a sugar, a nitrogen-containing base, and a phosphate group. **Deoxyribonucleic acid (DNA)** and **ribonucleic acid (RNA)** are the two main nucleic acids. DNA is a double-stranded nucleic acid. DNA is the molecule that stores our genetic information (**Figure** 3.8). The single-stranded RNA is involved in making proteins. **ATP (adenosine triphosphate)**, known as the "energy currency" of the cell, is also a nucleic acid.

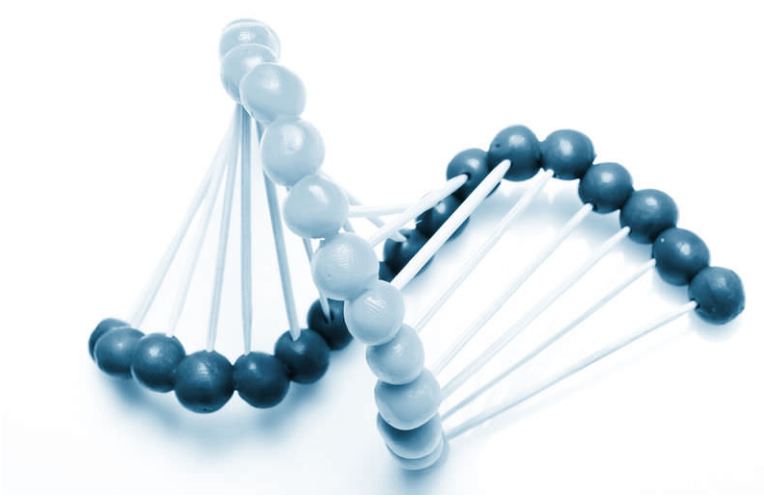

FIGURE 3.8
A model representing DNA, a nucleic acid.

Science Friday: The Agony and Ecstasy of Capsaicin

Have you ever tasted something spicy? In this video by Science Friday, Dr. Marco Tizzano discusses how capsaicin creates the burning sensation that some people enjoy.

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Summary

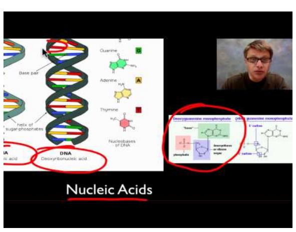
- Living organisms are comprised of organic compounds, molecules built around the element carbon.
- Living things are made of just four classes of organic compounds: proteins, carbohydrates, lipids, and nucleic acids.

Explore More

Use the resources below to answer the questions that follow.

Explore More I

- **Molecules of Life** at http://www.youtube.com/watch?v=QWf2jcznLsY (10:47)



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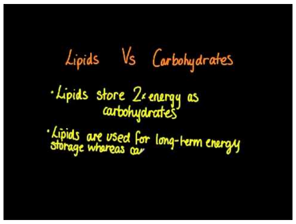
1. What four categories of macromolecules make up cells?
2. What about carbon makes it valuable to organisms?
3. What do functional groups do? How are they important to organisms?
4. What smaller units can proteins be broken down into?
5. What two nucleic acids are used by organisms?
6. What are three different types of carbohydrates?

Explore More II

- **Lipids vs. Carbohydrates** at http://www.youtube.com/watch?v=zTUCEY6CpVI (0:43)



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1. What function do both lipids and carbohydrates share? How do they differ in this regard?
2. How is the solubility of lipids different than the solubility of carbohydrates?

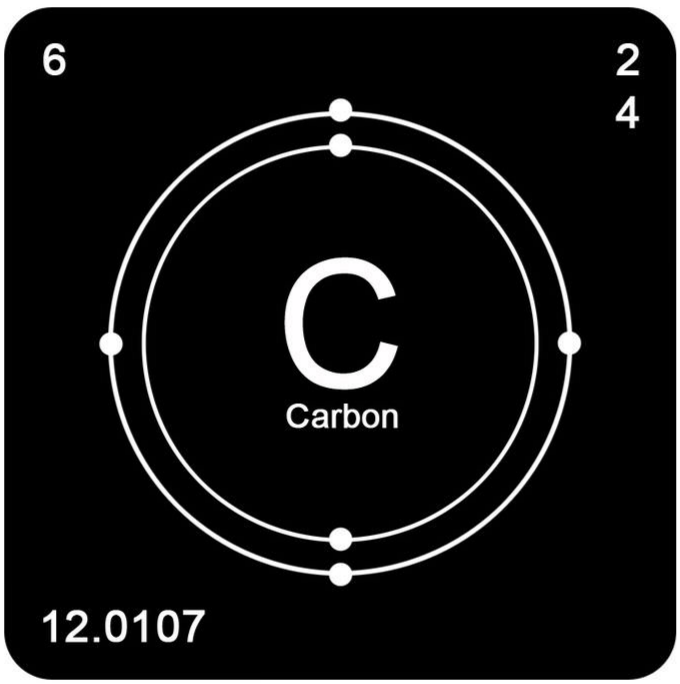
Review

1. What are the four main types of organic compounds that make up living things?
2. What are the monomers used to make carbohydrates, proteins, and nucleic acids?
3. What are examples of lipids?
4. What are examples of proteins?

3.3 Significance of Carbon

Learning Objectives

- Explain why carbon is essential to life on Earth.
- List the four major types of organic compounds.
- Name the monomers of carbohydrates, proteins, and nucleic acids.
- Identify the main functions of the four types of organic compounds.



Carbon. Element number six. Right in the middle of the first row of the Periodic Table.

Carbon is the most important element to life. Without this element, life as we know it would not exist. As you will see, carbon is the central element in compounds necessary for life.

The Significance of Carbon

A compound found mainly in living things is known as an **organic compound**. Organic compounds make up the cells and other structures of organisms and carry out life processes. Carbon is the main element in organic compounds, so carbon is essential to life on Earth. Without carbon, life as we know it could not exist.

Compounds

A **compound** is a substance that consists of two or more elements. A compound has a unique composition that is always the same. The smallest particle of a compound is called a molecule. Consider water as an example. A molecule of water always contains one atom of oxygen and two atoms of hydrogen. The composition of water is expressed by the chemical formula H_2O. A model of a water molecule is shown in **Figure** 3.26. Water is not an organic compound.

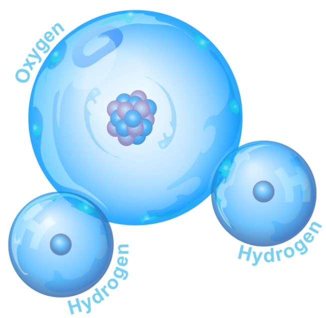


FIGURE 3.9
A water molecule always has this composition, one atom of oxygen and two atoms of hydrogen.

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

Carbon

Why is carbon so basic to life? The reason is carbon's ability to form stable bonds with many elements, including itself. This property allows carbon to form a huge variety of very large and complex molecules. In fact, there are nearly 10 million carbon-based compounds in living things! However, the millions of organic compounds can be grouped into just four major types: **carbohydrates**, **lipids**, **proteins**, and **nucleic acids**. You can compare the four types in **Table** 3.2. Each type is also described below.

TABLE 3.2: Types of Organic Compounds

Type of Compound	Examples	Elements	Functions	Monomer
Carbohydrates	sugars, starches	carbon, hydrogen, oxygen	provides energy to cells, stores energy, forms body structures	monosaccharide
Lipids	fats, oils	carbon, hydrogen, oxygen	stores energy, forms cell membranes, carries messages	
Proteins	enzymes, antibodies	carbon, hydrogen, oxygen, nitrogen, sulfur	helps cells keep their shape, makes up muscles, speeds up chemical reactions, carries messages and materials	amino acid

TABLE 3.2: (continued)

Type of Compound	Examples	Elements	Functions	Monomer
Nucleic Acids	DNA, RNA	carbon, hydrogen, oxygen, nitrogen, phosphorus	contains instructions for proteins, passes instructions from parents to offspring, helps make proteins	nucleotide

Carbohydrates, proteins, and nucleic acids are large molecules (macromolecules) built from smaller molecules (monomers) through dehydration reactions. In a dehydration reaction, water is removed as two monomers are joined together.

Energy From Carbon?

Is it possible to extract energy from leftovers? Can organic waste become useful? It may look like waste, but to some people it's green power. Find out how California dairy farms and white tablecloth restaurants are taking their leftover waste and transforming it into clean energy.

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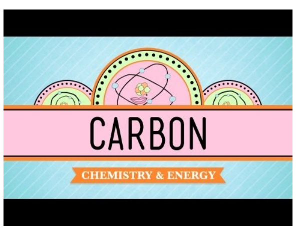

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Summary

- Carbon is the main element in organic compounds. Carbon can form stable bonds with many elements, including itself.
- There are four major types of organic compounds: carbohydrates, lipids, proteins, and nucleic acids.

Review

1. What is a compound?

2. Explain why carbon is essential to all known life on Earth.
3. What are the four main types of organic compounds?
4. Which type(s) of organic compounds provide energy?
5. Which organic compound stores genetic information?
6. Examples of proteins include ____________.

3.4 Carbohydrates

Learning Objectives

- Identify the chemical formula of glucose.
- Describe the structure and function of monosaccharides.
- List significant polysaccharides.
- Identify the role of significant polysaccharides.

Sugar. Does this look like biological energy?

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

Carbohydrates

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

Monosaccharides and Disaccharides

A **monosaccharide** is a simple sugar such as fructose or glucose. Fructose is found in fruits, whereas glucose generally results from the digestion of other carbohydrates. **Glucose** ($C_6H_{12}O_6$) is used for energy by the cells of most organisms, and is a product of photosynthesis.

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

$(CH_2O)_n$,

where n can be any number greater than two. For example, in glucose n is 6, and the formula is:

$C_6H_{12}O_6$.

Another monosaccharide, fructose, has the same chemical formula as glucose, but the atoms are arranged differently. Molecules with the same chemical formula but with atoms in a different arrangement are called **isomers**. Compare the glucose and fructose molecules in **Figure** 3.10. Can you identify their differences? The only differences are the positions of some of the atoms. These differences affect the properties of the two monosaccharides.

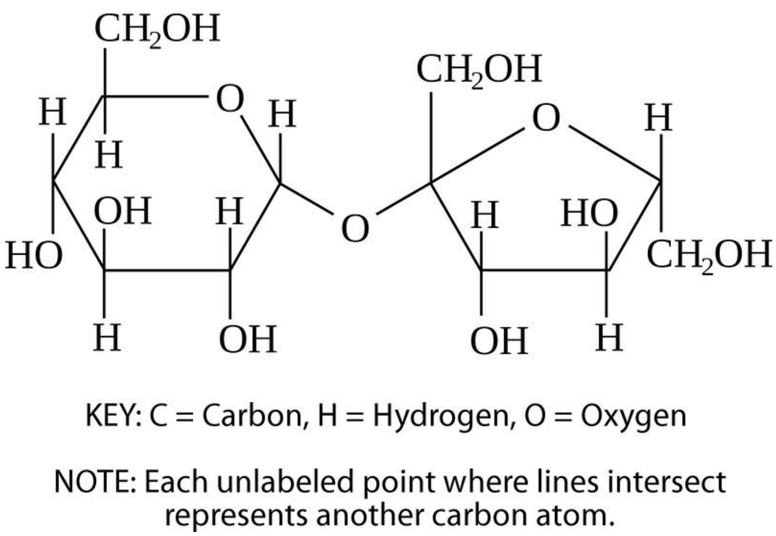


FIGURE 3.10

Sucrose Molecule. This sucrose molecule is a disaccharide. It is made up of two monosaccharides: glucose on the left and fructose on the right.

If two monosaccharides bond together, they form a carbohydrate called a **disaccharide**. An example of a disaccharide is sucrose (table sugar), which consists of the monosaccharides glucose and fructose (**Figure** 3.10). Monosaccharides and disaccharides are also called **simple sugars**. They provide the major source of energy to living cells

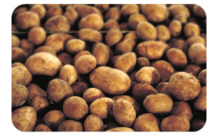
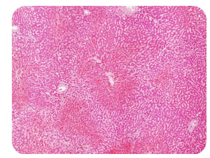
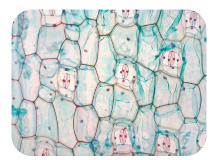
Polysaccharides

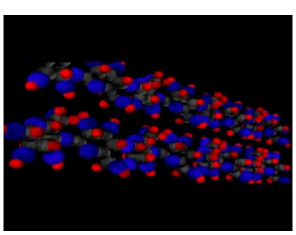
A **polysaccharide** is a complex carbohydrate that forms when simple sugars bind together in a chain. Polysaccharides may contain just a few simple sugars or thousands of them. Complex carbohydrates have two main functions: storing energy and forming structures of living things. Some examples of complex carbohydrates and their functions are shown in **Table** 3.3. Which type of complex carbohydrate does your own body use to store energy?

TABLE 3.3: Complex Carbohydrates

Name	Function	Example

TABLE 3.3: (continued)

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



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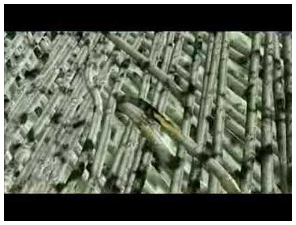
Biofuels: From Sugar to Energy

For years there's been buzz, both positive and negative, about generating ethanol fuel from corn. Is this a good idea? Is it necessary? These questions need to be discussed. However, the Bay Area of California is rapidly becoming a world center for the next generation of green fuel alternatives. The Joint BioEnergy Institute is developing methods to isolate biofuels from the sugars in cellulose.



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As you view *Biofuels: Beyond Ethanol,* focus on these concepts:

1. the use of "cellulosic biomass,"
2. what is meant by "directed evolution."

Summary

- Carbohydrates are organic compounds used to store energy.
- A monosaccharide is a simple sugar, such as fructose or glucose.
- Complex carbohydrates have two main functions: storing energy and forming structures of living things.

Review

1. What is a carbohydrate?
2. List three facts about glucose.
3. Assume that you are trying to identify an unknown organic molecule. It contains only carbon, hydrogen, and oxygen and is found in the cell walls of a newly discovered plant species. What type of organic compound is it? Why?
4. Compare and contrast the structures and functions of simple sugars and complex carbohydrates.

3.5 Lipids

Learning Objectives

- Distinguish between saturated and unsaturated fatty acids.
- List and describe the function of the main types of lipids.

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

Oil is a lipid. The property of chemically not being able to mix with water gives lipids some very important biological functions. Lipids form the outer membrane of cells. Why?

Lipids

A **lipid** is an organic compound such as fat or oil. Organisms use lipids to store energy, but lipids have other important roles as well. Lipids consist of repeating units called fatty acids. **Fatty acids** are organic compounds that have the general formula $CH_3(CH_2)_nCOOH$, where n usually ranges from 2 to 28 and is always an even number. There are two types of fatty acids: saturated fatty acids and unsaturated fatty acids.

Saturated Fatty Acids

In **saturated fatty acids**, carbon atoms are bonded to as many hydrogen atoms as possible. This causes the molecules to form straight chains, as shown in **Figure** 3.11. The straight chains can be packed together very tightly, allowing them to store energy in a compact form. This explains why saturated fatty acids are solids at room temperature. Animals use saturated fatty acids to store energy.

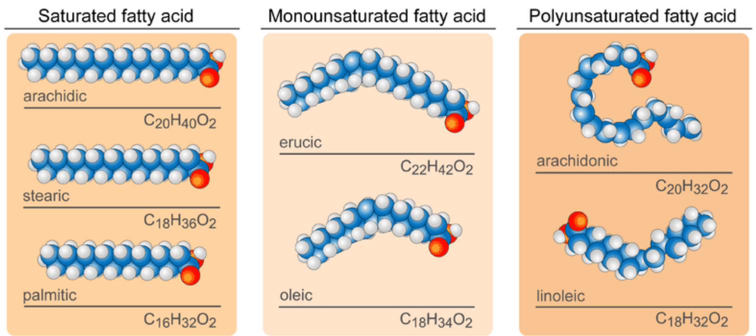


FIGURE 3.11
Fatty Acids. Saturated fatty acids have straight chains, like the three fatty acids shown in the upper left. Unsaturated fatty acids have bent chains, like all the other fatty acids in the figure.

Unsaturated Fatty Acids

In **unsaturated fatty acids**, some carbon atoms are not bonded to as many hydrogen atoms as possible. Instead, they are bonded to other groups of atoms. Wherever carbon binds with these other groups of atoms, it causes chains to bend (see **Figure** 3.11). The bent chains cannot be packed together very tightly, so unsaturated fatty acids are liquids at room temperature. Plants use unsaturated fatty acids to store energy. Some examples are shown in **Figure** 3.12.

FIGURE 3.12
These plant products all contain unsaturated fatty acids.

Types of Lipids

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

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

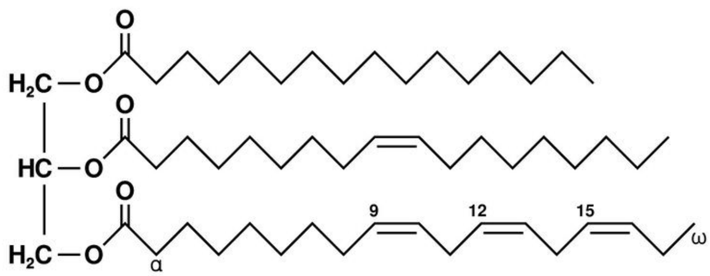
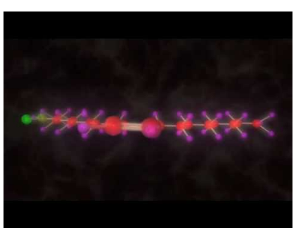


FIGURE 3.13
Triglyceride Molecule. The left part of this triglyceride molecule represents glycerol. Each of the three long chains on the right represents a different fatty acid. From top to bottom, the fatty acids are palmitic acid, oleic acid, and alpha-linolenic acid. The chemical formula for this triglyceride is $C_{55}H_{98}O_6$. KEY:H=hydrogen, C=carbon, O=oxygen

Lipids and Diet

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

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



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Summary

- Organisms use lipids to store energy. There are two types of fatty acids: saturated fatty acids and unsaturated fatty acids.
- Animals use saturated fatty acids to store energy. Plants use unsaturated fatty acids to store energy.
- Phospholipids are the major components of cell membranes.
- Excess dietary lipids can be harmful.

Review

1. What is a lipid? Give three examples.
2. Butter is a fat that is a solid at room temperature. What type of fatty acid does butter contain? How do you know?
3. Explain why molecules of saturated and unsaturated fatty acids have different shapes.
4. Which lipid is the main component of cell membranes?

3.6 Proteins

Learning Objectives

- Describe the composition of a protein.
- Distinguish between the four levels of protein structure.
- Summarize significant protein functions.

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

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

Proteins

A **protein** is an organic compound made up of small molecules called **amino acids**. There are 20 different amino acids commonly found in the proteins of living organisms. Small proteins may contain just a few hundred amino acids, whereas large proteins may contain thousands of amino acids. The largest known proteins are titins, found in muscle, which are composed from over 27,000 amino acids.

Protein Structure

When amino acids bind together, they form a long chain called a **polypeptide**. A protein consists of one or more polypeptide chains. A protein may have up to four levels of structure. The lowest level, a protein's primary structure,

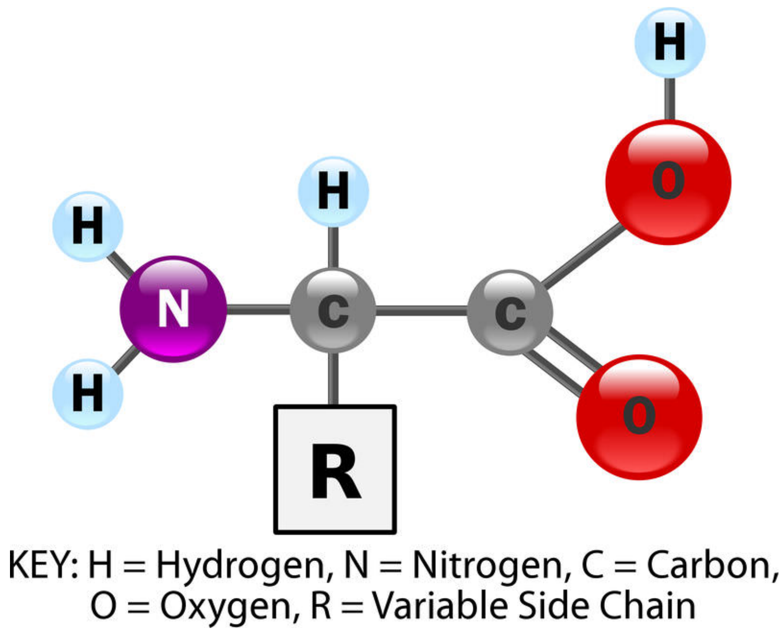


FIGURE 3.14
General Structure of Amino Acids. This model shows the general structure of all amino acids. Only the side chain, R, varies from one amino acid to another. For example, in the amino acid glycine, the side chain is simply hydrogen (H). In glutamic acid, in contrast, the side chain is CH_2CH_2COOH. Variable side chains give amino acids different chemical properties. The order of amino acids, together with the properties of the amino acids, determines the shape of the protein, and the shape of the protein determines the function of the protein. KEY: H = hydrogen, N = nitrogen, C = carbon, O = oxygen, R = variable side chain

is its sequence of amino acids. Higher levels of protein structure are described in **Figure** 15.8. The complex structures of different proteins give them unique properties, which they need to carry out their various jobs in living organisms.

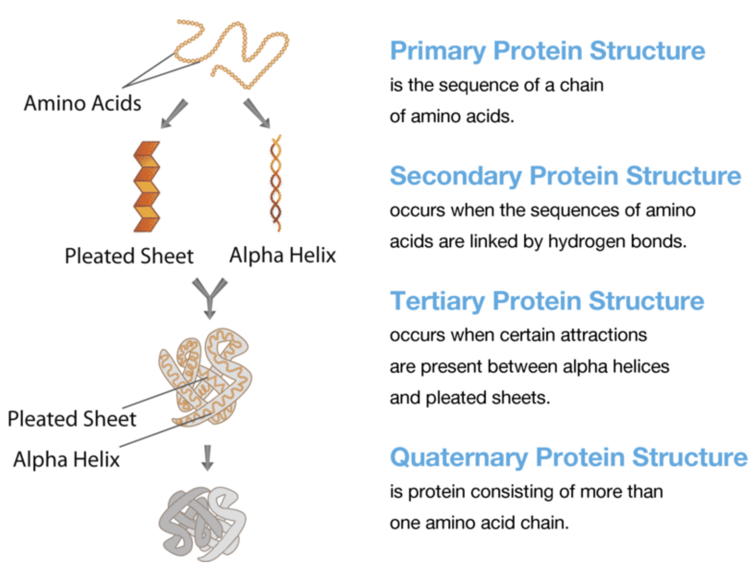


FIGURE 3.15
Protein Structure. The structure of a protein starts with its sequence of amino acids. What determines the secondary structure of a protein? What are two types of secondary protein structure?

Functions of Proteins

Proteins play many important roles in living things. Some proteins help cells keep their shape (structural proteins), some, such as connective and motor proteins, make up muscle tissues, and some transport items in and out of cells (transport proteins). Some proteins act as signals, and other proteins receive those signals. **Enzymes** are proteins that speed up chemical reactions in cells. Other proteins are **antibodies**, which bind to foreign substances such as bacteria and target them for destruction. Still other proteins carry messages or transport materials. For example, human red blood cells contain a protein called **hemoglobin**, which binds with oxygen. Hemoglobin allows the blood to carry oxygen from the lungs to cells throughout the body. A model of the hemoglobin molecule is shown in **Figure** 15.9.

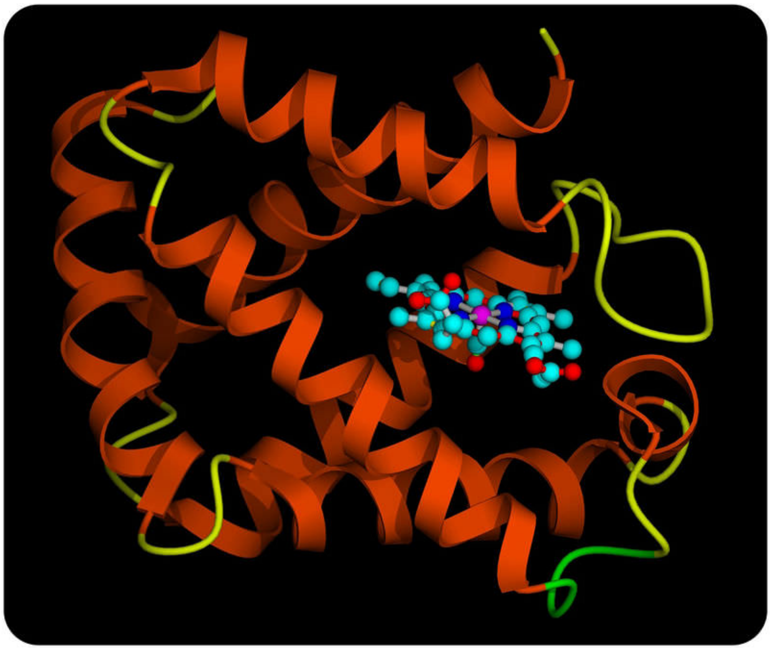
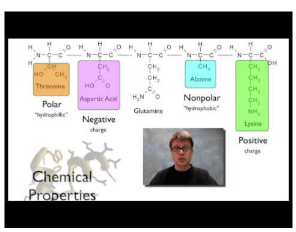


FIGURE 3.16

Hemoglobin Molecule. This model represents the protein hemoglobin. The purple part of the molecule contains iron. The iron binds with oxygen molecules.



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Proteins and Diet

Proteins in the diet are necessary for life. Dietary proteins are broken down into their component amino acids when food is digested. Cells can then use the components to build new proteins. Humans are able to synthesize all but eight of the twenty common amino acids. These eight amino acids, called **essential amino acids**, must be consumed in foods. Like dietary carbohydrates and lipids, dietary proteins can also be broken down to provide cells with energy.

Science Friday: The Medical Wonders of Worm Spit

How useful is worm spit? It turns out that worm spit, also known as silk, is a very useful material in medicine. In this video by Science Friday, Dr. David Kaplan describes how silk is used in a variety of medical applications.

MEDIA

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Summary

- Proteins are organic compounds made up of amino acids.
- A protein may have up to four levels of structure. The complex structures of different proteins give them unique properties.
- Enzymes are proteins that speed up biochemical reactions in cells. Antibodies are proteins that target pathogens for destruction.

Review

1. Proteins are made out of ____________.
2. What determines the primary structure of a protein?
3. State two functions of proteins.
4. What are enzymes?
5. Describe the role of hemoglobin.

3.7 Types of Nutrients

Learning Objectives

- Identify sources of nutrients.
- Identify the roles of carbohydrates, proteins, and lipids.
- Distinguish simple carbohydrates from complex carbohydrates.
- Distinguish saturated fats from unsaturated fats.

What nutrients are in this meal?

There are many different nutrients that are present in this meal. For example, the steak is a source of protein. The french fries are a source of carbohydrates. Both these nutrients help supply the body with energy.

Nutrients

Carbohydrates, proteins, and lipids contain energy. When your body digests food, it breaks down the molecules of these nutrients. This releases the energy so your body can use it.

Carbohydrates

Carbohydrates are nutrients that include sugars, starches, and fiber. There are two types of carbohydrates: simple and complex. Pictured below are some foods that are good sources of carbohydrates (**Figure** 3.17).

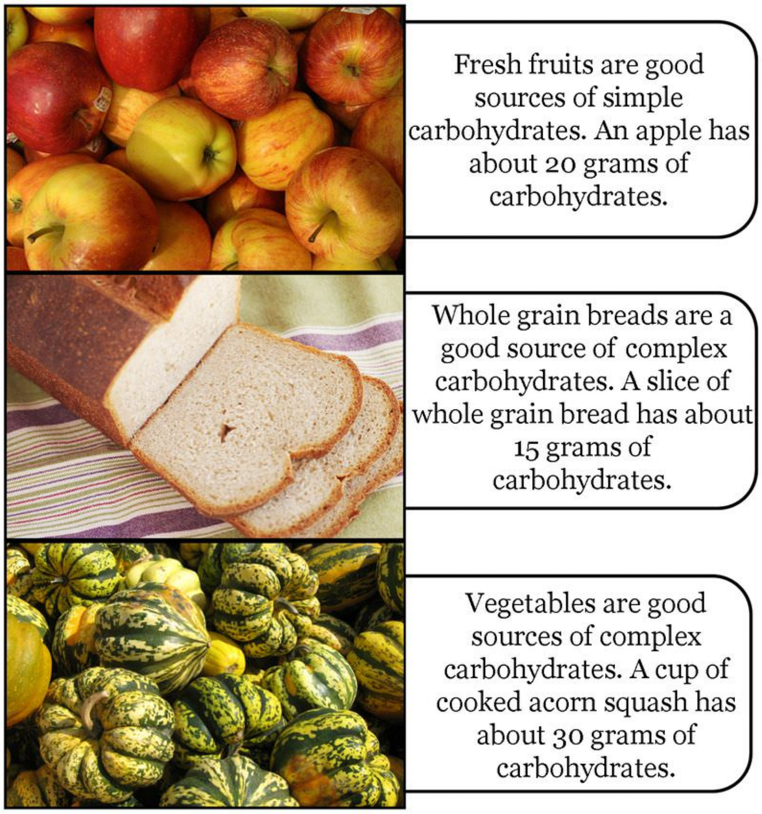

FIGURE 3.17
Up to the age of 13 years, you need about 130 grams of carbohydrates a day. Most of the carbohydrates should be complex. They are broken down by the body more slowly than simple carbohydrates. Therefore, they provide energy longer and more steadily.

Simple Carbohydrates

Sugars are small, simple carbohydrates that are found in foods such as fruits and milk. The sugar found in fruits is called fructose. The sugar found in milk is called lactose. These sugars are broken down by the body to form glucose ($C_6H_{12}O_6$), the simplest sugar of all.

Where does glucose come from? Recall that glucose is the product of photosynthesis, so some organisms such as plants are able to make their own glucose. As animals cannot photosynthesize, they must eat to obtain carbohydrates. Through the process of **cellular respiration**, glucose is converted by cells into energy that is usable by the cell (ATP).

Complex Carbohydrates

Starch is a large, complex carbohydrate made of thousands of glucose units (monomers) joined together. Starches are found in foods such as vegetables and grains. Starches are broken down by the body into sugars that provide energy. Breads and pasta are good sources of complex carbohydrates.

Fiber is another type of large, complex carbohydrate that is partly indigestible. Unlike sugars and starches, fiber does not provide energy. However, it has other important roles in the body. For example, fiber is important for maintaining the health of your gastrointestinal tract. Eating foods high in fiber also helps fill you up without providing too many calories. Most fruits and vegetables are high in fiber. Some examples are pictured below (**Figure** 3.18).

Proteins

Proteins are nutrients made up of smaller molecules called **amino acids**. Recall that there are 20 different amino acids arranged like "beads on a string" to form proteins. These amino acid chains then fold up into a three-

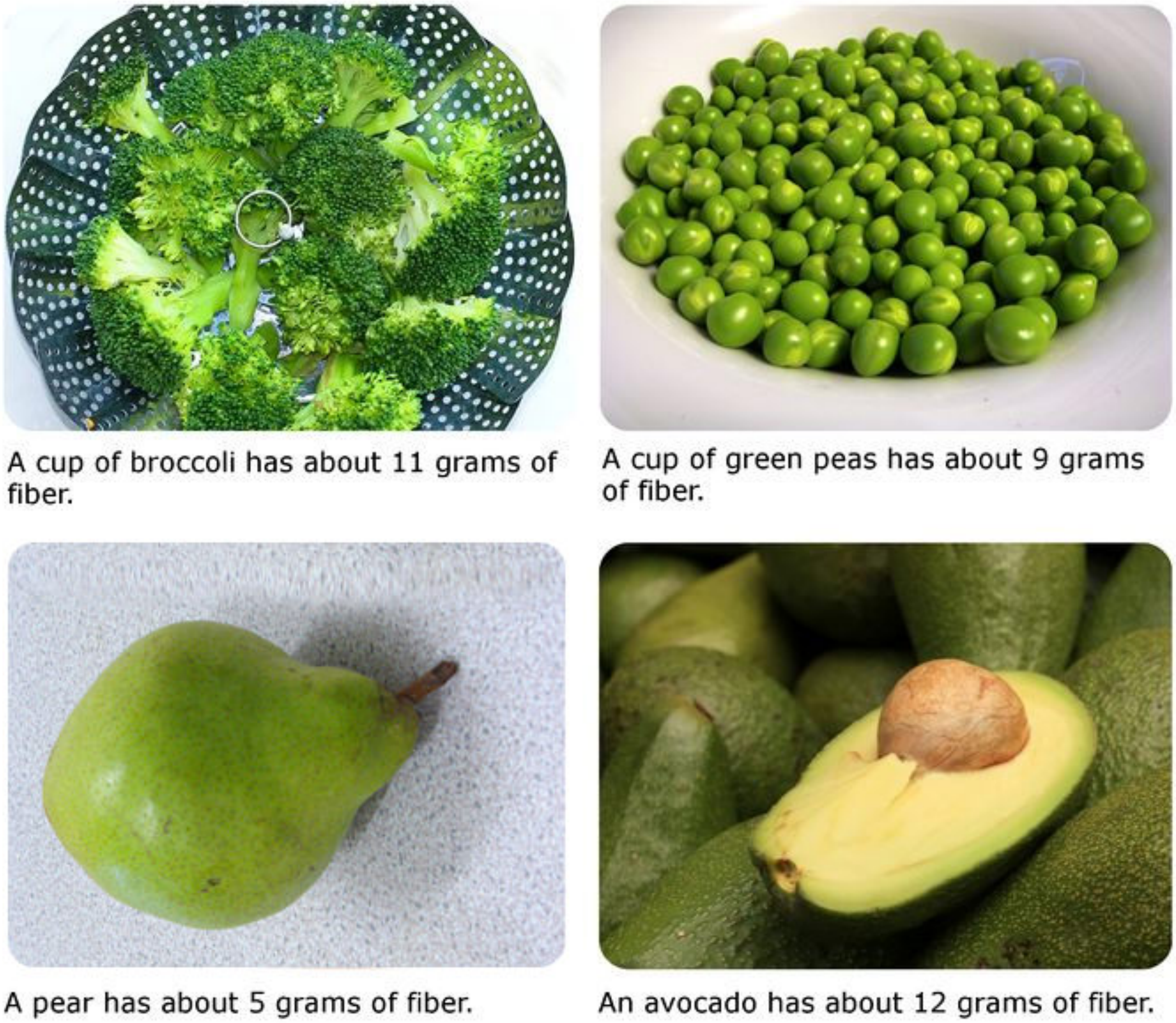

FIGURE 3.18
Between the ages of 9 and 13 years, girls need about 26 grams of fiber per day, and boys need about 31 grams of fiber per day.

dimensional molecule, giving the protein a specific function. Proteins have several important roles in the body. For example, proteins make up antibodies, muscle fibers and enzymes that help control cell and body processes. You need to make sure you have enough protein in your diet to obtain the necessary amino acids to make your proteins.

If you eat more than you need for these purposes, the extra protein is used for energy. The image below shows how many grams of protein you need each day (**Figure** 3.19). It also shows some foods that are good sources of protein.

Lipids

Lipids are nutrients, such as fats that store energy. Lipids also have several other roles in the body. For example,

FIGURE 3.19

Between the ages of 9 and 13 years, you need about 34 grams of proteins a day. Seafood and eggs are other good sources of protein.

lipids protect nerves and make up the membranes that surround cells.

Fats are one type of lipid. Stored fat gives your body energy to use for later. It's like having money in a savings account: it's there in case you need it. Stored fat also cushions and protects internal organs. In addition, it insulates the body. It helps keep you warm in cold weather.

There are two main types of fats, saturated and unsaturated.

1. **Saturated fats** can be unhealthy, even in very small amounts. They are found mainly in animal foods, such as meats, whole milk, and eggs. So even though these foods are good sources of proteins, they should be eaten in limited amounts. Saturated lipids increase cholesterol levels in the blood. Too much cholesterol in the blood can lead to heart disease.
2. **Unsaturated fats** are found mainly in plant foods, such as vegetable oil, olive oil, and nuts. Unsaturated lipids are also found in fish, such as salmon. Unsaturated lipids are needed in small amounts for good health. Most lipids in your diet should be unsaturated.

Another type of lipid is called **trans fat**. Trans fats are manufactured and added to certain foods to keep them fresher for longer. Foods that contain trans fats include cakes, cookies, fried foods, and margarine. Eating foods that contain trans fats increases the risk of heart disease.

Beginning with Denmark in 2003, many nations now limit the amount of trans fat that can be in food products or ban these products all together. On January 1, 2008, Calgary became the first city in Canada to ban trans fats from restaurants and fast food chains. Beginning in 2010, California banned trans fats from restaurant products, and in 2011, from all retail baked goods.

Summary

- Carbohydrates, proteins, and lipids provide energy and have other important roles in the body.
- Unsaturated fats are better for your health than trans fats or saturated fats.

Explore More

Use the resource below to answer the questions that follow.

- **Nutrients Your Body Needs** at http://www.pbs.org/wgbh/nova/body/nutrients-body-needs.html

1. What does your body use iodine for? What are good sources of iodine? What are some of the problems of iodine deficiency?
2. What does your body use magnesium for? What are good sources of magnesium? What problems come from magnesium deficiency?
3. What does your body use riboflavin for? What are good sources of riboflavin? What can happen if your diet is deficient in riboflavin?

Review

1. Which nutrients can be used for energy?
2. What is starch?
3. Why is it important that you get enough proteins in foods?
4. What foods contain saturated fats? How much of these foods should you eat? Why?

3.8 Food and Nutrients

Learning Objectives

- Explain why the body needs food.
- Define nutrient.
- List and describe the five types of nutrients.

What happens when you don't eat?

Refusing one meal won't stunt your growth. But lack of proper food over a period of time can lead to malnutrition. That means, the body is not getting enough nutrients to grow and stay healthy. Kids who are malnourished may not grow as tall as they would otherwise.

Why We Need Food

Did you ever hear the old saying, *An apple a day keeps the doctor away*? Do apples really prevent you from getting sick? Probably not, but eating apples and other fresh fruits can help keep you healthy. Do you eat your vegetables? Maybe you do, but you may have friends who won't touch a piece of broccoli or asparagus. Should you eat these foods and food like them? The girls pictured in the **Figure** 3.20 are eating salads. Why do you need foods like these for good health? What role does food play in the body?

Your body needs food for three reasons:

FIGURE 3.20
These girls are eating leafy green vegetables. Fresh vegetables such as these are excellent food choices for good health.

1. Food gives your body energy. You need energy for everything you do. Remember that **cellular respiration** converts the glucose in the food you eat into **ATP**, or cellular energy. Which has more glucose, a salad or a piece of meat? Do you remember what types of foods produce glucose? Recall that glucose is the product of photosynthesis.
2. Food provides building materials for your body. Your body needs building materials so it can grow and repair itself. Specifically, it needs these materials to produce more cells and its components.
3. Food contains substances that help control body processes. Your body processes must be kept in balance for good health.

For all these reasons, you must have a regular supply of nutrients. **Nutrients** are chemicals in food that your body needs. There are five types of nutrients.

1. **Carbohydrates**
2. **Proteins**
3. **Lipids**
4. **Vitamins**
5. **Minerals**

Carbohydrates, proteins, and lipids are categories of organic compounds. They give your body energy, though carbohydrates are the main source of energy. Proteins provide building materials, such as amino acids to build your own proteins. Proteins, vitamins, and minerals also help control body processes. Carbohydrates include sugars such as the glucose made by photosynthesis. Often glucose is stored in large molecules such as starch. Proteins are found in foods like meats and nuts. Lipids includes fats and oils. Though you should stay away from many types of fats, others are needed by your body. Important vitamins include vitamins A, B (multiple types) C, D, and E. Important minerals include calcium and potassium. What should you drink to get calcium? Milk is a good source.

Summary

- Your body needs food to obtain energy, to get building blocks for your body, and to get substances that help control body processes.
- Nutrients, chemicals in food that your body needs, include carbohydrates, proteins, lipids, vitamins, and minerals.

Explore More

Use the resource below to answer the questions that follow.

- **Nutrition** at http://www.youtube.com/watch?v=2xbD6–X0IA (6:39)

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1. What is nutrition?
2. What do organisms use "food" for?
3. What is a heterotroph? Are humans autotrophic or heterotrophic?
4. What are the three types of heterotrophic organisms?

Review

1. Why does your body need food? Give two reasons.
2. What are nutrients?
3. What are the five types of nutrients?
4. Why are carbohydrates a necessary part of your diet?
5. Why are proteins a necessary part of your diet?

3.9 Balanced Eating

- Describe how to choose foods wisely for optimal health.
- Explain MyPyramid and MyPlate.
- List eating healthy guidelines.
- Read and understand a nutrition facts label.
- Define obesity.

Which foods would be the best choice?

Each day you make many food choices. You decide which lunch line to get into. Then you may choose an after-school snack. How can you make the most healthy decisions?

Choosing Healthy Foods

Foods such as whole grain breads, fresh fruits, and fish provide nutrients you need for good health. But different foods give you different types of nutrients. You also need different amounts of each nutrient. How can you choose the right mix of foods to get the proper balance of nutrients? Three tools can help you choose foods wisely: MyPyramid, MyPlate, and food labels.

MyPyramid

MyPyramid (**Figure** 3.21) is a diagram that shows how much you should eat each day of foods from six different food groups. It recommends the amount of nutrients you need based on your age, your gender, and your level of activity. The six food groups in MyPyramid are:

- Grains, such as bread, rice, pasta, and cereal.
- Vegetables, such as spinach, broccoli, carrots, and sweet potatoes.
- Fruits, such as oranges, apples, bananas, and strawberries.
- Oils, such as vegetable oil, canola oil, olive oil, and peanut oil.
- Dairy, such as milk, yogurt, cottage cheese, and other cheeses.
- Meat and beans, such as chicken, fish, soybeans, and kidney beans.

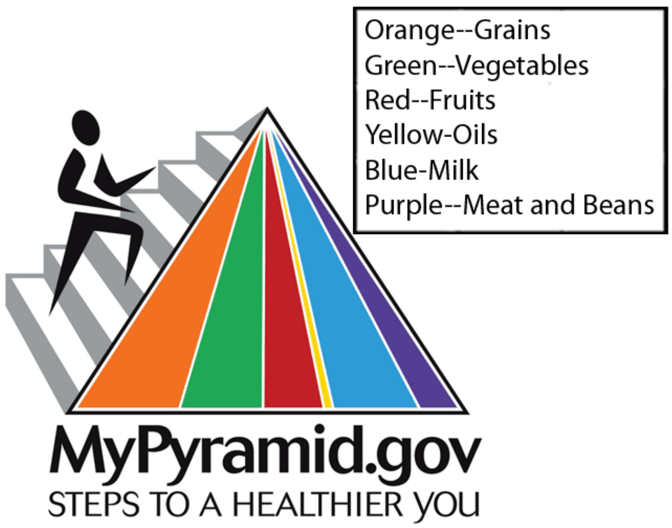


FIGURE 3.21
MyPyramid can help you choose foods wisely for good health. Each colored band represents a different food group. The key shows which food group each color represents. Which colored band of MyPyramid is widest? Which food group does it represent?

In MyPyramid, each food group is represented by a band of a different color. For example, grains are represented by an orange band, and vegetables are represented by a green band. The wider the band, the more foods you should choose from that food group each day.

The orange band in MyPyramid is the widest band. This means that you should choose more foods from the grain group than from any other single food group. The green, blue, and red bands are also relatively wide. Therefore, you should choose plenty of foods from the vegetable, dairy, and fruit groups as well. You should choose the fewest foods from the food group with the narrowest band. Which band is narrowest? Which food group does it represent?

Are you wondering where foods like ice cream, cookies, and potato chips fit into MyPyramid? The white tip of MyPyramid represents foods such as these. These are foods that should be eaten only in very small amounts and not very often. Such foods contain very few nutrients and are called nutrient-poor. Instead, they are high in fats, sugars, and sodium, which are nutrients that you should limit in a healthy eating plan. Ice cream, cookies, and potato chips are also high in calories. Eating too much of them may lead to unhealthy weight gain.

Healthy Eating Guidelines

- Make at least half your daily grain choices whole grains. Examples of whole grains are whole wheat bread, whole wheat pasta, and brown rice.

- Choose a variety of different vegetables each day. Be sure to include both dark green vegetables, such as spinach and broccoli, and orange vegetables, such as carrots and sweet potatoes.
- Choose a variety of different fruits each day. Select mainly fresh fruits rather than canned fruits, and whole fruits instead of fruit juices.
- When choosing oils, choose unsaturated oils, such as olive oil, canola oil, or vegetable oil.
- Choose low-fat or fat-free milk and other dairy products. For example, select fat-free yogurt and low-fat cheese.
- For meats, choose fish, chicken, and lean cuts of beef. Also, be sure to include beans, nuts, and seeds.

MyPlate

In June 2011, the United States Department of Agriculture replaced My Pyramid with **MyPlate.** MyPlate depicts the relative daily portions of various food groups (**Figure** 3.22). See http://www.choosemyplate.gov/ for more information.

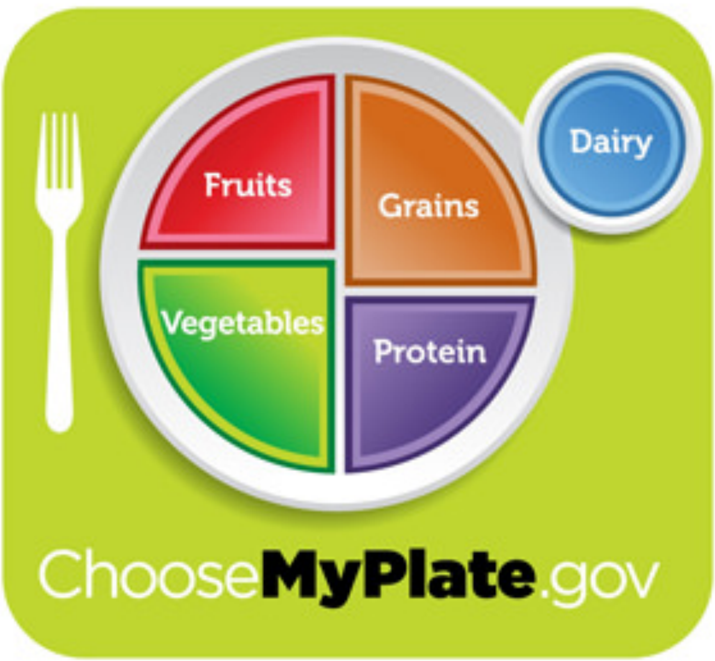


FIGURE 3.22
MyPlate is a visual guideline for balanced eating, replacing MyPyramid in 2011.

The following guidelines accompany MyPlate:

1. Balancing Calories

- Enjoy your food, but eat less.
- Avoid oversized portions.

2. Foods to Increase

- Make half your plate fruits and vegetables.
- Make at least half your grains whole grains.
- Switch to fat-free or low-fat (1%) milk.

3. Foods to Reduce

- Compare sodium in foods like soup, bread, and frozen meals; choose the foods with lower levels.
- Drink water instead of drinks with high levels of sugar.

Using Nutrition Facts Labels

In the United States and other nations, packaged foods are required by law to have nutrition facts labels. A **nutrition facts label** (**Figure** 3.23) shows the nutrients in a food. Packaged foods are also required to list their ingredients.

The information listed at the right of the label tells you what to look for. At the top of the label, look for the serving size. The serving size tells you how much of the food you should eat to get the nutrients listed on the label. A cup of food from the label pictured below is a serving. The calories in one serving are listed next. In this food, there are 250 calories per serving.

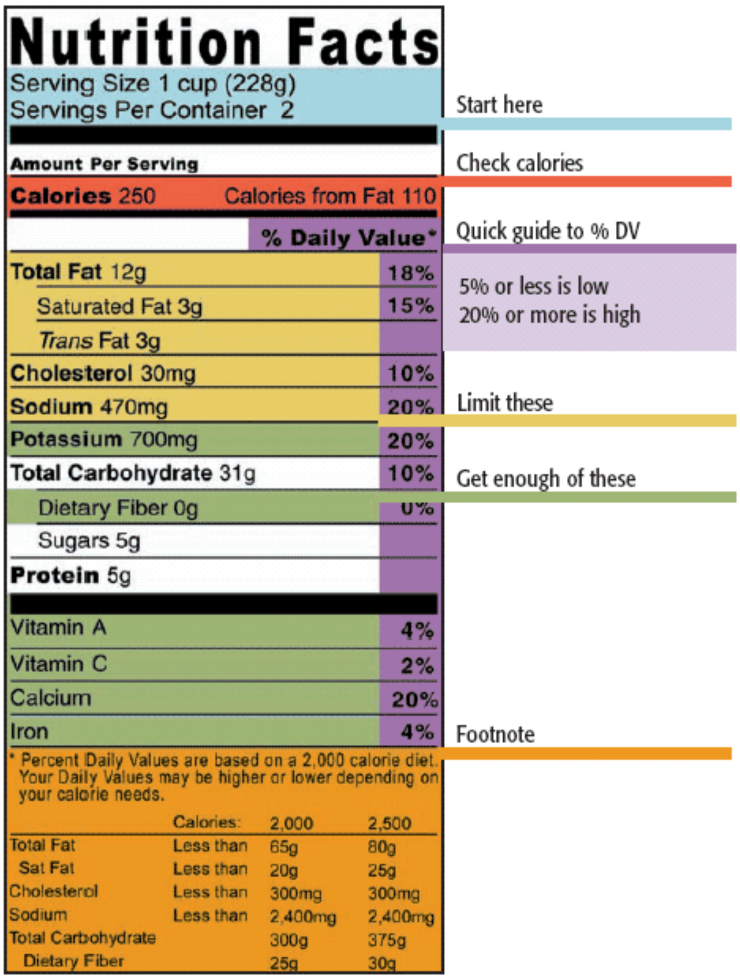


FIGURE 3.23

Reading nutrition facts labels can help you choose healthy foods. Look at the nutrition facts label shown here. Do you think this food is a good choice for a healthy eating plan? Why or why not?

Next on the nutrition facts label, look for the percent daily values (% DV) of nutrients. Remember the following tips when reading a food label:

- A food is low in a nutrient if the percent daily value of the nutrient is 5% or less.
- The healthiest foods are low in nutrients such as fats and sodium.
- A food is high in a nutrient if the percent daily value of the nutrient is 20% or more.
- The healthiest foods are high in nutrients such as fiber and proteins.

Look at the percent daily values on the food label (**Figure** 3.23). Which nutrients have values of 5% or less? These are the nutrients that are low in this food. They include fiber, vitamin A, vitamin C, and iron. Which nutrients have values of 20% or more? These are the nutrients that are high in this food. They include sodium, potassium, and calcium.

Balancing Food with Exercise

Look at MyPyramid (**Figure** 3.21). Note the person walking up the side of the pyramid. This shows that exercise is important for balanced eating. Exercise helps you use any extra energy in the foods you eat. The more active you are, the more energy you use. You should try to get at least an hour of physical activity just about every day. Pictured below are some activities that can help you use extra energy (**Figure** 3.24).

Weight Gain and Obesity

Any unused energy in food is stored in the body as fat. This is true whether the extra energy comes from carbohydrates, proteins, or lipids. What happens if you take in more energy than you use, day after day? You will store more and more fat and become overweight.

Eventually, you may become obese. **Obesity** is having a very high percentage of body fat. Obese people are at least 20 percent heavier than their healthy weight range. The excess body fat of obesity is linked to many diseases. Obese people often have serious health problems, such as diabetes, high blood pressure, and high cholesterol. They are also more likely to develop arthritis and some types of cancer. People who remain obese during their entire adulthood usually do not live as long as people who stay within a healthy weight range.

The current generation of children and teens is the first generation in our history that may have a shorter life than their parents. The reason is their high rate of obesity and the health problems associated with obesity. You can avoid gaining weight and becoming obese. The choice is yours. Choose healthy foods by using MyPyramid and reading food labels. Then get plenty of exercise to balance the energy in the foods you eat.

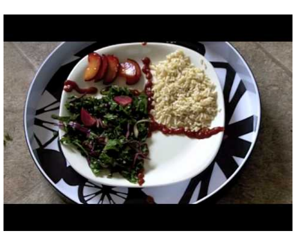
Summary

- MyPlate, MyPyramid, and food labels are tools that can help you choose the best foods for healthy eating.
- Eating too much and exercising too little can lead to weight gain and obesity.

Explore More

Use the resource below to answer the questions that follow.

- **How To Create A Balanced Meal** at http://www.youtube.com/watch?v=KchFa8QCQSk (4:25)



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1. What should the biggest section of your plate be filled with?

FIGURE 3.24

All of these activities are good ways to exercise and use extra energy. The calories given for each activity are the number of calories used in an hour by a person that weighs 100 pounds. Which of these activities uses the most calories? Which of the activities do you enjoy?

2. What does it mean when vegetables have bright colors?
3. Why are whole grains better for you than refined grains?
4. What are good five sources of whole grains?

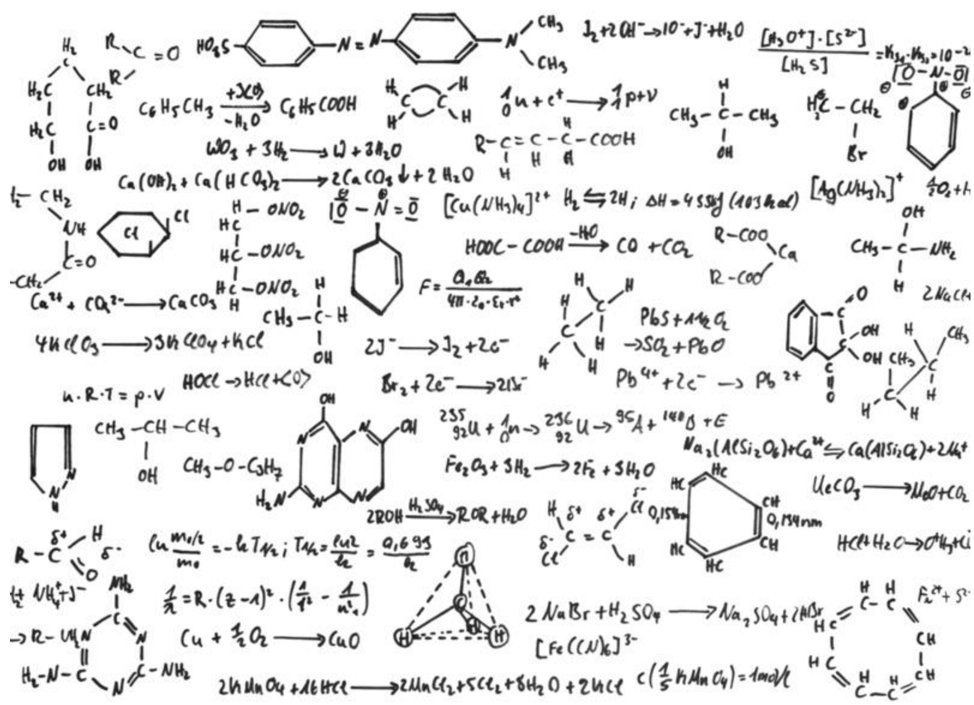
Review

1. Which food group contains soybeans, kidney beans, and fish?
2. Complete this sentence: The healthiest foods are low in nutrients such as _______ and _______, and high in nutrients such as _______ and _______.
3. What happens if you take in more energy than you use, day after day?
4. According to MyPyramid, you should eat most from what group of foods each day?

3.10 Chemical Substances - Advanced

Learning Objectives

- Distinguish between atoms, elements, and ions.
- Compare ionic bonds to covalent bonds.
- Define organic compound.
- Describe elements and compounds, and explain how mixtures differ from compounds.



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

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

Chemical Substances

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

Elements

An **element** is a pure substance that cannot be broken down into different types of substances. There are almost 120 known elements (**Figure** 3.25), each with its own personality. The chemical and physical properties of one element differ from any other. Elements are arranged according to their properties in the **Periodic Table**.

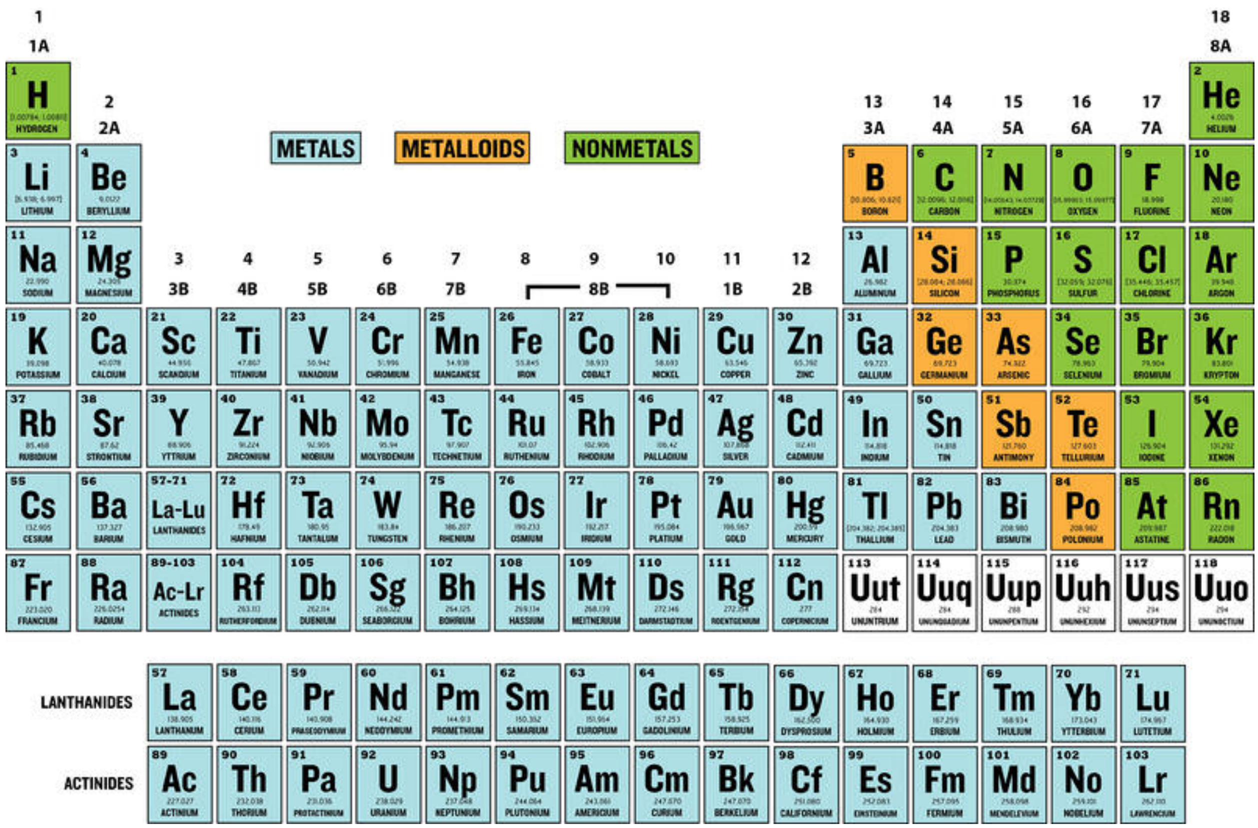


FIGURE 3.25

The Periodic Table.

Examples of elements include carbon, oxygen, hydrogen, gold, silver and iron. Each element is made up of just one type of atom. An **atom** is the smallest particle of an element that still characterizes the element. As shown in **Figure ??**, at the center of an atom is a nucleus. The nucleus contains positively charged particles called protons and electrically neutral particles called neutrons. Surrounding the nucleus is a much larger electron cloud consisting of negatively charged electrons. Electrons are arranged into distinct energy levels, at various distances from the nucleus. An atom is electrically neutral if it has the same number of protons as electrons. Each element has atoms with a characteristic number of protons, which defines the atomic number of the element. For example, all carbon atoms have six protons, and all oxygen atoms have eight protons. A combination of the number of protons and neutrons in the nucleus gives the approximate atomic mass of the atom, measured in an amu, or atomic mass unit. For example, hydrogen has an atomic number of 1 and an atomic mass of 1.00794 amu; carbon has an atomic number of 6 and an atomic mass of 12.0107 amu; oxygen has an atomic number of 8 and an atomic mass of 15.9994 amu.

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

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Chemical Compounds

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

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

An example of a chemical compound is water. A water molecule forms when oxygen (O) and hydrogen (H) atoms react and are held together by covalent bonds. Like other compounds, water always has the same chemical composition: a 2:1 ratio of hydrogen atoms to oxygen atoms. This is expressed in the chemical formula H_2O. A model of a water molecule is shown in **Figure** 3.26.

Compounds that contain mainly the elements carbon and hydrogen are called **organic compounds**. This is because they are found mainly in living organisms. Most organic compounds are held together by covalent bonds. An example of an organic compound is glucose ($C_6H_{12}O_6$), which is shown in **Figure** 3.27. Glucose is a simple sugar that living cells use for energy. All other compounds are called inorganic compounds. Water is an example of an inorganic compound.

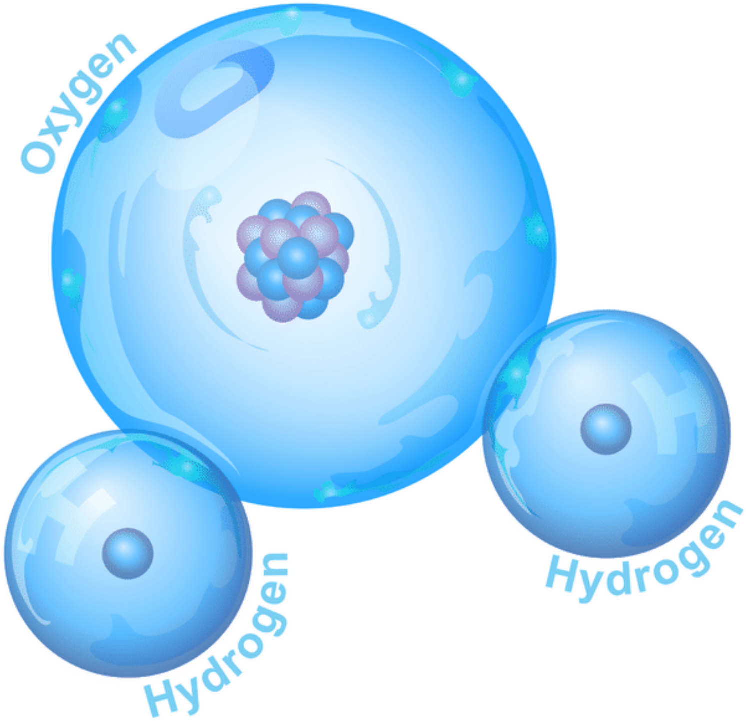

FIGURE 3.26
Model of a water molecule, showing the arrangement of hydrogen and oxygen atoms. The protons (8 in oxygen, 1 in hydrogen) and neutrons (8 in oxygen) are depicted in the nucleus.

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Mixtures vs. Compounds

Like a chemical compound, a **mixture** consists of more than one chemical substance. Unlike a compound, a mixture does not have a fixed chemical composition. The substances in a mixture can be combined in any proportions. A mixture also does not involve a chemical reaction. Therefore, the substances in a mixture are not changed into unique new substances, and they can be separated from each other without a chemical reaction.

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

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

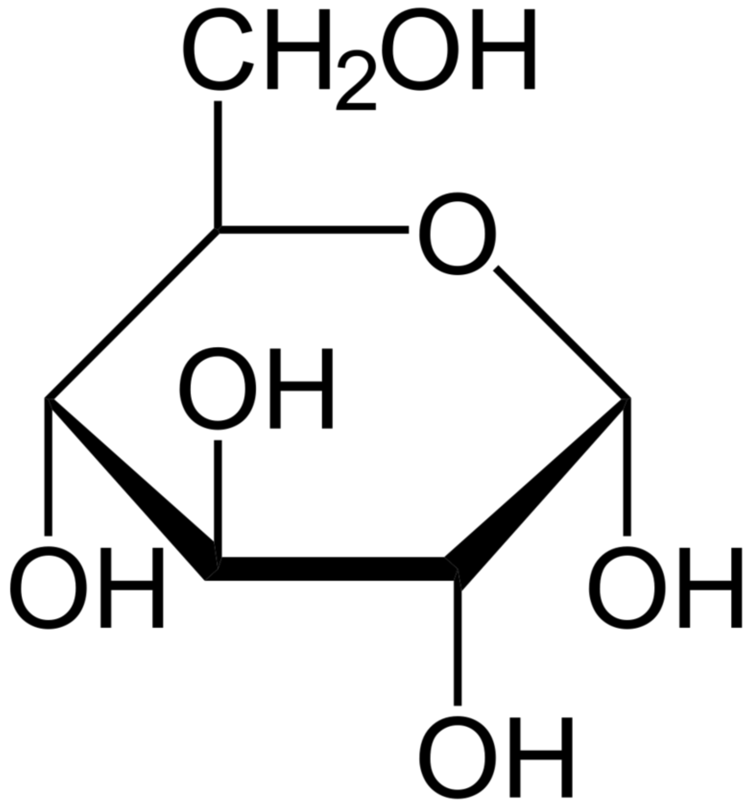


FIGURE 3.27

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

mechanically separate the iron from the iron sulfide because metallic iron does not exist in the compound. Instead, another chemical reaction is required to separate the iron and sulfur.

Summary

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

Review

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

3.11 Energy and Biochemical Reactions

Learning Objectives

- Define energy.
- Distinguish between an exothermic reaction and an endothermic reaction.
- Describe the role of energy in chemical reactions.
- Explain the significance of activation energy.

What is energy? Where does your energy come from? Can energy be recycled?

This team of ants is breaking down a dead tree. A classic example of teamwork. And all that work takes energy. In fact, each chemical reaction - the chemical reactions that allow the cells in those ants to do the *work* - needs energy to get started. And all that energy comes from the food the ants eat. Whatever eats the ants gets their energy from the ants. Energy passes through an ecosystem in one direction only.

Chemical Reactions and Energy

Chemical reactions always involve energy. **Energy** is a property of matter that is defined as the ability to do work. When methane burns, for example, it releases energy in the form of heat and light. Other chemical reactions absorb energy rather than release it.

Exothermic Reactions

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

Reactants → Products + Heat

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

Endothermic Reaction

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

Reactants + Heat → Products

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

Activation Energy

All chemical reactions need energy to get started. Even reactions that release energy need a boost of energy in order to begin. The energy needed to start a chemical reaction is called **activation energy**. Activation energy is like the push a child needs to start going down a playground slide. The push gives the child enough energy to start moving, but once she starts, she keeps moving without being pushed again. Activation energy is illustrated in **Figure** 3.28.

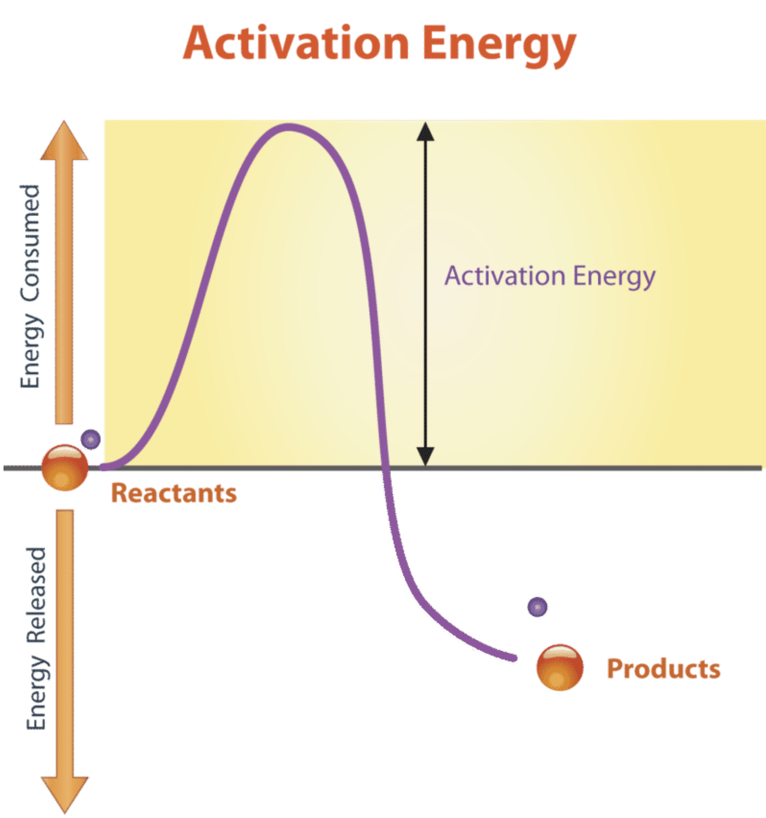
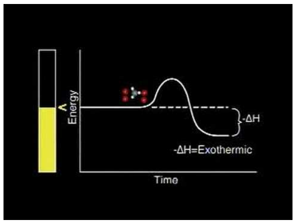


FIGURE 3.28

Activation Energy. Activation energy provides the "push" needed to start a chemical reaction. Is the chemical reaction in this figure an exothermic or endothermic reaction?

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



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As you view *Activation energy*, focus on these concepts:

1. the role of activation energy,
2. what an energy diagram demonstrates.

Summary

- Chemical reactions always involve energy. A chemical reaction that releases energy is an exothermic reaction, and a chemical reaction that absorbs energy is an endothermic reaction. The energy needed to start a chemical reaction is the activation energy.

Review

1. What is an exothermic reaction?
2. What is the general chemical equation for an endothermic reaction?
3. What is the activation energy?
4. Why do all chemical reactions require activation energy?

3.12 Digestive System Organs

Learning Objectives

- Identify the organs and functions of the digestive system.
- Describe the gastrointestinal tract.
- Explain peristalsis.
- Compare mechanical digestion to chemical digestion.
- Describe absorption and elimination.

Specifically, our energy comes from what?

The respiratory and circulatory systems work together to provide cells with the oxygen they need for cellular respiration. Cells also need glucose for cellular respiration. Glucose is a simple sugar that comes from the food we eat. To get glucose from food, digestion must occur. This process is carried out by the digestive system.

Overview of the Digestive System

The **digestive system** consists of organs that break down food and absorb nutrients such as glucose. Organs of the digestive system are shown in **Figure** 3.29. Most of the organs make up the **gastrointestinal tract**. The rest of the organs are called **accessory organs**.

The Gastrointestinal Tract

The gastrointestinal (GI) tract is a long tube that connects the mouth with the anus. It is more than 9 meters (30 feet) long in adults and includes the esophagus, stomach, and small and large intestines. Food enters the mouth, passes

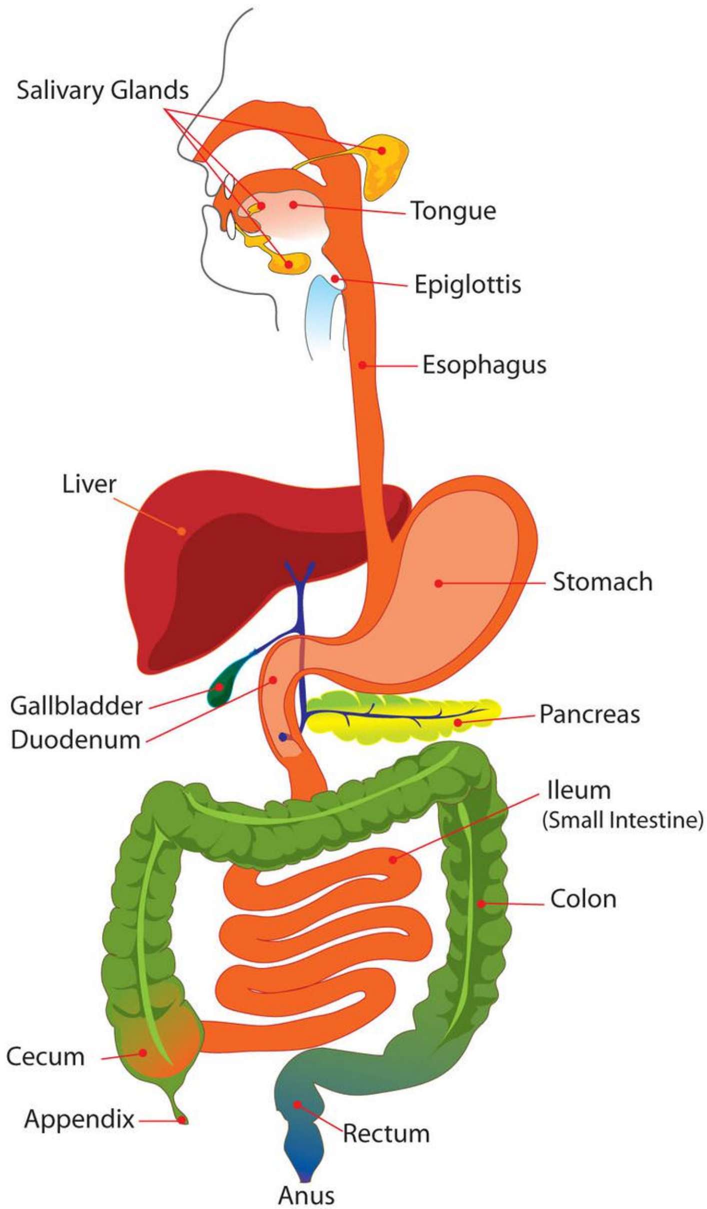
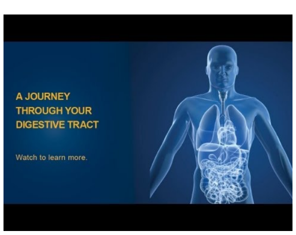


FIGURE 3.29
The digestive system includes organs from the mouth to the anus.

through the other organs of the GI tract, and then leaves the body through the anus.



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The organs of the GI tract are lined with **mucous membranes** that secrete digestive enzymes and absorb nutrients. The organs are also covered by layers of muscle that enable peristalsis. **Peristalsis** is an involuntary muscle contraction that moves rapidly along an organ like a wave (see **Figure** 3.30).

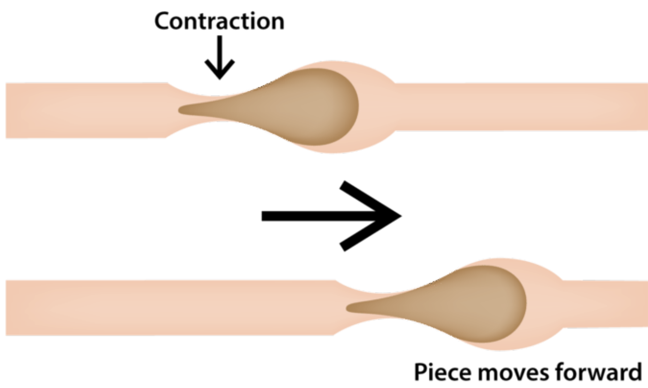

FIGURE 3.30
Peristalsis pushes food through the GI tract.

Accessory Organs of Digestion

Other organs involved in digestion include the liver, gall bladder, and pancreas. They are called accessory organs because food does not pass through them. Instead, they secrete or store substances needed for digestion.

Functions of the Digestive System

The digestive system has three main functions: digestion of food, absorption of nutrients, and elimination of solid food waste. **Digestion** is the process of breaking down food into components the body can absorb. It consists of two types of processes: mechanical digestion and chemical digestion.

- **Mechanical digestion** is the physical breakdown of chunks of food into smaller pieces. This type of digestion takes place mainly in the mouth and stomach.
- **Chemical digestion** is the chemical breakdown of large, complex food molecules into smaller, simpler nutrient molecules that can be absorbed by the blood. This type of digestion begins in the mouth and stomach but occurs mainly in the small intestine.

After food is digested, the resulting nutrients are absorbed. **Absorption** is the process in which substances pass into the bloodstream, where they can circulate throughout the body. Absorption of nutrients occurs mainly in the small intestine. Any remaining matter from food that cannot be digested and absorbed passes into the large intestine as waste. The waste later passes out of the body through the anus in the process of **elimination**.

Summary

- The digestive system consists of organs that break down food, absorb nutrients, and eliminate waste.
- The breakdown of food occurs in the process of digestion.

Review

1. What organs make up the gastrointestinal tract? What are the accessory organs of digestion?
2. Describe peristalsis and its role in digestion.
3. Define mechanical and chemical digestion.

3.13 References

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7. Sam McCabe;Milk: Mark Skipper; Chicken: Flickr:TheCulinaryGeek; Beans: U.S. Department of Agriculture. CK-12 Foundation;Milk: http://www.flickr.com/photos/bitterjug/389464179/; Chicken: http://www.flickr.com/photos/preppybyday/4944774499/; Beans: http://commons.wikimedia.org/wiki/File:DarkRedKidney.jpg . CC BY-NC 3.0;Milk, Chicken: CC BY 2.0; Beans: Public Domain
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37. Basketball: Thomas Soerenes; Jump rope: Rich Brooks; Walkers: Sarah Finucane; Soccer: Derek Jensen. Basketball: http://www.flickr.com/photos/toska92/8589516335/; Jump rope: http://www.flickr.com/photos/therichbrooks/3732325510/; Walkers: http://www.publicdomainpictures.net/view-image.php?image=26461&picture=me-and-my-grandpa-walking; Soccer: http://commons.wikimedia.org/wiki/File:Youth-soccer-indiana.jpg . Basketball, Jump rope: CC BY 2.0; Walkers, Soccer: Public Domain
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CHAPTER 4 Matter and Energy: Photosynthesis

Chapter Outline

4.1 Photosynthesis

Learning Objectives

- Define photosynthesis.
- Distinguish between autotrophs and heterotrophs.
- Explain the importance of photosynthesis.

What can a tiny plant do that you can't do?

This tiny plant can use the energy of the sun to make its own food. You can't make food by just sitting in the sun. Plants are not the only organisms that can get energy from the sun, however. Some protists, such as algae, and some bacteria can also use the energy of the sun to make their own food.

What is Photosynthesis?

If a plant gets hungry, it cannot walk to a local restaurant and buy a slice of pizza. So, how does a plant get the food it needs to survive? Plants are **producers**, which means they are able to make, or produce, their own food. They also produce the "food" for other organisms. Plants are also **autotrophs.** Autotrophs are the organisms that collect the energy from the sun and turn it into organic compounds. Using the energy from the sun, they produce complex organic compounds from simple inorganic molecules. So once again, how does a plant get the food it needs to survive?

Through photosynthesis. **Photosynthesis** is the process plants use to make their own “food” from the sun’s energy, carbon dioxide, and water. During photosynthesis, carbon dioxide and water combine with solar energy to create **glucose**, a carbohydrate ($C_6H_{12}O_6$), and oxygen.

The process can be summarized as: in the presence of sunlight, carbon dioxide + water $\rightarrow$ glucose + oxygen.

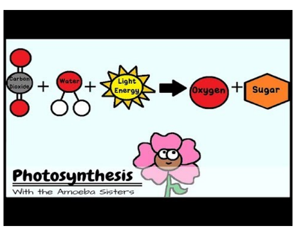
Glucose, the main product of photosynthesis, is a sugar that acts as the "food" source for plants. The glucose is then converted into usable chemical energy, **ATP**, during **cellular respiration**. The oxygen formed during photosynthesis, which is necessary for animal life, is essentially a waste product of the photosynthesis process.

Actually, almost all organisms obtain their energy from photosynthetic organisms. For example, if a bird eats a caterpillar, then the bird gets the energy that the caterpillar gets from the plants it eats. So the bird indirectly gets energy that began with the glucose formed through photosynthesis. Therefore, the process of photosynthesis is central to sustaining life on Earth. In eukaryotic organisms, photosynthesis occurs in **chloroplasts**. Only cells with chloroplasts—plant cells and algal (protist) cells—can perform photosynthesis. Animal cells and fungal cells do not have chloroplasts and, therefore, cannot photosynthesize. That is why these organisms, as well as the non-photosynthetic protists, rely on other organisms to obtain their energy. These organisms are **heterotrophs.**

Watch the Amoeba Sister’s video to learn how the light dependent and light independent cycle work together to create glucose for plants.

Photosynthesis and the Teeny Tiny Pigment Pancakes

https://www.youtube.com/watch?v=uixA8ZXx0KU



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Why do leaves change color each fall? This MIT video demonstrates an experiment about the different pigments in leaves. See the video at https://www.youtube.com/watch?v=_v6_5Zxdb68 .

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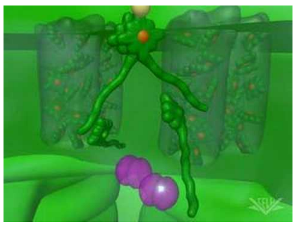
Summary

- All the energy used by living things on Earth came from the process of photosynthesis.
- During photosynthesis, carbon dioxide and water combine with solar energy to create glucose and oxygen.

Explore More

Use the resource below to answer the following questions.

- **Photosynthesis** at http://www.youtube.com/watch?v=hj_WKgnL6MI (5:04)



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1. Where does the energy for photosynthesis come from?
2. In photosynthesis, how does the movement of electrons along the electron transport chain affect hydrogen ions (H^+)? How does this compare to what happens in the mitochondria during cellular respiration?
3. Do all organisms which carry out photosynthesis have chloroplasts? Explain your answer as fully as you can.
4. What is the function of mobile electron carriers? What is their relationship to the embedded protein complexes in the membrane?

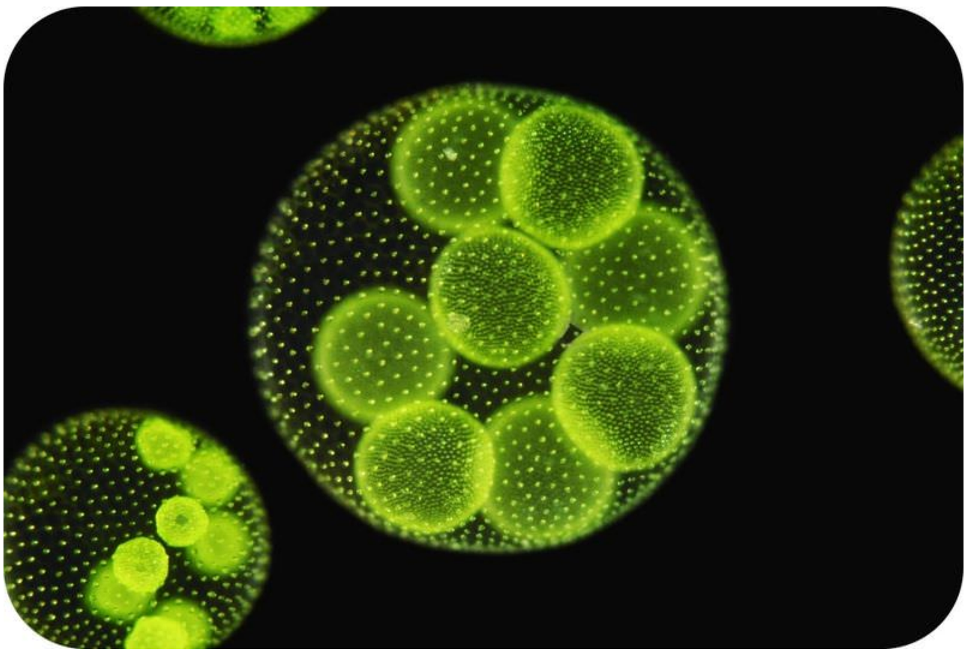
Review

1. How is the process of photosynthesis central to sustaining life on Earth?
2. What are the two products produced by photosynthesis?
3. What two raw materials are needed by plants in order to perform photosynthesis?

4.2 Light Reactions

Learning Objectives

- Describe the structure of a chloroplast.
- Write the chemical reaction of photosynthesis.
- Name the reactants and products of photosynthesis.
- Summarize the process of photosynthesis.



Are plants the only organisms that perform photosynthesis?

Although we generally discuss plants when learning about photosynthesis, keep in mind that plants are not the only organisms that can make their own food. Some bacteria and some protists, such as the algae pictured here, also perform photosynthesis. This alga has chloroplasts and photosynthesizes just like a plant.

The Process of Photosynthesis

In the Presence of Sunlight, Carbon Dioxide Water → Glucose Oxygen

Photosynthesis takes place in the organelle of the plant cell known as the chloroplasts. **Chloroplasts** are one of the main differences between plant and animal cells. Animal cells do not have chloroplasts, so they cannot photosynthesize. Photosynthesis occurs in two stages. During the first stage, the energy from sunlight is absorbed by the chloroplast. Water is used, and oxygen is produced during this part of the process. During the second stage, carbon dioxide is used, and glucose is produced.

Chloroplasts contain stacks of **thylakoids**, which are flattened sacs of membrane. Energy from sunlight is absorbed by the pigment **chlorophyll** in the thylakoid membrane. There are two separate parts of a chloroplast: the space inside the chloroplast itself, and the space inside the thylakoids (**Figure** 4.1).

- The inner compartments inside the thylakoids are called the thylakoid space (or lumen). This is the site of the first part of photosynthesis.
- The interior space that surrounds the thylakoids is filled with a fluid called **stroma**. This is where carbon dioxide is used to produce glucose, the second part of photosynthesis.

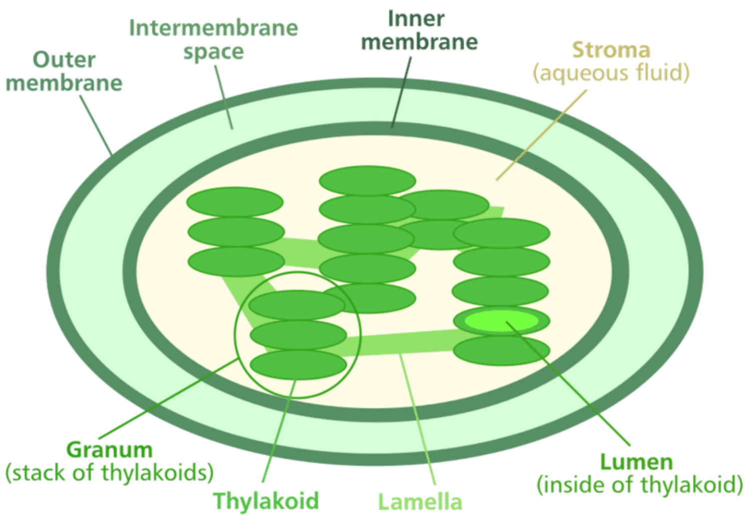


FIGURE 4.1
The chloroplast is the photosynthesis factory of the plant.

The Reactants

What goes into the plant cell to start photosynthesis? The **reactants** of photosynthesis are carbon dioxide and water. These are the molecules necessary to begin the process. But one more item is necessary, and that is sunlight. All three components, carbon dioxide, water, and the sun's energy are necessary for photosynthesis to occur. These three components must meet in the chloroplast of the leaf cell for photosynthesis to occur. How do these three components get to the cells in the leaf?

- Chlorophyll is the green pigment in leaves that captures energy from the sun. Chlorophyll molecules are located in the thylakoid membranes inside chloroplasts.
- The *veins* in a plant carry water from the roots to the leaves.
- Carbon dioxide enters the leaf from the air through special openings called **stomata** (**Figure** 4.2).

The Products

What is produced by the plant cell during photosynthesis? The **products** of photosynthesis are glucose and oxygen. This means they are produced at the end of photosynthesis. **Glucose**, the food of plants, can be used to store energy in the form of large carbohydrate molecules. Glucose is a simple sugar molecule which can be combined with other glucose molecules to form large carbohydrates, such as starch. Oxygen is a waste product of photosynthesis. It is released into the atmosphere through the stomata. As you know, animals need oxygen to live. Without photosynthetic organisms like plants, there would not be enough oxygen in the atmosphere for animals to survive.

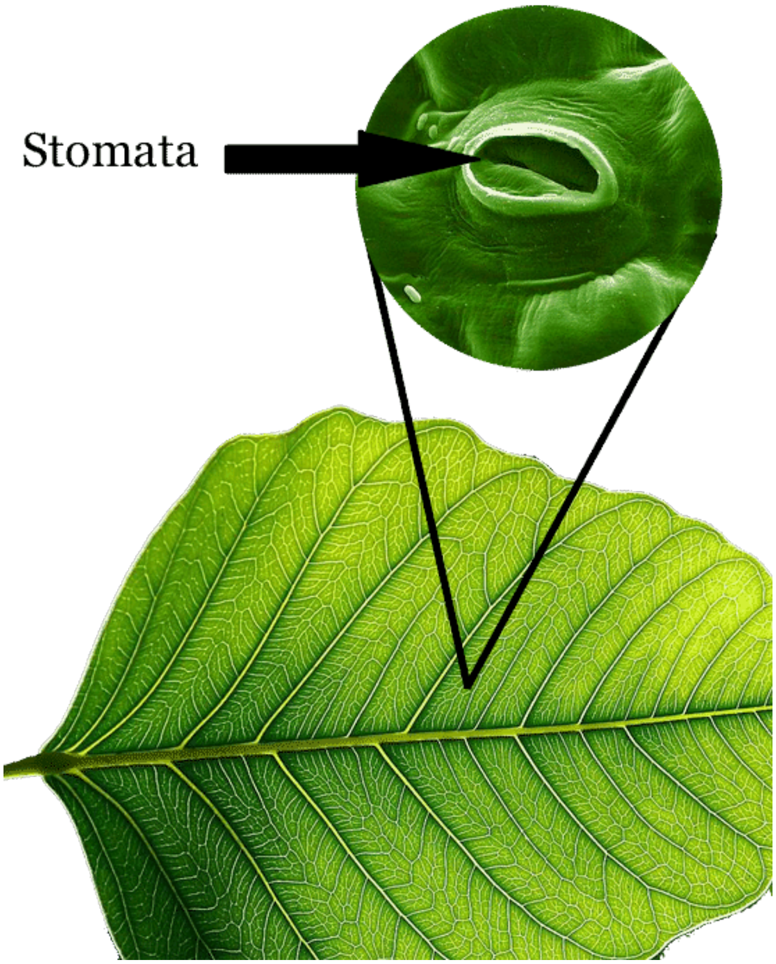


FIGURE 4.2
Stomata are special pores that allow gasses to enter and exit the leaf.

The Chemical Reaction

The overall chemical reaction for photosynthesis is 6 molecules of carbon dioxide (CO_2) and 6 molecules of water (H_2O), with the addition of solar energy. This produces 1 molecule of glucose ($C_6H_{12}O_6$) and 6 molecules of oxygen (O_2). Using chemical symbols, the equation is represented as follows: $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$. Though this equation may not seem that complicated, photosynthesis is a series of chemical reactions divided into two stages, the light reactions and the Calvin cycle (**Figure** 4.3).

The Light Reactions

Photosynthesis begins with the **light reactions.** It is during these reactions that the energy from sunlight is absorbed by the pigment chlorophyll in the thylakoid membranes of the chloroplast. The energy is then temporarily transferred to two molecules, ATP and NADPH, which are used in the second stage of photosynthesis. ATP and NADPH are generated by two **electron transport chains**. During the light reactions, water is used and oxygen is produced. These reactions can only occur during daylight as the process needs sunlight to begin.

The Calvin Cycle

The second stage of photosynthesis is the production of glucose from carbon dioxide. This process occurs in a continuous cycle, named after its discover, Melvin Calvin. The **Calvin cycle** uses CO_2 and the energy temporarily stored in ATP and NADPH to make the sugar glucose.

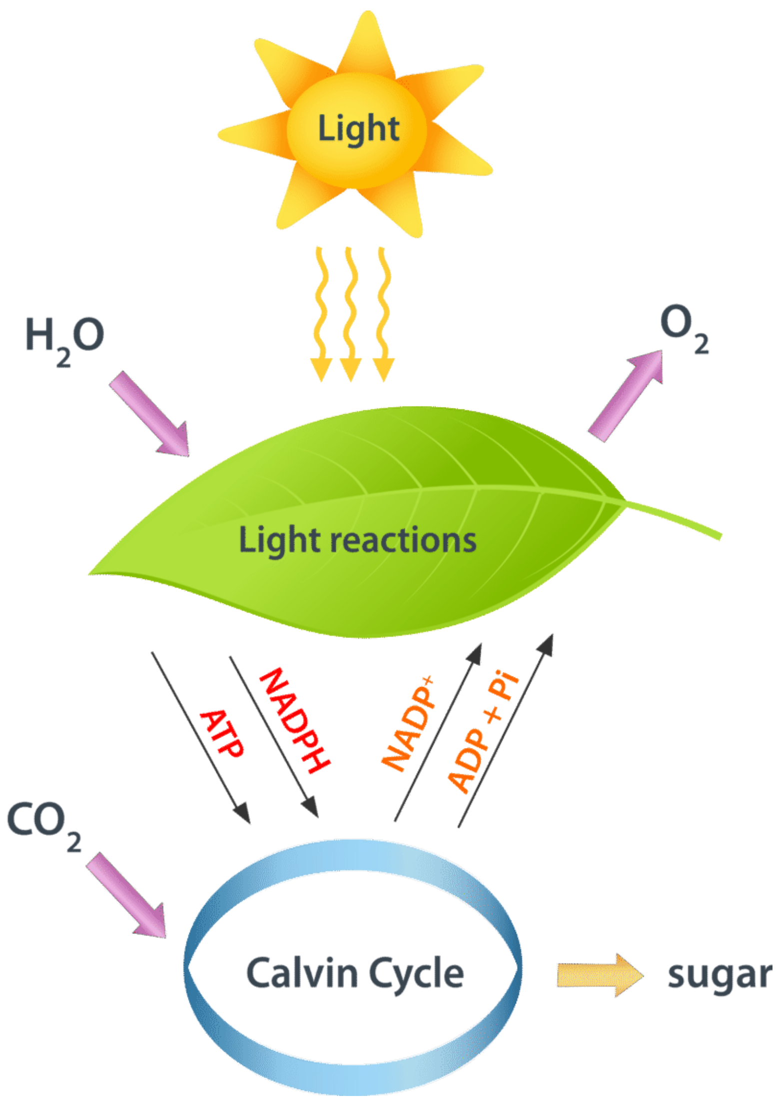


FIGURE 4.3

Photosynthesis is a two stage process. As is depicted here, the energy from sunlight is needed to start photosynthesis. The initial stage is called the light reactions as they occur only in the presence of light. During these initial reactions, water is used and oxygen is released. The energy from sunlight is converted into a small amount of ATP and an energy carrier called NADPH. Together with carbon dioxide, these are used to make glucose (sugar) through a process called the Calvin Cycle. $NADP^+$ and ADP (and Pi, inorganic phosphate) are regenerated to complete the process.

Summary

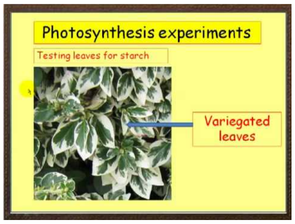
- Photosynthesis occurs in the chloroplast of the plant cell.
- Carbon dioxide, water, and the sun's energy are necessary for the chemical reactions of photosynthesis.
- The products of photosynthesis are glucose and oxygen.

Explore More

Use the resources below to answer the following questions.

Explore More I

- **Photosynthesis** at http://www.youtube.com/watch?v=RNufj-64OO0 (7:08)



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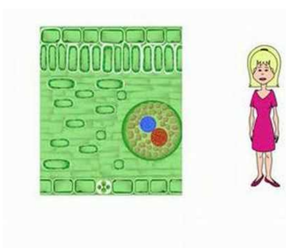
1. How do autotrophs differ from heterotrophs? How are they the same?
2. What do plants do with most of the sugar they produce during photosynthesis?
3. How do decreasing levels of CO_2 affect plants? How do you think increasing levels of CO_2 affect plants?

Explore More II

- **Photosynthesis** at http://www.youtube.com/watch?v=mpPwmvtDjWw (2:41)



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1. Where do plants get the raw materials for photosynthesis?
2. What do plants take up through their roots? Which of these substances are used for photosynthesis?
3. Where does the chemical reactions of photosynthesis take place?

Review

1. Describe the structures of the chloroplast where photosynthesis takes place.
2. What would happen if the stomata of a plant leaf were glued shut? Would that plant be able to perform photosynthesis? Why or why not?
3. What are the reactants needed to perform photosynthesis? The products?
4. What happens to the products of photosynthesis?

4.3 Calvin Cycle

Learning Objectives

- Write the overall photosynthesis equation.
- Describe the function of the Calvin cycle.
- Explain RuBisCo.
- Describe the roles of NADPH and ATP in the Calvin Cycle.
- Summarize how photosynthesis stores energy in sugar.

Other than being green, what do all these fruits and vegetables have in common?

They are full of energy. Energy in the form of glucose. The energy from sunlight is briefly held in NADPH and ATP, which is needed to drive the formation of sugars such as glucose. And this all happens in the Calvin cycle.

The Calvin Cycle

Making Food "From Thin Air"

You've learned that the first, light-dependent stage of photosynthesis uses two of the three reactants, water and light, and produces one of the products, oxygen gas (a waste product of this process). All three necessary conditions are required - chlorophyll pigments, the chloroplast "theater," and enzyme catalysts. The first stage transforms light energy into chemical energy, stored to this point in molecules of ATP and NADPH. Look again at the overall equation below. What is left?

$$\underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} + \underset{\text{light energy}}{\text{light}} \longrightarrow \underset{\substack{\text{glucose} \\ \text{(stored chemical energy)}}}{C_6H_{12}O_6} + \underset{\text{oxygen gas}}{6O_2}$$

Waiting in the wings is one more reactant, carbon dioxide, and yet to come is the star product, which is food for all life - glucose. These key players perform in the second act of the photosynthesis drama, in which food is "made from thin air!"

The second stage of photosynthesis can proceed without light, so its steps are sometimes called "light-independent" or "dark" reactions (though the term "dark" reactions can be misleading). Many biologists honor the scientist, Melvin Calvin, who won a 1961 Nobel Prize for working out this complex set of chemical reactions, naming it the **Calvin cycle**.

The Calvin cycle has two parts. First carbon dioxide is "fixed". Then ATP and NADPH from the light reactions provide energy to combine the fixed carbons to make sugar.

Carbon Dioxide is "Fixed"

Why does carbon dioxide need to be fixed? Was it ever broken?

Life on Earth is carbon-based. Organisms need not only energy but also carbon atoms for building bodies. For nearly all life, the ultimate source of carbon is carbon dioxide (CO_2), an inorganic molecule. CO_2 makes up less than 1% of the Earth's atmosphere.

Animals and most other heterotrophs cannot take in CO_2 directly. They must eat other organisms or absorb **organic molecules** to get carbon. Only autotrophs can build low-energy inorganic CO_2 into high-energy organic molecules like glucose. This process is **carbon fixation**.

Plants have evolved three pathways for carbon fixation.

The most common pathway combines one molecule of CO_2 with a 5-carbon sugar called ribulose biphosphate (RuBP). The enzyme which catalyzes this reaction (nicknamed **RuBisCo**) is the most abundant enzyme on earth! The resulting 6-carbon molecule is unstable, so it immediately splits into two 3-carbon molecules. The 3 carbons in the first stable molecule of this pathway give this largest group of plants the name "C_3."

Dry air, hot temperatures, and bright sunlight slow the C_3 pathway for carbon fixation. This is because **stomata**, tiny openings under the leaf which normally allow CO_2 to enter and O_2 to leave, must close to prevent loss of water vapor (**Figure** 4.4). Closed stomata lead to a shortage of CO_2. Two alternative pathways for carbon fixation demonstrate biochemical adaptations to differing environments.

Plants such as corn solve the problem by using a separate compartment to fix CO_2. Here CO_2 combines with a 3-carbon molecule, resulting in a 4-carbon molecule. Because the first stable organic molecule has four carbons, this adaptation has the name C_4. Shuttled away from the initial fixation site, the 4-carbon molecule is actually broken back down into CO_2, and when enough accumulates, RuBisCo fixes it a second time! Compartmentalization allows efficient use of low concentrations of carbon dioxide in these specialized plants.

Cacti and succulents such as the jade plant avoid water loss by fixing CO_2 only at night. These plants close their stomata during the day and open them only in the cooler and more humid nighttime hours. Leaf structure differs slightly from that of C_4 plants, but the fixation pathways are similar. The family of plants in which this pathway was discovered gives the pathway its name, Crassulacean Acid Metabolism, or CAM (**Figure** 4.5). All three carbon fixation pathways lead to the Calvin cycle to build sugar.

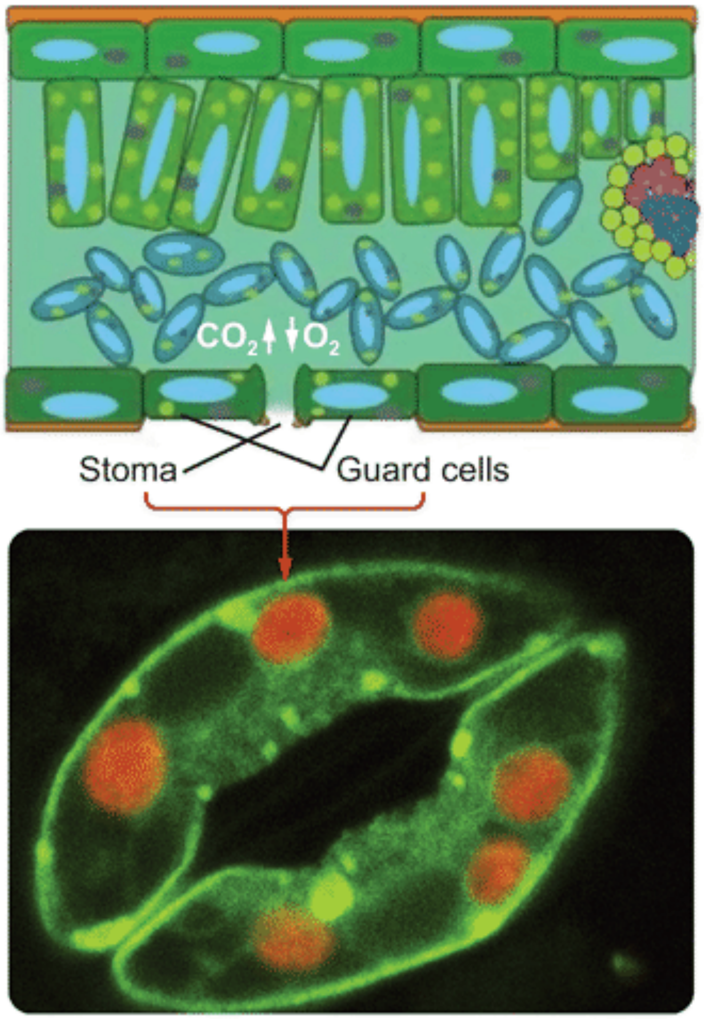

FIGURE 4.4

Stomata on the underside of leaves take in CO_2 and release water and O_2. Guard cells close the stomata when water is scarce. Leaf cross-section (above) and stoma (below).

How Does the Calvin Cycle Store Energy in Sugar?

As Melvin Calvin discovered, carbon fixation is the first step of a cycle. Like an electron transport chain, the Calvin cycle, shown in **Figure** 4.6, transfers energy in small, controlled steps. Each step pushes molecules uphill in terms of energy content. Recall that in the electron transfer chain, excited electrons lose energy to NADPH and ATP. In the Calvin cycle, NADPH and ATP formed in the light reactions lose their stored chemical energy to build glucose.

Use **Figure** 4.6 to identify the major aspects of the process:

- the general cycle pattern
- the major reactants
- the products

First, notice where carbon is fixed by the enzyme nicknamed RuBisCo. In C_3, C_4, and CAM plants, CO_2 enters the cycle by joining with 5-carbon ribulose bisphosphate to form a 6-carbon intermediate, which splits (so quickly that it isn't even shown!) into two 3-carbon molecules.

Now look for the points at which ATP and NADPH (made in the light reactions) add chemical energy ("Reduction" in the diagram) to the 3-carbon molecules. The resulting "half-sugars" can enter several different metabolic pathways.

FIGURE 4.5

Even chemical reactions adapt to specific environments! Carbon fixation pathways vary among three groups. Temperate species (maple tree, left) use the C_3 pathway. C_4 species (corn, center) concentrate CO_2 in a separate compartment to lessen water loss in hot bright climates. Desert plants (jade plant, right) fix CO_2 only at night, closing stomata in the daytime to conserve water.

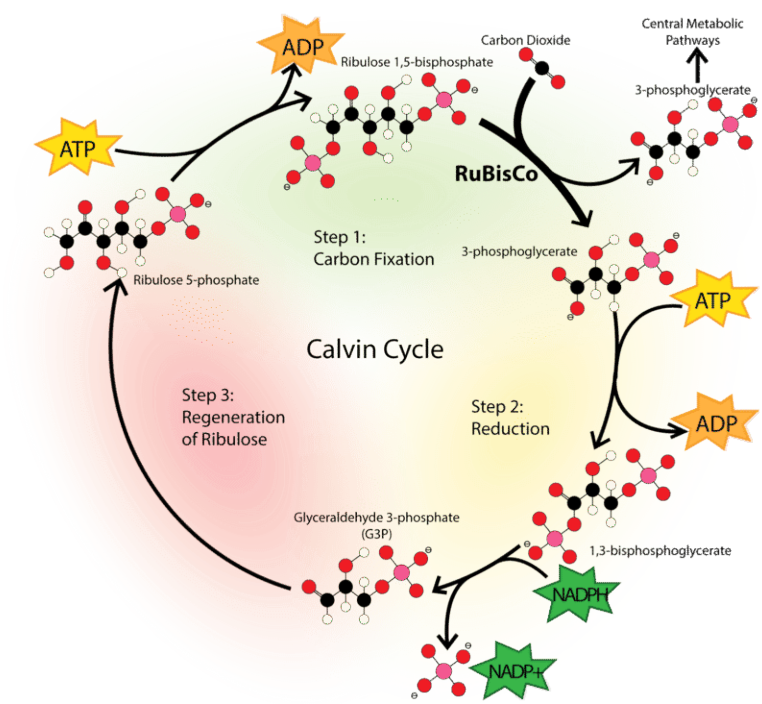

FIGURE 4.6

Overview of the Calvin Cycle Pathway.

One recreates the original 5-carbon precursor, completing the cycle. A second combines two of the 3-carbon molecules to form glucose, universal fuel for life.

The cycle begins and ends with the same molecule, but the process combines carbon and energy to build carbohydrates - food for life.

So, how does photosynthesis store energy in sugar? Six "turns" of the Calvin cycle use chemical energy from ATP to combine six carbon atoms from six CO_2 molecules with 12 "hot hydrogens" from NADPH. The result is one molecule of glucose, $C_6H_{12}O_6$.

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Summary

- The reactions of the Calvin cycle add carbon (from carbon dioxide in the atmosphere) to a simple five-carbon molecule called RuBP.
- These reactions use chemical energy from NADPH and ATP that were produced in the light reactions.
- The final product of the Calvin cycle is glucose.

Review

1. What happens during the carbon fixation step of the Calvin cycle?
2. What is special about RuBisCo?
3. What are stomata?
4. Explain what might happen if the third step of the Calvin cycle did not occur. Why?
5. What is the main final product of the Calvin cycle? How many turns of the Calvin cycle are needed to produce this product?

4.4 Photosynthesis Summary

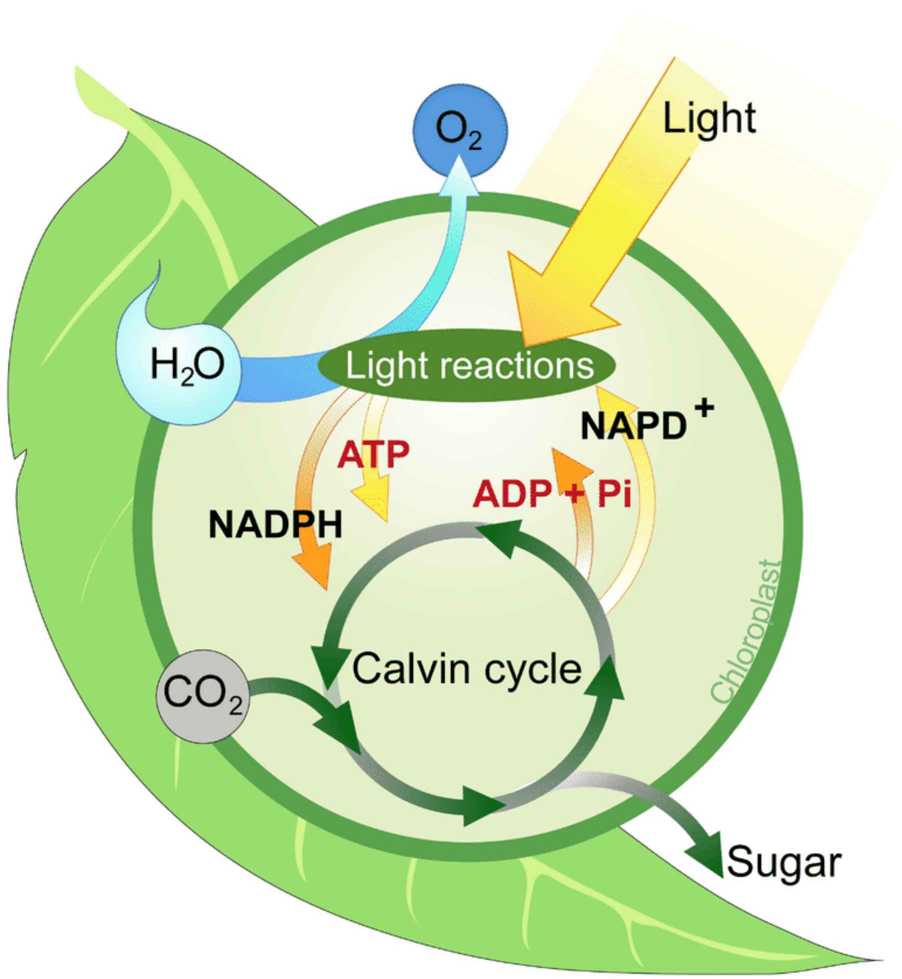
Learning Objectives

- Summarize photosynthesis.

What is photosynthesis?

The process of using the energy in sunlight to make food (glucose). Is it really as simple as that? Of course not. As you have seen, photosynthesis includes many steps all conveniently condensed into one simple equation. In the five concepts describing photosynthesis, this process has been presented in an introductory fashion. Obviously, much more details could have been included, though those are beyond the scope of these concepts.

Photosynthesis



The following 10 points summarize photosynthesis.

1. $6CO_2 + 6H_2O$ + Light Energy $\rightarrow C_6H_{12}O_6 + 6O_2$
2. Autotrophs store chemical energy in carbohydrate food molecules they build themselves. Most autotrophs make their "food" through photosynthesis using the energy of the sun.
3. Photosynthesis occurs in the chloroplast, an organelle specific to plant cells.
4. The light reactions of photosynthesis occur in the thylakoid membranes of the chloroplast.
5. Electron carrier molecules are arranged in electron transport chains that produce ATP and NADPH, which temporarily store chemical energy.
6. The light reactions capture energy from sunlight, which they change to chemical energy that is stored in molecules of NADPH and ATP.
7. The light reactions also release oxygen gas as a waste product.
8. The reactions of the Calvin cycle add carbon (from carbon dioxide in the atmosphere) to a simple five-carbon molecule called RuBP.
9. The Calvin cycle reactions use chemical energy from NADPH and ATP that were produced in the light reactions.
10. The final product of the Calvin cycle is glucose.

What is photosynthesis?

The process of using the energy in sunlight to make food (glucose). But of course it is much more complex than that simple statement. Photosynthesis is a multistep biochemical pathway that uses the energy in sunlight to fix carbon dioxide, transferring the energy into carbohydrates, and releasing oxygen in the process.

What is NADPH?

Nicotinamide adenine dinucleotide phosphate, an energy carrier molecule produced in the light reactions of photosynthesis. NADPH is the reduced form of the electron acceptor $NADP^+$. At the end of the light reactions, the energy from sunlight is transferred to $NADP^+$, producing NADPH. This energy in NADPH is then used in the Calvin cycle.

Where do the protons used in the light reactions come from?

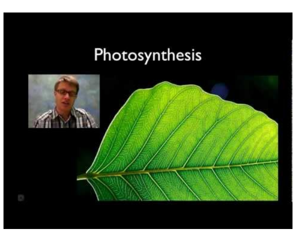
The protons used in the light reactions come from photolysis, the splitting of water, in which H_2O molecules are broken into hydrogen ions, electrons, and oxygen atoms. In addition, the energy from sunlight is used to pump protons into the thylakoid lumen during the first electron transport chain, forming a chemiosmotic gradient.

How do you distinguish between the Calvin cycle and the Krebs cycle?

The Calvin cycle is part of the light-independent reactions of photosynthesis. The Calvin cycle uses ATP and NADPH. The Krebs cycle is part of cellular respiration. This cycle makes ATP and NAPH.

Do photosynthesis and cellular respiration occur at the same time in a plant?

Yes. Photosynthesis occurs in the chloroplasts, whereas cellular respiration occurs in the mitochondria. Photosynthesis makes glucose and oxygen, which are then used as the starting products for cellular respiration. Cellular respiration makes carbon dioxide and water (and ATP), which are the starting products (together with sunlight) for photosynthesis.



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Common Misconceptions

- A common student misconception is that plants photosynthesize only during daylight and conduct cellular respiration only at night. Some teaching literature even states this. Though it is true the light reactions can only occur when the sun is out, cellular respiration occurs continuously in plants, not just at night.

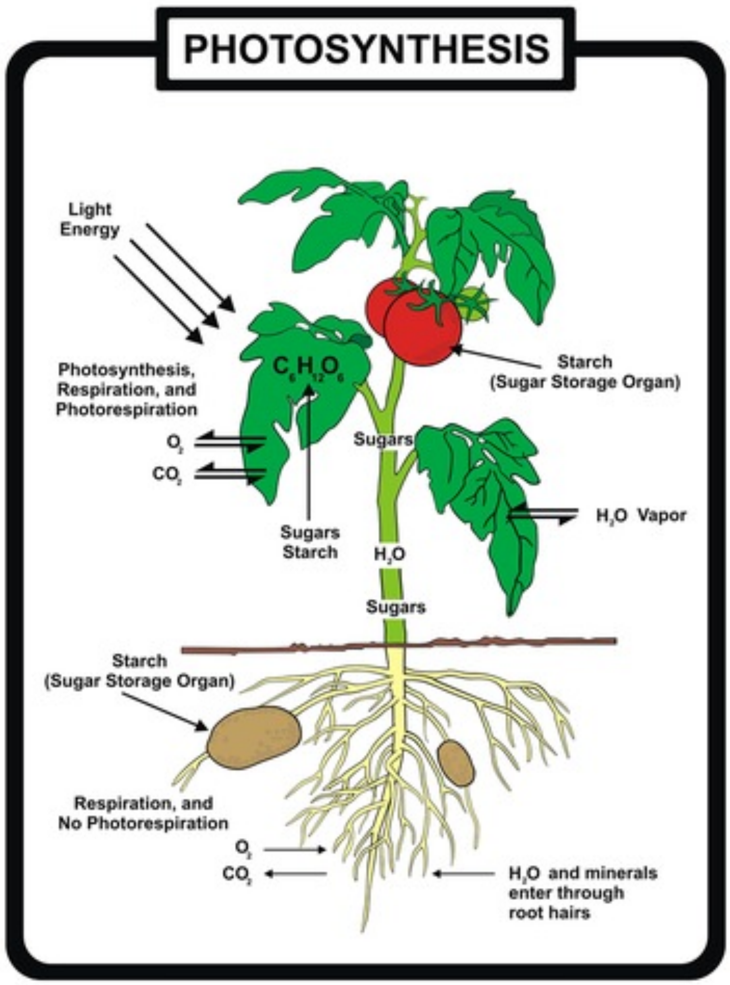
- The "dark reactions" of photosynthesis are a misnomer that often leads students to believe that photosynthetic carbon fixation occurs at night. This is not true. It is preferable to use the term Calvin cycle or light-independent reactions instead of dark reactions.

- Though the final product of photosynthesis is glucose, the glucose is conveniently stored as starch. Starch is approximated as $(C_6H_{10}O_5)_n$, where n is in the thousands. Starch is formed by the condensation of thousands of glucose molecules.

4.5 The Photosynthesis Reaction - Advanced

Learning Objectives

- Summarize the process of photosynthesis and write out the overall chemical equation for photosynthesis.
- Identify reactants, necessary conditions, and products in the chemical equation for photosynthesis.
- Understand that hundreds of years of scientific exploration have contributed to our understanding of photosynthesis.

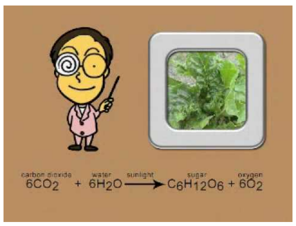


What is the most common biochemical reaction ever?

Well, it may or may not be this one. Every split second that sunlight strikes a plant's leaf, the process of photosynthesis begins. That's on every leaf, on every plant, including all the blades of grass. All over the world.

Photosynthesis: The Most Important Chemical Reaction for Life on Earth

What do pizza, campfires, dolphins, automobiles, and glaciers have in common? In the following section, you'll learn that all five rely on photosynthesis, some in more ways than one. Photosynthesis is often considered the most important chemical reaction for life on earth. Let's delve into how this process works and why we are so indebted to it.



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Photosynthesis involves a complex series of chemical reactions, each of which convert one substance to another. These reactions taken as a whole can be summarized in a single symbolic representation - as shown in the chemical equation below.

$$6CO_2 + 6H_2O + \text{light} \xrightarrow{\substack{\text{Chloroplast} \\ \text{Chlorophyll} \\ \text{Enzymes}}} C_6H_{12}O_6 + 6O_2$$

We can substitute words for the chemical symbols. Then the equation appears as below.

$$\text{Carbon dioxide} + \text{water} + \text{light energy} \xrightarrow{\substack{\text{Chloroplast} \\ \text{Chlorophyll} \\ \text{Enzymes}}} \text{glucose} + \text{oxygen gas}$$

Like all chemical equations, this equation for photosynthesis shows reactants connected by plus signs on the left and products, also connected by plus signs, on the right. An arrow indicating the process or chemical change leads from the reactants to the products, and conditions necessary for the chemical reaction are written above the arrow. Note that the same kinds of atoms, and number of atoms, are found on both sides of the equation, but the kinds of compounds they form change.

You use chemical reactions every time you cook or bake. You add together ingredients (the reactants), place them in specific conditions (often heat), and enjoy the results (the products). A recipe for chocolate chip cookies written in chemical equation form is shown below.

$$\underbrace{\text{Butter} + \text{sugar} + \text{eggs} + \text{flour} + \text{chocolate chips}}_{\text{REACTANTS}} \underbrace{\xrightarrow{\substack{375^{\circ}\text{F} \\ 8\text{—}10\text{ minutes}}}}_{\text{NECESSARY CONDITIONS}} \underbrace{\text{chocolate chip cookies}}_{\text{PRODUCT}}$$

Compare this familiar recipe to photosynthesis below.

$$6CO_2 + 6H_2O + \text{light} \xrightarrow[\text{Enzymes}]{\text{Chloroplast Chlorophyll}} C_6H_{12}O_6 + 6O_2$$

The equation shows that the "ingredients" for photosynthesis are carbon dioxide, water, and light energy. Plants, algae, and photosynthetic bacteria take in light from the sun, molecules of carbon dioxide from the air, and water molecules from their environment and combine these reactants to produce food (glucose).

Of course, light, carbon dioxide, and water mix in the air even without plants. But they do not chemically change to make food without very specific necessary conditions which are found only in the cells of photosynthetic organisms. Necessary conditions include:

1. **enzymes** - proteins which speed up chemical reactions
2. **chlorophyll** - a pigment within plant cells which absorbs light
3. **chloroplasts** - organelles whose membranes embed chlorophyll, accessory pigments, and enzymes in patterns which maximize photosynthesis

Within plant cells or algal cells, chloroplasts organize the enzymes, chlorophyll, and accessory pigment molecules necessary for photosynthesis.

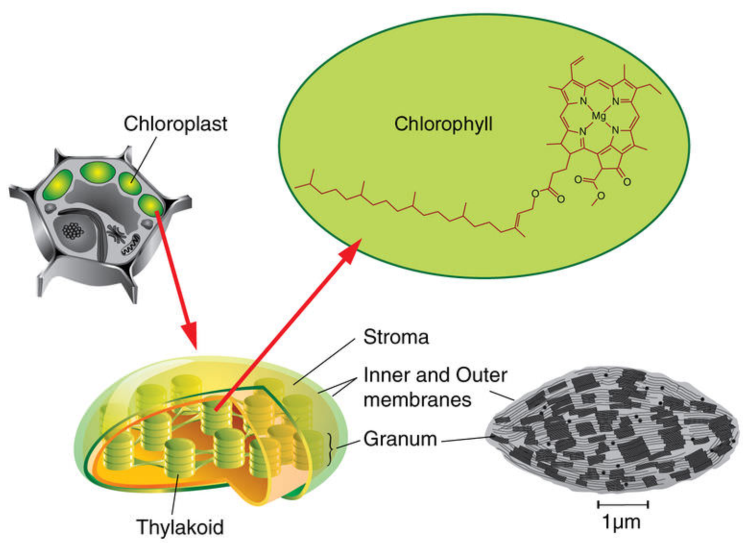


FIGURE 4.7
Within plant cells or algal cells, chloroplasts organize the enzymes, chlorophyll, and accessory pigment molecules necessary for photosynthesis.

When the reactants meet inside chloroplasts, or the very similar cells of blue-green bacteria, chemical reactions combine them to form two products: energy-rich glucose molecules and molecules of oxygen gas. Photosynthetic organisms store the glucose (usually as starch) and release the oxygen gas into the atmosphere as waste.

Let's review the chemical equation for photosynthesis once more, this time at the level of atoms as in the equation below.

$$6CO_2 + 6H_2O + \text{light} \xrightarrow[\text{Enzymes}]{\text{Chloroplast Chlorophyll}} C_6H_{12}O_6 + 6O_2$$

Look closely at its primary purpose: storing energy in the chemical bonds of food molecules. The source of energy for food is sunlight energy. The source of carbon atoms for the food molecules is carbon dioxide from the air, and the source of hydrogen atoms is water. Inside the cells of plants, algae, and photosynthetic bacteria, chlorophyll, and enzymes use the light energy to rearrange the atoms of the reactants to form the products, molecules of glucose and oxygen gas. Light energy is thus transformed into chemical energy, stored in the bonds which bind six atoms each of carbon and oxygen to twelve atoms of hydrogen - forming a molecule of glucose. This energy rich carbohydrate molecule becomes food for the plants, algae, and bacteria themselves as well as for the heterotrophs which feed on them.

One last detail: why do "6"s precede the CO_2, H_2O, and O_2? Look carefully, and you will see that this "balances" the equation: the numbers of each kind of atom on each side of the arrow are equal. Six molecules each of CO_2 and H_2O make 1 molecule of glucose and 6 molecules of oxygen gas.

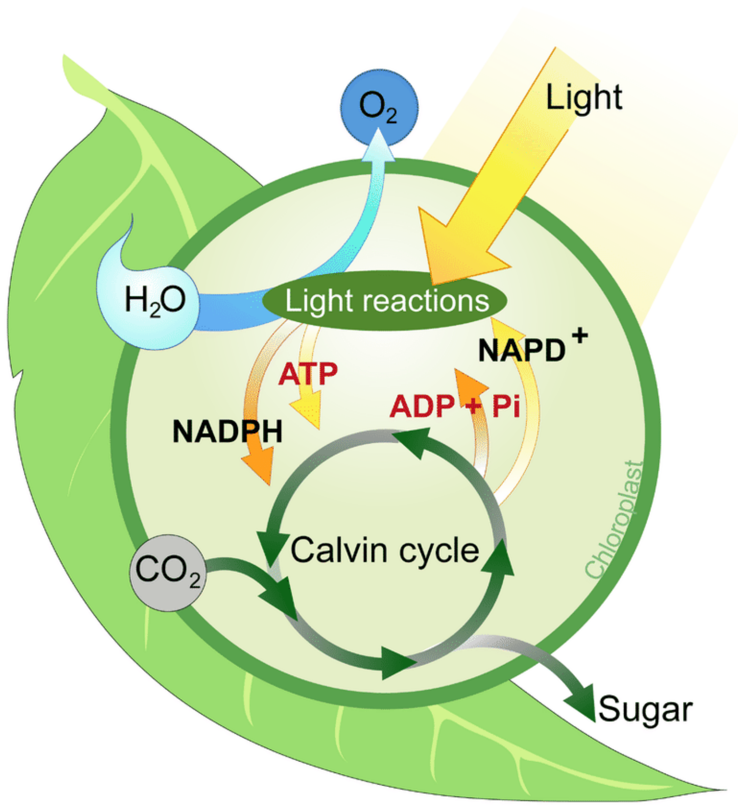


FIGURE 4.8
The two stages of photosynthesis are the light reactions and the Calvin cycle. Do you see how the two stages are related?

Historical Perspective

Life requires photosynthesis for fuel and for the oxygen to burn that fuel. Since the Industrial Revolution (late 18th and early 19th centuries), we humans have relied on products of ancient photosynthesis for enormous quantities of fossil fuel energy. And, knowingly or not, we have also benefited from photosynthesis to remove the carbon dioxide produced when we burn those fuels. So it may not surprise you that biologists have studied this critical process in great detail.

Although photosynthesis may seem straightforward in this form, such simplicity is deceiving for two reasons. First, the photosynthesis equation summarizes dozens of individual chemical reactions involving many intermediate compounds. And second, just discovering major players like CO_2 and O_2 was challenging, because our ordinary senses cannot detect these molecules in "thin air!"

How do we know that the chemical reaction in photosynthesis really happens? Two famous historical experiments help us begin to understand this process. In the 17^{th} century, people who thought about it at all assumed that plants get their food from the soil. Many people, encouraged by sellers of "plant food," still do. In 1638, Jan Baptist Van Helmont planted a 5 pound willow tree, like the one shown in **Figure** 4.9, in a 200 pound tub of soil. After 5 years of watering the plant, he weighed both again. The willow had gained over 160 pounds, but the soil had lost only 2 ounces. Van Helmont concluded that plants do not get their materials from soil, and inferred that they grow using materials from water (which he did not measure). As you know now, he was half right. Although soil provides important nutrients to plants, it supplies neither the energy nor the vast majority of the materials to build the plant. We must excuse him, because no one in the 17^{th} century knew that carbon atoms form the basis of life, or that they float around in air in the form of carbon dioxide.

FIGURE 4.9

In the 17^{th} century, Jan Van Helmont, a Flemish chemist, physiologist, and physician, weighed and potted a willow tree, showing that plants do not get food from the soil.

In the late 1770s, minister and natural philosopher Joseph Priestley burned a candle in a jar of air and observed that the candle burned out long before it ran out of wax. A similar experiment with a mouse resulted in the mouse's death. Priestley suggested that animals, like candles, "injure" the air. Adding a mint plant, as shown in **Figure** 4.10, however, "restored" the air which had been "injured" by the mouse or the candle. Only later, after many chemistry experiments, did Priestley publish his discovery of "dephlogisticated air." But in his studies of mice, plants, and candles, he had shown that plants produce, and animals consume, oxygen gas.

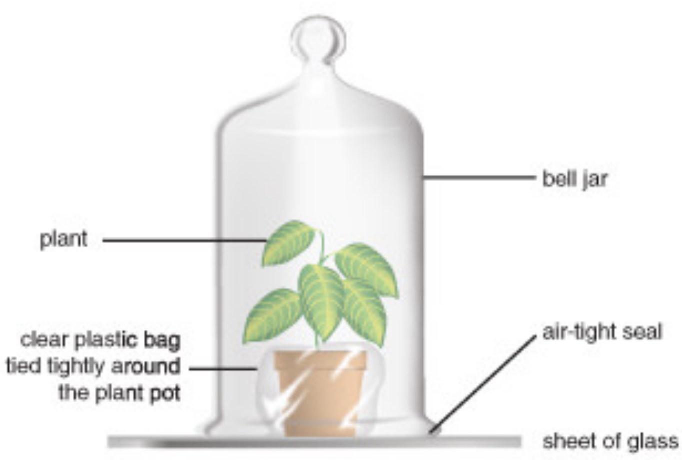


FIGURE 4.10

Joseph Priestley's bell jar experiment.

During the 20^{th} century, scientists learned that photosynthesis involves much more than just the three reactants, the three necessary conditions, and the two products shown in the equation. Using powerful microscopes, scientists narrowed the process to one type of organelle within the plant - the chloroplast.

Summary

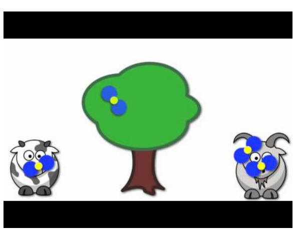
- The photosynthesis chemical equation states that the reactants (carbon dioxide, water and sunlight), yield two products, glucose and oxygen gas.
- The single chemical equation represents the overall process of photosynthesis. It also summarizes many individual chemical reactions that were understood only after hundreds of years of scientific exploration.
- Chloroplasts are the organelles within plant and algal cells that organize enzymes and pigments so that the chemical reactions proceed efficiently.
- Chlorophyll is a pigment that absorbs sunlight energy.

Review

1. Using symbols, write the overall chemical equation for photosynthesis, labeling the reactants, necessary conditions, and products.
2. Summarize Jan Van Helmont's willow tree experiment. State his conclusion and the inference he made after his experiment, and explain how his data supports each. Finally, relate his findings to what we know today about the overall process of photosynthesis.
3. Using the overall equation for photosynthesis, explain which components relate to J.B. Priestley's observation that "Plants restore the air that animals injure."

Explore More

Use this resource to answer the questions that follow.



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1. What are the "raw materials" of photosynthesis? Where do these materials come from?
2. What are the products of photosynthesis? How are these products made?
3. Where does photosynthesis occur?
4. What happens to the glucose molecules?

4.6 References

1. Dartmouth Electron Microscope Facility; Jon Sullivan. http://commons.wikimedia.org/wiki/File:Tomato_leaf_stomate_1-color.jpg; http://commons.wikimedia.org/wiki/File:Leaf_1_web.jpg . CC BY-NC 3.0
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3. Ollin. http://commons.wikimedia.org/w/index.php?title=File:Chloroplast_diagram.svg . Public Domain
4. Dartmouth Electron Microscope Facility; Jon Sullivan. http://commons.wikimedia.org/wiki/File:Tomato_leaf_stomate_1-color.jpg; http://commons.wikimedia.org/wiki/File:Leaf_1_web.jpg . Public Domain
5. Hana Zavadska;Dartmouth Electron Microscope Facility; Jon Sullivan. CK-12 Foundation;http://commons.wikimedia.org/wiki/File:Tomato_leaf_stomate_1-color.jpg; http://commons.wikimedia.org/wiki/File:Leaf_1_-web.jpg . CC BY-NC 3.0;Public Domain
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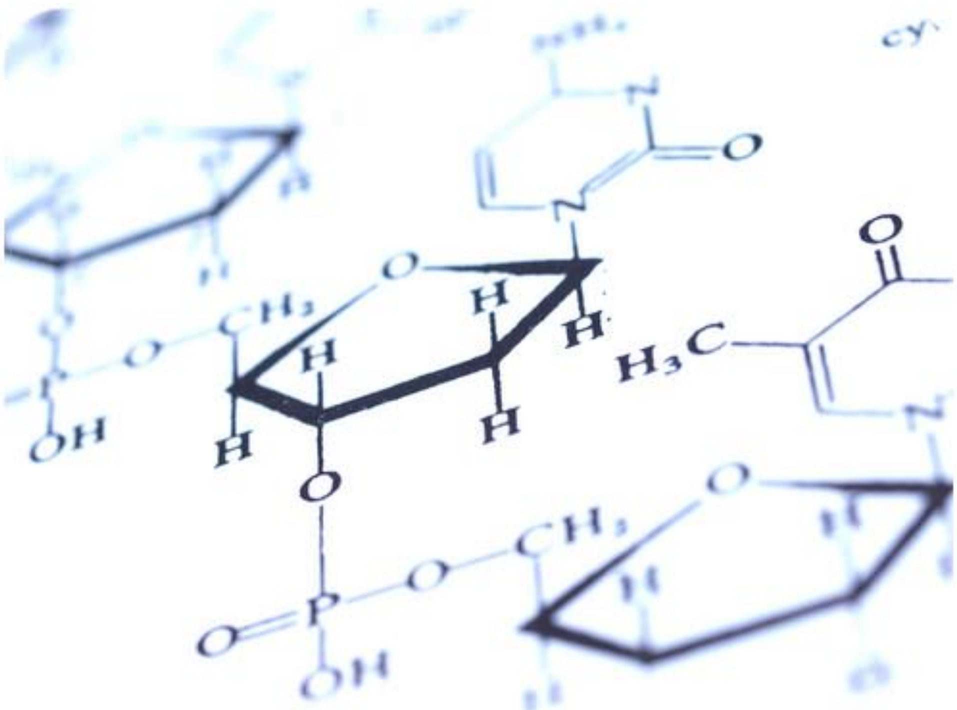
CHAPTER 5 Matter and Energy: Cellular Respiration

Chapter Outline

5.1 Biochemical Reactions

Learning Objectives

- Distinguish between a reactant and a product.
- Describe what happens in chemical reactions.
- Identify a chemical equation.



Understanding chemistry is essential to fully understand biology. Why?

A general understanding of chemistry is necessary to understand biology. Essentially, our cells are just thousands of chemicals — made of elements like carbon, hydrogen, oxygen, nitrogen, phosphorus and sulfur — in just the right combinations. And these chemicals combine through chemical reactions.

Chemical Reactions

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

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

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

Chemical Equations

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

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

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

Conservation of Matter

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

MEDIA

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Summary

- A chemical reaction is a process that changes some chemical substances into others. During a chemical reaction, the reactants are used up to create the products.
- In a chemical reaction, matter is always conserved.

Review

1. Define a chemical reaction.
2. Describe the roles of reactants and products in chemical reactions.
3. How does a chemical equation show that matter is always conserved in a chemical reaction?
4. Knowing that water (H_2O) forms from hydrogen (H^+) and oxygen (O_2), write a chemical equation for the formation of water from these two elements.

5.2 Cellular Respiration

Learning Objectives

- Define the role of cellular respiration.
- Name the three stages of cellular respiration.
- Describe the structure of a mitochondrion.

Why eat?

Because we're hungry? Not necessarily. But biologically speaking. . . we eat to get energy. The food we eat is broken down, the glucose extracted, and that energy is converted into ATP.

Cellular Respiration

What happens to the energy stored in glucose during photosynthesis? How do living things make use of this stored energy? The answer is **cellular respiration**. This process releases the energy in glucose to make **ATP** (adenosine triphosphate), the molecule that powers all the work of cells.

Stages of Cellular Respiration

Cellular respiration involves many chemical reactions. The reactions can be summed up in this equation:

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

The reactions of cellular respiration can be grouped into three stages: **glycolysis** (stage 1), the **Krebs cycle**, also called the **citric acid cycle** (stage 2), and **electron transport** (stage 3). **Figure** 6.1 gives an overview of these three stages, which are further discussed in the concepts that follow. Glycolysis occurs in the cytosol of the cell and does not require oxygen, whereas the Krebs cycle and electron transport occur in the mitochondria and do require oxygen.

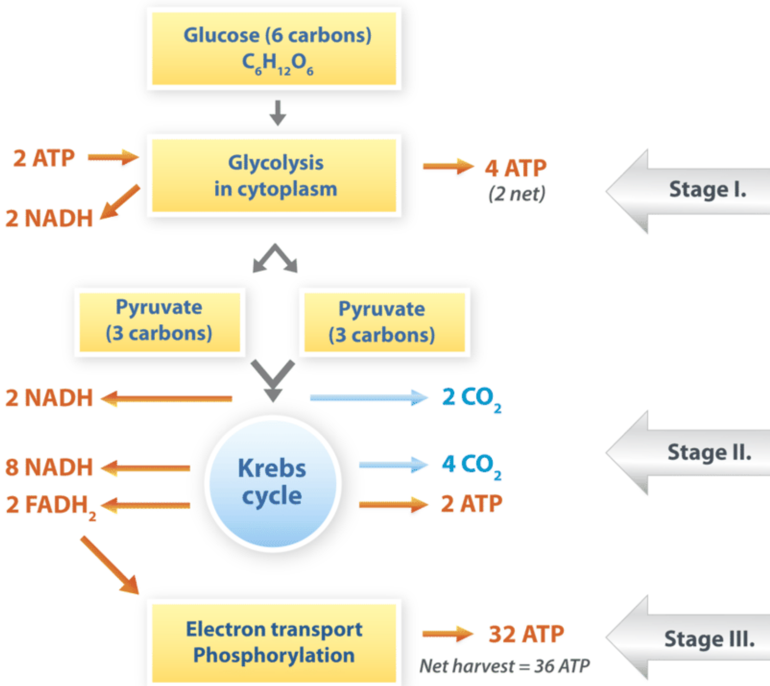

FIGURE 5.1

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

Structure of the Mitochondrion: Key to Aerobic Respiration

The structure of the mitochondrion is key to the process of **aerobic** (in the presence of oxygen) cellular respiration, especially the Krebs cycle and electron transport. A diagram of a mitochondrion is shown in **Figure** 6.2.

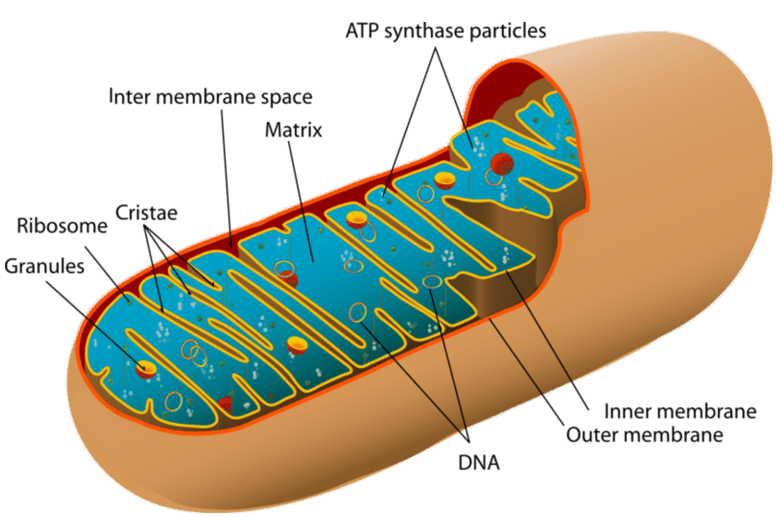

FIGURE 5.2

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

As you can see from **Figure** 6.2, a mitochondrion has an inner and outer membrane. The space between the inner and outer membrane is called the intermembrane space. The space enclosed by the inner membrane is called the matrix. The second stage of cellular respiration, the Krebs cycle, takes place in the matrix. The third stage, electron transport, takes place on the inner membrane.

Multimedia

MEDIA

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Summary

- Cellular respiration takes the energy stored in glucose and transfers it to ATP.
- Cellular respiration has three stages: glycolysis: the Krebs cycle and electron transport.
- The inner and outer membranes of the mitochondrion play an important roles in aerobic respiration.

Review

1. Define cellular respiration.
2. What are the three stages of cellular respiration?
3. Describe the structure of the mitochondrion and discuss the importance of this structure in cellular respiration.
4. Assume that a new species of organism has been discovered. Scientists have observed its cells under a microscope and determined that they lack mitochondria. What type of cellular respiration would you predict that the new species uses? Explain your prediction.
5. When you exhale onto a cold window pane, water vapor in your breath condenses on the glass. Where does the water vapor come from?

5.3 Cellular Respiration Process

Learning Objectives

- Describe the structure of a mitochondrion.
- List the three steps of cellular respiration.
- Write the chemical reaction of cellular respiration.
- Explain the process of cellular respiration.

Why do you need to breathe?

Of course if you didn't breathe, you couldn't survive. Why do you need air to live? You need the gas oxygen to perform cellular respiration to get energy from your food.

The Process of Cellular Respiration

Cellular respiration is the process of extracting energy in the form of **ATP** from the glucose in the food you eat. How does cellular respiration happen inside of the cell? Cellular respiration is a three step process. Briefly:

1. In stage one, glucose is broken down in the cytoplasm of the cell in a process called **glycolysis**.
2. In stage two, the pyruvate molecules are transported into the mitochondria. The **mitochondria** are the organelles known as the energy "powerhouses" of the cells (**Figure** 5.3). In the mitochondria, the pyruvate, which have been converted into a 2-carbon molecule, enter the **Krebs cycle.** Notice that mitochondria have an inner membrane with many folds, called **cristae**. These cristae greatly increase the membrane surface area where many of the cellular respiration reactions take place.

3. In stage three, the energy in the energy carriers enters an **electron transport chain**. During this step, this energy is used to produce ATP.

Oxygen is needed to help the process of turning glucose into ATP. The initial step releases just two molecules of ATP for each glucose. The later steps release much more ATP.

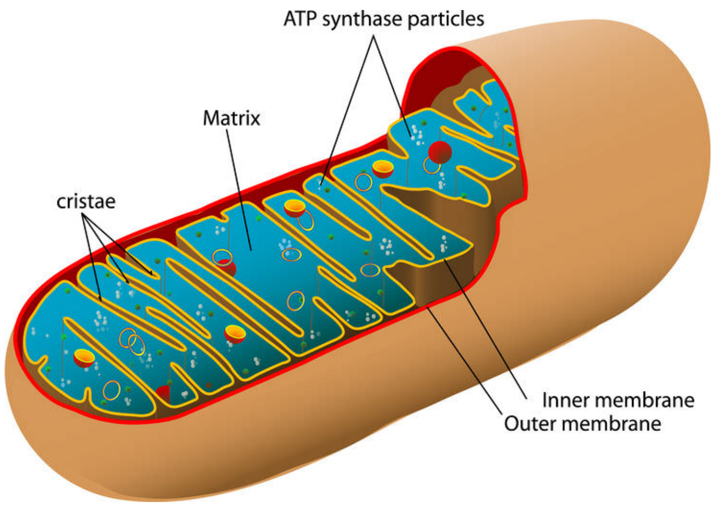

FIGURE 5.3
Most of the reactions of cellular respiration are carried out in the mitochondria.

The Reactants

What goes into the cell? Oxygen and glucose are both **reactants** of cellular respiration. Oxygen enters the body when an organism breathes. Glucose enters the body when an organism eats.

The Products

What does the cell produce? The **products** of cellular respiration are carbon dioxide and water. Carbon dioxide is transported from your mitochondria out of your cell, to your red blood cells, and back to your lungs to be exhaled. ATP is generated in the process. When one molecule of glucose is broken down, it can be converted to a net total of 36 or 38 molecules of ATP. This only occurs in the presence of oxygen.

The Chemical Reaction

The overall chemical reaction for cellular respiration is one molecule of glucose ($C_6H_{12}O_6$) and six molecules of oxygen (O_2) yields six molecules of carbon dioxide (CO_2) and six molecules of water (H_2O). Using chemical symbols the equation is represented as follows:

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

ATP is generated during the process. Though this equation may not seem that complicated, cellular respiration is a series of chemical reactions divided into three stages: glycolysis, the Krebs cycle, and the electron transport chain.

Glycolysis

Stage one of cellular respiration is glycolysis. Glycolysis is the splitting, or *lysis* of glucose. Glycolysis converts the 6-carbon glucose into two 3-carbon **pyruvate** molecules. This process occurs in the cytoplasm of the cell, and it occurs in the presence or absence of oxygen. During glycolysis a small amount of NADH is made as are four ATP. Two ATP are used during this process, leaving a net gain of two ATP from glycolysis. The NADH temporarily holds energy, which will be used in stage three.

The Krebs Cycle

In the presence of oxygen, under **aerobic** conditions, pyruvate enters the mitochondria to proceed into the Krebs cycle. The second stage of cellular respiration is the transfer of the energy in pyruvate, which is the energy initially in glucose, into two energy carriers, NADH and $FADH_2$. A small amount of ATP is also made during this process. This process occurs in a continuous cycle, named after its discover, Hans Krebs. The Krebs cycle uses a 2-carbon molecule (acetyl-CoA) derived from pyruvate and produces carbon dioxide.

The Electron Transport Chain

Stage three of cellular respiration is the use of NADH and $FADH_2$ to generate ATP. This occurs in two parts. First, the NADH and $FADH_2$ enter an electron transport chain, where their energy is used to pump, by active transport, protons (H^+) into the intermembrane space of mitochondria. This establishes a proton gradient across the inner membrane. These protons then flow down their concentration gradient, moving back into the matrix by facilitated diffusion. During this process, ATP is made by adding inorganic phosphate to ADP. Most of the ATP produced during cellular respiration is made during this stage.

For each glucose that starts cellular respiration, in the presence of oxygen (aerobic conditions), 36-38 ATP are generated. Without oxygen, under **anaerobic** conditions, much less (only two!) ATP are produced.

Summary

- Most of the steps of cellular respiration take place in the mitochondria.
- Oxygen and glucose are both reactants in the process of cellular respiration.
- The main product of cellular respiration is ATP; waste products include carbon dioxide and water.

Explore More

Use the resources below to answer the following questions

Explore More I

- **Glycolysis** at http://www.youtube.com/watch?v=piIrBw24c8M (0:44)

MEDIA

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URL: http://www.ck12.org/flx/render/embeddedobject/57355

1. Where does glycolysis occur?
2. When glucose is broken down what is produced?
3. Does glycolysis require oxygen?

Explore More II

- **Krebs Cycle** at http://www.youtube.com/watch?v=O6bInBQXtmM (5:30)

MEDIA

Click image to the left or use the URL below.

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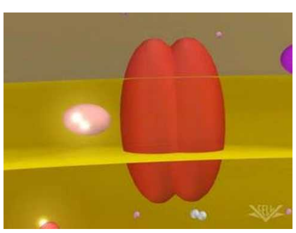
1. Which types of cells have mitochondria?
2. What is the cristae? Where does it occur? Why is this structure important?
3. What high energy electron carriers are produced by the Krebs cycle? Where do they carry their electrons?
4. What is the role of acetyl-CoA? Where does it fit into the Krebs cycle?
5. How much ATP is made by the Krebs cycle for every molecule of Pyruvate that enter the cycle?

Explore More III

- **Electron Transport Chain** at http://www.youtube.com/watch?v=xbJ0nbzt5Kw (3:50)



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1. What is the name of the protein complex that makes ATP?
2. What is the final electron acceptor at the end of the electron transport chain?
3. What is a "mobile transfer molecule"? What is their function?
4. How is the hydrogen ion gradient formed?
5. What is the purpose of the proton (hydrogen ion) gradient?

Review

1. Where is glucose broken down to form ATP? What is this process called? Does this process need oxygen?
2. Write the chemical reaction for the overall process of cellular respiration.
3. What is necessary for the Krebs cycle to proceed?
4. What happens during the Krebs cycle?
5. What is pyruvate?
6. What happens during the electron transport chain?
7. How is ATP made during the third stage of cellular respiration?

5.4 Cellular Respiration Overview - Advanced

Learning Objectives

- Trace the flow of energy from food molecules through ATP to its use in cellular work.
- Compare cellular respiration to burning.
- Analyze the chemical equation for cellular respiration.
- Briefly describe the role of mitochondria in producing ATP.
- Compare cellular respiration to photosynthesis.

Why eat?

Because we're hungry. Not necessarily. Biologically speaking, we eat to get energy. The food we eat is broken down, the glucose extracted, and that energy is converted into ATP. And this happens most efficiently in the presence of oxygen.

An Overview of Cellular Respiration

Another way to think about the role of oxygen in your body - and a good starting point for understanding the whole process of cellular respiration - is to recall (or imagine) the last time you sat by a campfire (see **Figure** 5.4) and noticed that it was "dying." Often people will blow on a campfire to keep it from "dying out." How does blowing help? What happens in a campfire?

FIGURE 5.4
Analyzing what happens when wood burns in a campfire is a good way to begin to understand cellular respiration.

You know that a fire produces light and heat energy. However, it cannot create energy (remember that energy cannot be created or destroyed). Fire merely transforms the energy stored in its fuel - chemical energy - into light and heat. Another way to describe this energy transformation is to say that burning releases the energy stored in fuel. As energy is transformed, so are the compounds that make up the fuel. In other words, burning is a chemical reaction. We could write our understanding of this energy-releasing chemical reaction up to this point as:

$$\underset{\text{Stored chemical Energy}}{\text{Wood Fuel}} \xrightarrow{\text{Spark or match}} \text{light energy} + \text{heat energy}$$

Now return to what happens when you blow on a fire. The fire was "dying out," so you blew on it to get it going again. Was it movement or something in the air that promoted the chemical reaction? If you have ever "smothered" a fire, you know that a fire needs something in the air to keep burning. That something turns out to be oxygen. Oxygen gas is a **reactant** in the burning process. At this point, our equation is:

$$O_2 + \underset{\text{Stored chemical Energy}}{\text{Wood Fuel}} \xrightarrow{\text{Spark or match}} \text{light energy} + \text{heat energy}$$

To complete this equation, we need to know what happens to matter, to the atoms of oxygen, and to the atoms of the fuel during the burning. If you collect the gas rising above a piece of burning wood in an inverted test tube, you will notice condensation - droplets appearing on the sides of the tube. To identify the **products**, the experiment shown below can be performed. Cobalt chloride paper will change from blue to pink, confirming that these droplets are water. If you add bromothymol blue (BTB) to a second tube of collected gases, the blue solution will change to green or yellow (**Figure** 5.5), indicating the presence of carbon dioxide. Thus, carbon dioxide and water are products of burning wood fuel. The oxygen atoms have been incorporated into carbon dioxide and water.

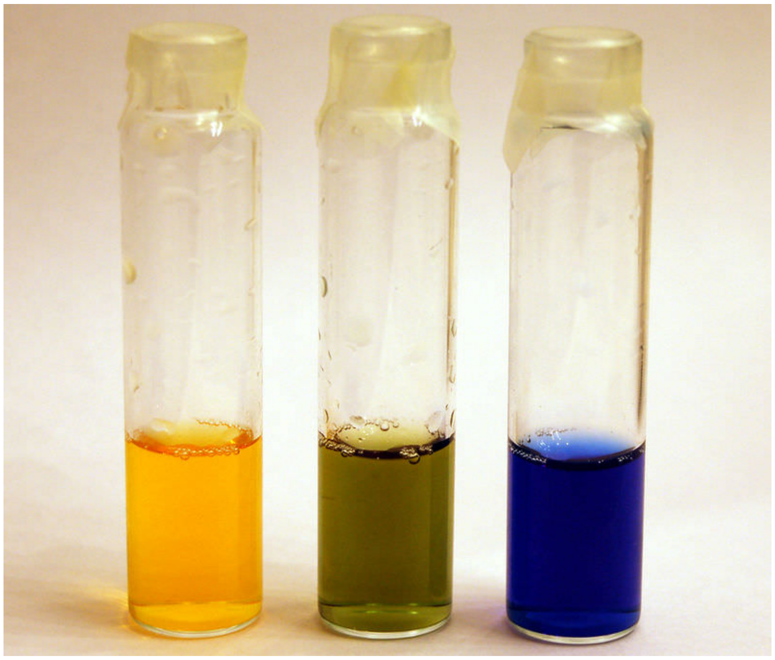

FIGURE 5.5

Bromothymol blue (BTB) changes from blue to green to yellow as carbon dioxide is added. Thus, it is a good indicator for this product of burning or cellular respiration.

$$O_2 + \underset{\substack{\text{Stored chemical}\\ \text{Energy}}}{\text{Wood Fuel}} \xrightarrow{\text{Spark or match}} CO_2 + H_2O + \text{light energy} + \text{heat energy}$$

The oxygen atoms have been incorporated into carbon dioxide and water, but what is the sources of the carbon atoms in the CO_2 and of the hydrogen atoms in the water. These atoms make up the wood fuel - and nearly all fuels we burn, from coal to propane to candle wax to gasoline. Overall, burning is the combining of oxygen with hydrogen and carbon atoms in a fuel (combustion or oxidation) to release the stored chemical energy as heat and light. Products of combustion are CO_2 (oxidized carbon) and H_2O (oxidized hydrogen). The equation can be modified to:

$$O_2 + \underset{\substack{\text{Stored chemical}\\ \text{Energy}}}{C_x\text{-}H_y} \xrightarrow{\text{Spark or match}} CO_2 + H_2O + \text{light energy} + \text{heat energy}$$

Cellular Respiration

Recall that breathing rate and oxygen intake is related to energy use. Burning consumes oxygen as it releases stored chemical energy, transforming it into light and heat. **Cellular respiration** is actually a slow burn. Your cells absorb the oxygen carried by your blood from your lungs, and use the O_2 to release stored chemical energy so that you can use it.

Stages of Cellular Respiration

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

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

The reactions of cellular respiration can be grouped into three stages: glycolysis, the Krebs cycle (also called the citric acid cycle), and electron transport. **Figure** 6.1 gives an overview of these three stages, which are also described below.

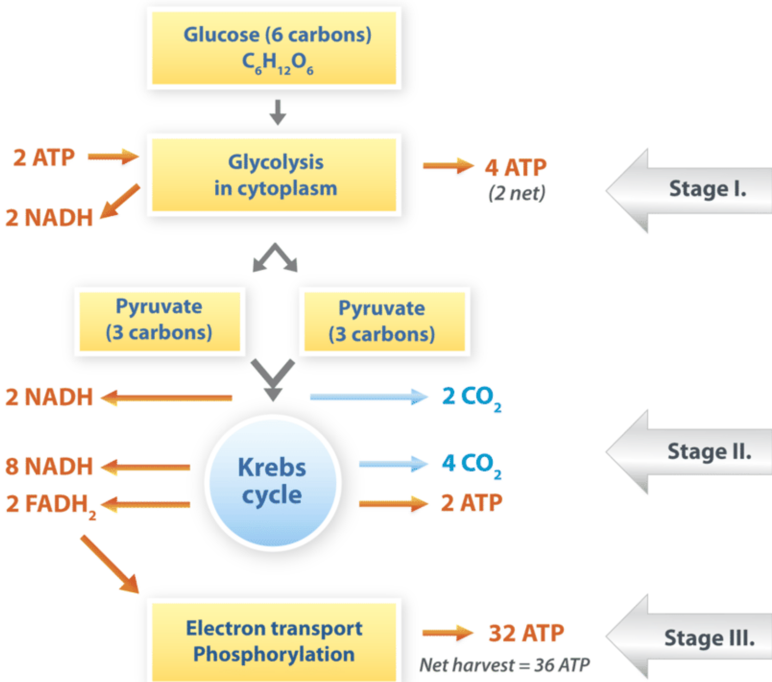

FIGURE 5.6

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

ATP

However, releasing energy within cells does not produce light or intense heat. Cells run on chemical energy - specifically, the small amount temporarily stored in **ATP** molecules. Cellular respiration transfers chemical energy from a "deliverable" fuel molecule - **glucose** - to many "usable" molecules of ATP. Like oxygen, glucose is delivered by your blood to your cells. If ATP were delivered to cells, more than 60,221,417,930,000,000,000,000 of these large molecules (which contain relatively small amounts of energy) would clog your capillaries each day. Pumping them across cell membranes would "cost" a great deal of energy. A molecule of glucose contains a larger amount of chemical energy in a smaller package. Therefore, glucose is much more convenient for bloodstream delivery, but too "powerful" to work within the cell. The process of cellular respiration uses oxygen to help transfer the chemical energy from glucose to ATP, which can be used to do work in the cell. This chemical equation expresses what we have worked out:

$$O_2 + \underbrace{C_6H_{12}O_6}_{\text{stored chemical energy, deliverable}} \longrightarrow \underbrace{ATP}_{\text{stored chemical energy, usable}}$$

As with burning, we must trace what happens to atoms during cellular respiration. You can readily see that when the carbon atoms in glucose are combined with oxygen, they again form carbon dioxide. And when the hydrogen atoms in glucose are oxidized, they form water, as in burning. You can detect these products of cellular respiration in your breath on a cold day (as water condensation) and in the lab (BTB turns yellow when you blow into it through a straw).

$$O_2 + \underset{\text{stored chemical energy, deliverable}}{C_6H_{12}O_6} \longrightarrow \underset{\text{stored chemical energy, usable}}{ATP} + CO_2 + H_2O$$

This equation accounts for the energy transfer and the carbon, hydrogen, and oxygen atoms, but it does not show the "raw materials" or reactants which build ATP. Recall that the energy temporarily stored in ATP is released for use when the bond between the second and third phosphates is broken. The resulting ADP can be recycled within the cell by recombining it with inorganic phosphate (P_i).

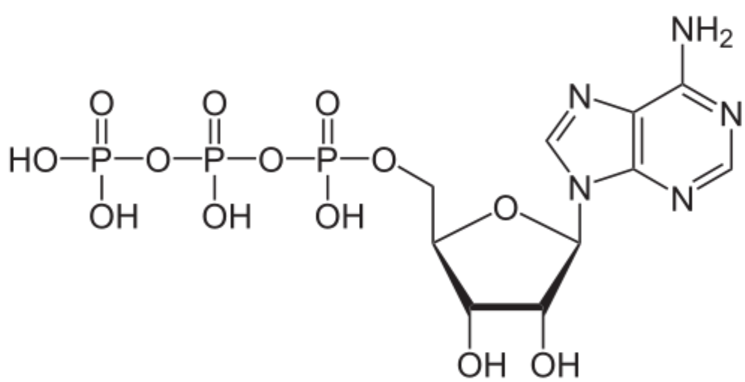

FIGURE 5.7

Like recharging batteries, cells recycle ATP and ADP (and AMP) molecules by combining them with inorganic phosphate. When the high-energy bond between phosphate groups in ATP breaks, its chemical energy can do cellular work. The bonds between phosphate groups can be broken and reformed, recycling this cellular energy.

The source of energy for re-attaching the phosphate and making ATP is the chemical energy in glucose. Materials cycle and recycle, but energy gets used up and must be replaced. That is the key to understanding cellular respiration: it is a "recharging of the batteries" - ATP molecules - which power cellular work. How many ATP can be made by harnessing the energy in a single glucose molecule? Although this number varies under certain conditions, most cells can capture enough energy from one molecule of glucose to build 38 molecules of ATP. Our equation becomes:

$$O_2 + \underset{\text{stored chemical energy, deliverable}}{C_6H_{12}O_6} + 38ADP + 38P_i \longrightarrow \underset{\text{stored chemical energy, usable}}{38\ ATP} + CO_2 + H_2O$$

Mitochondria

This equation for cellular respiration is not quite complete, however, because we can easily mix air and glucose sugar (even adding ADP and P_i) and nothing will happen. For the campfire, we indicated above the arrow that a necessary condition was a spark or match to start the reaction. A spark or match would damage or destroy living tissue. What necessary condition initiates the slow burn that is cellular respiration? Recall that **enzymes** are highly specific proteins which "speed up" or catalyze chemical reactions in living cells. More than 20 different enzymes are necessary to carry out cellular respiration. Recall also that membranes within organelles often sequence enzymes for efficiency, as in chloroplasts for photosynthesis, you will not be surprised that a specific organelle, the **mitochondrion** (**Figure** 5.8), is also a necessary condition of cellular respiration - at least in eukaryotes.

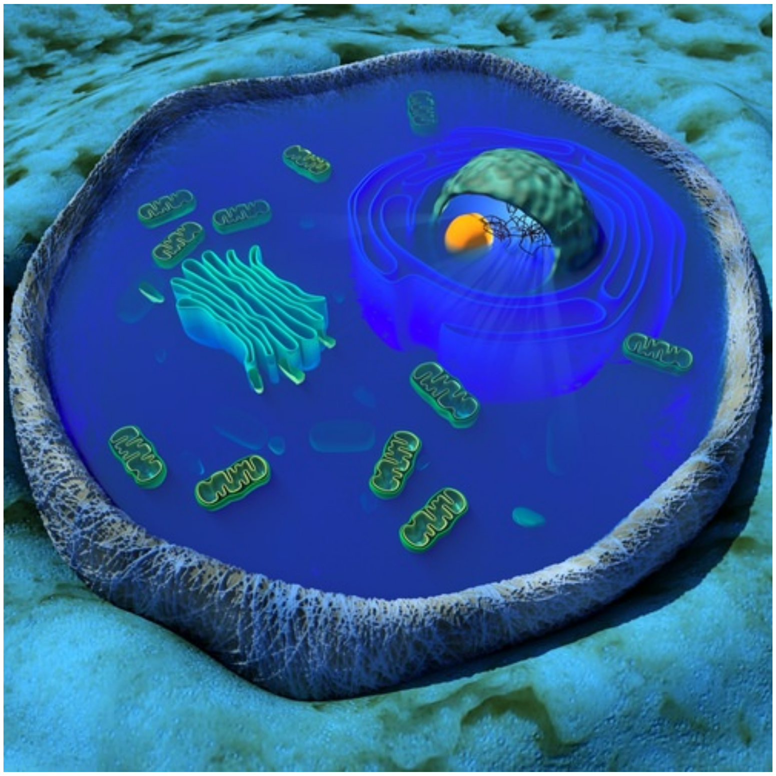

FIGURE 5.8
Mitochondria, shown here as the green ovals in this animal cell, are membranous organelles which sequence enzyme and electron carrier molecules to make cellular respiration highly efficient. Mitochondria have both an inner and outer membrane, with a matrix inside the inner membrane. The inner membrane has many internal folds, increasing the surface area for proteins and molecules involved in cellular respiration.

Within each eukaryotic cell, the membranes of a few to a few thousand mitochondria sequence enzymes and electron carriers and compartmentalize ions so that cellular respiration proceeds efficiently. Mitochondria, like chloroplasts, contain their own DNA and ribosomes and resemble certain bacteria. The **Theory of Endosymbiosis** holds that mitochondria, like chloroplasts, were once independently living prokaryotes. Larger prokaryotes engulfed (or enslaved) these smaller aerobic cells, forming eukaryotic cells. Many prokaryotes today can perform cellular respiration; perhaps they and mitochondria have common ancestors. Their expertise in generating ATP made mitochondria highly valued **symbionts**.

Including these necessary conditions and balancing numbers of atoms on both sides of the arrow, our final equation for the overall process of cellular respiration is:

$$6O_2 + \underset{\text{stored chemical energy, deliverable}}{C_6H_{12}O_6} + 38ADP + 38P_i \xrightarrow[\text{mitochondria}]{\text{enzymes}} \underset{\text{stored chemical energy, usable}}{38ATP} + 6CO_2 + 6H_2O$$

In words, cellular respiration uses oxygen gas to break apart the carbon-hydrogen bonds in glucose and release their energy to build 38 molecules of ATP. Most of this process occurs within the mitochondria of the cell. Carbon dioxide and water are waste products. This is similar to burning, in which oxygen breaks the carbon-hydrogen bonds in a fuel and releases their chemical energy as heat and light. Again, carbon dioxide and water are waste.

Cellular Respiration and Photosynthesis

Comparing this process to that of photosynthesis, the similarity between the two processes is striking. Both are processes within the cell which make chemical energy available for life. Photosynthesis transforms light energy into chemical energy stored in glucose, and cellular respiration releases the energy from glucose to build ATP, which does the work of life. Moreover, photosynthesis reactants CO_2 and H_2O are products of cellular respiration. And the reactants of respiration, $C_6H_{12}O_6$ and O_2, are the products of photosynthesis. This interdependence is the basis of the **carbon-oxygen cycle** (**Figure** 5.9), which connects producers to consumers and their environment. At first glance, the cycle merely seems to show mitochondria undoing what chloroplasts do; but the cycle's energy transformations power all the diversity, beauty, and mystery of life.

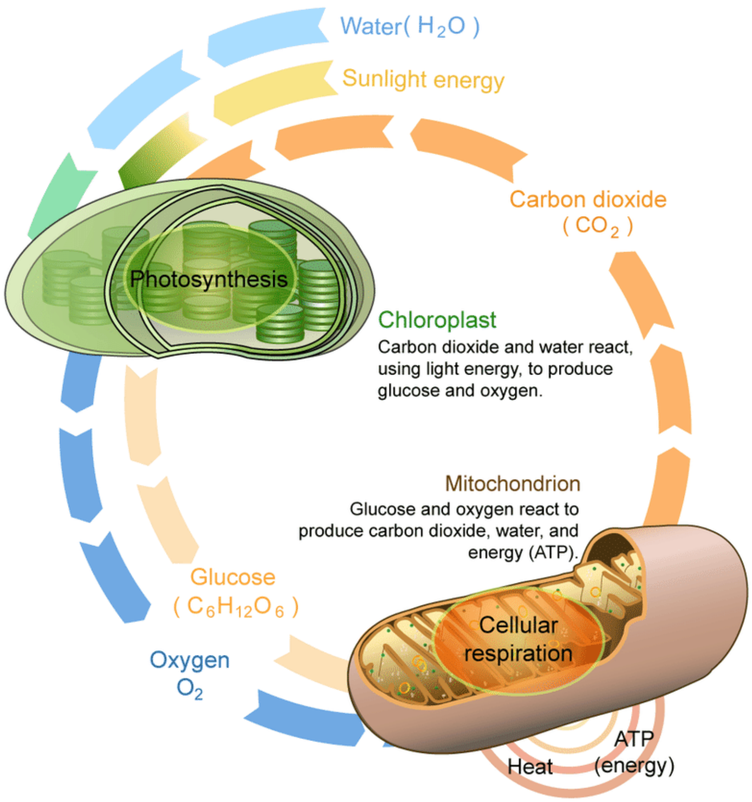

FIGURE 5.9

Photosynthesis in the chloroplast and cellular respiration in the mitochondrion show the interdependence of producers and consumers, the flow of energy from sunlight to heat, and the cycling of carbon and oxygen between living world and environment.

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Summary

- Cellular respiration is a series of chemical reactions which transfer energy from glucose (deliverable or fuel energy) to ATP (usable energy).
- Analyzing a campfire can clarify your understanding of cellular respiration. A campfire breaks chemical bonds in wood, releasing stored energy as light and heat; respiration breaks chemical bonds in glucose, releasing stored energy and transferring some to 38 ATP; some energy is lost as heat.

- This equation summarizes the process of cellular respiration:

$$6O_2 + \underbrace{C_6H_{12}O_6}_{\text{stored chemical energy, deliverable}} + 38ADP + 38P_i \xrightarrow[]{\text{enzymes mitochondria}} \underbrace{38ATP}_{\text{stored chemical energy, usable}} + 6CO_2 + 6H_2O$$

- In eukaryotic cells, mitochondria organize enzymes and electron carriers and compartmentalize ions so that cellular respiration proceeds efficiently.
- Cellular respiration, in many ways the opposite of photosynthesis, shows the interdependence of producers and consumers. Combined, the two equations demonstrate how energy flows and the carbon and oxygen cycle between organisms and environment.

Review

1. What source of energy do cells use to build ATP by cellular respiration?
2. Compare the purpose and energy content of glucose to the function and energy content of ATP; in other words, why do organisms need both kinds of energy-rich molecules?
3. Compare the process of burning gasoline in your automobile's engine to the process of cellular respiration in terms of reactants, products, and necessary conditions.
4. Write out the chemical reaction which summarizes the overall process of cellular respiration, first in symbols as a chemical equation, and then in words in a complete sentence.
5. In what eukaryote organelle does cellular respiration take place? Does this mean that prokaryotes cannot carry out the entire process of cellular respiration? Explain.
6. Compare and contrast cellular respiration and photosynthesis.

5.5 Glycolysis

Learning Objectives

- Summarize glycolysis.
- List the products of glycolysis.

How do you slice a molecule of glucose in half?

With sharp knives? Not really. But you essentially slice it in half through glycolysis. This is an extremely important part of cellular respiration. It happens all the time, both with and without oxygen. And in the process, transfers some energy to ATP.

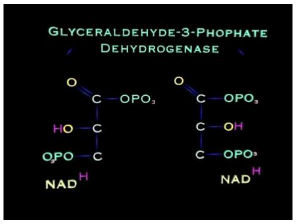
Cellular Respiration Stage I: Glycolysis

The first stage of cellular respiration is **glycolysis**. It does not require oxygen, and it does not take place in the mitochondrion - it takes place in the cytosol of the cytoplasm.

When was the last time you enjoyed yogurt on your breakfast cereal, or had a tetanus shot? These experiences may appear unconnected, but both relate to bacteria which do not use oxygen to make ATP. In fact, tetanus bacteria cannot survive if oxygen is present. However, *Lactobacillus acidophilus* (bacteria which make yogurt) and *Clostridium tetani* (bacteria which cause tetanus or lockjaw) share with nearly all organisms the first stage of cellular respiration, glycolysis. Because glycolysis is universal, whereas **aerobic** (oxygen-requiring) cellular respiration is not, most biologists consider it to be the most fundamental and primitive pathway for making ATP.

Splitting Glucose

The word *glycolysis* means "glucose splitting," which is exactly what happens in this stage. Enzymes split a molecule of glucose into two molecules of **pyruvate** (also known as pyruvic acid). This occurs in several steps, as shown in **Figure** 5.10.



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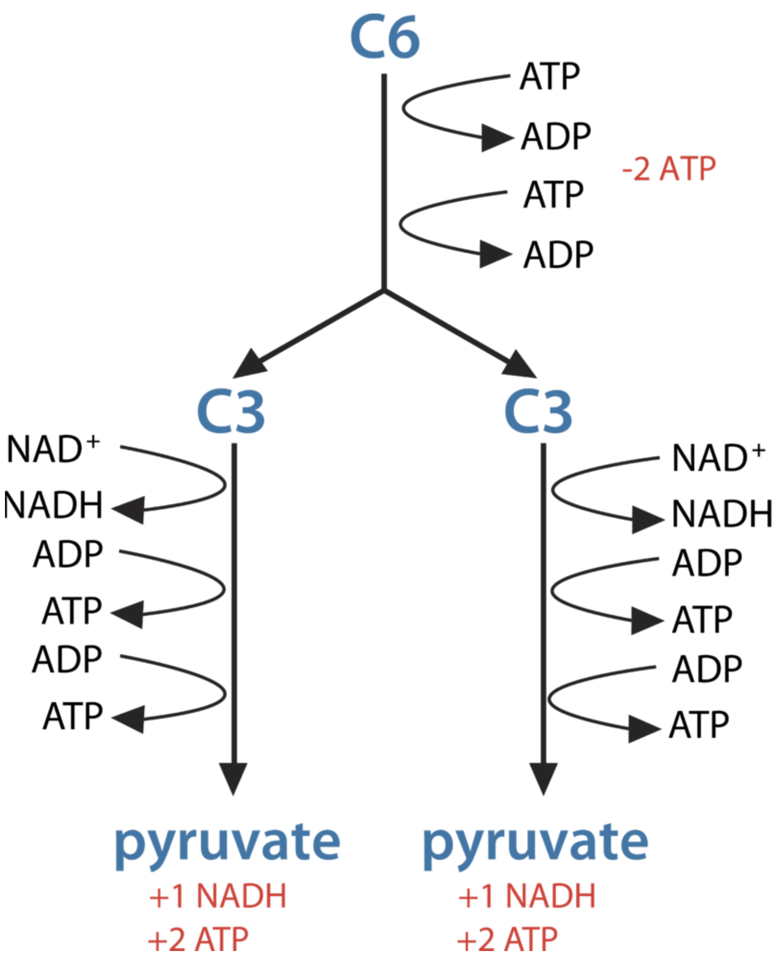


FIGURE 5.10

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

Results of Glycolysis

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

Summary

- The first stage of cellular respiration is glycolysis. It does not require oxygen.
- During glycolysis, one glucose molecule is split into two pyruvate molecules, using 2 ATP while producing 4 ATP and 2 NADH molecules.

Review

1. What is glycolysis?
2. Describe what happens during glycolysis. How many ATP and NADH molecules are gained during this stage?
3. Defend this statement: "Glycolysis is a universal and ancient pathway for making ATP".

5.6 Krebs Cycle

Learning Objectives

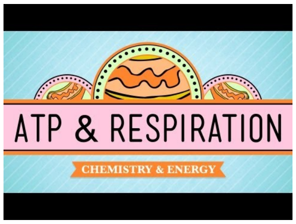
- Summarize the Krebs cycle
- Identify the products of the Krebs cycle.

What type of acid do these fruits contain?

Citric acid. Citric acid is also the first product formed in the Krebs cycle, and therefore this acid occurs in the metabolism of virtually all living things.

Cellular Respiration Stage II: The Krebs Cycle

Recall that glycolysis, stage I of cellular respiration, produces two molecules of pyruvate. These molecules enter the matrix of a mitochondrion, where they start the **Krebs cycle**. The reactions that occur next are shown in **Figure ??**.



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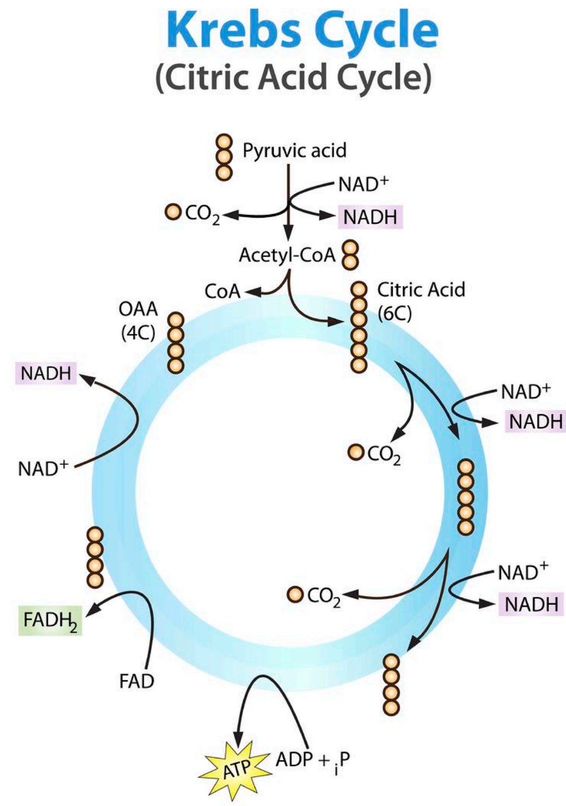

The Krebs cycle starts with pyruvic acid from glycolysis. Each small circle in the diagram represents one carbon atom. For example, citric acid is a six carbon molecule, and OAA (oxaloacetate) is a four carbon molecule. Follow what happens to the carbon atoms as the cycle proceeds. In one turn through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

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

Steps of the Krebs Cycle

The Krebs cycle itself actually begins when acetyl-CoA combines with a four-carbon molecule called OAA (oxaloacetate) (see **Figure ??**). This produces citric acid, which has six carbon atoms. This is why the Krebs cycle is also called the **citric acid cycle**.

After citric acid forms, it goes through a series of reactions that release energy. The energy is captured in molecules of NADH, ATP, and $FADH_2$, another energy-carrying compound. Carbon dioxide is also released as a waste product of these reactions.

The final step of the Krebs cycle regenerates OAA, the molecule that began the Krebs cycle. This molecule is needed for the next turn through the cycle. Two turns are needed because glycolysis produces two pyruvic acid molecules when it splits glucose.

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Results of the Krebs Cycle

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

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

Summary

- The Krebs cycle is the second stage of cellular respiration.
- During the Krebs cycle, energy stored in pyruvate is transferred to NADH and $FADH_2$, and some ATP is produced.

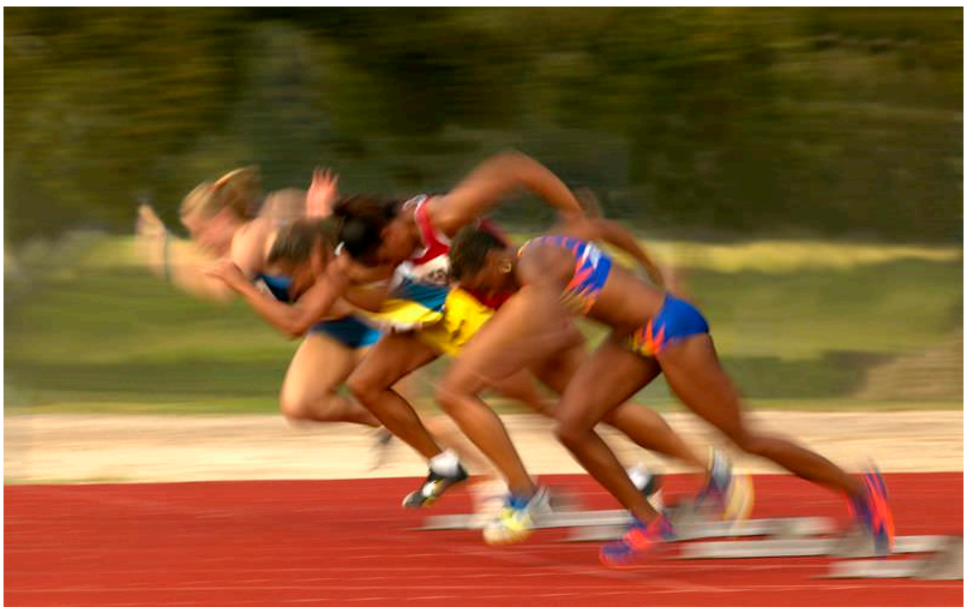
Review

1. What is the Krebs cycle?
2. What are the products of the Krebs cycle?
3. Explain why two turns of the Krebs cycle are needed for each molecule of glucose.

5.7 Lactic Acid Fermentation - Advanced

Learning Objectives

- Describe lactic acid fermentation.
- Describe how bacteria, including those we employ to make yogurt, make ATP in the absence of oxygen.
- Discuss how your muscles continue to work for you even when your respiratory and cardiovascular system can no longer keep up a continuous supply of oxygen.



Is there enough ATP?

Yes. But not to keep this effort up for a long time. Short spurts of sprinting are sustained by fermentation in muscle cells. This produces just enough ATP to allow these short bursts of increased activity.

Lactic Acid Fermentation: Muscle Cells and Yogurt

For chicken or turkey dinners, do you prefer light meat or dark? Do you consider yourself a sprinter or a long distance runner? What is the biological difference between light meat or dark meat? Or between the two types of runners? Would you believe it has something to do with muscle color?

Are Drumsticks and Athletic Prowess Related?

Muscle color reflects its specialization for aerobic or anaerobic metabolism. Although humans are **obligate aerobes**, our muscle cells have not given up on ancient pathways which allow them to keep producing ATP quickly when oxygen runs low. The difference is more pronounced in chickens and grouse (**Figure** 5.12), which stand around all day on their legs. For long periods of time, they carry out aerobic respiration in their "specialized-for-endurance" red muscles. If you are familiar with grouse, you know that these birds "flush" with great speed over short distances.

FIGURE 5.11
Light meat or dark? Sprinting or endurance? Muscle cells know two ways of making ATP - aerobic and anaerobic respiration.

Such "sprinting" flight depends on anaerobic respiration in the white cells of breast and wing muscle, allowing rapid production of ATP in low oxygen situations.

No human muscle is all red or all white, but chances are, if you excel at sprinting short distances or at a sport such as weight lifting, you have more white glycolytic fibers in your leg muscles, allowing anaerobic respiration. If you run marathons, you probably have more red oxidative fibers, performing aerobic respiration.

FIGURE 5.12
Ruffed grouse use anaerobic respiration (lactic acid fermentation) in wing and breast muscles for quick bursts of speed to escape from predators.

Lactic Acid Fermentation

You may have not been aware that your muscle cells can ferment. **Fermentation** is the process of producing ATP in the absence of oxygen, through glycolysis alone. Recall that glycolysis breaks a glucose molecule into two pyruvate molecules, producing a net gain of two ATP and two NADH molecules. **Lactic acid fermentation** is the type of anaerobic respiration carried out by yogurt bacteria (*Lactobacillus* and others) and by your own muscle cells when you work them hard and fast.

Lactic acid fermentation converts the 3-carbon pyruvate to the 3-carbon lactic acid ($C_3H_6O_3$) (see **Figure** 5.13) and regenerates NAD^+in the process, allowing glycolysis to continue to make ATP in low-oxygen conditions. Since there is a limited supply of NAD^+ available in any given cell, this electron acceptor must be regenerated to allow ATP production to continue. To achieve this, NADH donates its extra electrons to the pyruvate molecules, regenerating NAD^+. Lactic acid is formed by the reduction of pyruvate.

Lactic acid fermentation converts pyruvate to lactic acid, and regenerates NAD^+ from NADH:

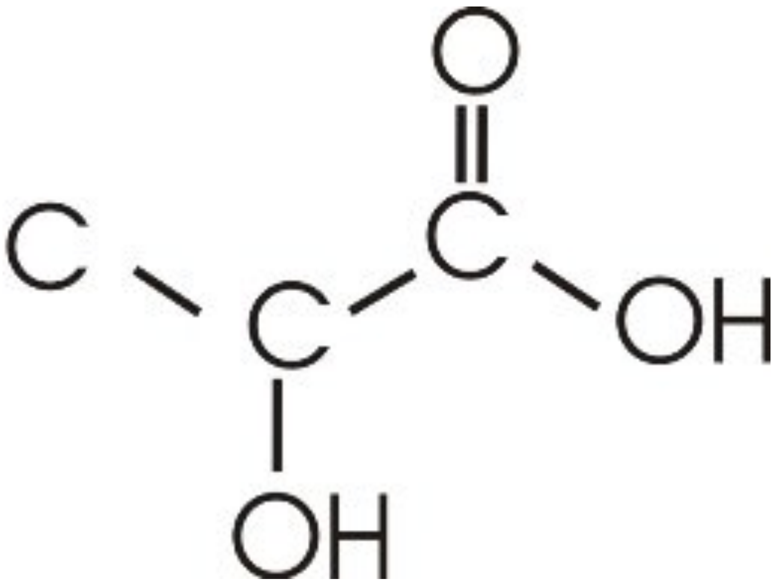


FIGURE 5.13
Lactic acid, $C_3H_6O_3$.

$C_3H_3O_3$ (pyruvate) + NADH $\rightarrow$ $C_3H_6O_3$ (lactic acid) + NAD^+

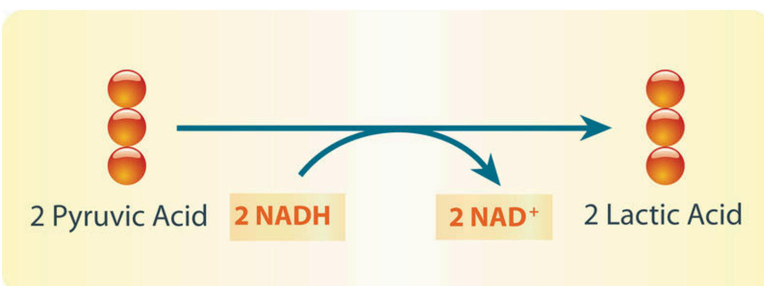


FIGURE 5.14
Lactic acid fermentation makes ATP in the absence of oxygen by converting glucose to lactic acid (through a pyruvate intermediate). Making lactic acid from pyruvate oxidizes NADH, regenerating NAD^+ so that glycolysis can continue to make more ATP rapidly. Each circle represents a carbon atom.

For *Lactobacillus* bacteria, the acid resulting from fermentation kills bacterial competitors in buttermilk, yogurt, and some cottage cheese. The benefits extend to humans who enjoy these foods, as well (**Figure** 5.15).

You may have noticed this type of fermentation in your own muscles, because muscle fatigue and pain are associated with lactic acid. Lactic acid accumulates in your muscle cells as fermentation proceeds during times of strenuous exercise. During these times, your respiratory and cardiovascular system cannot transport oxygen to your muscle cells, especially those in your legs, fast enough to maintain aerobic respiration. To allow the continuous production of some ATP, your muscle cells use lactic acid fermentation.

Summary

- Some bacteria, including those we employ to make yogurt, make ATP using lactic acid fermentation.
- Muscle cells can continue to produce ATP when oxygen runs low using lactic acid fermentation, but muscle fatigue and pain may result.

FIGURE 5.15

Lactobacillus bacteria use the same type of anaerobic respiration as our muscle cells. Lactic acid reduces competition from other bacteria and flavors yogurt.

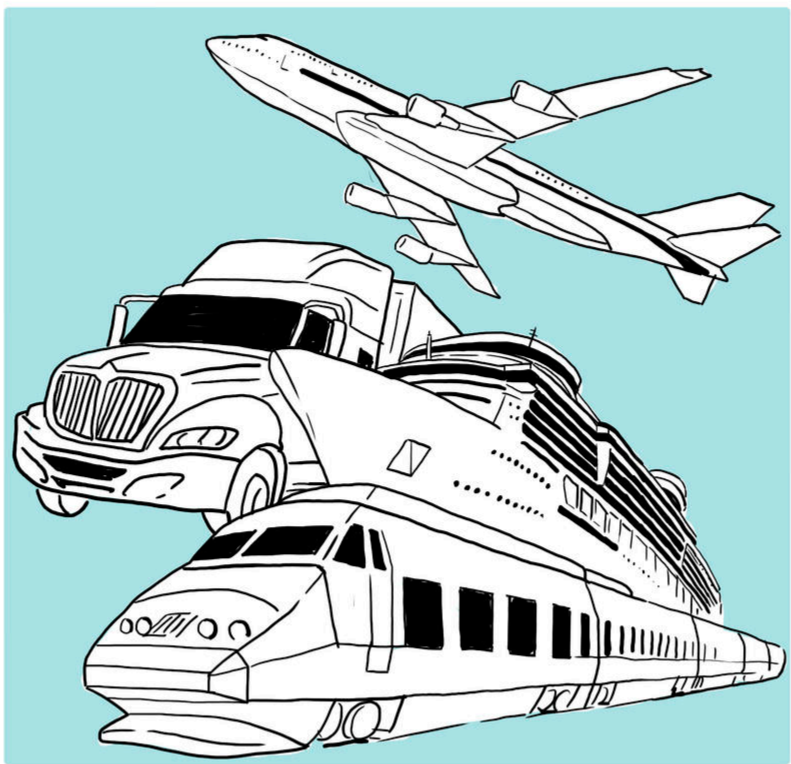
Review

1. Define lactic acid fermentation.
2. Identify yourself as a "sprinter" or an "endurance runner" and predict the type of muscle fiber (red or white) which predominates in your body. Explain your reasoning.
3. What is the chemical equation of lactic acid fermentation?

5.8 Electron Transport

Learning Objectives

- Summarize the mitochondrial electron transport chain.
- Identify the products of the Krebs cycle.
- Explain the necessity of oxygen for the mitochondrial electron transport chain.
- Describe a chemiosmotic gradient.
- Explain the synthesis of ATP.



Train, truck, boat or plane?

Ways to transport. To make ATP, energy must be “transported” - first from glucose to NADH, and then somehow passed to ATP. How is this done? With an electron transport chain.

Cellular Respiration Stage III: Electron Transport

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

Transporting Electrons

High-energy electrons are released from NADH and $FADH_2$, and they move along **electron transport chains**, like those used in photosynthesis. The electron transport chains are on the inner membrane of the mitochondrion. As the high-energy electrons are transported along the chains, some of their energy is captured. This energy is used to pump hydrogen ions (from NADH and $FADH_2$) across the inner membrane, from the matrix into the intermembrane space. Electron transport in a mitochondrion is shown in **Figure** 5.16.

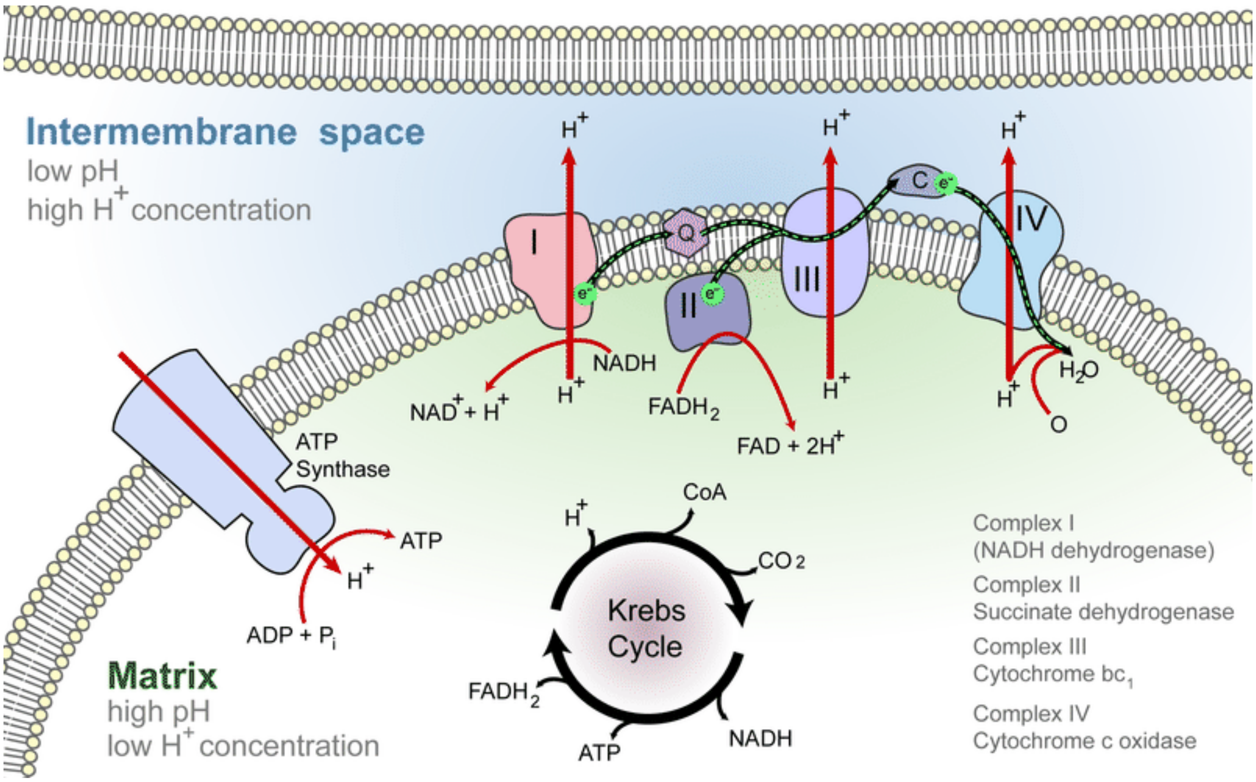


FIGURE 5.16

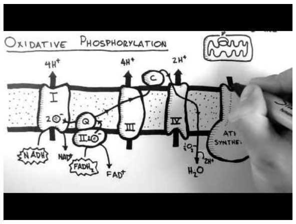
Electron-transport chains on the inner membrane of the mitochondrion carry out the last stage of cellular respiration.

Making ATP

The pumping of hydrogen ions across the inner membrane creates a greater concentration of the ions in the intermembrane space than in the matrix. This **chemiosmotic gradient** causes the ions to flow back across the membrane into the matrix, where their concentration is lower. **ATP synthase** acts as a channel protein, helping the hydrogen ions cross the membrane. It also acts as an enzyme, forming ATP from ADP and inorganic phosphate. After passing through the electron-transport chain, the "spent" electrons combine with oxygen to form water. This is why oxygen is needed; in the absence of oxygen, this process cannot occur.

How much ATP is produced? The two NADH produced in the cytoplasm produces 2 to 3 ATP each (4 to 6 total) by the electron transport system, the 8 NADH produced in the mitochondria produces three ATP each (24 total), and the 2 $FADH_2$ adds its electrons to the electron transport system at a lower level than NADH, so they produce two

ATP each (4 total). This results in the formation of 34 ATP during the electron transport stage.



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Summary

- Electron transport is the final stage of aerobic respiration. In this stage, energy from NADH and $FADH_2$ is transferred to ATP.
- During electron transport, energy is used to pump hydrogen ions across the mitochondrial inner membrane, from the matrix into the intermembrane space.
- A chemiosmotic gradient causes hydrogen ions to flow back across the mitochondrial membrane into the matrix, through ATP synthase, producing ATP.

Review

1. Summarize the overall task of Stage III of aerobic respiration.
2. Explain the chemiosmotic gradient.
3. What is the maximum number of ATP molecules that can be produced during the electron transport stage of aerobic respiration?

5.9 References

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CHAPTER 6 Matter and Energy: Cycles

Chapter Outline

6.1 Photosynthesis Summary

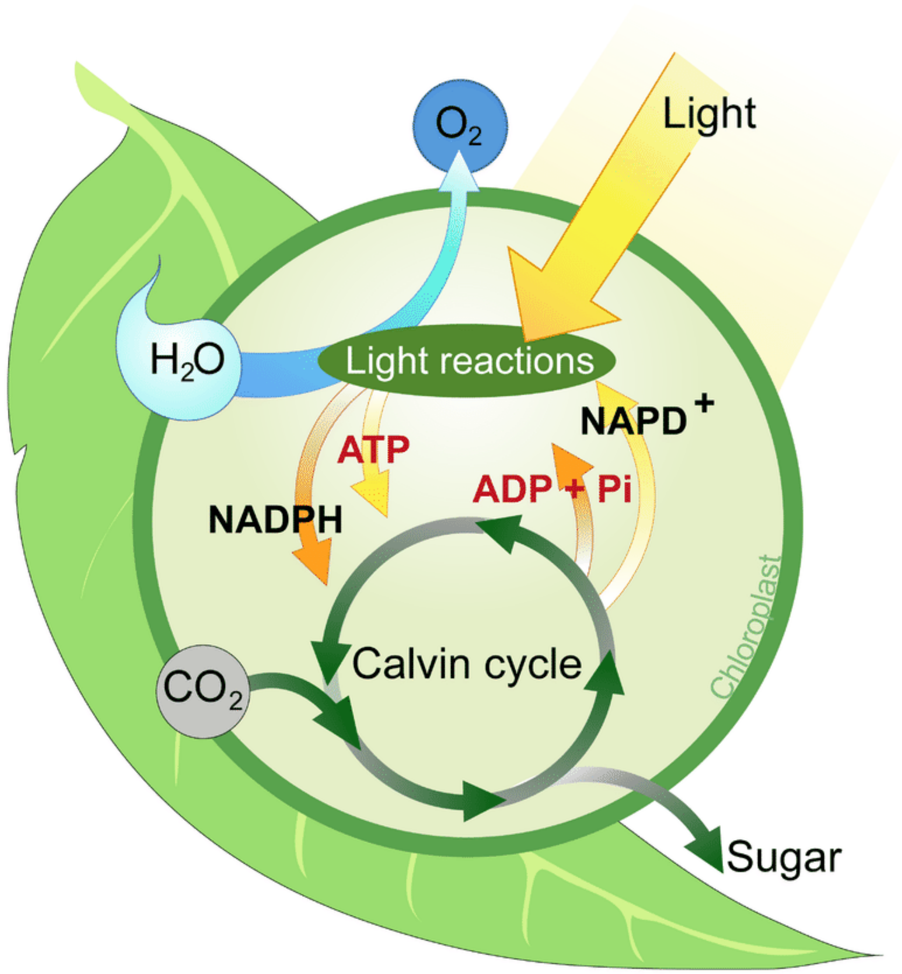
Learning Objectives

- Summarize photosynthesis.

What is photosynthesis?

The process of using the energy in sunlight to make food (glucose). Is it really as simple as that? Of course not. As you have seen, photosynthesis includes many steps all conveniently condensed into one simple equation. In the five concepts describing photosynthesis, this process has been presented in an introductory fashion. Obviously, much more details could have been included, though those are beyond the scope of these concepts.

Photosynthesis



The following 10 points summarize photosynthesis.

1. $6CO_2 + 6H_2O$ + Light Energy $\rightarrow C_6H_{12}O_6 + 6O_2$
2. Autotrophs store chemical energy in carbohydrate food molecules they build themselves. Most autotrophs make their "food" through photosynthesis using the energy of the sun.
3. Photosynthesis occurs in the chloroplast, an organelle specific to plant cells.
4. The light reactions of photosynthesis occur in the thylakoid membranes of the chloroplast.
5. Electron carrier molecules are arranged in electron transport chains that produce ATP and NADPH, which temporarily store chemical energy.
6. The light reactions capture energy from sunlight, which they change to chemical energy that is stored in molecules of NADPH and ATP.
7. The light reactions also release oxygen gas as a waste product.
8. The reactions of the Calvin cycle add carbon (from carbon dioxide in the atmosphere) to a simple five-carbon molecule called RuBP.
9. The Calvin cycle reactions use chemical energy from NADPH and ATP that were produced in the light reactions.
10. The final product of the Calvin cycle is glucose.

What is photosynthesis?

The process of using the energy in sunlight to make food (glucose). But of course it is much more complex than that simple statement. Photosynthesis is a multistep biochemical pathway that uses the energy in sunlight to fix carbon dioxide, transferring the energy into carbohydrates, and releasing oxygen in the process.

What is NADPH?

Nicotinamide adenine dinucleotide phosphate, an energy carrier molecule produced in the light reactions of photosynthesis. NADPH is the reduced form of the electron acceptor $NADP^+$. At the end of the light reactions, the energy from sunlight is transferred to $NADP^+$, producing NADPH. This energy in NADPH is then used in the Calvin cycle.

Where do the protons used in the light reactions come from?

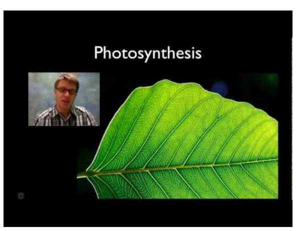
The protons used in the light reactions come from photolysis, the splitting of water, in which H_2O molecules are broken into hydrogen ions, electrons, and oxygen atoms. In addition, the energy from sunlight is used to pump protons into the thylakoid lumen during the first electron transport chain, forming a chemiosmotic gradient.

How do you distinguish between the Calvin cycle and the Krebs cycle?

The Calvin cycle is part of the light-independent reactions of photosynthesis. The Calvin cycle uses ATP and NADPH. The Krebs cycle is part of cellular respiration. This cycle makes ATP and NAPH.

Do photosynthesis and cellular respiration occur at the same time in a plant?

Yes. Photosynthesis occurs in the chloroplasts, whereas cellular respiration occurs in the mitochondria. Photosynthesis makes glucose and oxygen, which are then used as the starting products for cellular respiration. Cellular respiration makes carbon dioxide and water (and ATP), which are the starting products (together with sunlight) for photosynthesis.



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Common Misconceptions

- A common student misconception is that plants photosynthesize only during daylight and conduct cellular respiration only at night. Some teaching literature even states this. Though it is true the light reactions can only occur when the sun is out, cellular respiration occurs continuously in plants, not just at night.

- The “dark reactions” of photosynthesis are a misnomer that often leads students to believe that photosynthetic carbon fixation occurs at night. This is not true. It is preferable to use the term Calvin cycle or light-independent reactions instead of dark reactions.

- Though the final product of photosynthesis is glucose, the glucose is conveniently stored as starch. Starch is approximated as $(C_6H_{10}O_5)_n$, where n is in the thousands. Starch is formed by the condensation of thousands of glucose molecules.

6.2 Cellular Respiration

Learning Objectives

- Define the role of cellular respiration.
- Name the three stages of cellular respiration.
- Describe the structure of a mitochondrion.

Why eat?

Because we're hungry? Not necessarily. But biologically speaking. . . we eat to get energy. The food we eat is broken down, the glucose extracted, and that energy is converted into ATP.

Cellular Respiration

What happens to the energy stored in glucose during photosynthesis? How do living things make use of this stored energy? The answer is **cellular respiration**. This process releases the energy in glucose to make **ATP** (adenosine triphosphate), the molecule that powers all the work of cells.

Stages of Cellular Respiration

Cellular respiration involves many chemical reactions. The reactions can be summed up in this equation:

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

The reactions of cellular respiration can be grouped into three stages: **glycolysis** (stage 1), the **Krebs cycle**, also called the **citric acid cycle** (stage 2), and **electron transport** (stage 3). **Figure** 6.1 gives an overview of these three stages, which are further discussed in the concepts that follow. Glycolysis occurs in the cytosol of the cell and does not require oxygen, whereas the Krebs cycle and electron transport occur in the mitochondria and do require oxygen.

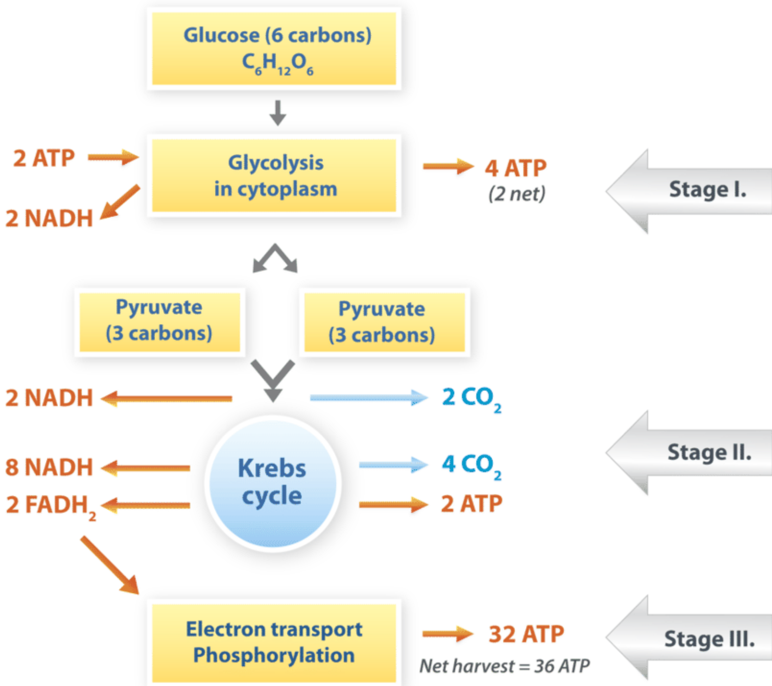

FIGURE 6.1

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

Structure of the Mitochondrion: Key to Aerobic Respiration

The structure of the mitochondrion is key to the process of **aerobic** (in the presence of oxygen) cellular respiration, especially the Krebs cycle and electron transport. A diagram of a mitochondrion is shown in **Figure** 6.2.

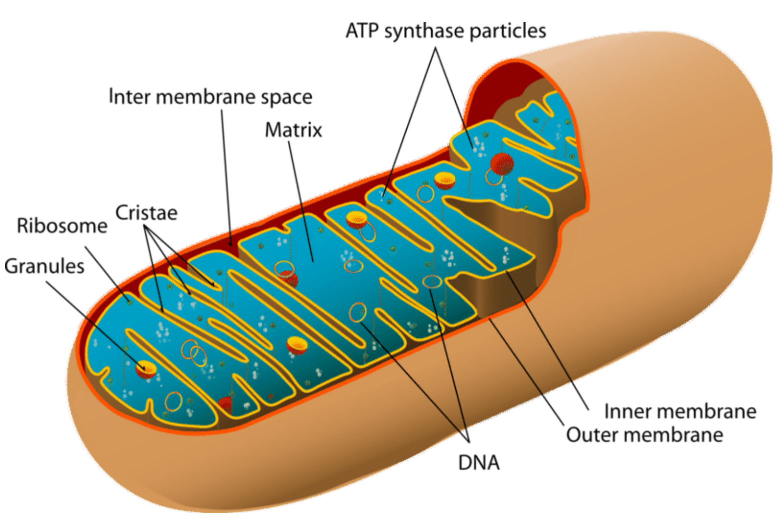

FIGURE 6.2

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

As you can see from **Figure** 6.2, a mitochondrion has an inner and outer membrane. The space between the inner and outer membrane is called the intermembrane space. The space enclosed by the inner membrane is called the matrix. The second stage of cellular respiration, the Krebs cycle, takes place in the matrix. The third stage, electron transport, takes place on the inner membrane.

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Summary

- Cellular respiration takes the energy stored in glucose and transfers it to ATP.
- Cellular respiration has three stages: glycolysis: the Krebs cycle and electron transport.
- The inner and outer membranes of the mitochondrion play an important roles in aerobic respiration.

Review

1. Define cellular respiration.
2. What are the three stages of cellular respiration?
3. Describe the structure of the mitochondrion and discuss the importance of this structure in cellular respiration.
4. Assume that a new species of organism has been discovered. Scientists have observed its cells under a microscope and determined that they lack mitochondria. What type of cellular respiration would you predict that the new species uses? Explain your prediction.
5. When you exhale onto a cold window pane, water vapor in your breath condenses on the glass. Where does the water vapor come from?

6.3 Anaerobic vs Aerobic Respiration

- Distinguish aerobic from anaerobic.
- Define aerobic and anaerobic respiration.

How long can you hold your breath?

With or without air? In terms of producing energy, that is the key question. Can cellular respiration occur without air? It can, but it does have limitations.

The Presence of Oxygen

There are two types of cellular respiration (see *Cellular Respiration* concept): aerobic and anaerobic. One occurs in the presence of oxygen (**aerobic**), and one occurs in the absence of oxygen (**anaerobic**). Both begin with **glycolysis** - the splitting of glucose.

Glycolysis (see "Glycolysis" concept) is an **anaerobic** process - it does not need oxygen to proceed. This process produces a minimal amount of ATP. The Krebs cycle and electron transport do need oxygen to proceed, and in the presence of oxygen, these process produce much more ATP than glycolysis alone.

Scientists think that glycolysis evolved before the other stages of cellular respiration. This is because the other stages need oxygen, whereas glycolysis does not, and there was no oxygen in Earth's atmosphere when life first evolved about 3.5 to 4 billion years ago. Cellular respiration that proceeds without oxygen is called **anaerobic respiration**.

Then, about 2 or 3 billion years ago, oxygen was gradually added to the atmosphere by early photosynthetic bacteria (cyanobacteria). After that, living things could use oxygen to break down glucose and make ATP. Today, most organisms make ATP with oxygen. They follow glycolysis with the Krebs cycle and electron transport to make more ATP than by glycolysis alone. Cellular respiration that proceeds in the presence of oxygen is called **aerobic respiration**.

Summary

- Cellular respiration always begins with glycolysis, which can occur either in the absence or presence of oxygen.
- Cellular respiration that proceeds in the absence of oxygen is anaerobic respiration.
- Cellular respiration that proceeds in the presence of oxygen is aerobic respiration.
- Anaerobic respiration evolved prior to aerobic respiration.

Explore More

Use this resource to answer the questions that follow.

- **Aerobic vs. Anaerobic Respiration** at http://www.diffen.com/difference/Aerobic_Respiration_vs_Anaerobic_Respiration .

1. What is the main difference between aerobic and anaerobic respiration?
2. What cells perform anaerobic respiration?
3. Compare the amount of ATP released by both aerobic and anaerobic respiration.
4. What are the two stages of anaerobic respiration?

Review

1. Define aerobic and anaerobic respiration.
2. What process is common to both aerobic and anaerobic respiration?
3. Why do scientists think that glycolysis evolved before the other stages of cellular respiration?

6.4 Energy Flow

Learning Objectives

- Describe energy flows through ecosystems.
- Distinguish photoautotrophs from chemoautotrophs.
- Distinguish herbivores from carnivores and omnivores.
- Explain the role of decomposers.
- Compare scavengers to detritivores and to saprotrophs.

What is happening inside each leaf and blade of grass?

Photosynthesis. Maybe the most important biochemical reaction of Earth. As sunlight shines down on this forest, the sunlight is being absorbed, and the energy from that sunlight is being transformed into chemical energy. That chemical energy is then distributed to all other living organisms in the ecosystem.

Flow of Energy

To survive, ecosystems need a constant influx of energy. Energy enters ecosystems in the form of sunlight or chemical compounds. Some organisms use this energy to make food. Other organisms get energy by eating the food.

Producers

Producers are organisms that produce food for themselves and other organisms. They use energy and simple inorganic molecules to make organic compounds. The stability of producers is vital to ecosystems because all organisms need organic molecules. Producers are also called **autotrophs**. There are two basic types of autotrophs: photoautotrophs and chemoautotrophs.

1. **Photoautotrophs** use energy from sunlight to make food by photosynthesis. They include plants, algae, and certain bacteria (see **Figure** 6.3).
2. **Chemoautotrophs** use energy from chemical compounds to make food by chemosynthesis. They include some bacteria and also archaea. Archaea are microorganisms that resemble bacteria.

FIGURE 6.3
Different types of photoautotrophs are important in different ecosystems.

Consumers

Consumers are organisms that depend on other organisms for food. They take in organic molecules by essentially "eating" other living things. They include all animals and fungi. (Fungi don't really "eat"; they absorb nutrients from other organisms.) They also include many bacteria and even a few plants, such as the pitcher plant shown in **Figure** 6.4. Consumers are also called heterotrophs. Heterotrophs are classified by what they eat:

- **Herbivores** consume producers such as plants or algae. They are a necessary link between producers and other consumers. Examples include deer, rabbits, and mice.
- **Carnivores** consume animals. Examples include lions, polar bears, hawks, frogs, salmon, and spiders. Carnivores that are unable to digest plants and must eat only animals are called obligate carnivores. Other carnivores can digest plants but do not commonly eat them.

- **Omnivores** consume both plants and animals. They include humans, pigs, brown bears, gulls, crows, and some species of fish.

FIGURE 6.4
Pitcher Plant. Virtually all plants are producers. This pitcher plant is an exception. It consumes insects. It traps them in a sticky substance in its "pitcher." Then it secretes enzymes that break down the insects and release nutrients. Which type of consumer is a pitcher plant?

Decomposers

When organisms die, they leave behind energy and matter in their remains. **Decomposers** break down the remains and other wastes and release simple inorganic molecules back to the environment. Producers can then use the molecules to make new organic compounds. The stability of decomposers is essential to every ecosystem. Decomposers are classified by the type of organic matter they break down:

- **Scavengers** consume the soft tissues of dead animals. Examples of scavengers include vultures, raccoons, and blowflies.
- **Detritivores** consume **detritus**—the dead leaves, animal feces, and other organic debris that collects on the soil or at the bottom of a body of water. On land, detritivores include earthworms, millipedes, and dung beetles (see **Figure** 6.5). In water, detritivores include "bottom feeders" such as sea cucumbers and catfish.
- **Saprotrophs** are the final step in decomposition. They feed on any remaining organic matter that is left after other decomposers do their work. Saprotrophs include fungi and single-celled protozoa. Fungi are the only organisms that can decompose wood.

KQED: Banana Slugs: The Ultimate Recyclers

One of the most beloved and iconic native species within the old growth redwood forests of California is the Pacific Banana Slug. These slimy friends of the forest are the ultimate recyclers. Feeding on fallen leaves, mushrooms or even dead animals, they play a pivotal role in replenishing the soil. QUEST goes to Henry Cowell Redwoods State Park near Santa Cruz, California on a hunt to find *Ariolimax dolichophallus*, a bright yellow slug with a very big personality.

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FIGURE 6.5
Dung Beetle. This dung beetle is rolling a ball of feces to its nest to feed its young.

Summary

- Ecosystems require constant inputs of energy from sunlight or chemicals.
- Producers use energy and inorganic molecules to make food.
- Consumers take in food by eating producers or other living things.
- Decomposers break down dead organisms and other organic wastes and release inorganic molecules back to the environment.

Review

1. Identify three different types of consumers. Name an example of each type.
2. What are photoautotrophs? Give an example of one.
3. What can you infer about an ecosystem that depends on chemoautotrophs for food?
4. What is the role of decomposers?
5. What do scavengers do? Give an example of a scavenger.

6.5 Carbon Cycle

Learning Objectives

- Give an overview of the carbon cycle.
- Discuss the roles of photosynthesis and cellular respiration in the carbon cycle.
- Describe processes that have led to increased atmospheric carbon dioxide levels.

How could releasing this much pollution into the atmosphere not be a poor idea?

Burning of fossil fuels, such as oil, releases carbon into the atmosphere. This carbon must be cycled - removed from the atmosphere - back into living organisms, or it stays in the atmosphere. Increased carbon in the atmosphere contributes to the greenhouse effect on Earth.

The Carbon Cycle

Flowing water can slowly dissolve carbon in sedimentary rock. Most of this carbon ends up in the ocean. The deep ocean can store carbon for thousands of years or more. Sedimentary rock and the ocean are major reservoirs of stored carbon. Carbon is also stored for varying lengths of time in the atmosphere, in living organisms, and as fossil fuel deposits. These are all parts of the **carbon cycle**, which is shown in **Figure** 6.6.

Why is recycling carbon important? Recall that carbon is the cornerstone of organic compounds, the compounds necessary for life. But do organisms make their own carbon? Do they have the genes that encode proteins necessary to make carbon? No. In fact, there are no such genes. Carbon must be recycled from other living organisms, from carbon in the atmosphere, and from carbon in other parts of the biosphere.

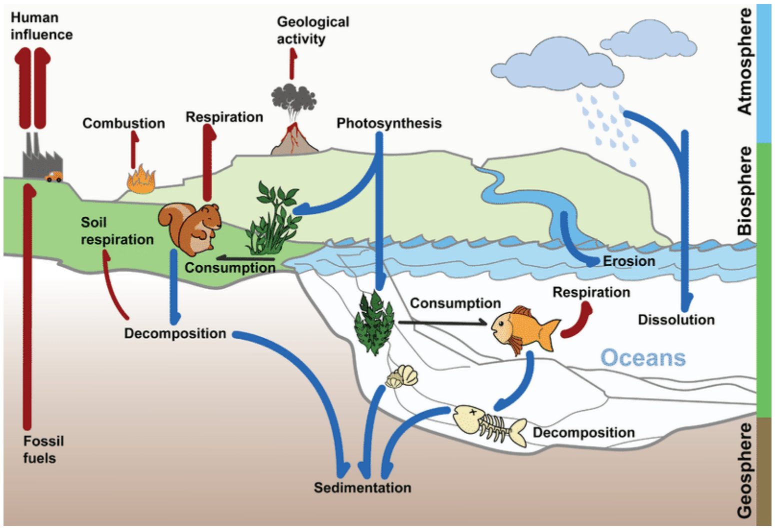

FIGURE 6.6
The Carbon Cycle. Carbon moves from one reservoir to another in the carbon cycle. What role do organisms play in this cycle?

Carbon in the Atmosphere

Though carbon can be found in ocean water, rocks and sediment and other parts of the biosphere, the atmosphere may be the most recognizable reservoir of carbon. Carbon occurs in various forms in different parts of the carbon cycle. Some of the different forms in which carbon appears are described in **Table** 6.1. KEY: C = Carbon, O = Oxygen, H = Hydrogen

TABLE 6.1: Forms of Carbon in the Carbon Cycle

Form of Carbon	Chemical Formula	State	Main Reservoir
Carbon Dioxide	CO_2	Gas	Atmosphere
Carbonic Acid	H_2CO_3	Liquid	Ocean
Bicarbonate Ion	HCO_3^-	Liquid(dissolved ion)	Ocean
Organic Compounds	*Examples:* $C_6H_{12}O_6$ (Glucose), CH_4 (Methane)	Solid Gas	Biosphere Organic Sediments (Fossil Fuels)
Other Carbon Compounds	*Examples:* $CaCO_3$ (Calcium Carbonate), $CaMg(CO_3)_2$ (Calcium Magnesium Carbonate)	Solid Solid	Sedimentary Rock, Shells, Sedimentary Rock

Carbon in Carbon Dioxide

Carbon cycles quickly between organisms and the atmosphere. In the atmosphere, carbon exists primarily as carbon dioxide (CO_2). Carbon dioxide cycles through the atmosphere by several different processes, including those listed below.

- Living organisms release carbon dioxide as a byproduct of **cellular respiration**.
- **Photosynthesis** removes carbon dioxide from the atmosphere and uses it to make organic compounds.
- Carbon dioxide is given off when dead organisms and other organic materials decompose.
- Burning organic material, such as fossil fuels, releases carbon dioxide.
- Carbon cycles far more slowly through geological processes such as **sedimentation**. Carbon may be stored in sedimentary rock for millions of years.
- When volcanoes erupt, they give off carbon dioxide that is stored in the mantle.
- Carbon dioxide is released when limestone is heated during the production of cement.
- Ocean water releases dissolved carbon dioxide into the atmosphere when water temperature rises.

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Summary

- Carbon must be recycled through living organisms or it stays in the atmosphere.
- Carbon cycles quickly between organisms and the atmosphere.
- Due to human activities, there is more carbon dioxide in the atmosphere today than in the past hundreds of thousands of years.

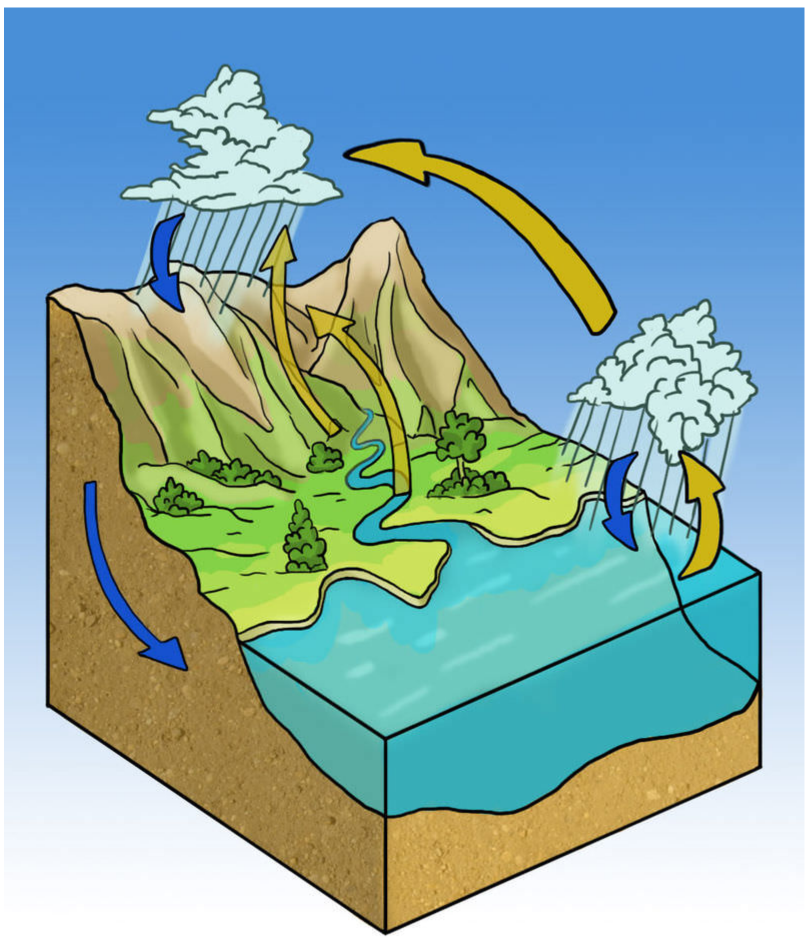
Review

1. What is the role of the carbon cycle?
2. Why is cycling carbon important?
3. Describe a major method that carbon is cycled.
4. How have human activities increased atmospheric carbon dioxide levels?

6.6 Water Cycle

Learning Objectives

- Define biogeochemical cycle.
- Compare an exchange pool to a reservoir.
- Describe the water cycle and its processes.
- Compare evaporation to sublimation and to transpiration.
- Explain the roles of condensation and precipitation in the water cycle.



Where does the water come from that is needed by your cells?

Unlike energy, matter is not lost as it passes through an ecosystem. Instead, matter, including water, is recycled. This recycling involves specific interactions between the biotic and abiotic factors in an ecosystem. Chances are, the water you drank this morning has been around for millions of years, or more.

The Water Cycle

The chemical elements and water that are needed by organisms continuously recycle in ecosystems. They pass through biotic and abiotic components of the biosphere. That's why their cycles are called **biogeochemical cycles**. For example, a chemical might move from organisms (*bio*) to the atmosphere or ocean (*geo*) and back to organisms again. Elements or water may be held for various periods of time in different parts of a cycle.

- Part of a cycle that holds an element or water for a short period of time is called an **exchange pool**. For example, the atmosphere is an exchange pool for water. It usually holds water (in the form of water vapor) for just a few days.
- Part of a cycle that holds an element or water for a long period of time is called a **reservoir**. The ocean is a reservoir for water. The deep ocean may hold water for thousands of years.

Water on Earth is billions of years old. However, individual water molecules keep moving through the water cycle. The **water cycle** is a global cycle. It takes place on, above, and below Earth's surface, as shown in **Figure** 6.7.

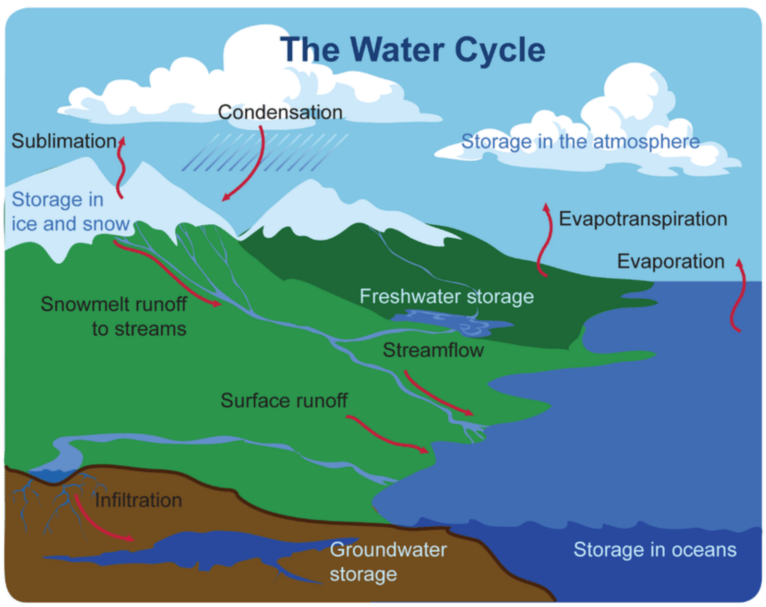


FIGURE 6.7
Like other biogeochemical cycles, there is no beginning or end to the water cycle. It just keeps repeating.

During the water cycle, water occurs in three different states: gas (water vapor), liquid (water), and solid (ice). Many processes are involved as water changes state in the water cycle.

Evaporation, Sublimation, and Transpiration

Water changes to a gas by three different processes:

1. **Evaporation** occurs when water on the surface changes to water vapor. The sun heats the water and gives water molecules enough energy to escape into the atmosphere.
2. **Sublimation** occurs when ice and snow change directly to water vapor. This also happens because of heat from the sun.
3. **Transpiration** occurs when plants release water vapor through leaf pores called stomata (see **Figure** 6.8).

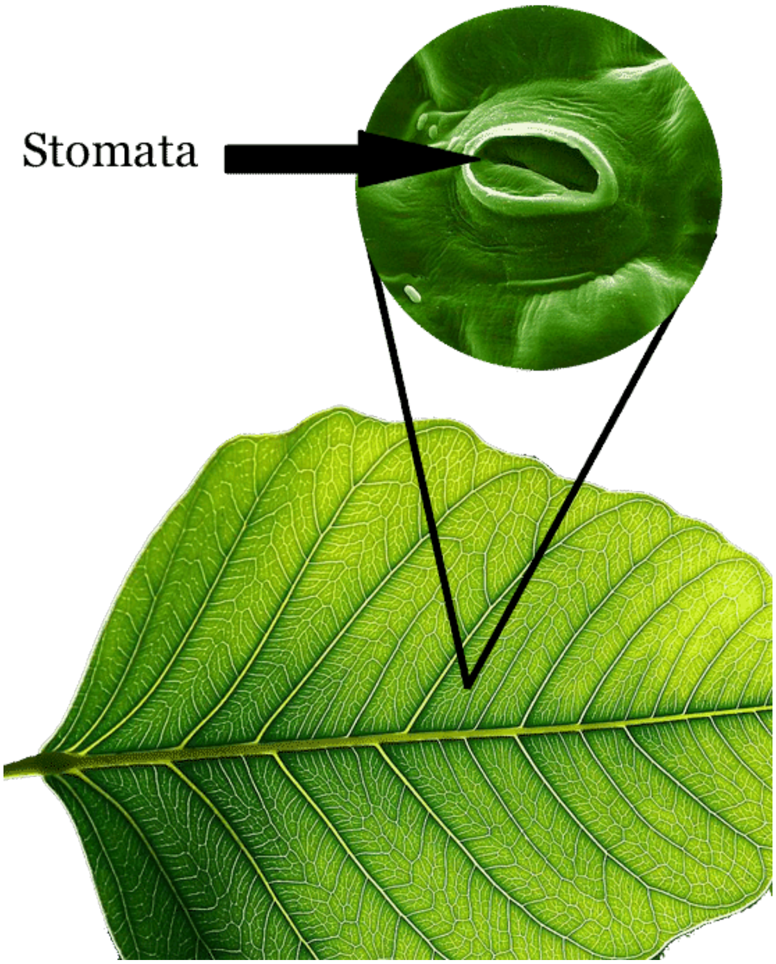


FIGURE 6.8
Plant leaves have many tiny stomata. They release water vapor into the air.

Condensation and Precipitation

Rising air currents carry water vapor into the atmosphere. As the water vapor rises in the atmosphere, it cools and condenses. **Condensation** is the process in which water vapor changes to tiny droplets of liquid water. The water droplets may form clouds. If the droplets get big enough, they fall as **precipitation**—rain, snow, sleet, hail, or freezing rain. Most precipitation falls into the ocean. Eventually, this water evaporates again and repeats the water cycle. Some frozen precipitation becomes part of ice caps and glaciers. These masses of ice can store frozen water for hundreds of years or longer.

Groundwater and Runoff

Precipitation that falls on land may flow over the surface of the ground. This water is called **runoff**. It may eventually flow into a body of water. Some precipitation that falls on land may soak into the ground, becoming **groundwater**. Groundwater may seep out of the ground at a spring or into a body of water such as the ocean. Some groundwater may be taken up by plant roots. Some may flow deeper underground to an **aquifer**. This is an underground layer of rock that stores water, sometimes for thousands of years.

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Science Friday: Forecasting the Meltdown: The Aerial Snow Observatory

75% of Southern California's water supply comes from the snowpack in the Sierra Nevada Mountain Range. This video by Science Fridayexplains how NASA uses the Airborne Snow Observatory that uses specialized instrumentation to carefully measure the water content.

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Summary

- Chemical elements and water are recycled through biogeochemical cycles. The cycles include both biotic and abiotic parts of ecosystems.
- The water cycle takes place on, above, and below Earth's surface. In the cycle, water occurs as water vapor, liquid water, and ice. Many processes are involved as water changes state in the cycle.
- The atmosphere is an exchange pool for water. Ice masses, aquifers, and the deep ocean are water reservoirs.

Review

1. What is a biogeochemical cycle? Name an example.
2. Identify and define two processes by which water naturally changes from a solid or liquid to a gas.
3. Define exchange pool and reservoir, and identify an example of each in the water cycle.
4. Assume you are a molecule of water. Describe one way you could go through the water cycle, starting as water vapor in the atmosphere.

6.7 Nitrogen Cycle

Learning Objectives

- Outline the steps of the nitrogen cycle.
- Explain nitrogen fixation.
- Discuss the roles of ammonification, nitrification and denitrification in the nitrogen cycle.

Alfalfa, clover, peas, beans, lentils, lupins, mesquite, carob, soy, and peanuts. What are these?

Legumes. Legume plants have the ability to fix atmospheric nitrogen, due to a mutualistic symbiotic relationship with bacteria found in root nodules of these plants.

The Nitrogen Cycle

Nitrogen makes up 78 percent of Earth's atmosphere. It's also an important part of living things. Nitrogen is found in proteins, nucleic acids, and chlorophyll. The **nitrogen cycle** moves nitrogen through the abiotic and biotic parts of ecosystems. **Figure** 6.9 shows how nitrogen cycles through a terrestrial ecosystem. Nitrogen passes through a similar cycle in aquatic ecosystems.

Even though nitrogen gas makes up most of Earth's atmosphere, plants cannot use this nitrogen gas to make organic compounds for themselves and other organisms. The two nitrogen atoms in a molecule of nitrogen gas are held together by a very stable triple bond. This bond must be broken for the nitrogen to be used. The nitrogen gas must be changed to a form called nitrates, which plants can absorb through their roots. The process of changing nitrogen

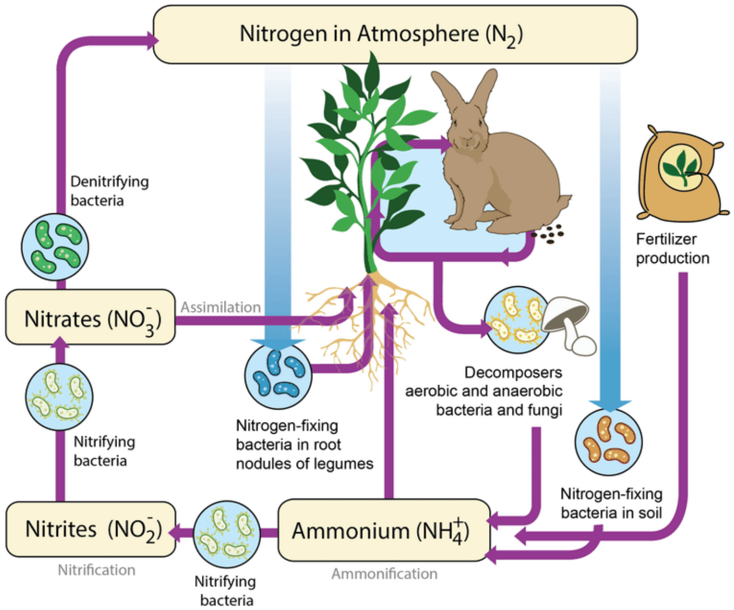

FIGURE 6.9

Nitrogen Cycle in a Terrestrial Ecosystem. Nitrogen cycles between the atmosphere and living things.

gas to nitrates is called **nitrogen fixation**. It is carried out by nitrogen-fixing bacteria. The bacteria live in soil and roots of legumes, such as peas.

When plants and other organisms die, decomposers break down their remains. In the process, they release nitrogen in the form of ammonium ions. This process is called **ammonification.** Nitrifying bacteria change the ammonium ions into nitrites and nitrates. Some of the nitrates are used by plants. The process of converting ammonium ions to nitrites or nitrates is called **nitrification.** Still other bacteria, called denitrifying bacteria, convert some of the nitrates in soil back into nitrogen gas in a process called **denitrification.** The process is the opposite of nitrogen fixation. Denitrification returns nitrogen gas back to the atmosphere, where it can continue the nitrogen cycle.

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Summary

- The nitrogen cycle moves nitrogen back and forth between the atmosphere and organisms.
- Bacteria change nitrogen gas from the atmosphere to nitrogen compounds that plants can absorb.
- Other bacteria change nitrogen compounds back to nitrogen gas, which re-enters the atmosphere.

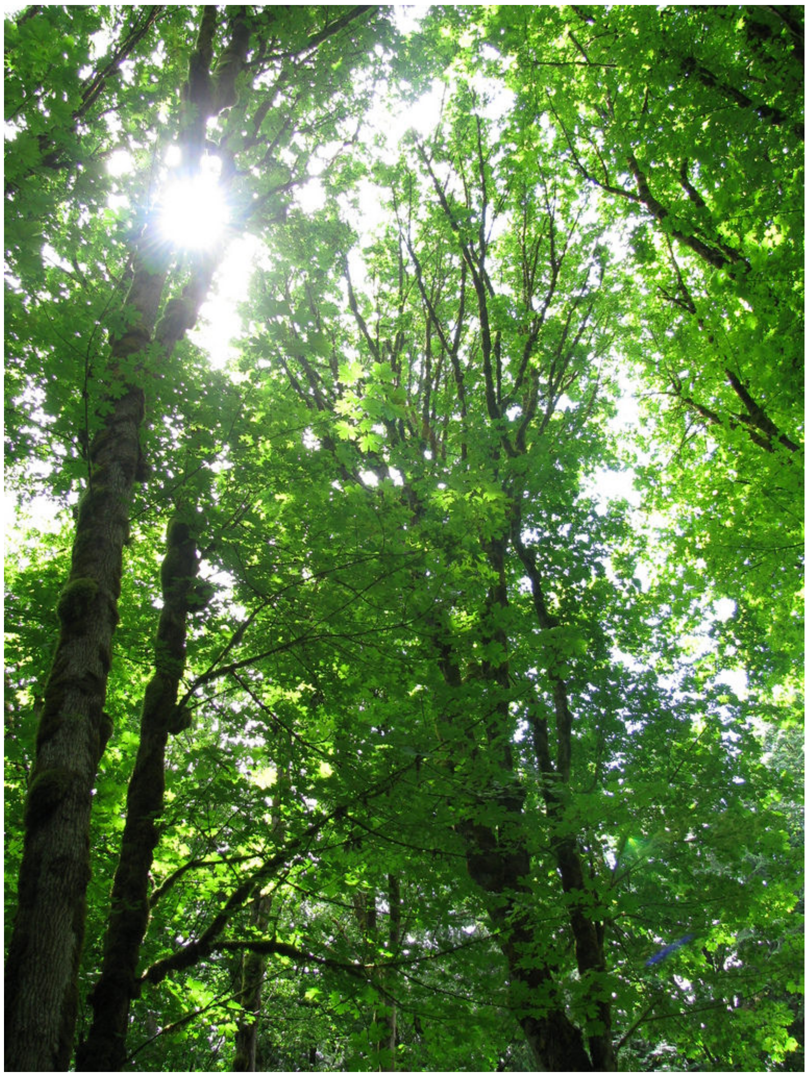
Review

1. Why can't plants use nitrogen gas directly?
2. What is nitrogen fixation?
3. Explain why bacteria are essential parts of the nitrogen cycle.
4. What is ammonification?

6.8 Cellular Respiration and Photosynthesis

Learning Objectives

- Name the products and reactants of photosynthesis and cellular respiration.
- Explain how cellular respiration and photosynthesis are connected.



How do trees help you breathe?

Recall that trees release oxygen as a byproduct of photosynthesis. And you need oxygen to breathe. Do you know why? So your cells can perform cellular respiration and make ATP.

Connecting Cellular Respiration and Photosynthesis

Photosynthesis and cellular respiration are connected through an important relationship. This relationship enables life to survive as we know it. The **products** of one process are the **reactants** of the other. Notice that the equation for **cellular respiration** is the direct opposite of **photosynthesis**:

- Cellular Respiration: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$
- Photosynthesis: $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

Photosynthesis makes the glucose that is used in cellular respiration to make ATP. The glucose is then turned back into carbon dioxide, which is used in photosynthesis. While water is broken down to form oxygen during photosynthesis, in cellular respiration oxygen is combined with hydrogen to form water. While photosynthesis requires carbon dioxide and releases oxygen, cellular respiration requires oxygen and releases carbon dioxide. It is the released oxygen that is used by us and most other organisms for cellular respiration. We breathe in that oxygen, which is carried through our blood to all our cells. In our cells, oxygen allows cellular respiration to proceed. Cellular respiration works best in the presence of oxygen. Without oxygen, much less ATP would be produced.

Cellular respiration and photosynthesis are important parts of the carbon cycle. The **carbon cycle** is the pathways through which carbon is recycled in the biosphere. While cellular respiration releases carbon dioxide into the environment, photosynthesis pulls carbon dioxide out of the atmosphere. The exchange of carbon dioxide and oxygen during photosynthesis (**Figure** 6.10) and cellular respiration worldwide helps to keep atmospheric oxygen and carbon dioxide at stable levels.

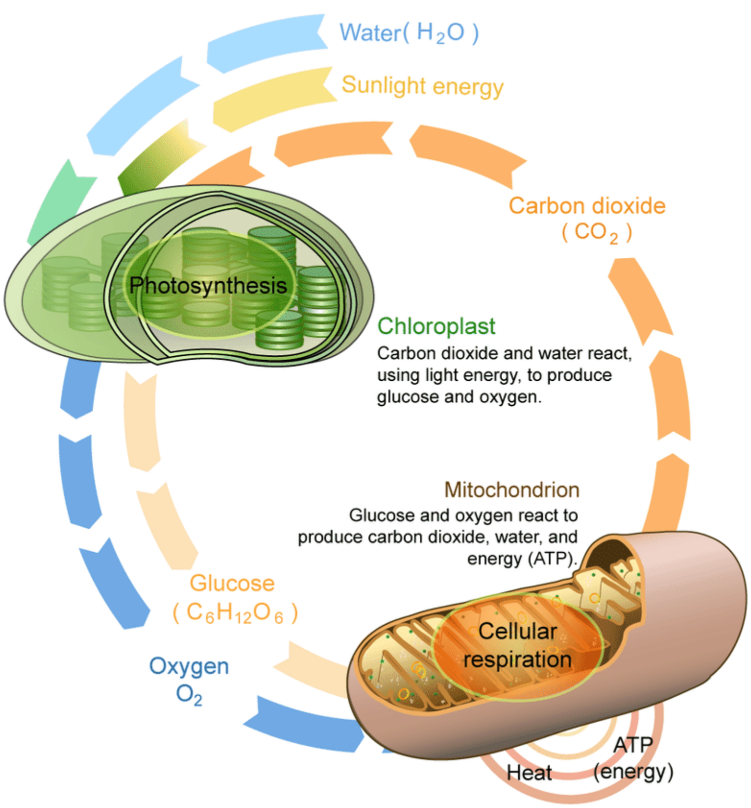


FIGURE 6.10

Cellular respiration and photosynthesis are direct opposite reactions. Energy from the sun enters a plant and is converted into glucose during photosynthesis. Some of the energy is used to make ATP in the mitochondria during cellular respiration, and some is lost to the environment as heat.

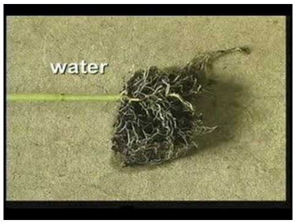
Summary

- The equation for cellular respiration is the direct opposite of photosynthesis.
- The exchange of carbon dioxide and oxygen thorough photosynthesis or cellular respiration worldwide helps to keep atmospheric oxygen and carbon dioxide at stable levels.

Explore More

Use the resource below to answer the questions that follow.

- **Photosynthesis and Respiration** at http://www.youtube.com/watch?v=JEnjph9miK4 (3:46)



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1. What is needed for photosynthesis to occur? Be specific.
2. What is needed for cellular respiration to occur?
3. What is ATP?
4. Do autotrophs need to carry out cellular respiration? Why or why not?

Review

1. How are the equations for photosynthesis and cellular respiration related?
2. What keeps atmospheric oxygen and carbon dioxide at stable levels?

6.9 References

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CHAPTER 7 Ecology: Carrying Capacity

Chapter Outline

7.1 Autotrophs and Heterotrophs

Learning Objectives

- Define photosynthesis.
- State the chemical reaction of photosynthesis.
- Describe how autotrophs and heterotrophs obtain energy.
- Explain the relationship between producers and consumers.
- Distinguish photosynthesis from chemosynthesis.

Name one major difference between a plant and an animal.

There are many differences, but in terms of energy, it all starts with sunlight. Plants absorb the energy from the sun and turn it into *food.* You can sit in the sun for hours and hours. You will feel warm, but you're not going to absorb any energy. You have to eat to obtain your energy.

Autotrophs vs. Heterotrophs

Living organisms obtain chemical energy in one of two ways.

Autotrophs, shown in **Figure** 7.1, store chemical energy in carbohydrate food molecules they build themselves. **Food** is chemical energy stored in organic molecules. Food provides both the energy to do work and the carbon to build bodies. Because most autotrophs transform sunlight to make food, we call the process they use **photosynthesis**. Only three groups of organisms - plants, algae, and some bacteria - are capable of this life-giving energy transformation. Autotrophs make food for their own use, but they make enough to support other life as well. Almost all other organisms depend absolutely on these three groups for the food they produce. The **producers**, as autotrophs are also known, begin **food chains** which feed all life. Food chains will be discussed in the "Food Chains and Food Webs" concept.

Heterotrophs cannot make their own food, so they must eat or absorb it. For this reason, heterotrophs are also known as **consumers**. Consumers include all animals and fungi and many protists and bacteria. They may consume autotrophs or other heterotrophs or organic molecules from other organisms. Heterotrophs show great diversity and may appear far more fascinating than producers. But heterotrophs are limited by our utter dependence on those autotrophs that originally made our food. If plants, algae, and autotrophic bacteria vanished from earth, animals, fungi, and other heterotrophs would soon disappear as well. All life requires a constant input of energy. Only autotrophs can transform that ultimate, solar source into the chemical energy in food that powers life, as shown in **Figure** 7.2.

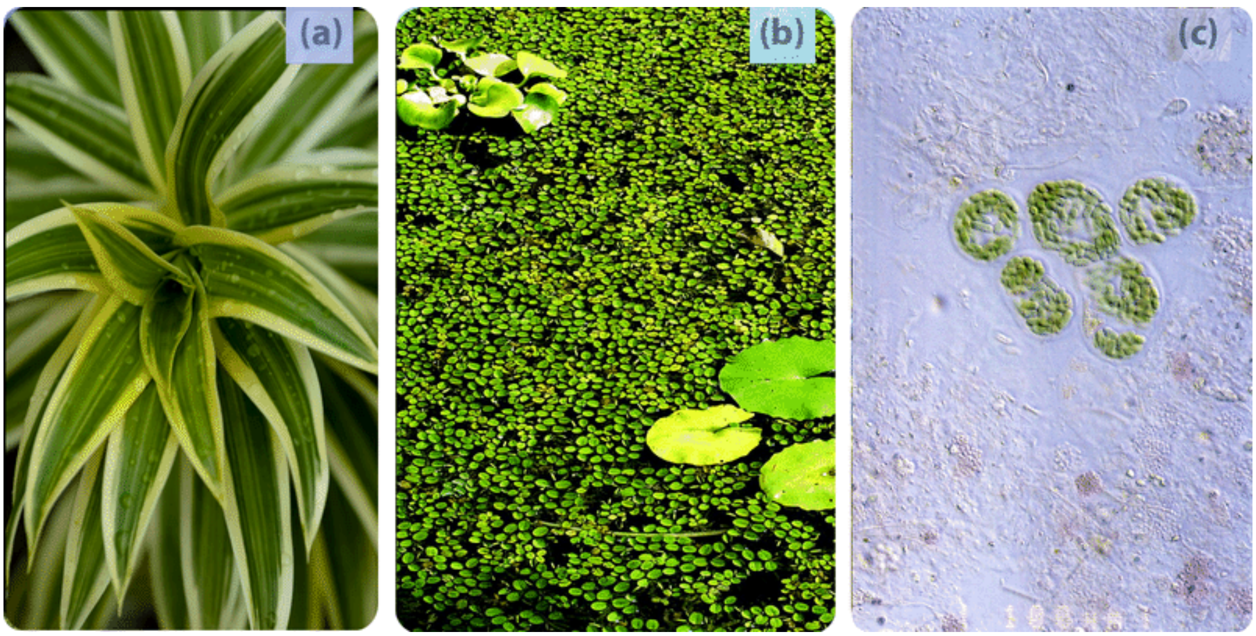


FIGURE 7.1

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

Photosynthesis provides over 99 percent of the energy for life on earth. A much smaller group of autotrophs - mostly bacteria in dark or low-oxygen environments - produce food using the chemical energy stored in inorganic molecules such as hydrogen sulfide, ammonia, or methane. While photosynthesis transforms light energy to chemical energy, this alternate method of making food transfers chemical energy from inorganic to organic molecules. It is therefore called **chemosynthesis**, and is characteristic of the tubeworms shown in **Figure** 7.3. Some of the most recently discovered chemosynthetic bacteria inhabit deep ocean hot water vents or “black smokers.” There, they use the energy in gases from the Earth’s interior to produce food for a variety of unique heterotrophs: giant tube worms, blind shrimp, giant white crabs, and armored snails. Some scientists think that chemosynthesis may support life below the surface of Mars, Jupiter’s moon, Europa, and other planets as well. Ecosystems based on chemosynthesis may seem rare and exotic, but they too illustrate the absolute dependence of heterotrophs on autotrophs for food.

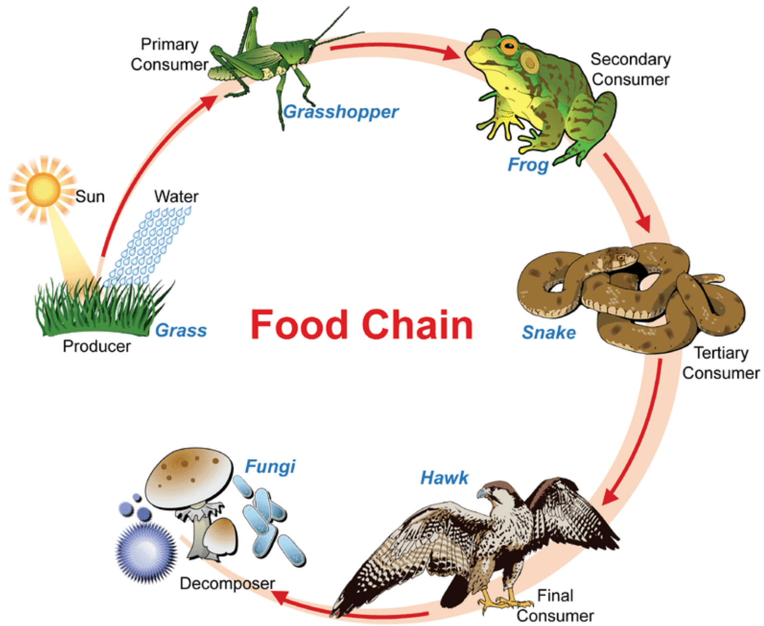


FIGURE 7.2

A food chain shows how energy and matter flow from producers to consumers. Matter is recycled, but energy must keep flowing into the system. Where does this energy come from? Though this food chains "ends" with decomposers, do decomposers, in fact, digest matter from each level of the food chain? (see the "Flow of Energy" concept.)

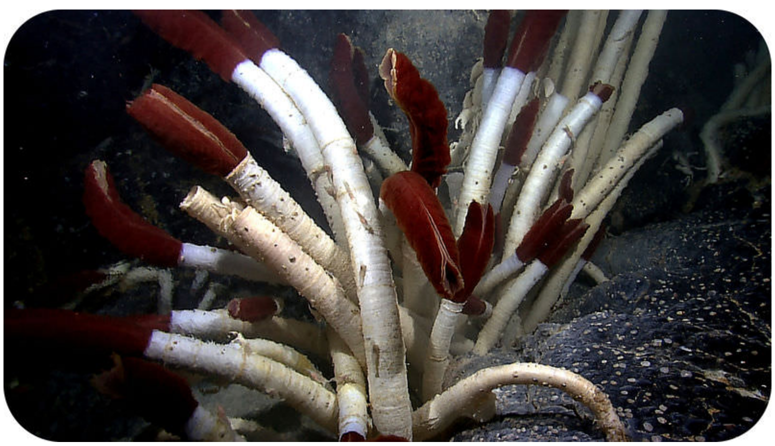


FIGURE 7.3

Tubeworms deep in the Galapagos Rift get their energy from chemosynthetic bacteria living within their tissues. No digestive systems needed!

Making and Using Food

The flow of energy through living organisms begins with photosynthesis. This process stores energy from sunlight in the chemical bonds of glucose. By breaking the chemical bonds in glucose, cells release the stored energy and make the ATP they need. The process in which glucose is broken down and ATP is made is called **cellular respiration**.

Photosynthesis and cellular respiration are like two sides of the same coin. This is apparent from **Figure** 7.4. The products of one process are the reactants of the other. Together, the two processes store and release energy in living organisms. The two processes also work together to recycle oxygen in Earth's atmosphere.

Photosynthesis

Photosynthesis is often considered to be the single most important life process on Earth. It changes light energy into chemical energy and also releases oxygen. Without photosynthesis, there would be no oxygen in the atmosphere.

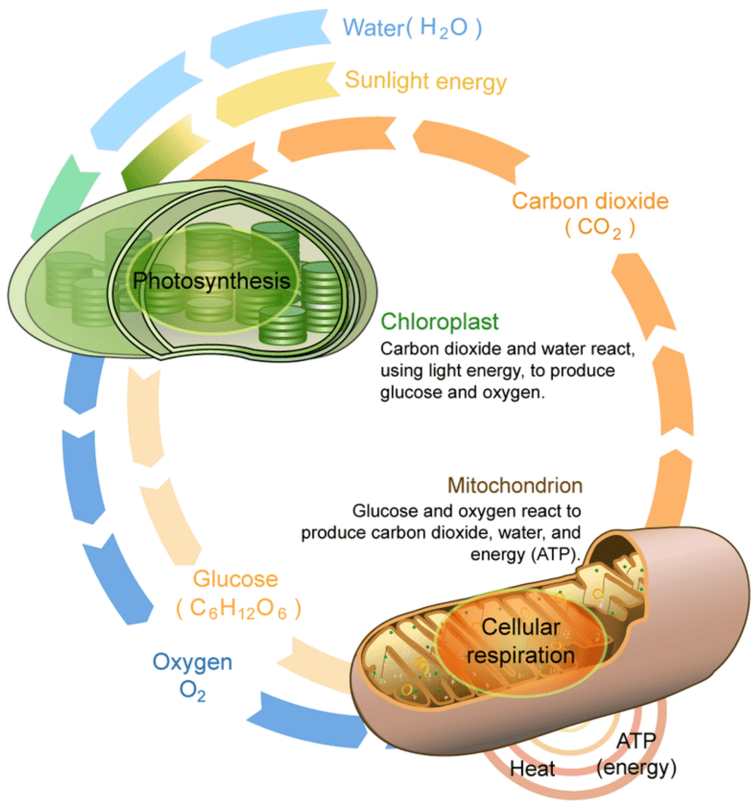


FIGURE 7.4
This diagram compares and contrasts photosynthesis and cellular respiration. It also shows how the two processes are related.

Photosynthesis involves many chemical reactions, but they can be summed up in a single chemical equation:

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

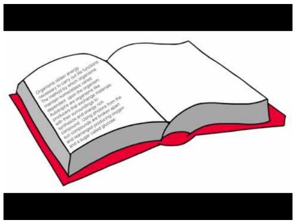
Photosynthetic autotrophs capture light energy from the sun and absorb carbon dioxide and water from their environment. Using the light energy, they combine the reactants to produce glucose and oxygen, which is a waste product. They store the glucose, usually as starch, and they release the oxygen into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

Cellular Respiration

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

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

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



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Summary

- Autotrophs store chemical energy in carbohydrate food molecules they build themselves. Most autotrophs make their "food" through photosynthesis using the energy of the sun.
- Heterotrophs cannot make their own food, so they must eat or absorb it.
- Chemosynthesis is used to produce food using the chemical energy stored in inorganic molecules.

Review

1. Compare autotrophs to heterotrophs, and describe the relationship between these two groups of organisms.
2. Name and describe the two types of food making processes found among autotrophs. Which is quantitatively more important to life on earth?
3. Describe the flow of energy through a typical food chain (describing "what eats what"), including the original source of that energy and its ultimate form after use.

7.2 Population Growth Limits

- Give examples of limiting factors to population growth.
- Explain how limiting factors affect population growth.

What happened during the Irish Potato Famine?

In the 1800s, a disease called potato blight destroyed much of the potato crop in Ireland. Since many Irish people depended on potatoes as their staple food, mass starvation and emigration resulted. This caused Ireland's population to dramatically decrease. Lack of food is one factor that can limit population growth.

Limiting Factors to Population Growth

For a population to be healthy, factors such as food, nutrients, water and space, must be available. What happens when there are not resources to support the population? **Limiting factors** are resources or other factors in the environment that can lower the population growth rate. Limiting factors include a low food supply and lack of space. Limiting factors can lower birth rates, increase death rates, or lead to emigration.

When organisms face limiting factors, they show **logistic growth** (S-shaped curve, curve B: **Figure** 7.10). Competition for resources like food and space cause the growth rate to stop increasing, so the population levels off. This flat upper line on a growth curve is the carrying capacity. The **carrying capacity** (K) is the maximum population size that can be supported in a particular area without destroying the habitat. Limiting factors determine the carrying capacity of a population. Recall that when there are no limiting factors, the population grows exponentially. In **exponential growth** (J-shaped curve, curve A: **Figure** 7.10), as the population size increases, the growth rate also increases.

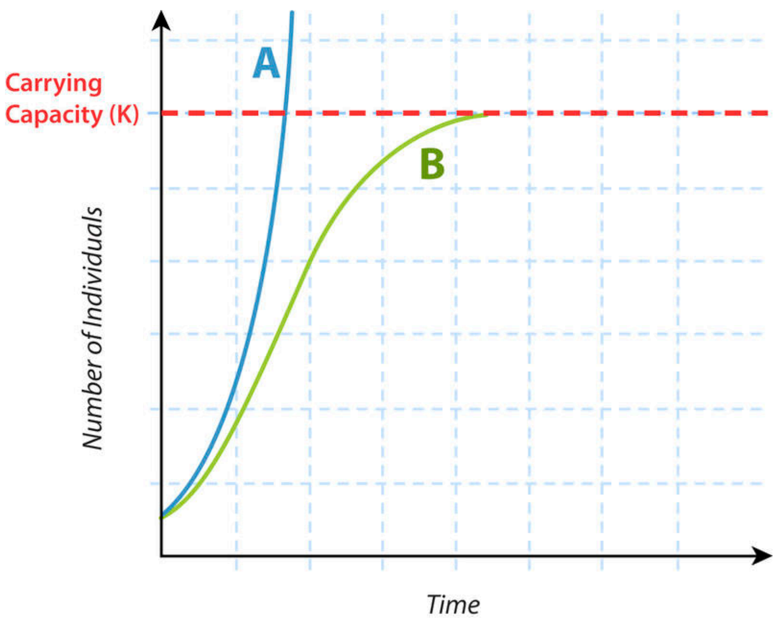

FIGURE 7.5
Exponential and Logistic Growth. Curve A shows exponential growth. Curve B shows logistic growth. Notice that the carrying capacity (K) is also shown.

Food Supply as Limiting Factor

If there are 12 hamburgers at a lunch table and 24 people sit down at a lunch table, will everyone be able to eat? At first, maybe you will split hamburgers in half, but if more and more people keep coming to sit at the lunch table, you will not be able to feed everyone. This is what happens in nature. But in nature, organisms that cannot get food will die or find a new place to live. It is possible for any resource to be a limiting factor, however, a resource such as food can have dramatic consequences on a population.

In nature, when the population size is small, there is usually plenty of food and other resources for each individual. When there is plenty of food and other resources, organisms can easily reproduce, so the birth rate is high. As the population increases, the food supply, or the supply of another necessary resource, may decrease. When necessary resources, such as food, decrease, some individuals will die. Overall, the population cannot reproduce at the same rate, so the birth rates drop. This will cause the population growth rate to decrease.

When the population decreases to a certain level where every individual can get enough food and other resources, and the birth and death rates become stable, the population has leveled off at its carrying capacity.

Other Limiting Factors

Other limiting factors include light, water, nutrients or minerals, oxygen, the ability of an ecosystem to recycle nutrients and/or waste, disease and/or parasites, temperature, space, and predation. Can you think of some other factors that limit populations?

Weather can also be a limiting factor. Whereas most plants like rain, an individual cactus-like *Agave americana* plant actually likes to grow when it is dry. Rainfall limits reproduction of this plant which, in turn, limits growth rate. Can you think of some other factors like this?

Human activities can also limit the growth of populations. Such activities include use of pesticides, such as DDT, use of herbicides, and habitat destruction.

Summary

- Limiting factors, or things in the environment that can lower the population growth rate, include low food supply and lack of space.
- When organisms face limiting factors, they show logistic type of growth (S-curve).

Explore More

Use the resource below to answer the questions that follow.

- **Biotic Potential** at http://www.youtube.com/watch?v=BSVbdaubxxg (2:58)

MEDIA
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URL: http://www.ck12.org/flx/render/embeddedobject/57338

1. What type of growth is characterized by a consistent increase in growth rate? How often is this type of growth actually seen in nature?
2. What factors keep populations from reaching their carrying capacity?
3. How do you think the length of an organism's life span will affect the species' ability to reach carrying capacity?
4. What would the growth equation look like for sessile populations (i.e. populations where individuals are fixed in space)?

Review

1. What is a limiting factor?
2. What are three examples of limiting factors?
3. When organisms face limiting factors, what type of growth do they show?

7.3 Population

- Define population.
- List ways in which a population can be described.
- Explain population density and dispersion.
- Explain how population growth is determined.

What is a population?

When you think of the word *population,* you might think of the number of people in your town or city. But humans are not the only species to have populations. Every species has a population. Or many populations. This group of penguins, which are all members of the same species and all living together in the same space, is a population.

What is a Population

A **population** is a group of organisms of the same species, all living in the same area and interacting with each other. Since they live together in one area, members of the same species reproduce together. Ecologists who study populations determine how healthy or stable the populations are. They also study how the individuals of a species interact with each other and how populations interact with the environment. If a group of similar organisms in the same area cannot reproduce with members of the other group, then they are members of two distinct species and form two populations.

Ecologists look at many factors that help to describe a population. First, ecologists can measure the number of individuals that make up the population, known as **population size**. They can then determine the **population density**, which is the number of individuals of the same species in an area. Population density can be expressed as *number per area*, such as 20 mice/acre, or 50 rabbits/square mile.

Ecologists also study how individuals in a population are spread across an environment. This spacing of individuals within a population is called **dispersion**. Some species may be clumped or clustered (**Figure** 7.6) in an area. Others may be evenly spaced (**Figure** 7.7). Still others may be spaced randomly within an area. The population density and dispersion have an effect on reproduction and population size. What do you think the relationship is between population density, dispersion and size?

FIGURE 7.6

Clumped species are closer together. This may allow for easier reproduction.

FIGURE 7.7

A population of cacti in the Sonoran Desert generally shows even dispersion due to competition for water.

Ecologists also study the birth and death rates of the population. Together these give the growth rate (the birth rate minus the death rate), which tells how fast (or slow) the population size is changing. The **birth rate** is the number of births within a population during a specific time period. The **death rate** is the number of deaths within a population during a specific time period. Knowing the birth and death rates of populations gives you information about a population's health. For example, when a population is made up of mostly young organisms and the birth rate is high, the population is growing. A population with equal birth and death rates will remain the same size. Populations that are decreasing in size have a higher death rate than birth rate.

Summary

- A population is a group of organisms of the same species, all living in the same area and interacting with each other.
- Scientists can study many aspects of a population, including density, dispersion, and birth and death rates.

Explore More

Use the resource below to answer the questions that follow.

- **Population Distributions** at http://www.youtube.com/watch?v=BMsmDy-2jbA (3:51)

MEDIA
Click image to the left or use the URL below.
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1. Is the distribution of organisms of a species constant with time?
2. What is the most common type of distribution? How does this distribution benefit the species?
3. What factors make a uniform distribution pattern a beneficial strategy for a species?
4. How do chemicals made by organisms help establish and maintain a uniform distribution pattern?
5. What factors contribute to a random distribution pattern? Why do animals not maintain this distribution pattern year round?

Review

1. Define population.
2. What is population dispersion? Describe the possible dispersion patterns for a population.
3. Would all the deer and mice living in a forest be a population? Why or why not?
4. What is the growth rate?

7.4 Population Size

Learning Objectives

- Describe the factors that regulate population size.

How many penguins are the right number for this beach?

As many as can survive and have healthy offspring! A population will tend to grow as big as it can for the resources it needs. Once it is too large, some of its members will die off. This keeps the population size at the right number.

Populations

Biotic and abiotic factors determine the population size of a species in an ecosystem. What are some important biotic factors? Biotic factors include the amount of food that is available to that species and the number of organisms that also use that food source. What are some important abiotic factors? Space, water, and climate all help determine a species population.

When does a population grow? A population grows when the number of births is greater than the number of deaths. When does a population shrink? When deaths exceed births.

What causes a population to grow? For a population to grow there must be ample resources and no major problems. What causes a population to shrink? A population can shrink either because of biotic or abiotic limits. An increase in predators, the emergence of a new disease, or the loss of habitat are just three possible problems that will decrease a population. A population may also shrink if it grows too large for the resources required to support it.

Carrying Capacity

When the number of births equals the number of deaths, the population is at its **carrying capacity** for that habitat. In a population at its carrying capacity, there are as many organisms of that species as the habitat can support. The carrying capacity depends on biotic and abiotic factors. If these factors improve, the carrying capacity increases. If the factors become less plentiful, the carrying capacity drops. If resources are being used faster than they are being replenished, then the species has exceeded its carrying capacity. If this occurs, the population will then decrease in size.

Limiting Factors

Every stable population has one or more factors that limit its growth. A **limiting factor** determines the carrying capacity for a species. A limiting factor can be any biotic or abiotic factor: nutrient, space, and water availability are examples (**Figure** 7.8). The size of a population is tied to its limiting factor.

FIGURE 7.8
In a desert such as this, what is the limiting factor on plant populations? What would make the population increase? What would make the population decrease?

What happens if a limiting factor increases a lot? Is it still a limiting factor? If a limiting factor increases a lot, another factor will most likely become the new limiting factor.

This may be a bit confusing, so let's look at an example of limiting factors. Say you want to make as many chocolate chip cookies as you can with the ingredients you have on hand. It turns out that you have plenty of flour and other ingredients, but only two eggs. You can make only one batch of cookies, because eggs are the limiting factor. But then your neighbor comes over with a dozen eggs. Now you have enough eggs for seven batches of cookies, but only two pounds of butter. You can make four batches of cookies, with butter as the limiting factor. If you get more butter, some other ingredient will be limiting.

Species ordinarily produce more offspring than their habitat can support (**Figure** 7.9). If conditions improve, more young survive and the population grows. If conditions worsen, or if too many young are born, there is competition between individuals. As in any competition, there are some winners and some losers. Those individuals that survive to fill the available spots in the niche are those that are the most fit for their habitat.

FIGURE 7.9
A frog in frog spawn. An animal produces many more offspring than will survive.

MEDIA
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Summary

- Biotic factors that a population needs include food availability. Abiotic factors may include space, water, and climate.
- The carrying capacity of an environment is reached when the number of births equal the number of deaths.
- A limiting factor determines the carrying capacity for a species.

Review

1. Why don't populations continue to grow and grow?
2. What happens if a population exceeds its carrying capacity?
3. What happens if a factor that has limited a population's size becomes more available?

Explore More

Use this resource to answer the questions that follow. (Note: that when he says "people," he's really talking about any population of organisms.)

MEDIA

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1. Under what circumstances can population growth be exponential?
2. What is carrying capacity?
3. What does reaching the carrying capacity do to population growth?
4. What does carrying capacity depend on?
5. What happens if a population exceeds its carrying capacity?
6. Is the carrying capacity constant? What changes it?
7. What are the two ways to eliminate a pest from your home?
8. Give the definition of density dependent factors that are limiting to population growth.
9. Give four examples and explain them for density dependent factors.
10. How do natural disasters affect the population size in a region?

7.5 Population Growth Patterns

Learning Objectives

- Compare and contrast exponential and logistic growth.
- Define carrying capacity.
- Distinguish K-selected from r-selected species.

What starts out very small and has the potential to grow considerably larger?

Trees, of course. But also populations. Give a population everything it needs to survive, and the growth of that population will be tremendous.

Patterns of Population Growth

Populations may show different patterns of growth. The growth pattern depends partly on the conditions under which a population lives.

Exponential Growth

Under ideal conditions, populations of most species can grow at exponential rates. Curve A in **Figure** 7.10 represents **exponential growth**. The population starts out growing slowly. As population size increases, the growth rate also increases. The larger the population becomes, the faster it grows.

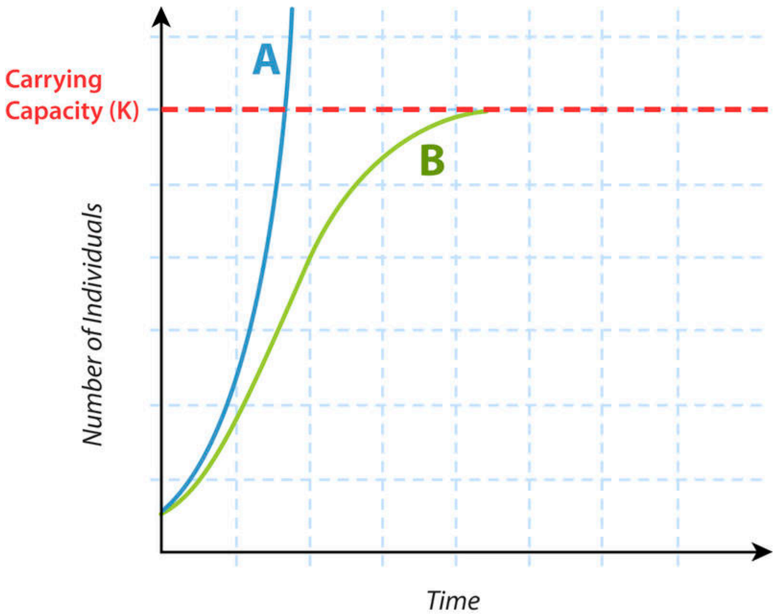


FIGURE 7.10

Exponential and Logistic Growth. Curve A shows exponential growth. Curve B shows logistic growth.

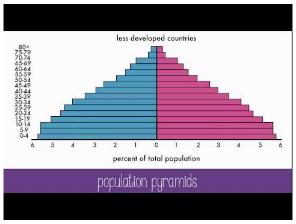
Logistic Growth

Most populations do not live under ideal conditions. Therefore, most do not grow exponentially. Certainly, no population can keep growing exponentially for very long. Many factors may limit growth. Often, the factors are density dependent (known as **density-dependent factors**). These are factors that are influential when the population becomes too large and crowded. For example, the population may start to run out of food or be poisoned by its own wastes. As a result, population growth slows and population size levels off. Curve B in **Figure** 7.10 represents this pattern of growth, which is called **logistic growth**.

At what population size does growth start to slow in the logistic model of growth? That depends on the population's carrying capacity (see **Figure** 7.10). The **carrying capacity** (K) is the largest population size that can be supported in an area without harming the environment. Population growth hits a ceiling at that size in the logistic growth model.

Species can be divided into two basic types when it comes to how their populations grow.

- Species that live in stable environments are likely to be ***K*-selected**. Their population growth is controlled by density-dependent factors. Population size is generally at or near the carrying capacity. These species are represented by curve B in **Figure** 7.10.
- Species that live in unstable environments are likely to be ***r*-selected**. Their potential population growth is rapid. For example, they have large numbers of offspring. However, individuals are likely to die young. Thus, population size is usually well below the carrying capacity. These species are represented by the lower part of curve A in **Figure** 7.10. (*r* is the population growth rate. See the "Population Growth" concept.)



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Summary

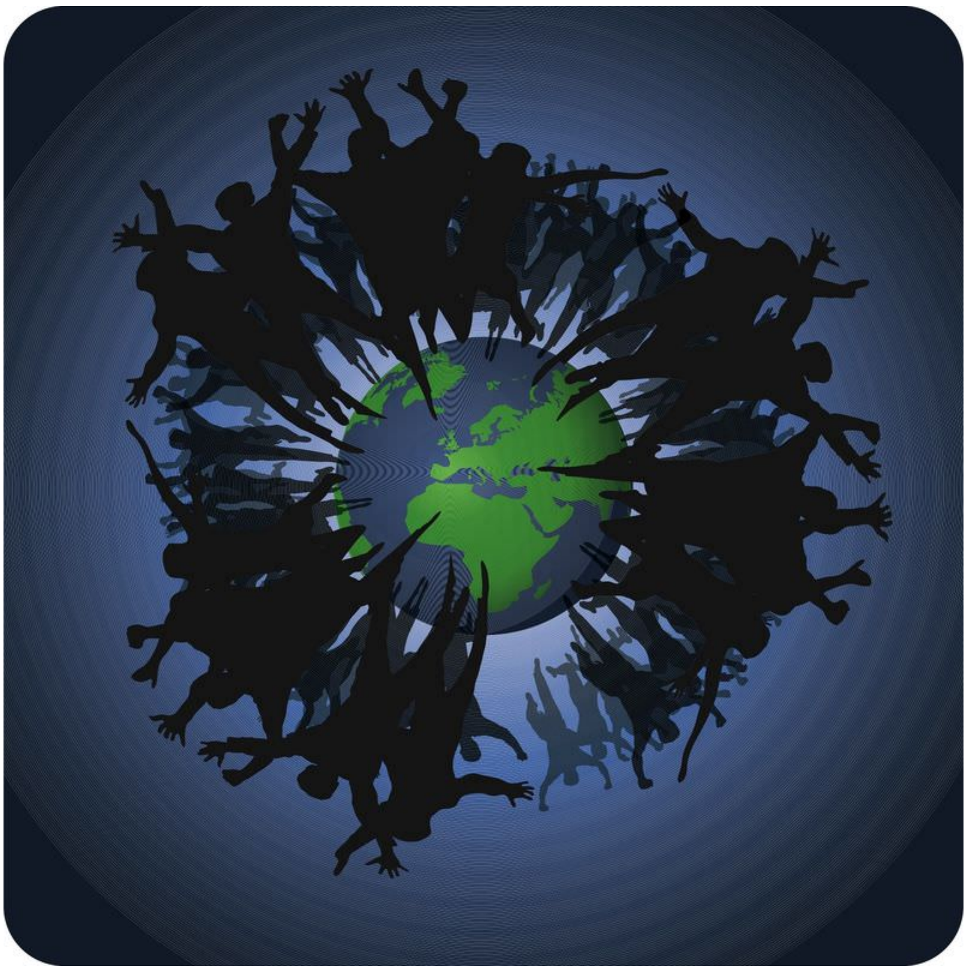
- Under ideal conditions, populations can grow exponentially.
- The growth rate increases as the population gets larger.
- Most populations do not live under ideal conditions and grow logistically instead.
- Density-dependent factors slow population growth as population size nears the carrying capacity.

Review

1. Describe exponential population growth.
2. Describe logistic growth.
3. What are density-dependent factors?
4. What does the carrying capacity refer to?
5. What are K-selected and r-selected species?

7.6 Human Population

- Describe how the human population has grown over the past 2,000 years.
- Discuss predictions for future human population growth.
- List the stages of human population growth.
- Compare Neo-Malthusians to Cornucopians.



Too many people?

In October 2011, the human population passed 7 billion people. What problems could result if the human population continues its rapid rise? One issue is that overpopulation makes many environmental issues more serious. More people on the planet means more food and water is needed and more pollution is generated. Is there a carrying capacity for the human population?

Human Population

How quickly is the human population growing? If we look at worldwide human population growth from 10,000 BCE through today, our growth looks like **exponential growth**. It increased very slowly at first, but later grew faster and faster as the population increased in size (**Figure** 7.11). And recently, the human population has increased at a faster pace than ever before. It has taken only 12 years for the world's population to increase from six billion to seven billion. Considering that in the year 1804, there were just one billion people, and in 1927, there were just two billion people (that's 123 years to increase from 1 to 2 billion), the recent increase in the human population growth rate is characteristic of exponential growth. Does this mean there are unlimited resources?

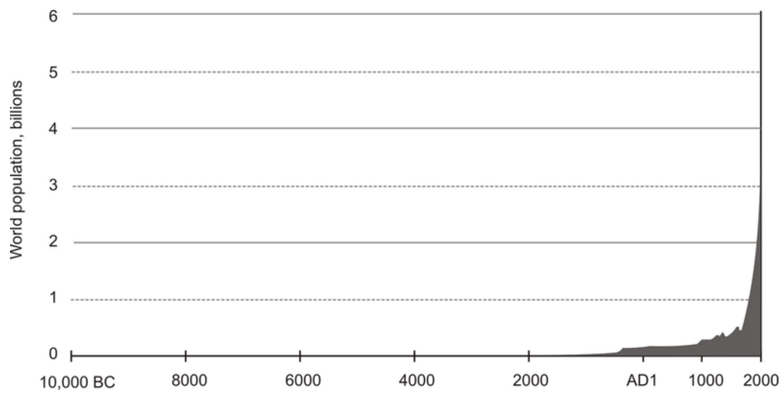


FIGURE 7.11
Worldwide human population growth from 10,000 BCE through today.

Five Stages

On the other hand, if you look at human population growth in specific countries, you may see a different pattern. On the level of a country, the history of human population growth can be divided into five stages, as described in **Table** 7.1. Some countries have very high birth rates, in some countries the growth rate has stabilized, and in some countries the growth rate is in decline.

TABLE 7.1: The Stages of Human Population Growth

Stage	Description
1	Birth and death rates are high and population growth is stable. This occurred in early human history.
2	Significant drop in death rate, resulting in exponential growth. This occurred in 18th- and 19th-century Europe.
3	Population size continues to grow.
4	Birth rates equal death rates and populations become stable.
5	Total population size may level off.

The United Nations and the U.S. Census Bureau predict that by 2050, the Earth will be populated by 9.4 billion people. Other estimates predict 10 to 11 billion.

Future Growth

There are two different beliefs about what type of growth the human population will undergo in the future:

1. **Neo-Malthusians** believe that human population growth cannot continue without destroying the environment, and maybe humans themselves.

2. **Cornucopians** believe that the Earth can give humans a limitless amount of resources. They also believe that technology can solve problems caused by limited resources, such as lack of food.

The Cornucopians believe that a larger population is good for technology and innovation. The 5-stage model above predicts that when all countries are industrialized, the human population will eventually level out. But many scientists and other Neo-Malthusians believe that humans have already gone over the Earth's **carrying capacity**. That means, we may have already reached the maximum population size that can be supported, without destroying our resources and habitat. If this is true, then human overpopulation will lead to a lack of food and other resources. Overpopulation may also lead to increased disease, and/or war. These problems may cause the population of humans to crash. If these issues are not controlled, could the human population go extinct?

Which of the above theories makes sense to you? Why?

Summary

- The human population is undergoing exponential growth.
- Future outlooks on human population growth differ; some think we will have a limitless amount of resources, while others think we have already reached our carrying capacity.

Explore More

Use the resource below to answer the questions that follow.

- **Urban Sprawl: Phoenix** from the American Museum of Natural History at http://www.youtube.com/watch?v=rCYYf3igZuM (2:37)

MEDIA
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1. How much land in the United States is lost to urban sprawl every year?
2. How has land use around Phoenix, Arizona changed since 1912?
3. How did urban areas change after agricultural expansion in Arizona?
4. How does urban growth affect water usage? What problems does this present for the sustainability of urban environments?

Review

1. Describe the rate of human population growth.
2. How long did it take for the world's population to grow from 6 billion to 7 billion?
3. What is the predicted human population by 2050?
4. How do the Cornucopians and Neo-Malthusians differ in their viewpoints?

7.7 References

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CHAPTER 8 Ecology: Impacts on Biodiversity

Chapter Outline

8.1 Biodiversity

Learning Objectives

- Define biodiversity.
- Distinguish between species diversity, genetic diversity, and ecosystem diversity.

What is biodiversity?

How many species exist? We don't really know for sure. But all those species together, from the smallest bacteria, the deadliest protist, the most bizarre fungi, the prettiest plant, and the biggest mammal, compile the diversity of life, or biodiversity.

What Is Biodiversity?

Biodiversity refers to the variety of life and its processes, including the variety of living organisms, the genetic differences among them, and the communities and ecosystems in which they occur. Scientists have identified about 1.9 million species alive today. They are divided into the six kingdoms of life shown in **Figure** 8.1. Scientists are still discovering new species. Thus, they do not know for sure how many species really exist today. Most estimates range from 5 to 30 million species.

Cogs and Wheels

"The first rule of intelligent tinkering is to save all the pieces." –attributed to Aldo Leopold, but probably a shortened version of: ***"To save every cog and wheel is the first precaution of intelligent tinkering."*** **- Aldo Leopold, *Round River: from the Journals of Aldo Leopold*, 1953**

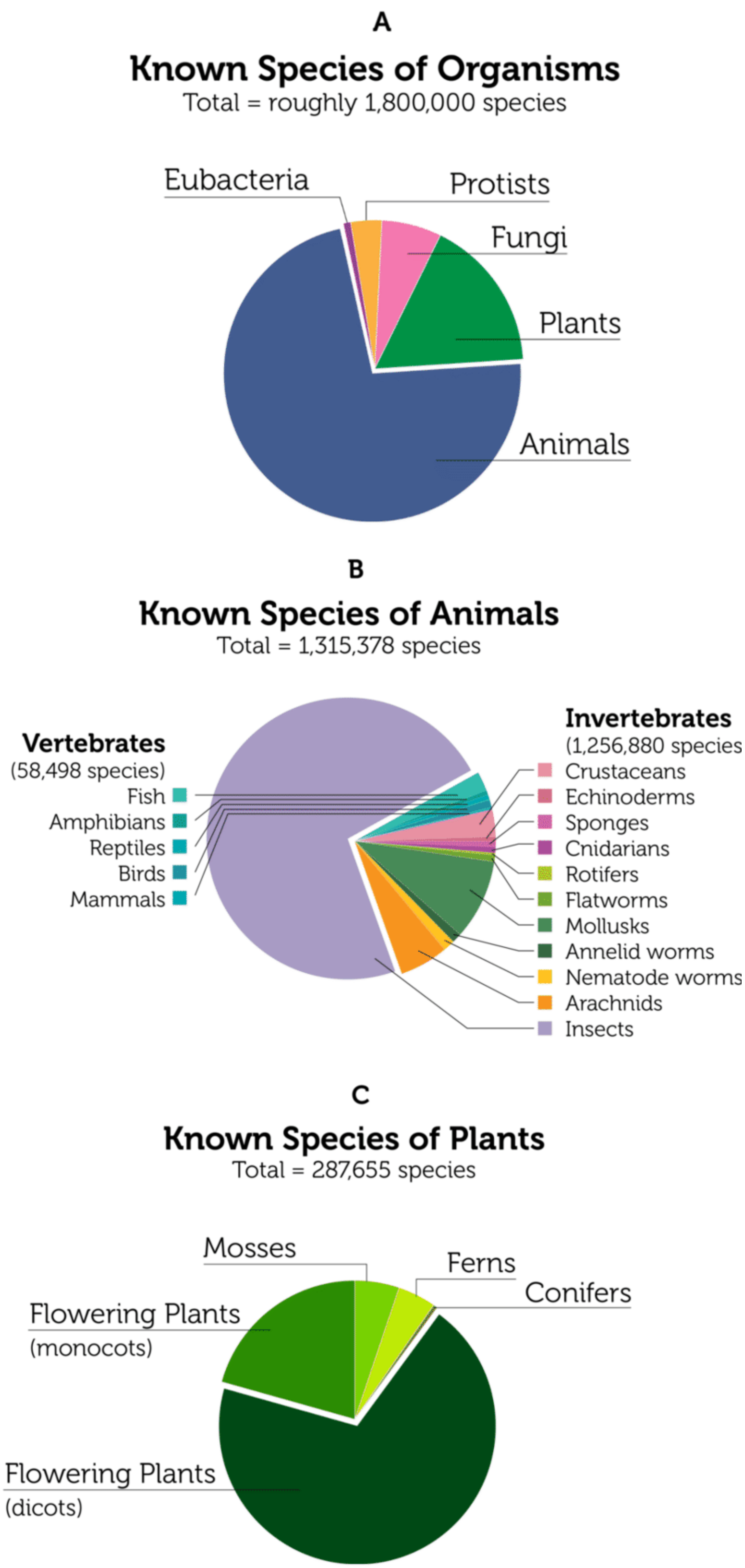

FIGURE 8.1

Known species represent only a fraction of all species that exist on Earth.

What are the “cogs” and “wheels” of life?

Although the concept of biodiversity did not become a vital component of biology and political science until nearly 40 years after Aldo Leopold’s death in 1948, Leopold - often considered the father of modern ecology - would have likely found the term an appropriate description of his “cogs and wheels.” Literally, biodiversity is the many different kinds (*diversity*) of life (*bio-*). Biologists, however, always alert to levels of organization, have identified three measures of life’s variation. **Species diversity** best fits the literal translation: the number of different species in a particular ecosystem or on Earth. A second measure recognizes variation within a species: differences among individuals or populations make up **genetic diversity**. Finally, as Leopold clearly understood, the “cogs and wheels” include not only life but also the land, sea, and air that support life. **Ecosystem diversity** describes the many types of functional units formed by living communities interacting with their environments. Although all three levels of diversity are important, the term biodiversity usually refers to species diversity.

MEDIA

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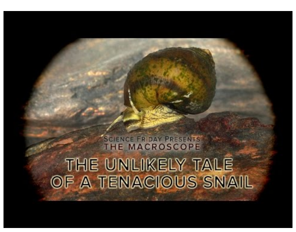
Science Friday: The Unlikely Tale of a Tenacious Snail

For over 70 years, no one had seen the oblong rocksnail. Declared extinct in 2000, the species was considered to be another native Alabaman mollusk gone and forgotten. But one day in the spring of 2011, biology grad student Nathan Whelan picked up a tiny rock and got a big surprise.



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Summary

- Biodiversity refers to the number of species in an ecosystem or the biosphere as a whole.

Review

1. What is biodiversity?
2. What are the three measures of life’s variations?
3. What is meant by ecosystem diversity?

8.2 Modern Biodiversity

Learning Objectives

- Describe modern biodiversity and its relationship to evolutionary adaptations.

How well do you know life on Earth?

It's possible that you could wake up on Earth right now and still not recognize the planet. That's because of the incredible diversity of species. Habitats that you've never encountered would be inhabited by organisms that you've never seen or known about.

Modern Biodiversity

There are more than 1 million species of plants and animals known to be currently alive on Earth (**Figure** 8.2) and many millions more that have not been discovered yet. The tremendous variety of creatures is due to the tremendous numbers of habitats that organisms have evolved to fill.

Adaptations

Many adaptations protect organisms from the external environment (**Figure** 8.3).

Other adaptations help an organism move or gather food. Reindeer have sponge-like hoofs that help them walk on snowy ground without slipping and falling. Hummingbirds have long, thin beaks that help them drink nectar from flowers. Organisms have special features that help them avoid being eaten. When a herd of zebras run away from lions, the zebras' dark stripes confuse the predators so that they have difficulty focusing on just one zebra during the

FIGURE 8.2

There is an amazing diversity of organisms on Earth. How do the organisms in this picture each make their living?

FIGURE 8.3

Cacti have thick, water- retaining bodies that help them conserve water.

chase. Some plants have poisonous or foul-tasting substances in them that keep animals from eating them. Their brightly colored flowers serve as a warning.

FIGURE 8.4

Poison dart frogs have toxins in their skin. Their bright colors warn potential predators not to take a bite!

Thousands of northern elephant seals — some weighing up to 4,500 pounds — make an annual migration to breed each winter at Año Nuevo State Reserve in California. Marine biologists are using high-tech tools to explore the secrets of these amazing creatures.

MEDIA

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MEDIA

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Summary

- There are 1 million known species, but many more have not been discovered.
- The enormous number of species is due to the tremendous variety of habitats.
- Organisms have adaptations that help them to find food or avoid being eaten.

Review

1. What are the adaptations of the cactus to its desert environment?
2. What are the adaptations of poison dart frogs to their environment?
3. How does adaptation lead to biodiversity?

Explore More

Use this resource to answer the questions that follow.

MEDIA

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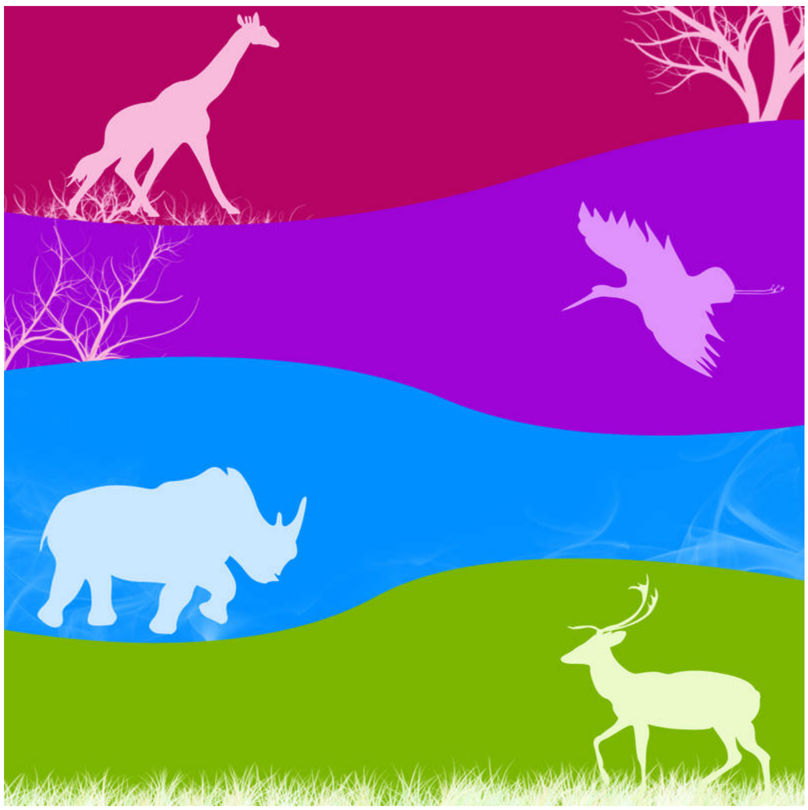
1. What is biodiversity?
2. How does evolutionary history lead to biodiversity?
3. What are the five categories of values that say that biodiversity is important?

4. What is the negative value of biodiversity?
5. What is the Anthropocene?
6. What are the challenges presented by biodiversity decline?
7. Is it possible to be optimistic about biodiversity decline?

8.3 Importance of Biodiversity

Learning Objectives

- Identify economic benefits of biodiversity.
- Discuss ecosystem services of biodiversity.



Why is biodiversity important?

Think about how many species exist. Most likely well over 5 million. Now think about how much information about those species we do not yet understand. We do not know what we can learn from them.

Why Is Biodiversity Important?

Human beings benefit in many ways from **biodiversity**. Biodiversity has direct economic benefits. It also provides services to entire ecosystems.

Economic Benefits of Biodiversity

The diversity of species provides humans with a wide range of economic benefits:

- Wild plants and animals maintain a valuable pool of **genetic variation**. This is important because domestic species are genetically uniform. This puts them at great risk of dying out due to disease.
- Other organisms provide humans with many different products. Timber, fibers, adhesives, dyes, and rubber are just a few.
- Certain species may warn us of toxins in the environment. When the peregrine falcon nearly went extinct, for example, it warned us of the dangers of DDT.
- More than half of the most important prescription drugs come from wild species. Only a fraction of species have yet been studied for their medical potential.
- Other living things provide inspiration for engineering and technology. For example, the car design in **Figure** 8.5 was based on a fish.

FIGURE 8.5

From flowers to fish, biodiversity benefits humans in many ways.

Ecosystem Services of Biodiversity

Biodiversity generally increases the productivity and stability of **ecosystems**. It helps ensure that at least some species will survive environmental change. It also provides many other ecosystem services. For example:

- Plants and algae maintain the atmosphere. During photosynthesis, they add oxygen and remove carbon dioxide.
- Plants help prevent soil erosion. They also improve soil quality when they decompose.
- Microorganisms purify water in rivers and lakes. They also return nutrients to the soil.
- Bacteria fix nitrogen and make it available to plants. Other bacteria recycle the nitrogen from organic wastes and remains of dead organisms.
- Insects and birds pollinate flowering plants, including crop plants.
- Natural predators control insect pests. They reduce the need for expensive pesticides, which may harm people and other living things.

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Summary

- Biodiversity has direct economic benefits. It also provides services to entire ecosystems.

Review

1. List three economic benefits of biodiversity.
2. Identify three ecosystem services of biodiversity.
3. Predict what would happen to other organisms in an ecosystem in which all the decomposers went extinct?

8.4 References

1. Barbara Akre and Jin Yu, based on data from http://cnx.org/content/m12174/latest/ and http://en.wikipedia.org/wiki/Biodive User:Ulhaspa/Wikimedia Commons; Fish: J. Petersen; Car: CK-12 Foundation. CK-12 Foundation;Flower: http://commons.wikimedia.org/wiki/File:Rosy_periwinkle.jpg; Fish: http://commons.wikimedia.org/wiki/File:Ostracion_cubicus.JPG . CC BY-NC 3.0;Flower: CC BY 3.0; Fish: CC BY 2.5; Car: CC BY-NC 3.0
2. Barbara Akre and Jin Yu, based on data from http://cnx.org/content/m12174/latest/ and http://en.wikipedia.org/wiki/Biodive User:Ulhaspa/Wikimedia Commons; Fish: J. Petersen; Car: CK-12 Foundation;Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. CK-12 Foundation;Flower: http://commons.wikimedia.org/wiki/File:Rosy_periwinkle.jpg; Fish: http://commons.wikimedia.org/wiki/File:Ostracion_cubicus.JPG . CC BY-NC 3.0;Flower: CC BY 3.0; Fish: CC BY 2.5; Car: CC BY-NC 3.0
3. . . CC BY-NC
4. Squid: Flickr:prilfish; Jellyfish: Will Brown; Snake: William Warby; Tiger: Brian Mckay; Beetle: Courtesy of the Agricultural Research Service/USDA. Squid: http://www.flickr.com/photos/silkebaron/296281228/; Jelly fish: http://www.flickr.com/photos/37428634@N04/7201323966/; Snake: http://www.flickr.com/photos/warby/2404711901/; Tiger: http://www.flickr.com/photos/tiger_feet/3967177554/; Beetle: http://commons.wikimedia.org/wiki/File:Aphthona_flava_flea_beetle.jpg . Beetle: Public Domain; Rest: CC BY 2.0
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8. Flower: User:Ulhaspa/Wikimedia Commons; Fish: J. Petersen; Car: CK-12 Foundation;Barbara Akre and Jin Yu, based on data from http://cnx.org/content/m12174/latest/ and http://en.wikipedia.org/wiki/Biodiversity. Flower: http://commons.wikimedia.org/wiki/File:Rosy_periwinkle.jpg; Fish: http://commons.wikimedia.org/wiki/File:Ostracion_cubicus.JPG;CK-12 Foundation . Flower: CC BY 3.0; Fish: CC BY 2.5; Car: CC BY-NC 3.0;CC BY-NC 3.0

CHAPTER 9 Ecology: Ecosystem Stability and Change

Chapter Outline

9.1 Ecological Organization

- Define population, community, and biosphere.
- Describe the levels of organization in ecology.
- Explain the components of an ecosystem.

How is your school organized?

Your school is organized at several levels. Individual students and teachers are divided into classes. These classes are organized into an entire middle school. Your middle school and other nearby schools are organized into a school district. Just like schools are organized, ecosystems are also organized into several different levels, and an ecosystem can be studied at any one of the various levels of organization.

Levels of Ecological Organization

Ecosystems can be studied at small levels or at large levels. The levels of organization are described below from the smallest to the largest:

- A **species** is a group of individuals that are genetically related and can breed to produce fertile young. Individuals are not members of the same species if their members cannot produce offspring that can also have children. The second word in the two word name given to every organism is the species name. For example, in *Homo sapiens*, sapiens is the species name.
- A **population** is a group of organisms belonging to the same species that live in the same area and interact with one another.
- A **community** is all of the populations of different species that live in the same area and interact with one another. A community is composed of all of the biotic factors of an area.
- An **ecosystem** includes the living organisms (all the populations) in an area and the non-living aspects of the environment (**Figure** 9.1). An ecosystem is made of the biotic and abiotic factors in an area.

FIGURE 9.1
Satellite image of Australia's Great Barrier Reef, an example of a marine ecosystem.

- The **biosphere** is the part of the planet with living organisms (**Figure** 9.2). The biosphere includes most of Earth, including part of the oceans and the atmosphere.

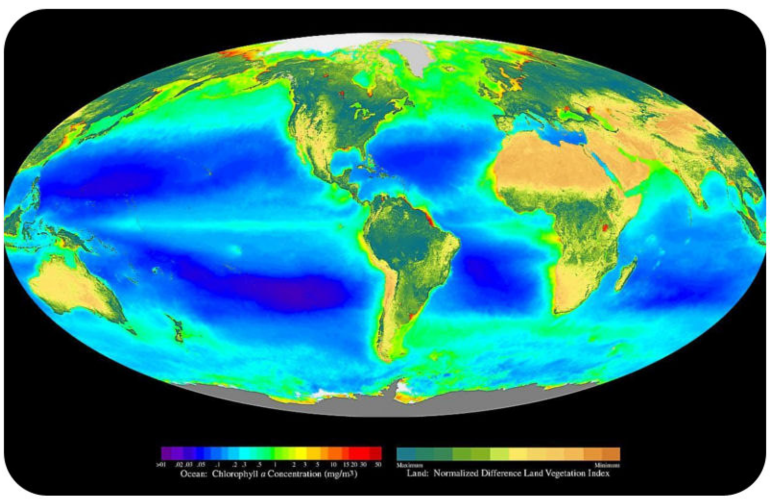


FIGURE 9.2
The global biosphere, which includes all areas that contain life, from the sea to the atmosphere.

Ecologists study ecosystems at every level, from the individual organism to the whole ecosystem and biosphere. They can ask different types of questions at each level. Examples of these questions are given in **Table** 9.1, using the zebra (*Equus zebra*) as an example.

TABLE 9.1: Ecological Questions

Ecosystem Level	Question
Individual	How do zebras keep water in their bodies?
Population	What causes the growth of a zebra populations?
Community	How does a disturbance, like a fire or predator, affect the number of mammal species in African grasslands?
Ecosystem	How does fire affect the amount of food available in grassland ecosystems?

TABLE 9.1: (continued)

Ecosystem Level	Question
Biosphere	How does carbon dioxide in the air affect global temperature?

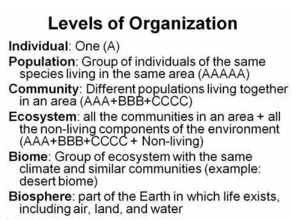
Summary

- Levels of organization in ecology include the population, community, ecosystem, and biosphere.
- An ecosystem is all the living things in an area interacting with all of the abiotic parts of the environment.

Explore More

Use the resource below to answer the questions that follow.

- **Ecology Levels and Populations** at http://www.youtube.com/watch?v=1JSS8XIYcgU (5:31)



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1. What is the relationship between an individual and a community?
2. What characteristics define a population?
3. Why is the distinction between a community and an ecosystem important to ecologists?

Review

1. Define species.
2. What is an ecosystem?
3. Define population. How is a population different from a community?

9.2 Producer

- Explain where all the energy in an ecosystem originates.
- Define photosynthesis and chemosynthesis.
- Describe how energy enters an ecosystem.
- Explain the role of a producer.

Where does all the bear's energy come from?

Bears get their energy from their food. Brown bears eat a varied diet, from nuts and berries to fish and other animals. When bears eat a berry, they are obtaining energy that the plant originally captured from the sun. Even when a bear eats another animal, the energy in that animal ultimately came from eating a producer that captured the sun's energy.

Producers

Energy is the ability to do work. In organisms, this work can be physical work, like walking or jumping, or it can be the work used to carry out the chemical processes in their cells. Every biochemical reaction that occurs in an organism's cells needs energy. All organisms need a constant supply of energy to stay alive.

Some organisms can get the energy directly from the sun. Other organisms get their energy from other organisms. Through **predator-prey relationships**, the energy of one organism is passed on to another. Energy is constantly flowing through a community. With just a few exceptions, all life on Earth depends on the sun's energy for survival.

The energy of the sun is first captured by **producers** (**Figure** 9.3), organisms that can make their own food. Many producers make their own food through the process of **photosynthesis**. The "food" the producers make is the sugar, **glucose**. Producers make food for the rest of the ecosystem. As energy is not recycled, energy must consistently be captured by producers. This energy is then passed on to the organisms that eat the producers, and then to the organisms that eat those organisms, and so on.

Recall that the only required ingredients needed for photosynthesis are sunlight, carbon dioxide (CO_2), and water (H_2O). From these simple inorganic ingredients, photosynthetic organisms produce the carbohydrate glucose ($C_6H_{12}O_6$), and other complex organic compounds. Essentially, these producers are changing the energy from the sunlight into a usable form of energy. They are also making the oxygen that we breathe. Oxygen is a waste product of photosynthesis.

The survival of every ecosystem is dependent on the producers. Without producers capturing the energy from the sun and turning it into glucose, an ecosystem could not exist. On land, plants are the dominant producers. **Phytoplankton**, tiny photosynthetic organisms, are the most common producers in the oceans and lakes. Algae, which is the green layer you might see floating on a pond, are an example of phytoplankton.

There are also bacteria that use chemical processes to produce food. They get their energy from sources other than the sun, but they are still called producers. This process is known as **chemosynthesis**, and is common in ecosystems without sunlight, such as certain marine ecosystems.

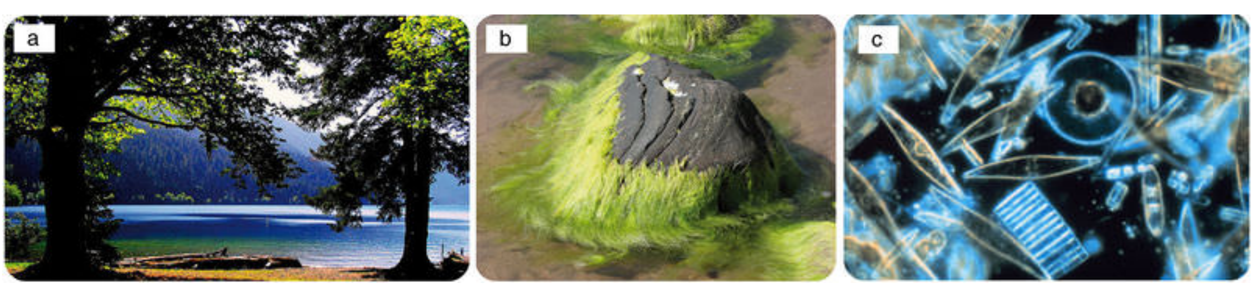


FIGURE 9.3

Producers include (a) plants, (b) algae, and (c) diatoms.

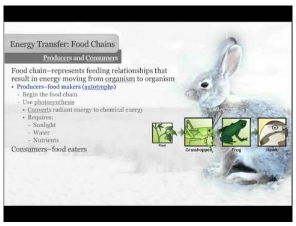
Summary

- With just a few exceptions, all life on Earth depends on the sun's energy for survival.
- Producers make food for the rest of the ecosystem through the process of photosynthesis, where the energy of the sun is used to convert carbon dioxide and water into glucose.

Explore More

Use the resource below to answer the questions that follow.

- **Producers and Consumers** at http://www.youtube.com/watch?v=P0a97kS_3SA (1:59)



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1. Can producers function without sunlight? Why or why not?
2. What are some examples of producers? Why are they called autotrophs?
3. How do some producers use sunlight to make "food"? What other resources do they require?

Review

1. Where does all the "food" in an ecosystem ultimately come from?
2. What is the most common method of producing energy for an ecosystem? What is the energy that is made?
3. What "ingredients" are needed for the process of photosynthesis?
4. Why are producers important to an ecosystem?

9.3 Ecosystems

- Define and describe an ecosystem.
- Give examples of biotic and abiotic factors.
- Explain the relationship between producers and consumers.
- Summarize the importance of biogeochemical cycles.

What nonliving things are essential for life?

Living organisms cannot exist without the nonliving aspects of the environment. For example: air, water, and sunlight, which are all nonliving, are all essential to living organisms. Both nonliving and living things make up an ecosystem.

What is an Ecosystem?

Ecology is the study of ecosystems. That is, ecology is the study of how living organisms interact with each other and with the nonliving part of their environment. An **ecosystem** consists of all the nonliving factors and living organisms interacting in the same **habitat**. Recall that living organisms are **biotic factors**. The biotic factors of an ecosystem include all the **populations** in a habitat, such as all the species of plants, animals, and fungi, as well as all the micro-organisms. Also recall that the nonliving factors are called **abiotic factors**. Abiotic factors include temperature, water, soil, and air.

You can find an ecosystem in a large body of fresh water or in a small aquarium. You can find an ecosystem in a large thriving forest or in a small piece of dead wood. Examples of ecosystems are as diverse as the rainforest, the savanna, the tundra, or the desert (**Figure** 9.4). The differences in the abiotic factors, such as differences in temperature, rainfall, and soil quality, found in these areas greatly contribute to the differences seen in these ecosystems. Ecosystems can include well known sites, such as the Great Barrier Reef off the coast of Australia and the Greater Yellowstone Ecosystem of Yellowstone National Park, which actually includes a few different ecosystems, some with geothermal features, such as Old Faithful geyser.

FIGURE 9.4

Desert Botanical Gardens in Phoenix, Arizona.

Ecosystems need energy. Many ecosystems get their energy in the form of sunlight, which enters the ecosystem through **photosynthesis**. This energy then flows through the ecosystem, passed from **producers** to **consumers**. Plants are producers in many ecosystems. Energy flows from plants to the herbivores that eat the plants, and then to carnivores that eat the herbivores. The flow of energy depicts interactions of organisms within an ecosystem.

Matter is also recycled in ecosystems. **Biogeochemical cycles** recycle nutrients, like carbon and nitrogen, so they are always available. These nutrients are used over and over again by organisms. Water is also continuously recycled. The flow of energy and the recycling of nutrients and water are examples of the interactions between organisms and the interactions between the biotic and abiotic factors of an ecosystem.

Summary

- An ecosystem consists of all the living things and nonliving things interacting in the same area.
- Matter is also recycled in ecosystems; recycling of nutrients is important so they can always be available

Explore More

Use the resource below to answer the questions that follow.

- **How Ecosystems Work** at http://www.youtube.com/watch?v=o_RBHfjZsUQ (3:24)

MEDIA

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1. How do land plants generate the energy they need for their metabolic energy? What do they do with excess energy?

2. Where do scavengers in an ecosystem obtain their energy from? How can scavenging be a beneficial strategy for an organism?
3. What is the role of decomposers?
4. What kind of problems can you foresee if every speck of carbon were turned into biomass? Why?
5. Complete this statement: Energy ___________ through an ecosystem, whereas nutrients are ____________.

Review

1. Define an ecosystem.
2. Distinguish between abiotic and biotic factors. Give examples of each.
3. Where does the energy come from for many ecosystems?
4. Name two nutrients that are recycled through an ecosystem.

9.4 Habitat and Niche

Learning Objectives

- Define habitat and niche.
- Describe the roles of the habitat and niche in an ecosystem.

What is your niche at school?

Are you on the basketball team? Are you a cheerleader? Do you play an instrument in the band? Your niche would be your role or place in the school. Organisms also each have their own niche in the ecosystem. Is an organism a producer or a consumer? How does the organism interact with other organisms? Is the organism involved in any symbiotic relationships?

Habitat and Niche

Niche

Each organism plays a particular role in its ecosystem. A **niche** is the role a species plays in the ecosystem. In other words, a niche is how an organism "makes a living." A niche will include the organism's role in the flow of energy through the ecosystem. This involves how the organism gets its energy, which usually has to do with what an organism eats, and how the organism passes that energy through the ecosystem, which has to do with what eats the organism. An organism's niche also includes how the organism interacts with other organisms, and its role in recycling nutrients.

Once a niche is left vacant, other organisms can fill that position. For example when the Tarpan, a small wild horse found mainly in southern Russia, became extinct in the early 1900s, its niche was filled by a small horse breed, the Konik (**Figure** 9.5). Often this occurs as a new species evolves to occupy the vacant niche.

FIGURE 9.5
The Konik horse.

A species' niche must be specific to that species; no two species can fill the same niche. They can have very similar niches, which can overlap, but there must be distinct differences between any two niches. If two species do fill the same niche, they will compete for all necessary resources. One species will out compete the other, forcing the other species to adapt or risk extinction. This is known as competitive exclusion.

When plants and animals are introduced, either intentionally or by accident, into a new environment, they can occupy the existing niches of native organisms. Sometimes new species out-compete native species, and the native species may go extinct. They can then become a serious pest. For example, kudzu, a Japanese vine, was planted in the southeastern United States in the 1870s to help control soil loss. Kudzu had no natural predators, so it was able to out-compete native species of vine and take over their niches (**Figure** 9.6).

Habitat

The **habitat** is the physical area where a species lives. Many factors are used to describe a habitat. The average amount of sunlight received each day, the range of annual temperatures, and average yearly rainfall can all describe a habitat. These and other **abiotic factors** will affect the kind of traits an organism must have in order to survive there. The temperature, the amount of rainfall, the type of soil and other abiotic factors all have a significant role in determining the plants that invade an area. The plants then determine the animals that come to eat the plants, and so on. A habitat should not be confused with an ecosystem: the habitat is the actual place of the ecosystem, whereas

FIGURE 9.6
Kudzu, a Japanese vine introduced intentionally to the southeastern United States, has out-competed the native vegetation.

the ecosystem includes both the **biotic** and abiotic factors in the habitat.

FIGURE 9.7
Santa Cruz Island off the California coast has diverse habitats including a coastline with steep cliffs, coves, gigantic caves, and sandy beaches.

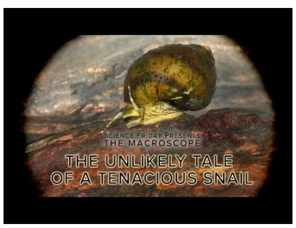
Habitat destruction means what it sounds like—an organism's habitat is destroyed. Habitat destruction can cause a population to decrease. If bad enough, it can also cause species to go extinct. Clearing large areas of land for housing developments or businesses can cause habitat destruction. Poor fire management, pest and weed invasion, and storm damage can also destroy habitats. National parks, nature reserves, and other protected areas all preserve habitats.

Science Friday: The Unlikely Tale of a Tenacious Snail

For over 70 years, no one had seen the oblong rocksnail. Declared extinct in 2000, the species was considered to be another native Alabaman mollusk gone and forgotten. But one day in the spring of 2011, biology grad student

FIGURE 9.8
The above image shows wetland reeds, another type of habitat.

Nathan Whelan picked up a tiny rock and got a big surprise.



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Science Friday: Invasion of the Zombees: A Bee Horror Film

What would cause bees to suddenly drop dead? In this video by Science Friday, Lila Higgins discusses the parasite this is quietly causing these bees to die.

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Summary

- The role a species plays in the ecosystem is called its niche.
- A habitat is the physical environment in which a species lives.

Explore More

Use the resource below to answer the questions that follow.

- **Competition, Predation, Symbiosis** at http://www.youtube.com/watch?v=D1aRSeT-mQE (3:20)

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1. How do you think rapid changes in the chracteristics of habitats affect the niches of animals occupying that habitat?
2. Do you think rapid or gradual environmental changes have a greater potential to affect an organism's niche? Explain your answer.
3. On a very broad scale, how are the niches of a carnivore and an herbivore in the same geographic area similar? How do they differ?

Review

1. What is a niche?
2. Can two species share the same niche? Why or why not?
3. Name three factors that can be used to describe a habitat.
4. Distinguish between a habitat and an ecosystem.

9.5 Food Chains and Food Webs - Advanced

Learning Objectives

- Describe food chains and food webs, and explain how energy is transferred between their trophic levels.

Who eats whom?

Describing the flow of energy within an ecosystem essentially answers this question. To survive, one must eat. Why? To get energy. Food chains and webs describe the transfer of energy within an ecosystem, from one organism to another. In other words, they show who eats whom.

Food Chains and Food Webs

Food chains and food webs represent the feeding relationships in ecosystems. They show who eats whom. Therefore, they model the flow of energy and materials through ecosystems.

Food Chains

A **food chain** represents a simple linear pathway through which energy and materials are transferred from one species to another in an ecosystem. In general, food chains show how energy and materials flow from producers to consumers. Energy and materials also flow from producers and consumers to decomposers, but this step usually is not included in food chains. Two examples of food chains are shown in **Figure** 9.10.

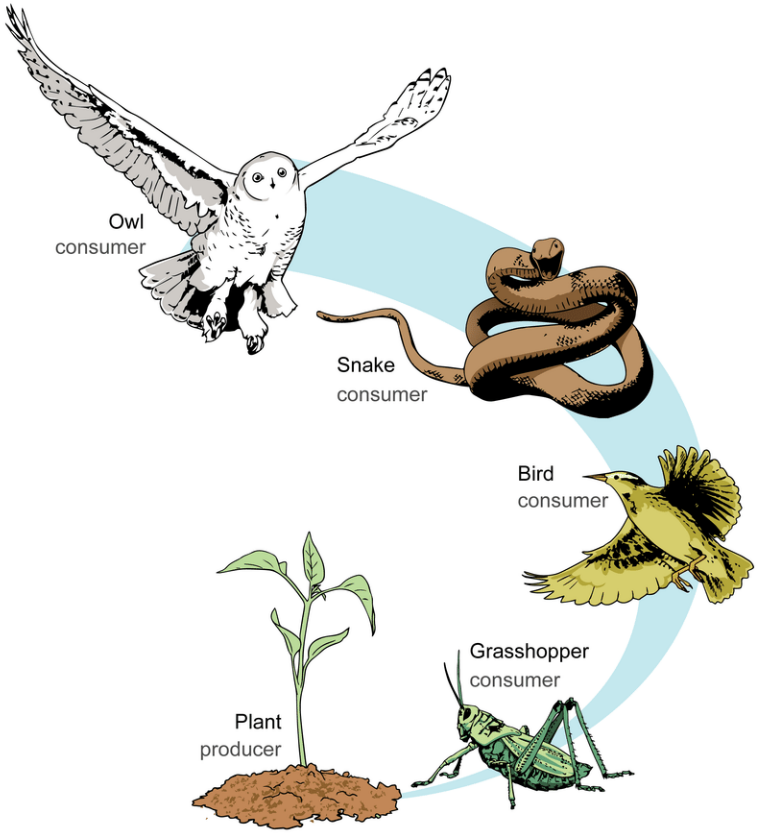
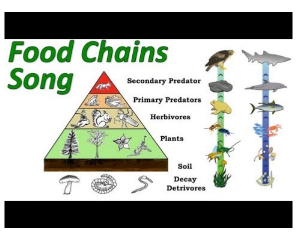


FIGURE 9.9
This food chain includes producers and consumers. How could you add decomposers to the food chain?



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Food Webs

Food chains tend to be overly simplistic representations of what really happens in nature. Most organisms consume multiple species and are, in turn, consumed by multiple other species. A food web represents these more complex interactions. A **food web** is a diagram of feeding relationships that includes multiple intersecting food chains. Examples of food webs are shown below.

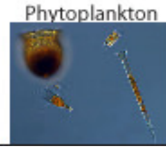
Trophic Level	Terrestrial (Grassland) Food Chain	Aquatic (Ocean) Food Chain
Quaternary Consumer	Hawk 	White Shark 
Tertiary Consumer	Snake 	Seal 
Secondary Consumer	Mouse 	Fish 
Primary Consumer	Grasshopper 	Zooplankton 
Producer	Grass 	Phytoplankton 

FIGURE 9.10

In the aquatic food chain on the right, phytoplankton is the producer. Phytoplankton is eaten by zooplankton, which is the primary consumer. Zooplankton, in turn, is eaten by fish (secondary consumers). Fish are eaten by seals (tertiary consumers), and seals are eaten by white sharks (quaternary consumers).

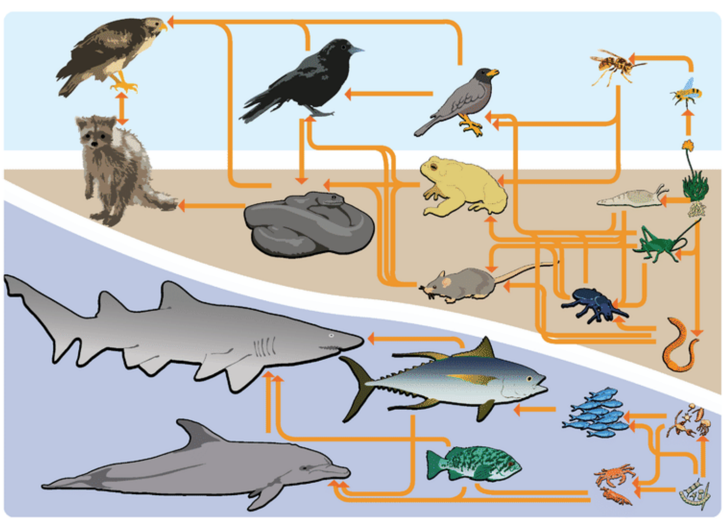


FIGURE 9.11

Examples of food webs.

Trophic Levels and Energy Transfer

The different feeding positions in a food chain or web are called **trophic levels**. The first trophic level consists of producers, the second of primary consumers, the third of secondary consumers, and so on. There usually are no more

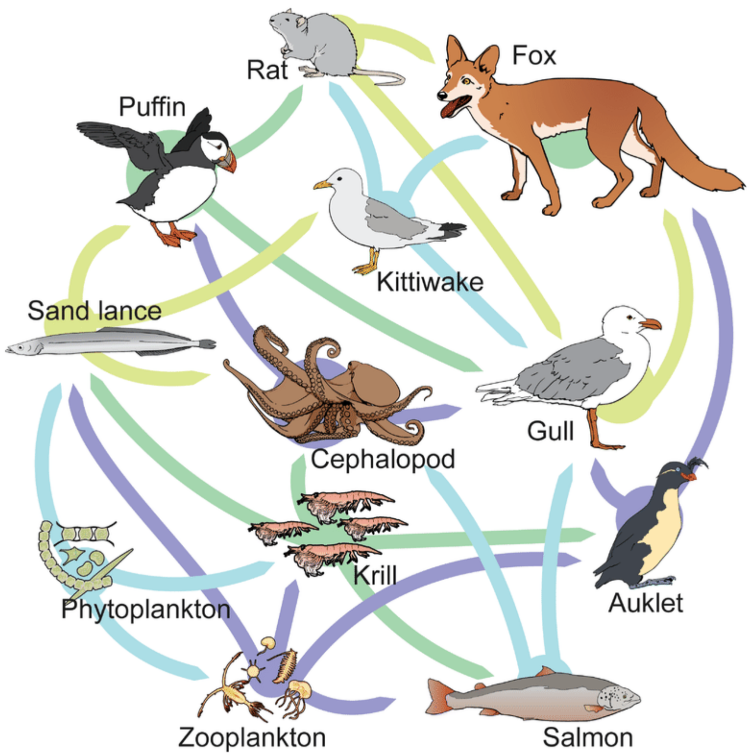


FIGURE 9.12
Food Web. This food web consists of several different food chains. Which organisms are producers in all of the food chains included in the food web?

than four or five trophic levels in a food chain or web. Humans may fall into second, third, and fourth trophic levels of food chains or webs. They eat producers such as grain, primary consumers such as cows, and tertiary consumers such as salmon.

Energy is passed up the food chain from one trophic level to the next. However, only about 10 percent of the total energy stored in organisms at one trophic level is actually transferred to organisms at the next trophic level. The rest of the energy is used for metabolic processes or lost to the environment as heat. As a result, less energy is available to organisms at each successive trophic level. This explains why there are rarely more than four or five trophic levels. The amount of energy at different trophic levels can be represented by an energy pyramid like the one in **Figure** 9.13.

TABLE 9.2:

Trophic Level	Where It Gets Food	Example
1st Trophic Level: Producer	Makes its own food	Plants make food
2nd Trophic Level: Primary Consumer	Consumes producers	Mice eat plant seeds
3rd Trophic Level: Secondary Consumer	Consumes primary consumers	Snakes eat mice
4th Trophic Level: Tertiary Consumer	Consumes secondary consumers	Hawks eat snakes

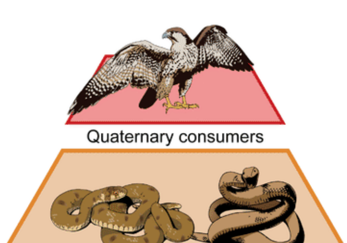


FIGURE 9.13
Ecological Pyramid. This pyramid

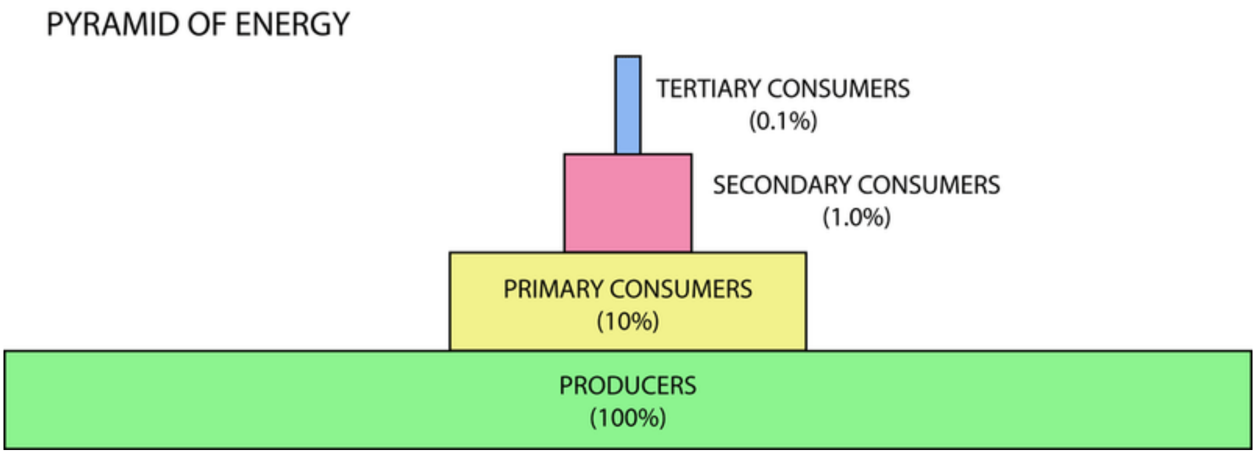


FIGURE 9.14
This pyramid shows the total energy stored in organisms at each trophic level in an ecosystem. Starting with primary consumers, each trophic level in the food chain has only 10 percent of the energy of the level below it. The pyramid makes it clear why there can be only a limited number of trophic levels in a food chain or web.

how biomass of organisms changes from first to higher trophic levels in a food chain.

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Pyramid of Biomass

The materials in dead organisms and wastes at all trophic levels are broken down by decomposers. Organisms such as detritivores and saprotrophs return needed elements to the ecosystem and use up most remaining energy. Because of the reduction in energy at each trophic level, virtually no energy remains. Therefore, energy must be continuously added to ecosystems by producers.

Summary

- Food chains and food webs model feeding relationships in ecosystems. They show how energy and materials are transferred between trophic level when consumers eat producers or other organisms.
- A food web is a diagram of feeding relationships that includes multiple intersecting food chains.
- Energy is passed up the food chain from one trophic level to the next but a lot of it is lost along the way.
- There is less biomass at the top of the food chain than there is at the bottom.

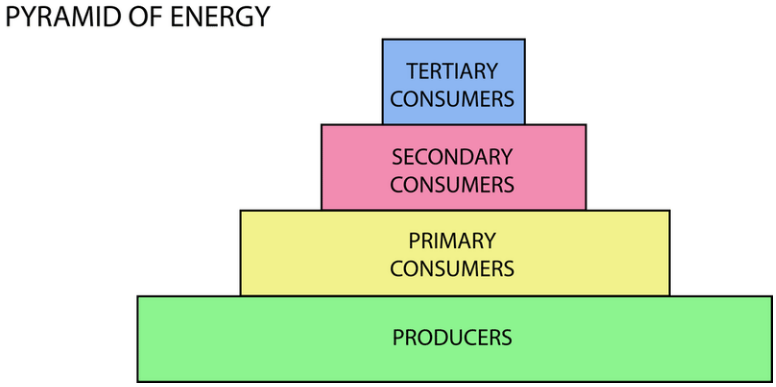

FIGURE 9.15
This pyramid shows the total biomass, or mass of organisms, at each trophic level in an ecosystem. How does this pyramid relate to the energy pyramid?

Review

1. How is energy transferred between trophic levels in a food chain?
2. In the food web figure, identify two independent food chains.
3. If one million kilocalories of energy are stored in producers in an ecosystem, how many kilocalories can be transferred to tertiary consumers in the ecosystem? Show the calculations that support your answer.
4. Draw a terrestrial food chain that includes four trophic levels.
5. All organisms consist of carbon compounds. Infer how the amount of carbon stored in organisms changes from one trophic level to the next. Explain your answer.

9.6 Food Chain

Learning Objectives

- Distinguish a food chain from a food web.
- Be able to draw and interpret a food web.
- Summarize the roles of producers, herbivores, and carnivores in a food web.

How do the grasshopper and the grass interact?

Grasshoppers don't just hop on the grass. They also eat the grass. Other organisms also eat the grass, and some animals even eat the grasshopper. These interactions can be visualized by drawing a food web.

Food Webs

Energy must constantly flow through an ecosystem for the system to remain stable. What exactly does this mean? Essentially, it means that organisms must eat other organisms. **Food chains** (**Figure** 9.16) show the eating patterns in an ecosystem. Food energy flows from one organism to another. Arrows are used to show the feeding relationship between the animals. The arrow points from the organism being eaten to the organism that eats it. For example, an arrow from a plant to a grasshopper shows that the grasshopper eats the leaves. Energy and nutrients are moving from the plant to the grasshopper. Next, a bird might prey on the grasshopper, a snake may eat the bird, and then an owl might eat the snake. The food chain would be:

plant $\rightarrow$ grasshopper $\rightarrow$ bird $\rightarrow$ snake $\rightarrow$ owl.

A food chain cannot continue to go on and on. For example the food chain could not be:

plant → grasshopper → spider → frog → lizard → fox → hawk.

Food chains only have 4 or 5 total levels. Therefore, a chain has only 3 or 4 levels for energy transfer.

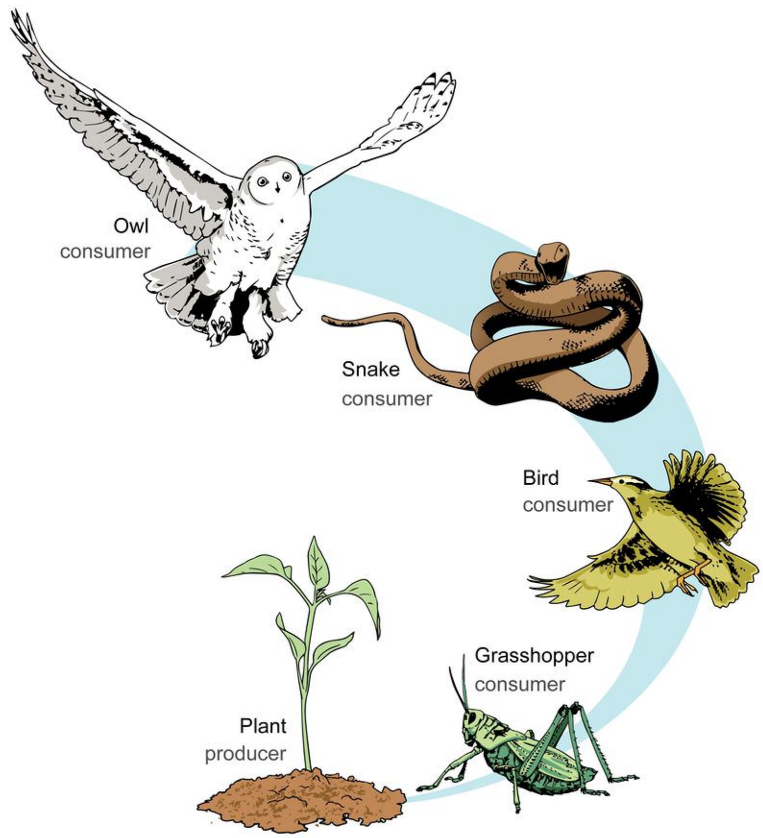

FIGURE 9.16
This food chain includes producers and consumers. How could you add decomposers to the food chain?

In an ocean ecosystem, one possible food chain might look like this: phytoplankton → krill → fish → shark. The **producers** are always at the beginning of the food chain, bringing energy into the ecosystem. Through photosynthesis, the producers create their own food in the form of glucose, but also create the food for the other organisms in the ecosystem. The **herbivores** come next, then the **carnivores**. When these **consumers** eat other organisms, they use the glucose in those organisms for energy. In this example, phytoplankton are eaten by krill, which are tiny, shrimp-like animals. The krill are eaten by fish, which are then eaten by sharks. Could **decomposers** be added to a food chain?

Each organism can eat and be eaten by many different types of organisms, so simple food chains are rare in nature. There are also many different species of fish and sharks. So a food chain cannot end with a shark; it must end with a distinct species of shark. A food chain does not contain the general category of "fish," it will contain specific species of fish. In ecosystems, there are many food chains.

Since feeding relationships are so complicated, we can combine food chains together to create a more accurate flow of energy within an ecosystem. A **food web** (**Figure** 9.17) shows the feeding relationships between many organisms in an ecosystem. If you expand our original example of a food chain, you could add deer that eat clover and foxes that hunt chipmunks. A food web shows many more arrows, but still shows the flow of energy. A complete food web may show hundreds of different feeding relationships.

For more information on food chains, see *A Million Sharks* at https://www.youtube.com/watch?v=QXMTzXaWJyk .

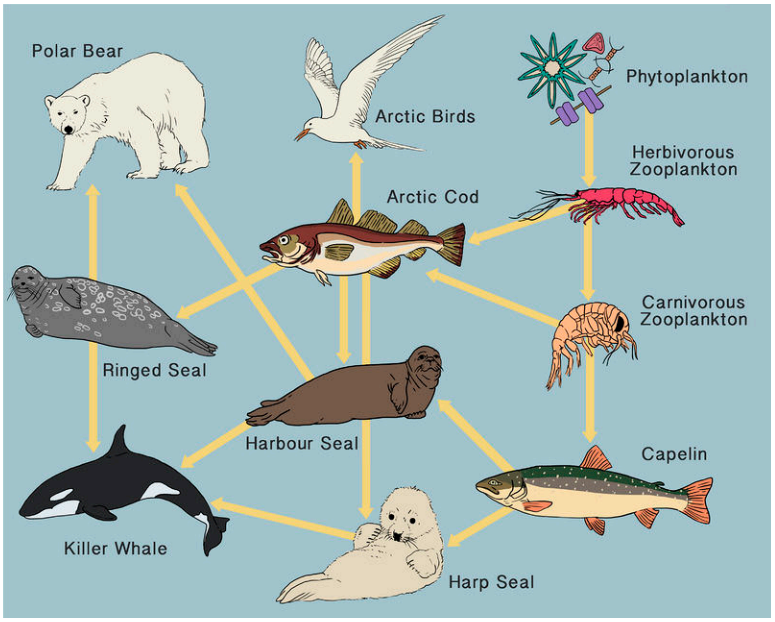

FIGURE 9.17
Food web in the Arctic Ocean.

Science Friday: Can Underwater Parks Protect Coral?

Coral communities are incredibly important for marine life. In this video by Science Friday, Marine scientists John Bruno and Elizabeth Selig describe the effects of local Marine Protection Areas on preserving coral.

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Summary

- A food chain is a diagram that shows feeding interactions in an ecosystem through a single pathway.
- A food web is a diagram that shows feeding interactions between many organisms in an ecosystem through multiple intersecting pathways.

Explore More

Use the resource below to answer the questions that follow.

- **Build A Food Web** at http://www.sciencesource2.ca/resources/SS_active_art/active_art/SEinteractive_gr09_ch01_pg31/index.html

1. What do the Loons and Arctic Tern have in common in the food web?
2. What do the Beluga and the sea duck have in common in the food web?
3. What species in the food web feed on zooplankton (animal plankton)?

4. When you build your own food web what must it contain to be healthy? How many healthy food webs could you build?

Review

1. What is the difference between a food chain and a food web?
2. Food chains always begin with what type of organism? Why?
3. What is the herbivore in the following food chain: algae $\rightarrow$ fish $\rightarrow$ herons?

9.7 Consumers and Decomposers

- Explain the roles of consumers and decomposers in an ecosystem.
- Distinguish herbivores from carnivores and omnivores.
- Classify organisms on the basis of how they obtain energy and describe examples of each.

What is breaking down this leaf?

Notice how this leaf is slowly being broken down. This process can be carried out by fungi and bacteria on the ground. Breaking down old leaves is an important process since it releases the nutrients in the dead leaves back into the soil for living plants to use.

Consumers and Decomposers

Recall that **producers** make their own food through photosynthesis. But many organisms are not producers and cannot make their own food. So how do these organisms obtain their energy? They must get their energy from other organisms. They must eat other organisms, or obtain their energy from these organisms some other way. The organisms that obtain their energy from other organisms are called **consumers**. All animals are consumers, and they eat other organisms. Fungi and many protists and bacteria are also consumers. But, whereas animals eat other organisms, fungi, protists, and bacteria "consume" organisms through different methods.

The consumers can be placed into different groups, depending on what they consume.

- **Herbivores** are animals that eat producers to get energy. For example, rabbits and deer are herbivores that eat plants. The caterpillar pictured below (**Figure** 9.18) is a herbivore. Animals that eat phytoplankton in aquatic environments are also herbivores.
- **Carnivores** feed on animals, either herbivores or other carnivores. Snakes that eat mice are carnivores. Hawks that eat snakes are also carnivores (**Figure** 9.18).

- **Omnivores** eat both producers and consumers. Most people are omnivores, since they eat fruits, vegetables, and grains from plants, and also meat and dairy products from animals. Dogs, bears, and raccoons are also omnivores.

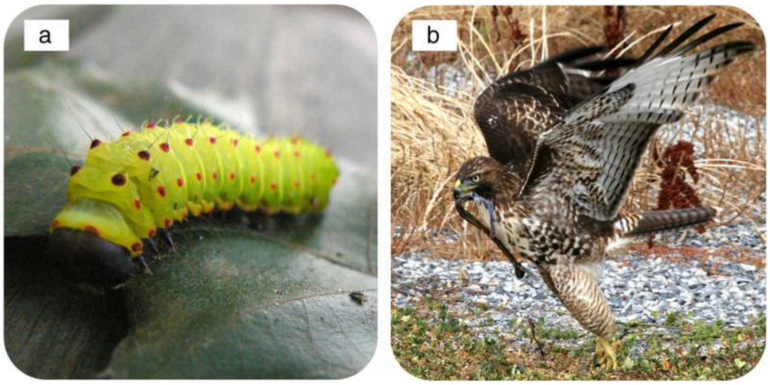

FIGURE 9.18
Examples of consumers are caterpillars (herbivores) and hawks (carnivore).

Decomposers and Stability

Decomposers (**Figure** 9.19) get nutrients and energy by breaking down dead organisms and animal wastes. Through this process, decomposers release nutrients, such as carbon and nitrogen, back into the environment. These nutrients are recycled back into the ecosystem so that the producers can use them. They are passed to other organisms when they are eaten or consumed. Many of these nutrients are recycled back into the soil, so they can be taken up by the roots of plants.

The stability of an ecosystem depends on the actions of the decomposers. Examples of decomposers include mushrooms on a decaying log. Bacteria in the soil are also decomposers. Imagine what would happen if there were no decomposers. Wastes and the remains of dead organisms would pile up and the nutrients within the waste and dead organisms would not be released back into the ecosystem. Producers would not have enough nutrients. The carbon and nitrogen necessary to build organic compounds, and then cells, allowing an organism to grow, would be insufficient. Other nutrients necessary for an organism to function properly would also not be sufficient. Essentially, many organisms could not exist.

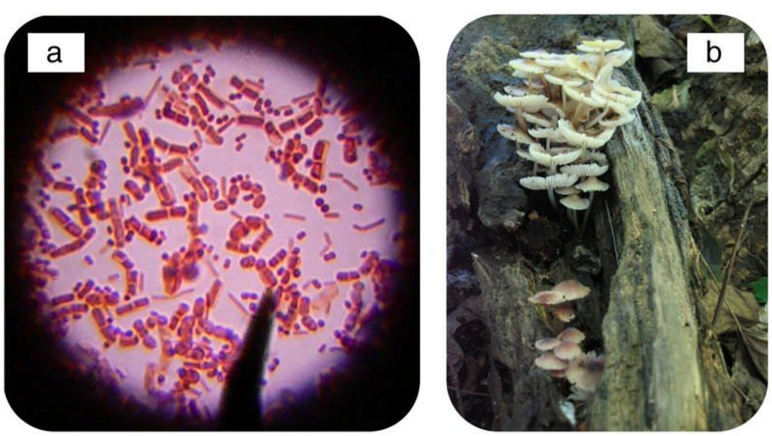

FIGURE 9.19
Examples of decomposers are (a) bacteria and (b) fungi.

Summary

- Consumers must obtain their nutrients and energy by eating other organisms.
- Decomposers break down animal remains and wastes to get energy.
- Decomposers are essential for the stability and survival of an ecosystem.

Explore More

Use the resource below to answer the questions that follow.

- **Decomposers** at http://www.youtube.com/watch?v=Z6V0a_7N1Mw (3:19)

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1. What is the role of decomposers in an ecosystem? What is the source of the matter which is decomposed?
2. How do the actions of earthworms improve soil quality? How does this impact the amount of biomass an ecosystem can support?
3. How do gastropods function as decomposers?

Review

1. What is a consumer?
2. What's the term for a consumer that eats both leaves and fish?
3. What are the different types of consumers?
4. Why are decomposers important in the ecosystem?

9.8 Energy Flow

- Define energy and energy pyramid.
- Explain the flow of energy through an ecosystem using an energy pyramid.
- Describe a trophic level.
- Explain the maximum number of trophic levels in an ecosystem.

How much energy could be gained from the warthog?

If the cheetah is successful in capturing the warthog, it would gain some energy by eating it. But would the cheetah gain as much energy as the warthog has ever consumed? No, the warthog has used up some of the energy it has consumed for its own needs. The cheetah will only gain a fraction of the energy that the warthog has consumed throughout its lifetime.

Energy Pyramids

When an herbivore eats a plant, the **energy** in the plant tissues is used by the herbivore. But how much of that energy is transferred to the herbivore? Remember that plants are **producers**, bringing the energy into the ecosystem by converting sunlight into glucose. Does the plant use some of the energy for its own needs? Recall the energy is the ability to do work, and the plant has plenty or "work" to do. So of course it needs and uses energy. It converts the glucose it makes into **ATP** through **cellular respiration** just like other organisms. After the plant uses the energy from glucose for its own needs, the excess energy is available to the organism that eats the plant.

The herbivore uses the energy from the plant to power its own life processes and to build more body tissues. However, only about 10% of the total energy from the plant gets stored in the herbivore's body as extra body tissue. The rest of the energy is used by the herbivore and released as heat. The next consumer on the food chain that eats the herbivore will only store about 10% of the total energy from the herbivore in its own body. This means the carnivore will store only about 1% of the total energy that was originally in the plant. In other words, only about 10% of energy of one step in a food chain is stored in the next step in the food chain. The majority of the energy is used by the organism or released to the environment.

Every time energy is transferred from one organism to another, there is a loss of energy. This loss of energy can be shown in an **energy pyramid**. An example of an energy pyramid is pictured below (**Figure** 9.20). Since there is energy loss at each step in a food chain, it takes many producers to support just a few carnivores in a community.

Each step of the food chain in the energy pyramid is called a **trophic level**. Plants or other photosynthetic organisms (**autotrophs**) are found on the first trophic level, at the bottom of the pyramid. The next level will be the herbivores, and then the carnivores that eat the herbivores. The energy pyramid (**Figure** 9.20) shows four levels of a food chain, from producers to carnivores. Because of the high rate of energy loss in food chains, there are usually only 4 or 5 trophic levels in the food chain or energy pyramid. There just is not enough energy to support any additional trophic levels. **Heterotrophs** are found in all levels of an energy pyramid other than the first level.

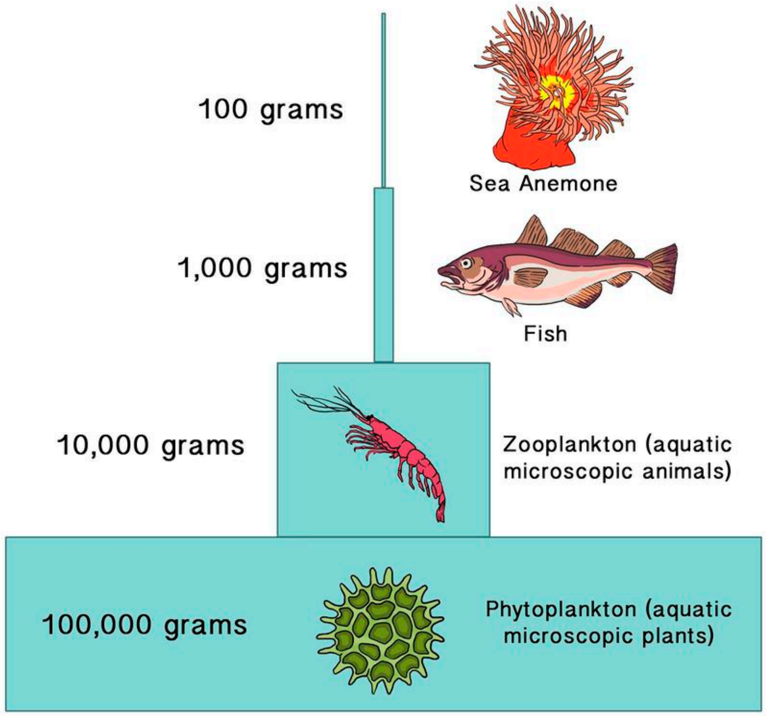


FIGURE 9.20
As illustrated by this ecological pyramid, it takes a lot of phytoplankton to support the carnivores of the oceans. This energy pyramid has four trophic levels, which signify the organisms place in the food chain from the original source of energy.

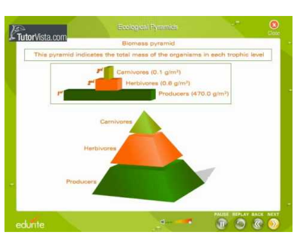
Summary

- As energy is transferred along a food chain, energy is lost as heat.
- Only about 10% of energy of one step in a food chain is stored in the next step in the food chain.

Explore More

Use the resource below to answer the questions that follow.

- **Ecological Pyramids** at http://www.youtube.com/watch?v=NJplkrliUEg (4:03)



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1. What are three types of ecological pyramids? How do their shapes compare?

2. Do you think it would be possible to construct a pyramid where the number of carnivores was more than the number of herbivores? Why or why not?
3. Do you think it would be possible to construct a pyramid where the biomass of carnivores was more than the biomass of herbivores? How does this compare to a numbers pyramid.
4. What consumes energy at each trophic level? How does this contribute to energy loss between trophic levels?

Review

1. When an herbivore eats a plant, what happens to 90% of the energy obtained from that plant?
2. What is a trophic level?
3. Why are the number of trophic levels limited?
4. In a forest community, caterpillars eat leaves, and birds eat caterpillars. Draw an energy pyramid using this information.

9.9 Symbiosis

Learning Objectives

- Define symbiosis.
- Distinguish mutualism from commensalism and parasitism.
- Give examples of the different kinds of symbiosis.

Is this little fish about to become lunch?

Actually, this big fish is not opening his mouth to munch on these little fish. He is opening his mouth to get his teeth cleaned! These small fish eat dead skin and parasites from his body. Both types of fish benefit from this relationship.

Symbiosis

Symbiosis describes a close and long-term relationship between different species. At least one species will benefit in a symbiotic relationship. These relationships are often necessary for the survival of one or both organisms. There are three types of symbiotic relationships: mutualism, communalism, and parasitism.

- **Mutualism** is a symbiotic relationship in which both species benefit.
- **Commensalism** is a symbiotic relationship in which one species benefits while the other is not affected.

- **Parasitism** is a symbiotic relationship in which the parasitic species benefits while the host species is harmed.

An example of a mutualistic relationship is between herbivores (plant-eaters) and the bacteria that live in their intestines. The bacteria get a place to live. Meanwhile, the bacteria help the herbivore digest food. Both species benefit, so this is a mutualistic relationship. The clownfish and the sea anemones also have a mutualistic relationship. The clownfish protects the anemone from anemone-eating fish, and the stinging tentacles of the anemone protect the clownfish from predators (**Figure** 9.21). Another example of this type of symbiotic relationship is the relationship between the plover bird and the African crocodile. The tiny blackbird acts as a toothpick for the fierce crocodile, and helps by removing tiny morsels of food that are stuck between the crocodile's teeth. These food remains are the source of food for the bird. Another example is between the ostrich and the zebra. The ostrich always moves with the herd of zebras since it has a poor sense of hearing and smell, whereas the zebra has very sharp senses. The ostrich has a keen sense of sight, which the zebra lacks. Hence, these two species depend on each other to warn one another of any nearby imposing dangers.

Commensal relationships may involve an organism using another for transportation or housing. For example, spiders build their webs on trees. The spider gets to live in the tree, but the tree is unaffected. Other commensal relationships exist between cattle egrets and livestock. Cattle egrets are mostly found in meadows and grasslands are always seen near cattle, horses and other livestock. These birds feed on the insects that come out of the field due to the movement of the animals. They even eat ticks, fleas, and other insects off the back of animals. The relationship between tigers and golden jackals is also commensalism. The jackal alerts the tiger to a kill and feeds on the remains of the prey left by the tiger. This is not a mutualistic relationship as the tiger does not provide anything to the jackal.

Parasites may live either inside or on the surface of their host. An example of a parasite is a hookworm. Hookworms are roundworms that affect the small intestine and lungs of a host organism. They live inside of humans and cause them pain. However, the hookworms must live inside of a host in order to survive. Parasites may even kill the host they live on, but then they also kill their host organism, so this is rare. Parasites are found in animals, plants, and fungi. Hookworms are common in the moist tropic and subtropic regions. There is very little risk of getting a parasite in industrialized nations.

FIGURE 9.21
Clownfish in a sea anemone.

Science Friday: Invasion of the Zombees: A Bee Horror Film

What would cause bees to suddenly drop dead? In this video by Science Friday, Lila Higgins discusses the parasite this is quietly causing these bees to die.

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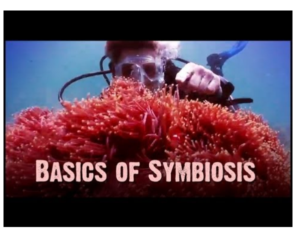
Summary

- Symbiosis describes a close and long-term interaction between different species.
- In a mutualism, both species benefit; in a commensalism, one species benefits while the other is not affected.
- In a parasitism, the parasitic species benefits, while the host species is harmed.

Explore More

Use the resource below to answer the questions that follow.

- **Symbiosis: Mutualism, Commensalsim and Parasitism** at http://www.youtube.com/watch?v=zSmL2F1t81Q (5:17)



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1. What defines a symbiotic relationship?
2. Is the benefit gained by each individual in a mutualistic relationship equal?
3. What could a mutualistic relationship, in which one organism receives little benefit, also be called?
4. What type of relationship exists between the clownfish and the sea anemone?
5. What are the two explanations for where a clownfish's protective mucus comes from?

Review

1. What is symbiosis?
2. Distinguish between mutualism and commensalism.
3. Describe an example of a symbiotic relationship.
4. What's an example of a parasite?

9.10 Succession

Learning Objectives

- Define succession.
- Distinguish between primary and secondary succession.
- Give examples of a pioneer species.
- Describe a climax community.

Can a plant really grow in hardened lava?

It can if it is very hardy and tenacious. And that is how succession starts. It begins with a plant that must be able to grow on new land with minimal soil or nutrients.

Ecological Succession

Communities are not usually static. The numbers and types of species that live in them generally change over time. This is called **ecological succession**. Important cases of succession are primary and secondary succession.

Primary Succession

Primary succession occurs in an area that has never before been colonized. Generally, the area is nothing but bare rock. This type of environment may come about when

- lava flows from a volcano and hardens into rock.

- a glacier retreats and leaves behind bare rock.
- a landslide uncovers an area of bare rock.

The first species to colonize a disturbed area such as this are called **pioneer species** (see **Figure** 9.22). They change the environment and pave the way for other species to come into the area. Pioneer species are likely to include bacteria and lichens that can live on bare rock. Along with wind and water, they help weather the rock and form soil. Once soil begins to form, plants can move in. At first, the plants include grasses and other species that can grow in thin, poor soil. As more plants grow and die, organic matter is added to the soil. This improves the soil and helps it hold water. The improved soil allows shrubs and trees to move into the area.

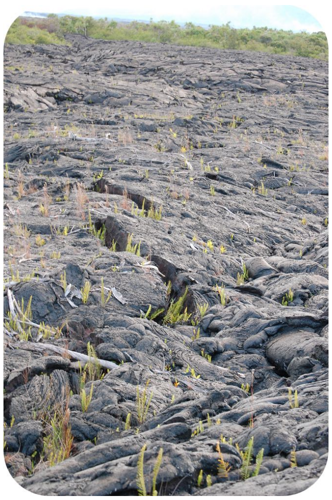

FIGURE 9.22

Primary Succession. New land from a volcanic eruption is slowly being colonized by a pioneer species.

Secondary Succession

Secondary succession occurs in a formerly inhabited area that was disturbed. The disturbance could be a fire, flood, or human action such as farming. This type of succession is faster because the soil is already in place. In this case, the pioneer species are plants such as grasses, birch trees, and fireweed. Organic matter from the pioneer species improves the soil. This lets other plants move into the area. An example of this type of succession is shown in **Figure** 9.23.

FIGURE 9.23

Secondary Succession. Two months after a forest fire, new plants are already sprouting among the charred logs.

Climax Communities

Many early ecologists thought that a community always goes through the same series of stages during succession. They also assumed that succession always ends with a final stable stage. They called this stage the **climax community**. Today, most ecologists no longer hold these views. They believe that continued change is normal in most ecosystems. They think that most communities are disturbed too often to become climax communities.

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Summary

- Ecological succession is the process in which a community changes through time.
- Primary succession occurs in an area that has never before been colonized.
- Secondary succession occurs in a formerly inhabited area that was disturbed.

Review

1. What is ecological succession?
2. Describe the main difference between primary and secondary succession.
3. Give two examples of habitats that will go through primary succession.
4. What is a climax community?
5. Summarize how ideas about ecological succession and climax communities have changed.

9.11 References

1. SeaWiFS Project, NASA/Goddard Space Flight Center and ORBIMAGE;Image copyright Monkey Business Images, 2014. http://commons.wikimedia.org/wiki/Image:Seawifs_global_biosphere.jpg;http://www.shutterstock.com . Public Domain;Used under license from Shutterstock.com
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CHAPTER 10 Ecology: Solutions to Human Impact

Chapter Outline

10.1 Habitat Destruction

- Define habitat destruction.
- Give examples of habitat destruction.
- Discuss what causes the destruction of habitats.
- Explain the effects of slash-and-burn agriculture.
- Give examples of invasive species.
- Describe the effects of non-native species.

What's happening to this land?

This picture, taken in southern Mexico, shows land being cleared for agriculture. The forest has been cut down and burned to make room for a a farm. In the process, homes to many plants and animals were destroyed. This is an example of habitat destruction.

Habitat Destruction

From a human point of view, a habitat is where you live, go to school, and go to have fun. Your habitat can be altered, and you can easily adapt. Most people live in a few different places and go to a number of different schools throughout their life. But a plant or animal may not be able to adapt to a changed habitat. A **habitat** is the natural home or environment of an organism. Humans often destroy the habitats of other organisms. Habitat destruction can cause the extinction of species. **Extinction** is the complete disappearance of a species. Once a species is extinct, it can never recover. Some ways humans cause habitat destruction are by clearing land and by introducing non-native species of plants and animals.

Land Loss

Clearing land for agriculture and development is a major cause of habitat destruction. Within the past 100 years, the amount of total land used for agriculture has almost doubled. Land used for grazing cattle has more than doubled. Agriculture alone has cost the United States half of its wetlands (**Figure** 10.1) and almost all of its tallgrass prairies. Native prairie ecosystems, with their thick fertile soils, deep-rooted grasses, diversity of colorful flowers, burrowing prairie dogs, and herds of bison and other animals, have virtually disappeared (**Figure** 10.3).

FIGURE 10.1
Wetlands such as this one in Cape May, New Jersey, filter water and protect coastal lands from storms and floods.

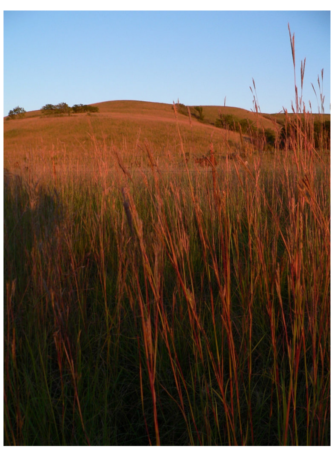

FIGURE 10.2
The Flint Hills contain some of the largest remnants of tallgrass prairie habitat remaining in North America.

Slash-and-Burn Agriculture

Other habitats that are being rapidly destroyed are forests, especially tropical rainforests. The largest cause of deforestation today is **slash-and-burn agriculture** (shown in the opening image). This means that when people want to turn a forest into a farm, they cut down all of the trees and then burn the remainder of the forest. This technique is used by over 200 million people in tropical forests throughout the world.

As a consequence of slash-and-burn agriculture, nutrients are quickly lost from the soil. This often results in people abandoning the land within a few years. Then the top soil erodes and desertification can follow. **Desertification**

FIGURE 10.3
Herds of bison also made up part of the tallgrass prairie community.

turns forest into a desert, where it is difficult for plants to grow. Half of the Earth's mature tropical forests are gone. At current rates of deforestation, all tropical forests will be gone by the year 2090.

Non-native Species

One of the main causes of extinction is introduction of exotic species into an environment. These exotic and new species can also be called **invasive species** or **non-native species**. These non-native species, being new to an area, may not have natural predators in the new habitat, which allows their populations to easily adapt and grow. Invasive species out-compete the native species for resources. Sometimes invasive species are so successful at living in a certain habitat that the native species go extinct (**Figure** 10.4).

Recently, cargo ships have transported zebra mussels, spiny waterfleas, and ruffe (a freshwater fish) into the Great Lakes (**Figure** 10.5). These invasive species are better at hunting for food. They have caused some of the native species to go extinct.

Invasive species can disrupt food chains, carry disease, prey on native species directly, and out-compete native species for limited resources, like food. All of these effects can lead to extinction of the native species.

Other Causes

Other causes of habitat destruction include poor fire management, overfishing, mining (**Figure** 10.6), pollution, and storm damage. All of these can cause irreversible changes to a habitat and ecosystem.

Examples of Habitat Destruction

A habitat that is quickly being destroyed is the **wetland**. By the 1980s, over 80% of all wetlands in parts of the U.S. were destroyed. In Europe, many wetland species have gone extinct. For example, many **bogs** in Scotland have been lost because of human development.

Another example of species loss due to habitat destruction happened on Madagascar's central highland plateau. From 1970 to 2000, slash-and-burn agriculture destroyed about 10% of the country's total native plants. The area turned into a wasteland. Soil from erosion entered the waterways. Much of the river ecosystems of several large

FIGURE 10.4
An exotic species, the brown tree snake, hitchhiked on an aircraft to the Pacific Islands, causing the extinctions of many bird and mammal species which had evolved in the absence of predators.

FIGURE 10.5
These zebra mussels, an invasive species, live on most man-made and natural surfaces. Here they have infested the walls of the Arthur V. Ormond Lock on the Arkansas River. They have caused significant damage to American waterways, locks, and power plants.

rivers were also destroyed. Several fish species are almost extinct. Also, some coral reef formations in the Indian Ocean are completely lost.

Summary

- There are many causes of habitat destruction, including clearing of land and introduction of invasive species.
- Slash-and-burn agriculture can lead to desertification, meaning the fertile top soil is lost.

Explore More

Use the resource below to answer the questions that follow.

FIGURE 10.6
Strip coal mining, pictured here, has destroyed the entire ecosystem.

Explore More I

- **Suburban Growth Stresses Streams** at http://www.youtube.com/watch?v=54k5vaWIRdA

MEDIA
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1. How does the loss of trees along streams affect steam ecosystems?
2. Loss of trees has destabilized some stream banks. How are aquatic insects affected by this situation?
3. How have urban areas affected the diversity of fish in streams? What types of fish are being selected for?

Explore More II

- **The Ecology of Climate Change** at http://www.youtube.com/watch?v=isPGjChdby8 (8:07)

MEDIA
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1. What types of trees dominate boreal forests?
2. How is climate change affecting the amount of fires occurring in Alaska? How is this affecting the ecosystem?
3. How do conifer forests differ from deciduous forest in their effect on carbon? How may this feed into climate change?

4. How may the thawing of permafrost affect the Global Carbon Cycle? How is the carbon in the permafrost similar to the carbon in fossil fuel?

Review

1. What is a habitat?
2. What are the primary ways that humans destroy habitats?
3. Why may invasive species thrive in a new area? Why is this an issue?
4. Describe slash-and-burn agriculture.

10.2 Mass Extinction

Learning Objectives

- Describe the sixth mass extinction.
- Relate human actions to the sixth mass extinction.
- Define habitat loss and exotic species.
- Give examples of the effects of extinction.
- Describe how biodiversity can be protected.

This is one of the most powerful birds in the world. Could it go extinct?

The Philippine Eagle, also known as the Monkey-eating Eagle, is among the rarest, largest, and most powerful birds in the world. It is critically endangered, mainly due to massive loss of habitat due to deforestation in most of its range. Killing a Philippine Eagle is punishable under Philippine law by twelve years in jail and heavy fines.

Human Actions and the Sixth Mass Extinction

Over 99 percent of all species that ever lived on Earth have gone extinct. Five mass extinctions are recorded in the fossil record. They were caused by major geologic and climatic events. Evidence shows that a **sixth mass extinction** is occurring now. Unlike previous mass extinctions, the sixth extinction is due to human actions.

Some scientists consider the sixth extinction to have begun with early hominids during the Pleistocene. They are blamed for over-killing big mammals such as mammoths. Since then, human actions have had an ever greater impact on other species. The present rate of extinction is between 100 and 100,000 species per year. In 100 years, we could lose more than half of Earth's remaining species.

Causes of Extinction

The single biggest cause of extinction today is **habitat loss**. Agriculture, forestry, mining, and urbanization have disturbed or destroyed more than half of Earth's land area. In the U.S., for example, more than 99 percent of tall-grass prairies have been lost. Other causes of extinction today include:

- **Exotic species** introduced by humans into new habitats. They may carry disease, prey on native species, and disrupt food webs. Often, they can out-compete native species because they lack local predators. An example is described in **Figure** 10.7.
- Over-harvesting of fish, trees, and other organisms. This threatens their survival and the survival of species that depend on them.
- Global climate change, largely due to the burning of fossil fuels. This is raising Earth's air and ocean temperatures. It is also raising sea levels. These changes threaten many species.
- Pollution, which adds chemicals, heat, and noise to the environment beyond its capacity to absorb them. This causes widespread harm to organisms.
- Human overpopulation, which is crowding out other species. It also makes all the other causes of extinction worse.

FIGURE 10.7
The brown tree snake is an exotic species that has caused many extinctions on Pacific islands such as Guam.

Effects of Extinction

The results of a study released in the summer of 2011 have shown that the decline in the numbers of large predators like sharks, lions and wolves is disrupting Earth's ecosystem in all kinds of unusual ways. The study, conducted by scientists from 22 different institutions in six countries, confirmed the sixth mass extinction. The study states that this mass extinction differs from previous ones because it is entirely driven by human activity through changes in land use, climate, pollution, hunting, fishing and poaching. The effects of the loss of these large predators can be seen in the oceans and on land.

- Fewer cougars in the western US state of Utah led to an explosion of the deer population. The deer ate more vegetation, which altered the path of local streams and lowered overall biodiversity.
- In Africa, where lions and leopards are being lost to poachers, there is a surge in the number of olive baboons, who are transferring intestinal parasites to humans living nearby.
- In the oceans, industrial whaling led a change in the diets of killer whales, who eat more sea lions, seals, and otters and have dramatically lowered the population counts of those species.

The study concludes that the loss of big predators has likely driven many of the pandemics, population collapses and ecosystem shifts the Earth has seen in recent centuries.

Disappearing Frogs

Around the world, frogs are declining at an alarming rate due to threats like pollution, disease, and climate change. Frogs bridge the gap between water and land habitats, making them the first indicators of ecosystem changes.

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Nonnative Species

Scoop a handful of critters out of the San Francisco Bay and you'll find many organisms from far away shores. Invasive kinds of mussels, fish, and more are choking out native species, challenging experts around the state to change the human behavior that brings them here.

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How You Can Help Protect Biodiversity

There are many steps you can take to help protect biodiversity. For example:

- Consume wisely. Reduce your consumption wherever possible. Re-use or recycle rather than throw out and buy new. When you do buy new, choose products that are energy efficient and durable.
- Avoid plastics. Plastics are made from petroleum and produce toxic waste.
- Go organic. Organically grown food is better for your health. It also protects the environment from pesticides and excessive nutrients in fertilizers.
- Save energy. Unplug electronic equipment and turn off lights when not in use. Take mass transit instead of driving.

Lost Salmon

Why is the salmon population of Northern California so important? Salmon do not only provide food for humans, but also supply necessary nutrients for their ecosystems. Because of a sharp decline in their numbers, in part due to human interference, the entire salmon fishing season off California and Oregon was canceled in both 2008 and 2009. The species in the most danger of extinction is the California coho salmon.

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Summary

- Evidence shows that a sixth mass extinction is occurring. The single biggest cause is habitat loss caused by human actions.
- There are many steps you can take to help protect biodiversity. For example, you can use less energy.

Review

1. How is human overpopulation related to the sixth mass extinction?
2. Why might the brown tree snake or the Philippine Eagle serve as "poster species" for causes of the sixth mass extinction?
3. Describe a hypothetical example showing how rising sea levels due to global warming might cause extinction.
4. Create a poster that conveys simple tips for protecting biodiversity.

Resources

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10.3 Climate Change

Lesson Objectives

- Describe some ways that climate change has been an important part of Earth history.
- Discuss what factors can cause climate to change and which of these can be exacerbated by human activities.
- Discuss the consequences of rising greenhouse gas levels in the atmosphere, the impacts that are already being measured, and the impacts that are likely to occur in the future.

Vocabulary

- El Niño
- global warming
- La Niña
- Milankovitch cycles
- slash-and-burn agriculture
- sunspot

Introduction

For the past two centuries, climate has been relatively stable. People placed their farms and cities in locations that were in a favorable climate without thinking that the climate could change. But climate has changed throughout Earth history, and a stable climate is not the norm. In recent years, Earth's climate has begun to change again. Most of this change is warming because of human activities that release greenhouse gases into the atmosphere. The effects of warming are already being seen and will become more extreme as temperature rise.

Climate Change in Earth History

Climate has changed throughout Earth history. Much of the time Earth's climate was hotter and more humid than it is today, but climate has also been colder, as when glaciers covered much more of the planet. The most recent ice ages were in the Pleistocene Epoch, between 1.8 million and 10,000 years ago (**Figure** 10.8). Glaciers advanced and retreated in cycles, known as glacial and interglacial periods. With so much of the world's water bound into the ice, sea level was about 125 meters (395 feet) lower than it is today. Many scientists think that we are now in a warm, interglacial period that has lasted about 10,000 years.

For the past 1500 years, climate has been relatively mild and stable when compared with much of Earth's history. Why has climate stability been beneficial for human civilization? Stability has allowed the expansion of agriculture and the development of towns and cities.

FIGURE 10.8

The maximum extent of Northern Hemisphere glaciers during the Pleistocene epoch.

Fairly small temperature changes can have major effects on global climate. The average global temperature during glacial periods was only about 5.5°C (10°F) less than Earth's current average temperature. Temperatures during the interglacial periods were about 1.1°C (2.0°F) higher than today (**Figure** 10.9).

Since the end of the Pleistocene, the global average temperature has risen about 4°C (7°F). Glaciers are retreating and sea level is rising. While climate is getting steadily warmer, there have been a few more extreme warm and cool times in the last 10,000 years. Changes in climate have had effects on human civilization.

- The Medieval Warm Period from 900 to 1300 A.D. allowed Vikings to colonize Greenland and Great Britain to grow wine grapes.
- The Little Ice Age, from the 14th to 19th centuries, the Vikings were forced out of Greenland and humans had to plant crops further south.

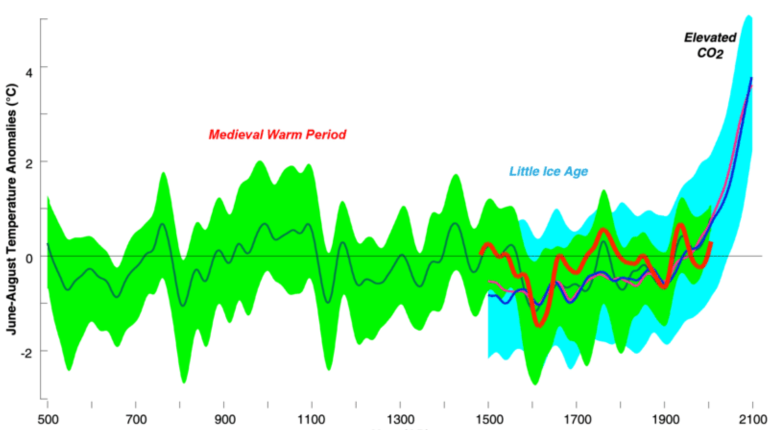

FIGURE 10.9

The graph is a compilation of 5 reconstructions (the green line is the mean of the five records) of mean temperature changes. This illustrates the high temperatures of the Medieval Warm Period, the lows of the Little Ice Age, and the very high (and climbing) temperature of this decade.

Short-Term Climate Changes

Short-term changes in climate are common (**Figure** 10.10). The largest and most important of these is the oscillation between El Niño and La Niña conditions. This cycle is called the ENSO (El Niño southern oscillation). The ENSO drives changes in climate that are felt around the world about every two to seven years.

In a normal year, the trade winds blow across the Pacific Ocean near the equator from east to west (toward Asia). A low pressure cell rises above the western equatorial Pacific. Warm water in the western Pacific Ocean and raises sea levels by one-half meter. Along the western coast of South America, the Peru Current carries cold water northward, and then westward along the equator with the trade winds. Upwelling brings cold, nutrient-rich waters from the deep sea.

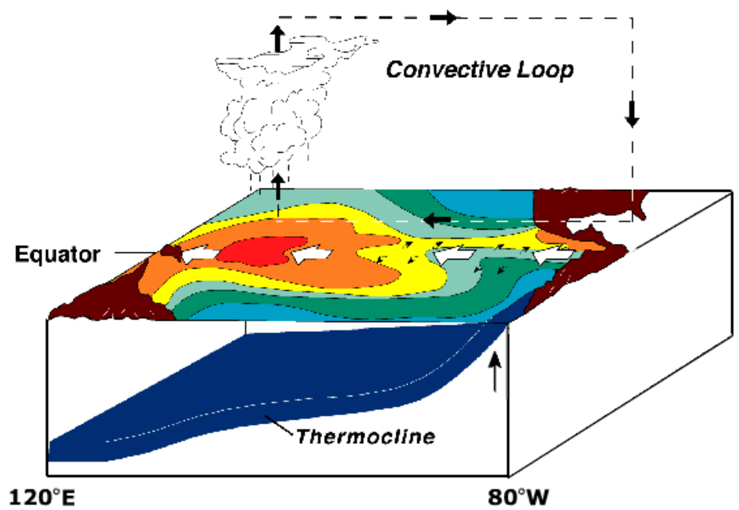

FIGURE 10.10
Under normal conditions, low pressure and warm water (shown in red) build up in the western Pacific Ocean. Notice that continents are shown in brown in the image. North and South America are on the right in this image.

In an **El Niño** year, when water temperature reaches around 28°C (82°F), the trade winds weaken or reverse direction and blow east (toward South America) (**Figure** 10.11). Warm water is dragged back across the Pacific Ocean and piles up off the west coast of South America. With warm, low-density water at the surface, upwelling stops. Without upwelling, nutrients are scarce and plankton populations decline. Since plankton form the base of the food web, fish cannot find food, and fish numbers decrease as well. All the animals that eat fish, including birds and humans, are affected by the decline in fish.

By altering atmospheric and oceanic circulation, El Niño events change global climate patterns.

- Some regions receive more than average rainfall, including the west coast of North and South America, the southern United States, and Western Europe.
- Drought occurs in other parts of South America, the western Pacific, southern and northern Africa, and southern Europe.

An El Niño cycle lasts one to two years. Often normal circulation patterns resume. Sometimes circulation patterns bounce back quickly and extremely (**Figure** 10.12). This is a **La Niña**.

In a La Niña year, as in a normal year, trade winds moves from east to west and warm water piles up in the western Pacific Ocean. Ocean temperatures along coastal South America are colder than normal (instead of warmer, as in El Niño). Cold water reaches farther into the western Pacific than normal.

An online guide to El Niño and La Niña events from the University of Illinois is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/eln/home.rxml .

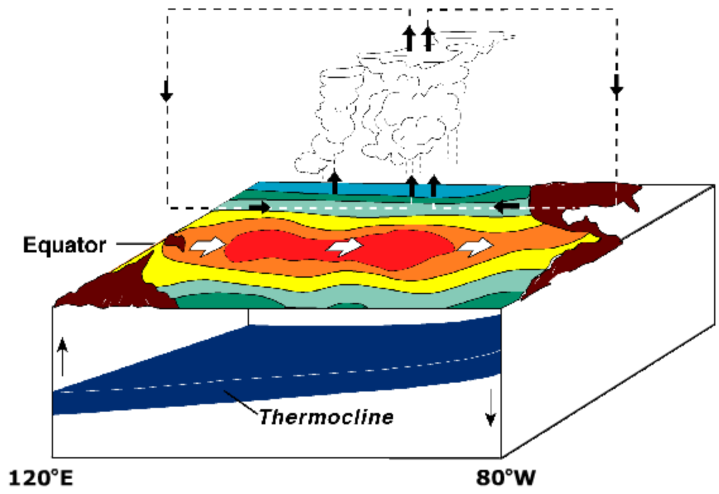

FIGURE 10.11
In El Niño conditions, the trade winds weaken or reverse directions. Warm water moves eastward across the Pacific Ocean and piles up against South America.

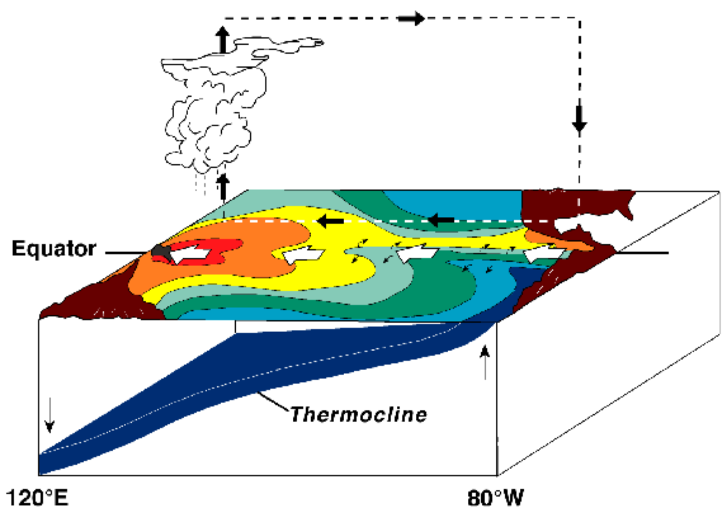

FIGURE 10.12
A La Niña year is like a normal year but the circulation patters are more extreme.

Other important oscillations are smaller and have a local, rather than global, effect. The North Atlantic Oscillation mostly alters climate in Europe. The Mediterranean also goes through cycles, varying between being dry at some times, and warm and wet at others.

The ABC News video explores the relationship of El Niño to global warming. El Niño is named as the cause of strange weather across the United States in the winter of 2007 in this video **(5g)**: http://www.youtube.com/watch?v=5uk9nwtAOio (3:33).

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Causes of Long-term Climate Change

Many processes can cause climate to change. These include changes:

- in the amount of energy the Sun produces over years.
- in the positions of the continents over millions of years.
- in the tilt of Earth's axis and orbit over thousands of years.
- that are sudden and dramatic because of random catastrophic events, such as a large asteroid impact.
- in greenhouse gases in the atmosphere, caused naturally or by human activities.

Solar Variation

The amount of energy the Sun radiates is variable. **Sunspots** are magnetic storms on the Sun's surface that increase and decrease over an 11-year cycle (**Figure** 10.13). When the number of sunspots is high, solar radiation is also relatively high. But the entire variation in solar radiation is tiny relative to the total amount of solar radiation that there is and there is no known 11-year cycle in climate variability. The Little Ice Age corresponded to a time when there were no sunspots on the Sun.

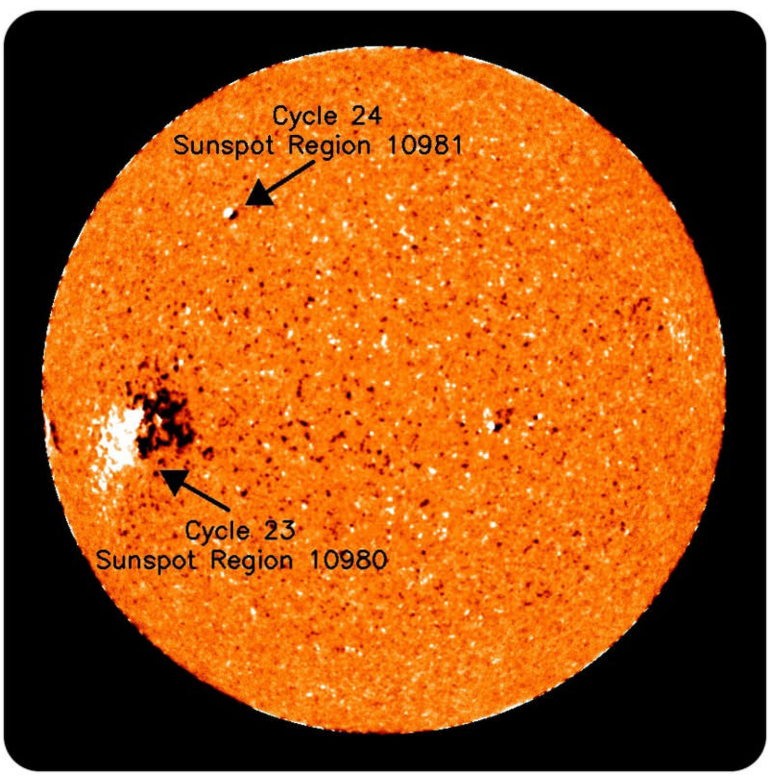

FIGURE 10.13
Sunspots on the face of the Sun.

Plate Tectonics

Plate tectonic movements can alter climate. Over millions of years as seas open and close, ocean currents may distribute heat differently. For example, when all the continents are joined into one supercontinent (such as Pangaea), nearly all locations experience a continental climate. When the continents separate, heat is more evenly distributed.

Plate tectonic movements may help start an ice age. When continents are located near the poles, ice can accumulate, which may increase albedo and lower global temperature. Low enough temperatures may start a global ice age.

Plate motions trigger volcanic eruptions, which release dust and CO_2 into the atmosphere. Ordinary eruptions, even large ones, have only a short-term effect on weather (**Figure** 10.14). Massive eruptions of the fluid lavas that create lava plateaus release much more gas and dust, and can change climate for many years. This type of eruption is exceedingly rare; none has occurred since humans have lived on Earth.

FIGURE 10.14

An eruption like Sarychev Volcano (Kuril Islands, northeast of Japan) in 2009 would have very little impact on weather.

Milankovitch Cycles

The most extreme climate of recent Earth history was the Pleistocene. Scientists attribute a series of ice ages to variation in the Earth's position relative to the Sun, known as **Milankovitch cycles**.

The Earth goes through regular variations in its position relative to the Sun:

1. The shape of the Earth's orbit changes slightly as it goes around the Sun. The orbit varies from more circular to more elliptical in a cycle lasting between 90,000 and 100,000 years. When the orbit is more elliptical, there is a greater difference in solar radiation between winter and summer.

2. The planet wobbles on its axis of rotation. At one extreme of this 27,000 year cycle, the Northern Hemisphere points toward the Sun when the Earth is closest to the Sun. Summers are much warmer and winters are much colder than now. At the opposite extreme, the Northern Hemisphere points toward the Sun when it is farthest from the Sun. This results in chilly summers and warmer winters.

3. The planet's tilt on its axis varies between 22.1° and 24.5°. Seasons are caused by the tilt of Earth's axis of rotation, which is at a 23.5° angle now. When the tilt angle is smaller, summers and winters differ less in temperature. This cycle lasts 41,000 years.

When these three variations are charted out, a climate pattern of about 100,000 years emerges. Ice ages correspond closely with Milankovitch cycles. Since glaciers can form only over land, ice ages only occur when landmasses cover the polar regions. Therefore, Milankovitch cycles are also connected to plate tectonics.

Changes in Atmospheric Greenhouse Gas Levels

Since greenhouse gases trap the heat that radiates off the planet's surfaces what would happen to global temperatures if atmospheric greenhouse gas levels decreased? What if greenhouse gases increased? A decrease in greenhouse gas levels decreases global temperature and an increase raises air temperature.

Greenhouse gas levels have varied throughout Earth history. For example, CO_2 has been present at concentrations less than 200 parts per million (ppm) and more than 5,000 ppm. But for at least 650,000 years, CO_2 has never risen above 300 ppm, during either glacial or interglacial periods (**Figure** 10.15).

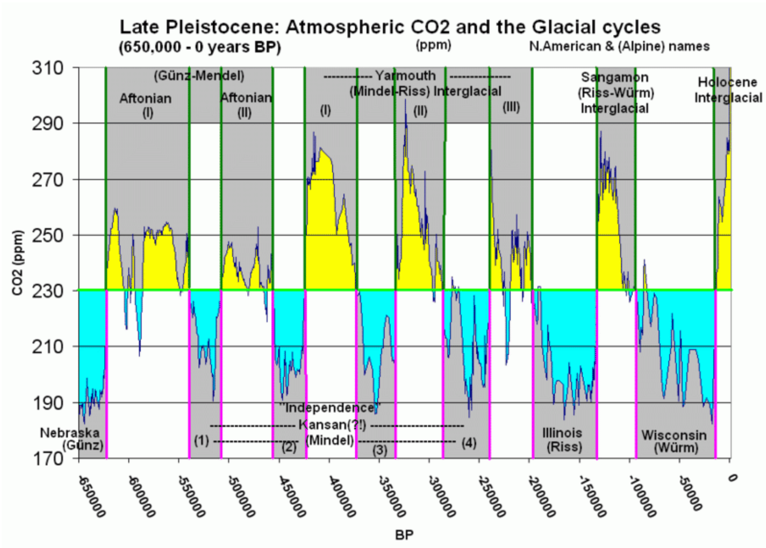

FIGURE 10.15

CO_2 levels during glacial (blue) and interglacial (yellow) periods. Are CO_2 levels relatively high or relatively low during interglacial periods? Current carbon dioxide levels are at 392 ppm, the highest level for the last 650,000 years. BP means years before present.

Natural processes add and remove CO_2 from the atmosphere

- Processes that add CO_2
  - volcanic eruptions
  - decay or burning of organic matter.
- Processes that remove CO_2
  - absorption by plant and animal tissue.

When plants are turned into fossil fuels the CO_2 in their tissue is stored with them. So CO_2 is removed from the atmosphere. What does this do to Earth's average temperature?

What happens to atmospheric CO_2 when the fossil fuels are burned? What happens to global temperatures?

Fossil fuel use has skyrocketed in the past few decades more people want more cars and industrial products. This has released CO_2 into the atmosphere.

Burning tropical rainforests, to clear land for agriculture, a practice called **slash-and-burn agriculture**, also increases atmospheric CO_2. By cutting down trees, they can no longer remove CO_2 from the atmosphere. Burning the trees releases all the CO_2 stored in the trees into the atmosphere.

There is now nearly 40% more CO_2 in the atmosphere than there was 200 years ago, before the Industrial Revolution. About 65% of that increase has occurred since the first CO_2 measurements were made on Mauna Loa Volcano, Hawaii, in 1958 (**Figure** 10.16).

- Methane: released from raising livestock, rice production, and the incomplete burning of rainforest plants.

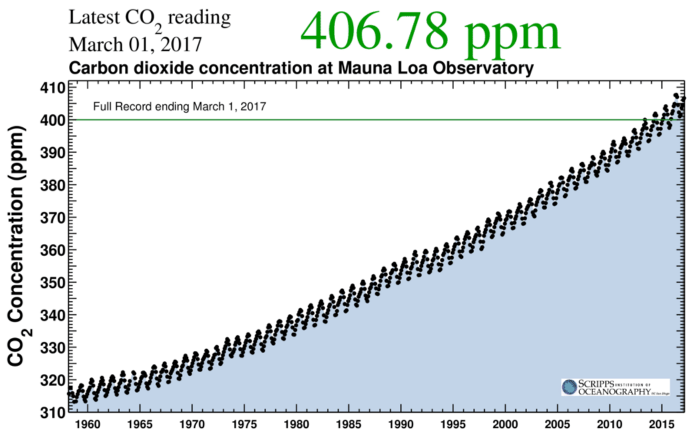

FIGURE 10.16

The Keeling Curve shows the increase in atmospheric CO_2 on Mauna Loa volcano since measurements began in 1958. The blue line shows yearly averaged CO_2. The red line shows seasonal variations in CO_2.

- Chlorofluorocarbons (CFCs): human-made chemicals that were invented and used widely in the 20th century.
- Tropospheric ozone: from vehicle exhaust, it has more than doubled since 1976.

Global Warming

With more greenhouse gases trapping heat, average annual global temperatures are rising. This is known as **global warming**.

Global warming - How Humans are Affecting our Planet from NASA, discusses the basics of global warming science **(4c)**: http://www.youtube.com/watch?v=VXvGPbHXxtc (7:58).

MEDIA

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Temperatures are Increasing

While temperatures have risen since the end of the Pleistocene, 10,000 years ago, this rate of increase has been more rapid in the past century, and has risen even faster since 1990. The nine warmest years on record have all occurred since 1998, and 16 of the 17 hottest years have occurred since 2001. The warmest year on record was 2016, with 2015 and 2014 being the second and third warmest (through 2016) (**Figure** below). People who are younger than 30, have never experienced a month in which Earth's average surface temperature was below average for that month during the 20^{th} century. The last time global temperatures were below that average was in February 1985.

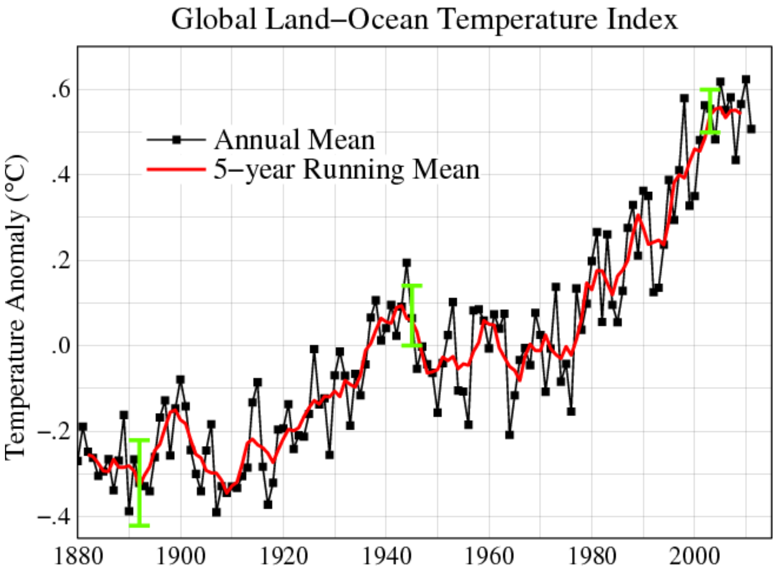

FIGURE 10.17

Recent temperature increases show how much temperature has risen since the Industrial Revolution began.

Annual variations aside, the average global temperature increased about 1.0°C (1.8°F) between 1880 and 2015, according to the Goddard Institute for Space Studies, NASA. This number doesn't seem very large. Why is it important?

http://www.giss.nasa.gov/research/news/20100121/

The United States has long been the largest emitter of greenhouse gases, with about 20% of total emissions in 2004 (**Figure** 10.18). As a result of China's rapid economic growth, its emissions surpassed those of the United States in 2008. However, it's also important to keep in mind that the United States has only about one-fifth the population of China. What's the significance of this? The average United States citizen produces far more greenhouse gases than the average Chinese person.

An animation of CO_2 released by different fossil fuels is seen here: CO_2 release by different fossil fuels at http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/CO2BTU_3.MPG

If nothing is done to decrease the rate of CO_2 emissions, by 2030, CO_2 emissions are projected to be 63% greater than they were in 2002.

A number of videos on the National Geographic site deal with global warming. Go to National Geographic Videos, Environment Videos, Global Warming, http://video.nationalgeographic.com/video/player/environment/ .

- A no-nonsense look at global warming and what we can do about it is found in "A Way Forward: Facing Climate Change."
- "Antarctic Ice" describes the changes that are already happening to Antarctica and what the consequences of future melting will be.
- "Glacier Melt" looks at melting in a large alpine glacier and the effects of glacier loss to Europe.
- In "Greenhouse Gases" researchers look at the effects of additional greenhouse gases on future forests.
- Researchers look for changes in the range of a mountain-top dwelling mammal, the pika.
- Polar bears, in their specialized habitat in the Arctic, are among the species already affected by warming temperatures.

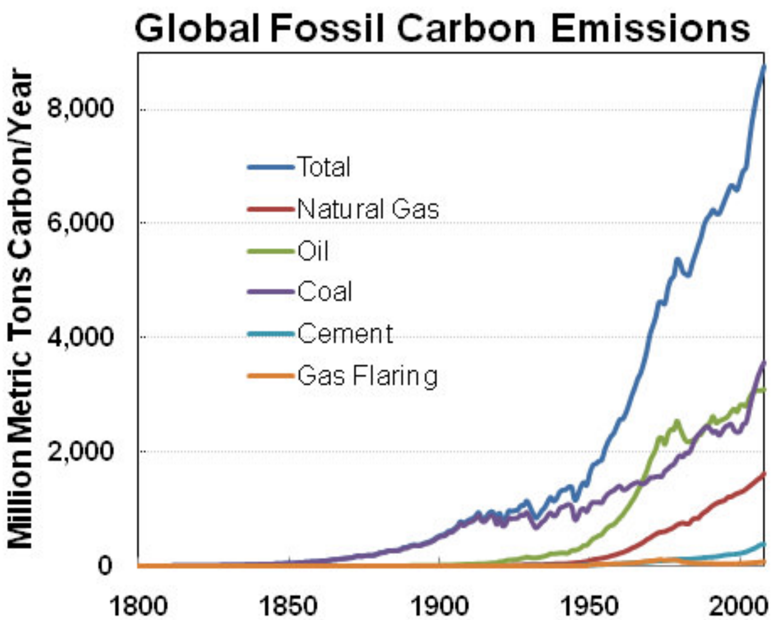

FIGURE 10.18

Global CO_2 emissions are rising rapidly. The industrial revolution began about 1850 and industrialization has been accelerating.

KQED: Climate Watch: California at the Tipping Point

Warming temperatures are bringing changes to much of the planet, including California. Sea level is rising, snow pack is changing and the ecology of the state is responding to these changes. Learn more in the video below:

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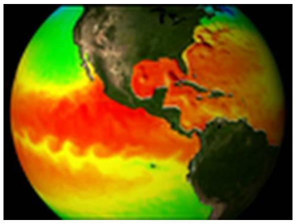
Future Warming

The amount CO_2 levels will rise in the next decades is unknown. What will this number depend on in the developed nations? What will it depend on in the developing nations? In the developed nations it will depend on technological advances or lifestyle changes that decrease emissions. In the developing nations, it will depend on how much their lifestyles improve and how these improvements are made.

Computer models are used to predict the effects of greenhouse gas increases on climate for the planet as a whole and also for specific regions. If nothing is done to control greenhouse gas emissions and they continue to increase at current rates, the surface temperature of the Earth can be expected to increase between 0.5°C and 2.0°C (0.9°F and 3.6°F) by 2050 and between 2° and 4.5°C (3.5° and 8°F) by 2100, with CO_2 levels over 800 parts per million (ppm). On the other hand, if severe limits on CO_2 emissions begin soon, temperatures could rise less than 1.1°C (2°F) by 2100.

This video explores the tools NASA scientists use to determine how the climate is changing **(6d)**: http://www.youtu be.com/watch?v=JRayIgKublg (4:00).



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Whatever the temperature increase, it will not be uniform around the globe. A rise of 2.8°C (5°F) would result in 0.6° to 1.2°C (1° to 2°F) at the equator, but up to 6.7°C (12°F) at the poles. So far, global warming has affected the North Pole more than the South Pole, but temperatures are still increasing at Antarctica (**Figure** 10.19).

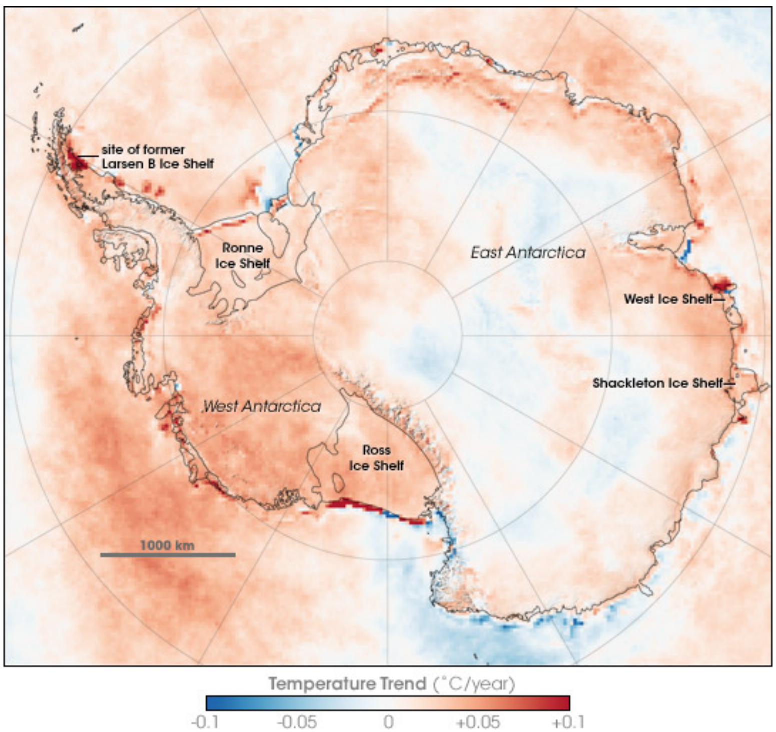

FIGURE 10.19

Temperature changes over Antarctica.

The following images show changes in the earth and organisms as a result of global warming: **Figure** 10.20, **Figure** 10.21, and **Figure** 10.22.

The timing of events for species is changing. Mating and migrations take place earlier in the spring months. Species that can are moving their ranges uphill. Some regions that were already marginal for agriculture are no longer farmable because they have become too warm or dry.

What are the two major effects being seen in this animation? Glaciers are melting and vegetation zones are moving uphill. If fossil fuel use exploded in the 1950s, why do these changes begin early in the animation? Does this mean that the climate change we are seeing is caused by natural processes and not by fossil fuel use?

Animations of temperature anomalies for 5- and 10-year periods: http://data.giss.nasa.gov/gistemp/animations/

As greenhouse gases increase, changes will be more extreme. Oceans will become slightly more acidic, making it more difficult for creatures with carbonate shells to grow, and that includes coral reefs. A study monitoring ocean

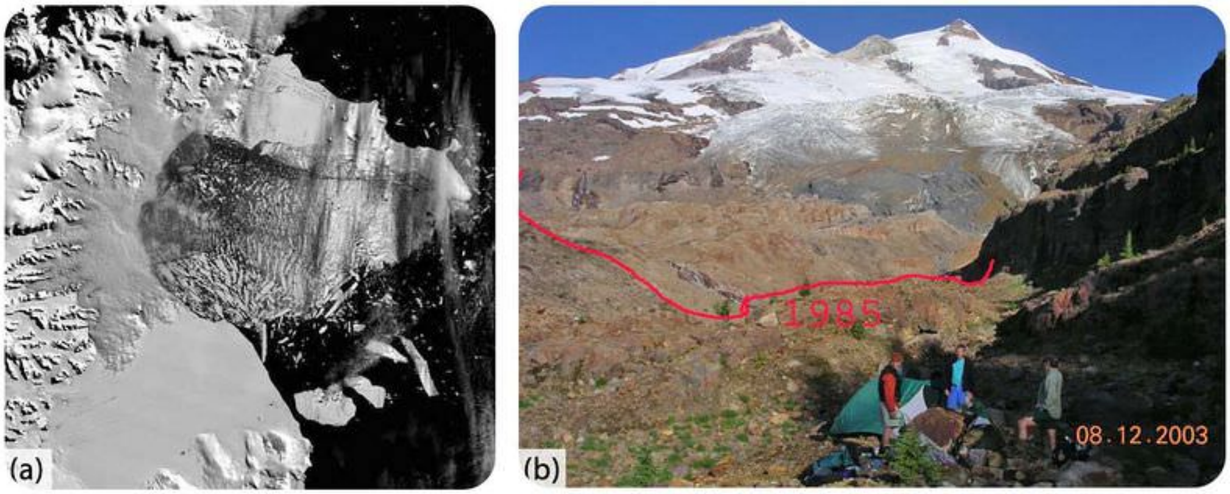

FIGURE 10.20
(a) Breakup of the Larsen Ice Shelf in Antarctica in 2002 was related to climate warming in the region. (b) The Boulder Glacier has melted back tremendously since 1985. Other mountain glaciers around the world are also melting.

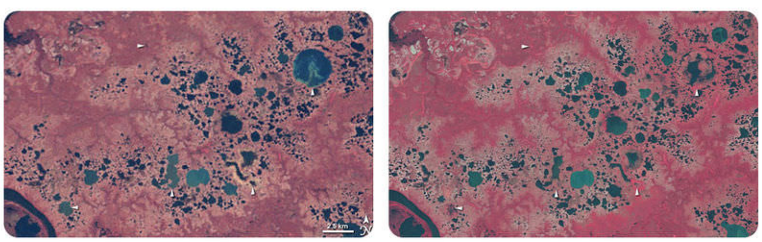

FIGURE 10.21
Permafrost is melting and its extent decreasing. There are now fewer summer lakes in Siberia.

acidity in the Pacific Northwest found ocean acidity increasing ten times faster than expected and 10% to 20% of shellfish (mussels) being replaced by acid tolerant algae.

Plant and animal species seeking cooler temperatures will need to move poleward 100 to 150 km (60 to 90 miles) or upward 150 m (500 feet) for each 1.0°C (8°F) rise in global temperature. There will be a tremendous loss of biodiversity because forest species can't migrate that rapidly. Biologists have already documented the extinction of high-altitude species that have nowhere higher to go.

Decreased snowpacks, shrinking glaciers, and the earlier arrival of spring will all lessen the amount of water available in some regions of the world, including the western United States and much of Asia. Ice will continue to melt and sea level is predicted to rise 18 to 97 cm (7 to 38 inches) by 2100 (**Figure** 10.23). An increase this large will gradually flood coastal regions where about one-third of the world's population lives, forcing billions of people to move inland.

Weather will become more extreme with heat waves and droughts. Some modelers predict that the Midwestern United States will become too dry to support agriculture and that Canada will become the new breadbasket. In all, about 10% to 50% of current cropland worldwide may become unusable if CO_2 doubles.

Although scientists do not all agree, hurricanes are likely to become more severe and possibly more frequent.

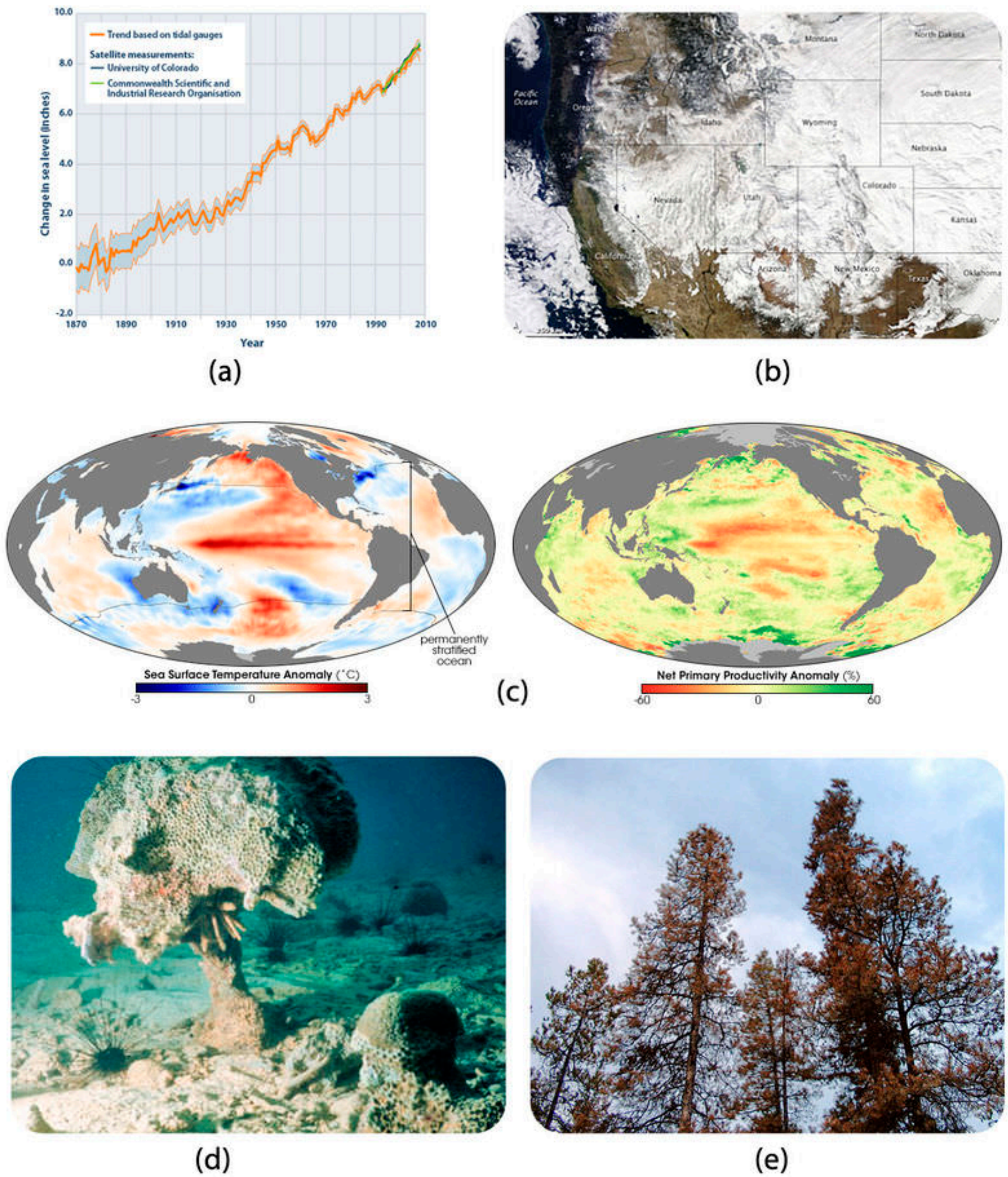

FIGURE 10.22

(a) Melting ice caps add water to the oceans, so sea level is rising. Remember that water slightly expands as it warms — this expansion is also causing sea level to rise. (b) Weather is becoming more variable with more severe storms and droughts. Snow blanketed the western United States in December 2009. (c) As surface seas warm, phytoplankton productivity has decreased. (d) Coral reefs are dying worldwide; corals that are stressed by high temperatures turn white. (e) Pine beetle infestations have killed trees in western North America The insects have expanded their ranges into areas that were once too cold.

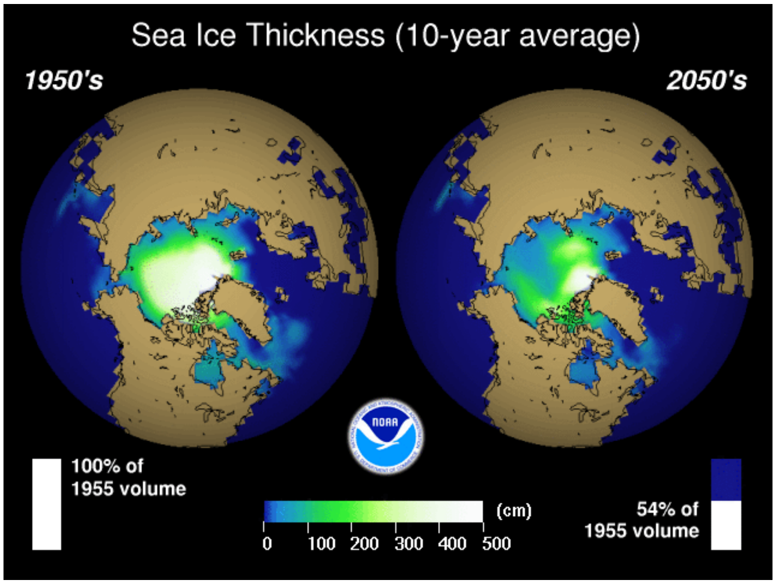

FIGURE 10.23
Sea ice thickness around the North Pole has been decreasing in recent decades and will continue to decrease in the coming decades.

Tropical and subtropical insects will expand their ranges, resulting in the spread of tropical diseases such as malaria, encephalitis, yellow fever, and dengue fever.

You may notice that the numerical predictions above contain wide ranges. Sea level, for example, is expected to rise somewhere between 18 and 97 cm — quite a wide range. What is the reason for this uncertainty? It is partly because scientists cannot predict exactly how the Earth will respond to increased levels of greenhouses gases. How quickly greenhouse gases continue to build up in the atmosphere depends in part on the choices we make.

An important question people ask is this: Are the increases in global temperature natural? In other words, can natural variations in temperature account for the increase in temperature that we see? The answer is no. Changes in the Sun's irradiance, El Niño and La Niña cycles, natural changes in greenhouse gas, and other atmospheric gases cannot account for the increase in temperature that has already happened in the past decades.

This video discusses how, by using the CERES satellite, scientists monitor energy in the atmosphere, including incoming solar energy and reflected and absorbed energy. Greenhouse warming that results from atmospheric greenhouse gasses is also monitored **(4c)**: http://www.youtube.com/watch?v=JFfD6jn_OvA (4:31).

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KQED: Going UP: Sea Level Rise in San Francisco Bay

Along with the rest of the world's oceans, San Francisco Bay is rising. Changes are happening slowly in the coastal arena of the San Francisco Bay Area and even the most optimistic estimates about how high and how quickly this rise will occur indicate potentially huge problems for the region. Learn more in the video below:

MEDIA

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Lesson Summary

- Climate has changed throughout Earth history. In general, when greenhouse gas levels are high, temperature is high.
- Greenhouse gases are now increasing because of human activities, especially fossil fuel use.
- We are already seeing the effects of these rising greenhouse gases in higher temperatures and changes to physical and biological systems.
- Society must choose to reduce greenhouse gas emissions or face more serious consequences.

Review Questions

1. Why is the climate currently warming?

2. Why does sea level rise and fall during interglacial and glacial periods?

3. How can the human history of Greenland be related to climate cycles?

4. If climate has been much warmer in Earth history, why do we need to worry about global warming now?

5. When the weather along coastal California is especially rainy with many winter storms, what is likely to be happening in the equatorial Pacific?

6. The Peruvian anchovy fishery collapsed in 1972. Using what you know about climate and food webs, can you devise an explanation for this event?

7. What two events must occur for there to be an ice age?

8. What human activities increase greenhouse gases in the atmosphere? Explain.

9. Why are CO_2 emissions projected to increase during the next few decades?

10. What role will the developed nations play in increasing CO_2 emissions in the next few decades?

11. Why do storms increase in frequency and intensity as global temperatures increase?

12. Earth is undergoing some important changes, some of which are known about because of and monitored by satellites. Describe the sort of global change that satellites can monitor.

13. What will happen if sea level rises by 60 cm (2 feet) by the end of this century? Which locations will be hardest hit?

14. What can be done to reduce greenhouse gas emissions?

Virtually all credible scientists agree that Earth is warming and human actions are largely to blame. The evidence comes from many areas of science: atmospheric chemistry, earth history, glaciology, ecology, astronomy (stars, the Sun), energy (fossil fuels), oceanography, remote sensing, agricultural science, and others. Because the media like to present a "balanced" story, media outlets often present the side of climate skeptics who do not believe that global warming is happening, or that if it is happening, that human actions are largely responsible.

From the following videos you can learn basic global warming science, the effects already being seen from changing climate, and learn a bit about risk assessment:

Global Warming 101 touches on all aspects of the global warming story in just a few minutes **(1l - IE Stand.)**: http://www.youtube.com/watch?v=-lubjnPA0b0 (1:28).

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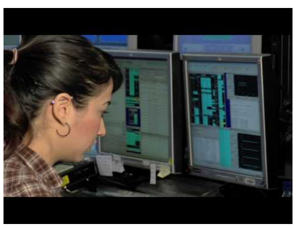
Observations made for the past decade by the TERRA satellite shows how Earth is changing because of warmer temperatures **(1l - IE Stand.)**: http://www.youtube.com/watch?v=h-VvMUseE_o (4:57).



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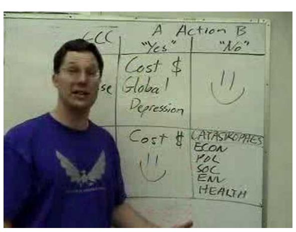
The Most Terrifying Video You'll Ever See evaluates the risks of choosing action or inaction on global warming **(1l - IE Stand.)**: http://www.youtube.com/watch?v=zORv8wwiadQ (9:34).



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There are many other videos that look at the issue of climate change, some by those who deny that it is happening. Look at some videos created by the so-called *climate skeptics* and write down their arguments, then write down the scientific counter-arguments. Next check out this series: Climate Crock of the Week *'(1l - IE Stand.)* http://www.youtube.com/watch?v=_KK8F5noCrA (2:02), which dismantles the arguments made by those who deny global warming science one by one.

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California has gone its own way by passing legislation to reduce the state's greenhouse gas emissions to 1990 levels. A strong proponent is Governor Arnold Schwarzenegger, who has broken with the Republican party in accepting that global warming is real and that something must be done to slow its effects. The following videos address California's cap-and-trade policy and the legislation:

Governor Schwarzenegger discusses why California Chose Cap-and-Trade in regulating carbon emissions **(1m - IE Stand.)**: http://www.youtube.com/watch?v=fON7t5DPQbk (3:40).

MEDIA

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URL: http://www.ck12.org/flx/render/embeddedobject/8472

Governor Arnold Schwarzenegger explains why the emissions standards adopted by California should be picked up by the rest of the country **(1m - IE Stand.)**: http://www.youtube.com/watch?v=VnZtT7Nj1rI (3:52).

MEDIA

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URL: http://www.ck12.org/flx/render/embeddedobject/8473

Here Governor Schwarzenegger addresses the impact of global warming on fires, attacks the Bush administration on its policies on global warming and drilling for oil off the coast of California, and reviews recent U.S. history on alternative energy research **(1m - IE Stand.)**: http://www.youtube.com/watch?v=osBNMvp2Cws (5:24).

MEDIA

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URL: http://www.ck12.org/flx/render/embeddedobject/8474

California water board official answers questions about California's legislation on global warming **(1m - IE Stand.)**: http://www.youtube.com/watch?v=h-ZMsNdd-34 (4:03).

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Further reading/supplemental links

Illustrating the concept of El Niño and La Niña: http://earthguide.ucsd.edu/enso/ .

Points to Consider

- Nearly all climate scientists agree that human activities are causing the accelerated warming of the planet that we see today. Why do you think that the media is still talking about the controversy about this idea when scientists are almost entirely in agreement?
- If greenhouse gas emissions must be lowered to avoid some of the more serious consequences of global warming, why have humans not done something to lower these emissions instead of letting them increase?
- In what ways can progress be made in reducing greenhouse gas emissions? Think about this on a variety of scales: for individuals, local communities, nations, and the global community.

10.4 Protecting Biodiversity - Advanced

Learning Objectives

- Acknowledge that your daily activities and decisions can significantly help to protect biodiversity.
- Evaluate your consumption - of food, clothing, furniture, and cleaning products.
- Appreciate the importance of water resources and know how to use them wisely.
- Evaluate your choice and use of energy sources.
- Assess the importance of minimizing waste, and of using best practices for waste disposal.
- Know how to avoid transporting and releasing exotic species.
- Realize that you can practice sustainable management of your own land, from small yards to local, state, and federal lands which also belong to you.
- Describe sustainability and its role in decision-making.
- Explain how learning and active citizenship can contribute to protecting biodiversity.

Why is biodiversity important?

There are numerous reasons. What can happen in an ecosystem even if just one species disappears? How does this affect the balance in that ecosystem? How does this affect us? What about all the species we do not even know anything about? What information is lost if those species vanish? All of these are important questions.

Protecting Biodiversity

Consider the following facts from the American Museum of Natural History's Center for Biodiversity and Conservation (AMNH-CBC) and the Environmental Protection Agency (EPA):

Every year, Americans:

- Throw away at least 2 billion disposable razors
- Discard enough paper and wood to heat 5 million homes for 200 years
- Drink more than two billion gallons of bottled water, costing 900 times more money than tap water - not counting the energy and toxics involved in packaging and shipping
- Retire up to 130 million cell phones, containing toxic metals such as arsenic, cadmium, and lead
- Generate about 3 million tons of toxic electronics waste (e-waste), and recycle only about 11%

Do any of these everyday experiences apply to you? You may be surprised to learn there is quite a lot you can do to help. Read carefully through the suggestions below, noting those that appeal to you strongly and those which seem most feasible. Many involve little more than awareness in decisions you already or will soon make.

Consume Thoughtfully and Wisely

Reduce Your Consumption Where Possible. Re-use, and Recycle. Make Durability and Efficiency Your Criteria for Product Purchases

In general, when you buy:

- Buy locally whenever possible to reduce transportation costs for you and for the environment.
- Be aware of the natural resources used to make and transport any product you buy.
- Substitute other materials for plastics - which are made from petroleum and produce toxic waste.

When you buy food, plan your diet for your own health and that of the environment. Eat low on the food chain; top carnivores get the least energy and acquire the most poison. Buy local produce in season - to reduce transportation costs and the need for pesticides. Buy produce at farmers' markets or a Community Supported Agriculture (CSA) programs to support local farmers and reduce demand for energy-consuming and polluting large-scale agriculture and marketing. Choose organic produce - for your own health and to protect the environment from excessive nutrients and pesticides (**Figure** 10.24).

When you buy fish for food or for your aquarium, check to be sure that commercial species are not from over harvested areas, and verify that tropical saltwater fish were not collected using cyanide.

When you need paper products, be sure they are made of recycled fiber, or consider alternative materials such as hemp, kenaf, cornstarch, or old money or maps. Replace paper napkins and paper towels with cloth materials. Reuse envelopes and boxes. Wrap gifts in the comics or reusable cloth gift bags.

When you buy products for cleaning, painting, or washing your car, check the ingredients to be sure you are not exposing yourself and the environment to unnecessary toxins. Vinegar and baking soda work wonders!

When you buy wood or wood products, be sure harvesting followed **sustainable forest management** practices which ensure future productivity, biodiversity, and ecosystem health. Look for SmartWood, FSC (Forest Stewardship Council) or similar labels, and consider recycled or salvaged wood.

When You Use Water, Remember Its Importance To All Life

- Check for water leaks and repair drips with new washers (**Figure** 10.25).

FIGURE 10.24
Eat with the environment and your health in mind! In the United States, the Department of Agriculture (USDA) sets standards for organic products and certification. The green-and-white seal identifies products which have at least 95% organic ingredients. The program is helpful to consumers, but not without controversy (read Barbara Kingsolver's *Animal, Vegetable, Miracle,* and/or Michael Pollan's *Omnivore's Dilemma*).

- Use low-flush toilets and low-flow faucets and shower heads.
- Have your tap water tested; use filters or refillable delivery if needed, rather than bottled water.

When You Must Use Energy, Consider Consequences and Choose Your Source Carefully

- Unplug electronic equipment such as fax machines, power tools, and anything connected to a remote control.
- Turn off power sources and lights when not in use.
- Use your bicycle, and support bike-friendly cities and roads.
- Walk! It's good for you, as well as the environment.
- Use public transportation, and support its expansion.
- Make energy-efficiency your #1 priority when you purchase appliances.
- Make fuel-efficiency your #1 priority if you purchase a car.
- Turn down your thermostat, especially at night. Just 2^{o}F saves 500 pounds of greenhouse-inducing CO_2!
- Weatherstrip and caulk doors and windows.
- Replace incandescent with fluorescent light bulbs, which are four times as efficient and last far longer.
- The EPA Energy Star Logo helps consumers to identify energy-efficient products. The less fossil fuel energy we use, the fewer greenhouse gases we release, reducing the threat of climate change.

When You Must Dispose of Waste, Learn the Best Practice for Its Disposal

- Reduce or eliminate your use of plastic bags, sandwich bags, and six-pack plastic rings (and don't release balloons!) so that endangered sea turtles do not mistake these for their favorite food - jellyfish.
- Minimize and compost food waste.
- Recycle motor oil and unused paint.
- Use appropriate local hazardous waste facilities for recommended chemicals and medicines.

FIGURE 10.25

One drop per second from a dripping faucet wastes 2,700 gallons of water per year and adds to sewer and/or septic costs, as well.

- Donate obsolete computers and other electronic equipment - or if you cannot, recycle such "e-waste" properly (**Figure** 10.26).

Don't Contribute to the Burgeoning Problem of Exotic Species

(The following points reference **Figure** 10.27.)

- Don't release aquarium fish, turtles, birds, or other pets into the wild.

- Clean your boat thoroughly after use, and avoid traveling with wild plants and animals.
- Your pet is also considered to be an exotic species. Don't let your pets hunt birds or wild animals.

Practice Sustainable Management on Your Own Land, Even If it is "Only" a Small Yard

- Minimize nonpoint source pollution by using organic or natural pesticides and fertilizers.

FIGURE 10.26
Computer equipment becomes obsolete quickly and contains toxins such as lead and mercury. Consider donating your obsolete equipment, and if you must discard it, be sure you follow specific guidelines for recycling and hazardous waste disposal.

FIGURE 10.27
Exotic (invasive or alien) species are often considered the #2 cause of extinction. Learn how to avoid transporting them!

- Plant shade trees for air-conditioning and to absorb CO_2.
- Water plants and lawns in the evening.
- Better yet, use native and/or drought-tolerant plants for landscaping.
- Remember that City, County, State, and Federal lands are your lands, too. Get involved in local zoning and land use planning to ensure that development follows sustainable guidelines.

Adopt and Spread Sustainable Perspectives and Philosophy

- Focus on diversity as a whole - genes, communities and ecosystems - rather than single "poster" species.
- Support the inclusion of ecosystems services in economic valuations.
- Encourage protection of areas large enough to accommodate migration, flooding, buffer zones, pollution from nearby development, and people and their activities.

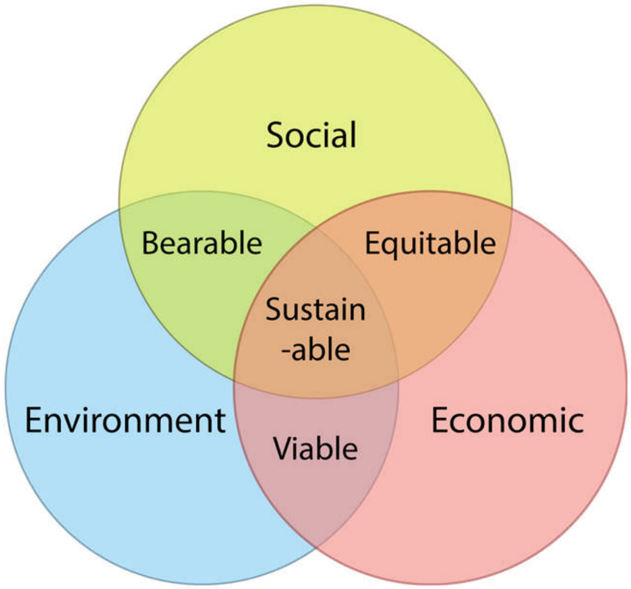

FIGURE 10.28
Sustainability as a goal in decision-making seeks the intersection of three sets of values. The environmental component includes maintaining ecosystem quality indefinitely.

- Realize that inequitable distribution of population, land, resources, education, and wealth threatens biodiversity.
- Promote the concept of sustainability as a guide for conservation decisions (**Figure** 10.28).
- Join philosophers and religious and community groups to explore environmental ethics.
- Help *everyone* understand basic ecology and the wealth of biodiversity shaped by billions of years of evolution.

Learn More!

- About the species with which you share the Earth.
- About local, national, and international threats to biodiversity
- About more solutions as they develop
- Jump in! Join local groups which monitor ecosystem health: Frog Watch, River Watch, or Bird Counts.
- Educate yourself about complex issues such as government subsidies and new technologies.
- Find out about local protected lands and volunteer your time and energy to restore native ecosystems.

Activate!

- Exercise your citizenship to protect biodiversity. Vote, communicate your views, and push for stronger environmental protection laws.
- Support organizations which promote national reserves, international treaties, and resource conservation.
- Support efforts by zoos, arboretums, museums and seed banks to help maintain genetic diversity through research, breeding, educational, and fundraising programs.

Summary

- After reducing consumption and reusing and recycling, careful consumption can help to conserve ecosystems.
- Our daily activities and decisions can significantly help to protect biodiversity.
- Local, seasonal products save energy costs for transportation.
- Durable and efficient products reduce long-term resource consumption.

- Wise use of water resources helps to prevent desertification of ecosystems.
- Energy alternatives to fossil fuels reduce greenhouse gases, although nuclear energy has its own dangers.
- After minimizing waste, best practices for waste disposal ensure less pollution of ecosystems.
- The threats to biodiversity posed by exotic species mean that everyone should learn to avoid transporting them.
- Sustainable management of land, from small yards to local, state, and federal lands, conserves ecosystems.
- Sustainability as a guide for decision-making balances social, economic, and environmental values to structure human activities such that they can continue indefinitely.
- Learning about biodiversity and ecology is an important part of valuing and protecting the diversity of life.
- Voting, membership in conservation organizations, and working toward protective legislation can contribute to genetic, species, and ecosystem diversity.

Review

1. "Reduce, Re-use, and Recycle" is so familiar to many people that it has lost much of its meaning. Yet it remains an efficient summary of the best conservation principles. Explain. Choose one new idea to add to these workhorses.
2. What ecological principles can govern your food choices to help protect your health, biodiversity, and even global stability?
3. How does the concept of sustainable use differ from "reduce, reuse, and recycle"? How is it similar?
4. According to Barry Commoner, there are Four Laws of Ecology. Explain how his laws govern the way nature does - and humans should - use energy and material resources in order to protect biodiversity. The Four Laws of Ecology:
   a. Everything is connected to everything else.
   b. Everything must go somewhere.
   c. Nature knows best.
   d. There is no such thing as a free lunch.

10.5 Renewable Energy Resources

Lesson Objectives

- Describe different renewable resources and understand why they are renewable.
- Discuss how the Sun is the source of most of Earth's energy.
- Describe how energy is carried from one place to another as heat and by moving objects.
- Discuss why some renewable energy sources cost less than others do and why some cause less pollution than others.
- Explain how renewable energy resources are turned into useful forms of energy.
- Describe how the use of different renewable energy resources affects the environment.

Vocabulary

- biofuel
- conduction
- radiation

Introduction

Fossil fuels have the advantage of being cheap and transportable, but they cause environmental damage and will eventually run out. Renewable energy sources, by definition, will not run out, and most do not cause much pollution. But renewable energy sources do have a downside, too. Both the advantages and disadvantages of solar, water, wind, biomass, and geothermal energy will be described in this lesson.

Solar Power

The Sun is Earth's main source of energy, making the development of solar power a natural choice for an alternative energy source.

Solar Energy

Energy from the Sun comes from the lightest element, hydrogen, fusing together to create the second lightest element, helium. Nuclear fusion releases tremendous amounts of solar energy. The energy travels to the Earth, mostly as visible light. The light carries the energy through the empty space between the Sun and the Earth as **radiation**.

Solar Power Use

Solar energy has been used for power on a small scale for hundreds of years, and plants have used it for billions of year. Unlike energy from fossil fuels, which almost always come from a central power plant or refinery, solar power can be harnessed locally (**Figure** 10.29). A set of solar panels on a home's rooftop can be used to heat water for a swimming pool or can provide electricity to the house.

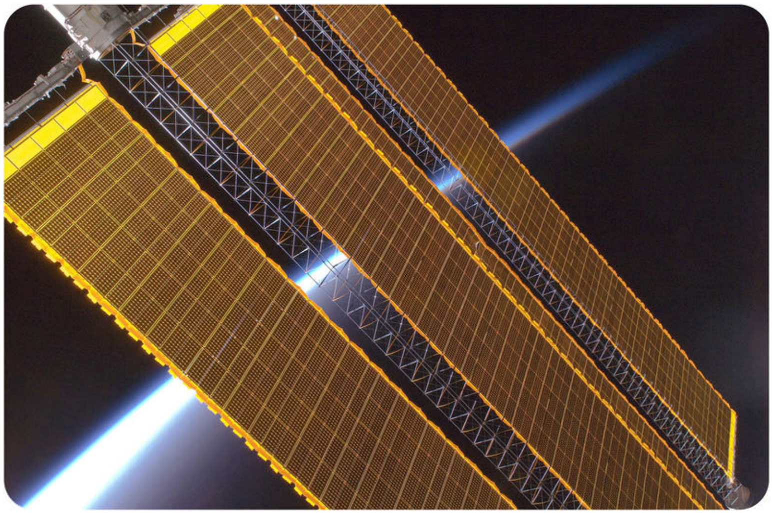

FIGURE 10.29
Solar panels supply power to the International Space Station.

Society's use of solar power on a larger scale is just starting to increase. Scientists and engineers have very active, ongoing research into new ways to harness energy from the Sun more efficiently. Because of the tremendous amount of incoming sunlight, solar power is being developed in the United States in southeastern California, Nevada, and Arizona.

Solar power plants turn sunlight into electricity using a large group of mirrors to focus sunlight on one place, called a receiver (**Figure** 10.30). A liquid, such as oil or water, flows through this receiver and is heated to a high temperature by the focused sunlight. The heated liquid transfers its heat to a nearby object that is at a lower temperature through a process called **conduction**. The energy conducted by the heated liquid is used to make electricity.

A video of how solar energy can be concentrated so that it can be used for power: http://www1.eere.energy.gov/multimedia/video_csp.html .

Consequences of Solar Power Use

Solar energy has many benefits. It is extremely abundant, widespread, and will never run out. But there are problems with the widespread use of solar power.

- Sunlight must be present. Solar power is not useful in locations that are often cloudy or at night. However, storage technology is being developed.
- The technology needed for solar power is still expensive. An increase in interested customers will provide incentive for companies to research and develop new technologies and to figure out how to mass-produce existing technologies (**Figure** 10.31).
- Solar panels require a lot of space. Fortunately, solar panels can be placed on any rooftop to supply at least some of the power required for a home or business.

FIGURE 10.30
This solar power plant uses mirrors to focus sunlight on the tower in the center. The sunlight heats a liquid inside the tower to a very high temperature, producing energy to make electricity.

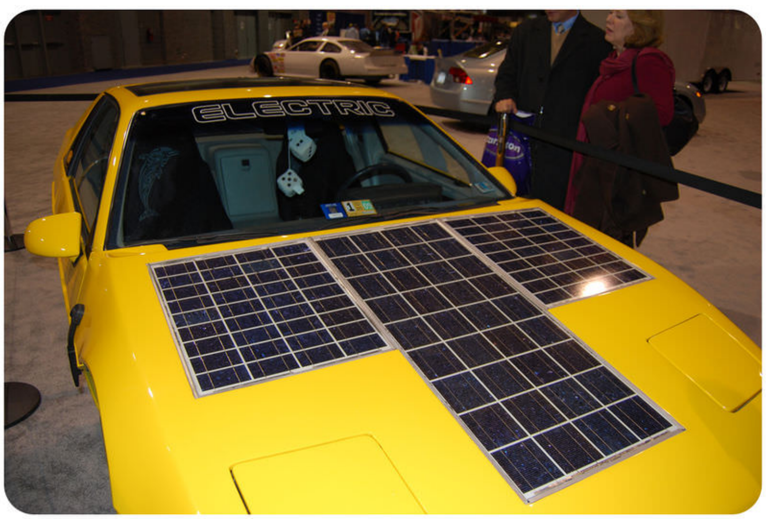

FIGURE 10.31
This experimental car is one example of the many uses that engineers have found for solar energy.

Water Power

Water covers 70% of the planet's surface, and water power (hydroelectric power) is the most widely used form of renewable energy in the world. Hydroelectric power from streams provides almost one fifth of the world's electricity.

Hydroelectric Power

Remember that potential energy is the energy of an object waiting to fall. Water held behind a dam has a lot of potential energy. In a hydroelectric plant, a dam across a riverbed holds a stream to create a reservoir. Instead of flowing down its normal channel, the water is allowed to flow into a large turbine. As the water moves, it has kinetic energy, which makes the turbine spin. The turbine is connected to a generator, which makes electricity (**Figure** 10.32).

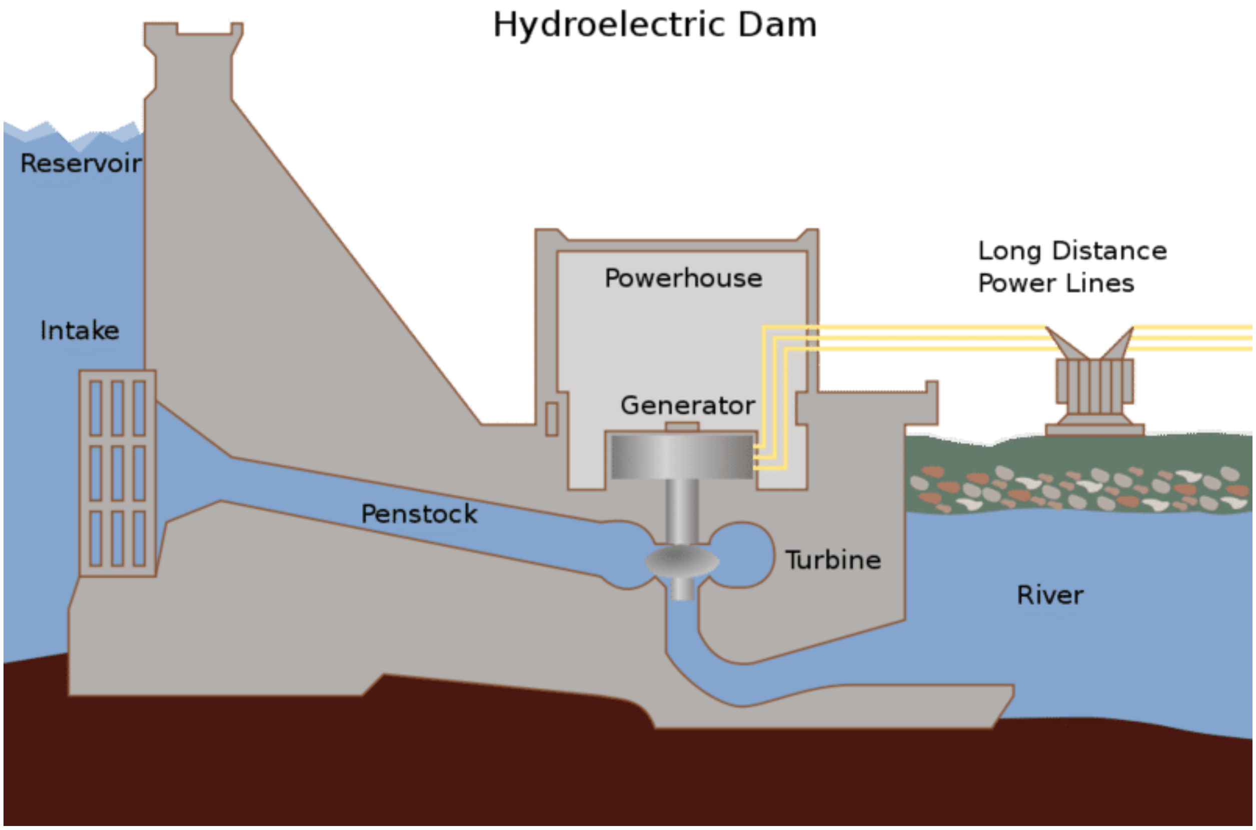

FIGURE 10.32
A cross-section of a hydroelectric plant.

Most of the streams in the United States and elsewhere in the developed world that are suitable for hydroelectric power have already been dammed (**Figure** 10.33). In California, about 14.5% of the total electricity comes from hydropower. The state's nearly 400 hydropower plants are mostly located in the eastern mountain ranges where large streams descend down a steep grade.

Consequences of Water Power Use

The major benefit of hydropower is that it generates power without releasing any pollution. Hydropower is also a renewable resource since the stream will keep on flowing. However, there are a limited number of suitable dam sites. Hydropower also has environmental problems. When a large dam disrupts a river's flow, it changes the ecosystem upstream. As the land is flooded by rising water, plants and animals are displaced or killed. Many beautiful landscapes, villages, and archeological sites have been drowned by the water in a reservoir (**Figure** 10.34).

The dam and turbines also change the downstream environment for fish and other living things. Dams slow the release of silt so that downstream deltas retreat and seaside cities become dangerously exposed to storms and rising sea levels.

FIGURE 10.33
Hydroelectric dams like this one use the power of moving water to create electricity.

FIGURE 10.34
Glen Canyon Dam in Arizona created Lake Powell. The dam was controversial because it flooded Glen Canyon, a beautiful desert canyon.

Ocean Water Power

The energy of waves and tides can be used to produce water power. Tidal power stations may need to close off a narrow bay or estuary. Wave power applications have to be able to withstand coastal storms and the corrosion of seawater. Because of the many problems with them, tide and wave power plants are not very common.

Wind Power

Wind power is the fastest growing renewable energy source in the world. Windmills are now seen in many locations, either individually or, more commonly, in large fields.

Wind Powering America follows the development of wind power in the United States over the past several years.

Wind Energy

Energy from the Sun also creates wind, which can be used as wind power. The Sun heats different locations on Earth by different amounts. Air that becomes warm rises and then sucks cooler air into that spot. The movement of air from one spot to another along the ground creates wind. Since wind is moving, it has kinetic energy.

Wind Power Use

Wind is the source of energy for wind power. Wind has been used for power for centuries. For example, windmills were used to grind grain and pump water. Sailing ships traveled by wind power long before ships were powered by fossil fuels. Wind can be used to generate electricity, as the moving air spins a turbine to create electricity (**Figure** 10.35).

FIGURE 10.35
Wind turbines like the ones shown here turn wind into electricity without creating pollution.

This animation shows how wind power works: http://www.energysavers.gov/your_home/electricity/index.cfm/mytopic=10501 .

Consequences of Wind Power

Wind power has many advantages. It does not burn, so it does not release pollution or carbon dioxide. Also, wind is plentiful in many places. Wind, however, does not blow all of the time, even though power is needed all of the time. Just as with solar power, engineers are working on technologies that can store wind power for later use.

Windmills are expensive and wear out quickly. A lot of windmills are needed to power a region, so nearby residents may complain about the loss of a nice view if a wind farm is built. Coastlines typically receive a lot of wind, but wind farms built near beaches may cause unhappiness for local residents and tourists.

The Cape Wind Project off of Cape Cod has been approved but is generating much controversy. Opponents are in favor of green power but not at that location. Proponents say that clean energy is needed and the project would supply 75% of the electricity needed for Cape Cod and nearby islands (**Figure** 10.36).

California was an early adopter of wind power. Windmills are found in mountain passes where the cooler Pacific Ocean air is sucked through on its way to warmer inland valleys. Large fields of windmills can be seen at Altamont

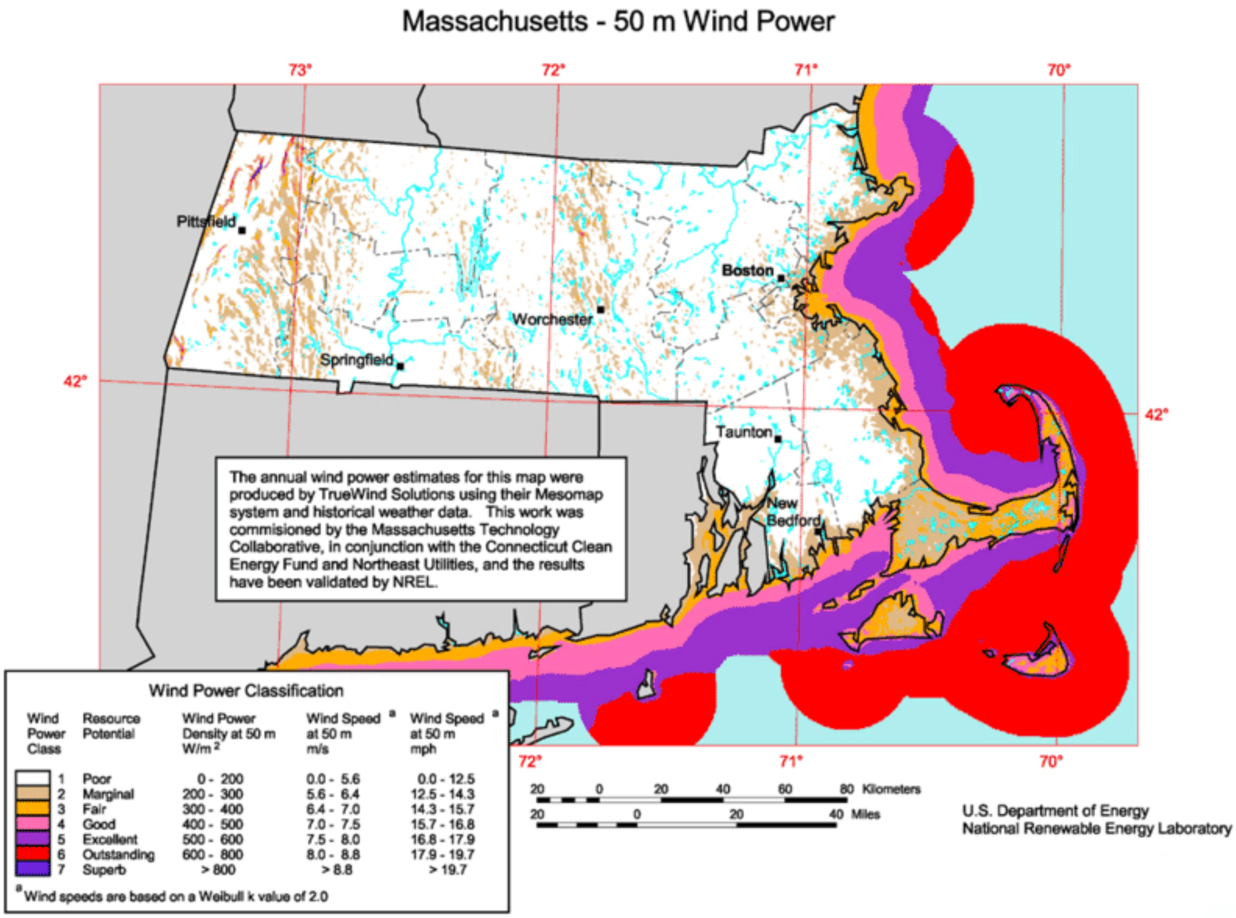

FIGURE 10.36

Cape Wind off of Cape Cod in Massachusetts receives a great deal of wind (red color) but is also popular with tourists for its beauty.

pass in the eastern San Francisco Bay Area, San Gorgonio Pass east of Los Angeles, and Tehachapi Pass at the southern end of the San Joaquin Valley.

Geothermal Power

Geothermal energy comes from heat deep below the surface of the Earth. Nothing must be done to the geothermal energy. It is a resource that can be used without processing.

Geothermal Energy

The heat that is used for geothermal power may come to the surface naturally as hot springs or geysers, like The Geysers in northern California. Where water does not naturally come to the surface, engineers may pump cool water into the ground. The water is heated by the hot rock and then pumped back to the surface for use. The hot water or steam from a geothermal well spins a turbine to make electricity.

Geothermal energy is clean and safe. The energy source is renewable since hot rock is found everywhere in the Earth, although in many parts of the world the hot rock is not close enough to the surface for building geothermal power plants. In some areas, geothermal power is common (**Figure** 10.37).

FIGURE 10.37

A geothermal energy plant in Iceland. Iceland gets about one fourth of its electricity from geothermal sources.

In the United States, California is a leader in producing geothermal energy. The largest geothermal power plant in the state is in the Geysers Geothermal Resource Area in Napa and Sonoma Counties, north of San Francisco. The source of heat is thought to be a large magma chamber lying beneath the area.

KQED: Geothermal Heats Up

Where Earth's internal heat gets close to the surface, geothermal power is a clean source of energy. In California, The Geysers supplies energy for many nearby homes and businesses.

MEDIA

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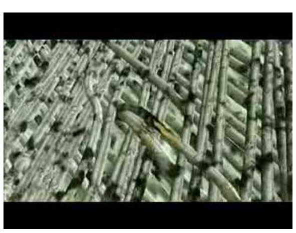
Biomass

Biomass is the material that comes from plants and animals that were recently living. Biomass can be burned directly, such as setting fire to wood. For as long as humans have had fire, people have used biomass for heating and cooking. People can also process biomass to make fuel, called **biofuel.** Biofuel can be created from crops, such as corn or algae, and processed for use in a car (**Figure** 10.38). The advantage to biofuels is that they burn more cleanly than fossil fuels. As a result, they create less pollution and less carbon dioxide. Critics say, however, that the amount of energy, fertilizer, and land needed to produce the crops used make biofuels only a slightly better alternative than fossil fuels.

FIGURE 10.38
Biofuels, such as ethanol, are added to gasoline to cut down the amount of fossil fuels that are used.

KQED: Biofuels: Beyond Ethanol

To generate biomass energy, break down the cell walls of plants to release the sugars and then ferment those sugars to create fuel. Corn is a very inefficient source; scientists are looking for much better sources of biomass energy.



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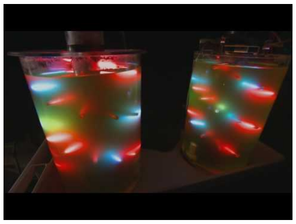
Algae Power

Many people think that the best source of biomass energy for the future is algae. Compared to corn, algae is not a food crop, it can grow in many places, its much easier to convert to a usable fuel and its carbon neutral.



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Lesson Summary

- Solar energy, water power, wind power, geothermal energy, and biomass energy are renewable energy sources.
- Solar energy can be used either by passively storing and holding the Sun's heat, converting it to electricity, or concentrating it.
- There are many ways to use the energy of moving water, including hydroelectric dams and tidal and wave plants.
- Wind power uses the energy of moving air to turn turbines.
- Geothermal energy uses heat from deep within the earth to heat homes or produce steam that turns turbines.
- Biomass energy uses renewable materials such as wood or grains to produce energy.

Review Questions

1. If you turn on the burner on a gas stove under a pan of cold water, energy moves from the burner to the pan of water. What is this type of energy transfer called? How does this energy move?
2. If solar power needs sunshine, how can solar power be a viable option for power?
3. If you burn wood in a fireplace, which type of energy resource are you using?
4. Which form of energy is an important factor in making electricity from water power?
5. Most of the energy that travels from the Sun to the Earth arrives in the form of visible light. What is this movement of energy called?
6. Explain how mirrors are used in some solar energy plants.
7. Explain how wind power uses kinetic energy.
8. NIMBY means "Not in My Backyard." How do various green energy projects, like Cape Wind, qualify as NIMBY projects?

Further Reading / Supplemental Links

- Cleveland, Cutler, "Energy Transitions Past and Future." Encyclopedia of Earth, 2007.

Points to Consider

- What areas do you think would be best for using solar energy?
- What causes the high temperatures deep inside the Earth that make geothermal energy possible?
- Do you think your town or city could use wind or water power?

10.6 Air Pollution

- Discuss the types of outdoor air pollution and their causes.
- Define primary pollutant and give examples.
- Define secondary pollutant and give examples.
- Summarize the effects of acid rain.
- Explain the relationship between greenhouse gases, deforestation, and global climate change.

What is this haze?

This picture shows a thick layer of smog and dust over a very polluted city (Singapore). Smog in the air is a serious health hazard for people living in many big cities around the globe. Smog is one example of air pollution.

Outdoor Air Pollution

Air is all around us. Air is essential for life. Sometimes, humans can pollute the air. For example, releasing smoke and dust from factories and cars can cause **air pollution**. Air pollution is due to chemical substances and particles released into the air mainly by human actions. This pollution affects entire ecosystems around the world. Pollution can also cause many human health problems, and it can also cause death. Air pollution can be found both outdoors and indoors.

Outdoor air pollution is made of chemical particles. When smoke or other pollutants enter the air, the particles found in the pollution mix with the air. Air is polluted when it contains many large toxic particles. Outdoor air pollution changes the natural characteristics of the atmosphere. **Primary pollutants** are added directly to the atmosphere. Fires add primary pollutants to the air. Particles released from the fire directly enter the air and cause pollution (**Figure** 10.39). Burning of **fossil fuels** such as oil and coal is a major source of primary pollutants (**Figure** 10.40).

Secondary pollutants are formed when primary pollutants interact with sunlight, air, or each other. They do not directly cause pollution. However, when they interact with other parts of the air, they do cause pollution. For example, **ozone** is created when some pollutants interact with sunlight. High levels of ozone in the atmosphere can cause problems for humans.

FIGURE 10.39
Wildfires, either natural or human-caused, release particles into the air, one of the many causes of air pollution.

FIGURE 10.40
A major source of air pollution is the burning of fossil fuels from factories, power plants, and motor vehicles.

Sources of Outdoor Air Pollution

Most air pollutants can be traced to the burning of fossil fuels. Fossil fuels are burned during many processes, including in power plants to create electricity, in factories to make machinery run, in power stoves and furnaces for heating, and in waste facilities. Perhaps one of the biggest uses of fossil fuels is in transportation. Fossil fuels are used in cars, trains, and planes.

Air pollution can also be caused by agriculture, such as cattle ranching and the use of fertilizers and pesticides. Other sources of air pollution include the production of plastics, refrigerants, and aerosols, in nuclear power and defense, from landfills and mining, and from biological warfare.

Acid Rain

One result of air pollution is acid rain. **Acid rain** is precipitation with a low (acidic) pH. This rain can be very destructive to wildlife. When acid rain falls in forests, freshwater habitats, or soils, it can kill insects and aquatic life. It causes this damage because of its very low pH. Sulfur oxides and nitrogen oxides in the air both cause acid rain to form (**Figure** 10.41). Sulfur oxides are chemicals that are released from coal-fired power plants. Nitrogen oxides are released from motor vehicle exhaust.

FIGURE 10.41
A forest in the Jizera Mountains of the Czech Republic shows effects caused by acid rain. What do you observe?

Global Warming

Pollutants also affect the atmosphere through their contribution to global warming. **Global warming** is an increase in the Earth's temperature. It is thought to be caused mostly by the increase of **greenhouse gases** like carbon dioxide. Greenhouse gases can be released by factories that burn fossil fuels. Over the past 20 years, burning fossil fuels has produced about three-quarters of the carbon dioxide from human activity. The rest of the carbon dioxide in the atmosphere is there because of deforestation, or cutting down trees (**Figure** 10.42). Trees absorb carbon dioxide during cellular respiration, so when trees are cut down, they cannot remove carbon dioxide from the air.

This increase in global temperature will cause the sea level to rise. It is also expected to produce an increase in extreme weather events and change the amount of precipitation. Global warming may also cause food shortages and species extinction.

Summary

- Air pollution is caused by chemical substances and particles released into the air, mainly by human activities.
- The major cause of outdoor air pollution is the burning of fossil fuels.
- Problems caused by the burning of fossil fuels include acid rain and global warming.

Explore More

Use the resource below to answer the questions that follow.

FIGURE 10.42
Deforestation, shown here as a result of burning for agriculture in southern Mexico, has produced significant increases in carbon dioxide emissions over the past 20 years.

- **Human Pollution** at http://www.youtube.com/watch?v=HRJ6njStTec (2:15)

MEDIA
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1. What are pollutants?
2. What are three sources of pollutants?
3. What are the two main categories of pollutants?

Review

1. What is air pollution?
2. What's the difference between primary and secondary pollutants? Give examples of each.
3. What are three ways that polluting fossil fuels are burned?
4. Why is acid rain dangerous.

10.7 Water Pollution

Learning Objectives

- Describe examples of water pollution.
- Distinguish point source pollution from nonpoint source pollution.

Is the ocean a good dumping ground?

Unfortunately some people think so. A lot of garbage ends up washing ashore, and some garbage stays floating out in the ocean. Animals can be strangled by floating trash or mistake inedible trash for food. Not only is the pollution of our oceans a problem, but also our precious freshwater resources are often polluted.

Sources of Water Pollution

While to many people clean water may seem limitless and everywhere, to many others this is not so. **Water pollution** is a serious issue facing hundreds of millions of people world-wide, having harmful effects on the lives of those people. Water is not in unlimited supply and cannot just be made fresh when it is wanted. Water is actually a limited resource, and for many people, fresh, unpolluted water is hard to find. A **limited resource** is one that we use faster than we can remake it. It is a resource that can be used up.

Water pollution happens when contaminants enter water bodies. **Contaminants** are any substances that harm the health of the environment or humans. Most contaminants enter the water because of humans. Surface water (river or lake) can be exposed to and contaminated by acid rain, storm water runoff, pesticide runoff, and industrial waste. This water is cleaned somewhat by exposure to sunlight, aeration, and microorganisms in the water. **Groundwater** (private wells and some public water supplies) generally takes longer to become contaminated, but the natural cleaning process also may take much longer. Groundwater can be contaminated by disease-producing pathogens, careless disposal of hazardous household chemical-containing products, agricultural chemicals, and leaking underground storage tanks.

FIGURE 10.43
Water pollution can cause harmful effects to ecology and human health. Shown is the pollution in Jakarta, Indonesia.

Natural events, like storms, volcanic eruptions and earthquakes can cause major changes in water quality. But human-caused contaminants have a much greater impact on the quality of the water supply. Water is considered polluted either when it does not support a human use, like clean drinking water, or a use for other animals and plants. The overgrowth of algae, known as an **algal bloom**, can result from the runoff of fertilizer into bodies of water. This excess of nutrients allows the algae to grow beyond control, bring harm to the rest of the ecosystem.

The main sources of water pollution can be grouped into two categories:

- **Point source pollution** results from the contaminants that enter a waterway or water body through a single site. Examples of this include untreated sewage, wastewater from a sewage treatment plant, and leaking underground tanks.
- **Nonpoint source pollution** is contamination that does not come from a single point source. Instead, it happens when there is a buildup of small amounts of contaminants that collect from a large area. Examples of this include fertilizer runoff from many farms flowing into groundwater or streams.

Science Friday: Poop and Paddle: An Eco-Friendly Floating Toilet

How do wetlands filter water? In this video by Science Friday, inventor Adam Katzman describes how his toilet-boat converts human waste into cattails and clean water.

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Summary

- Water is a limited resource, but it is often polluted by humans.
- Sources of water pollution can be grouped as point source pollution (large amounts entering through a single site) or nonpoint source pollution (small amounts entering from many sites.)

Explore More

Use the resource below to answer the questions that follow.

- **Water Pollution** at http://www.youtube.com/watch?v=ACgv19b-n5E (4:42)

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/57323

1. How can human sewage throw ecosystems out of balance? What nutrient cycle(s) are involved?
2. How does agriculture run-off effect ecosystems? How does this change move through the food web? What can the result be?
3. How can drugs excreted by humans affect aquatic organisms? How does this affect the ecosystem?
4. What is heat pollution? What affect can this have on aquatic ecosystems? Explain your answer as fully as possible.

Review

1. Why is fresh water a limited resource?
2. What is water pollution?
3. What are two main sources of pollution of surface water?
4. What are two main sources of groundwater pollution?
5. What's the difference between a point source and nonpoint source of water pollution?

10.8 References

1. Stephen Codringto. http://commons.wikimedia.org/wiki/File:Strip_coal_mining.jpg . CC BY 2.5
2. Courtesy of Anthony Bley, U.S. Army Corps of Engineers. http://commons.wikimedia.org/wiki/File:Wetlands_Cape_May_New_Jersey.jpg . Public Domain
3. USFWS Mountain Prairie. http://www.flickr.com/photos/usfwsmtnprairie/6196416662/ . CC BY 2.0
4. User:Reservoirhill/Wikipedia. http://commons.wikimedia.org/wiki/File:Tallgrass_Prairie_Nature_Preserve_-in_Osage_County.jpg . Public Domain
5. Courtesy of the National Park Service. http://commons.wikimedia.org/wiki/File:Brown_tree_snake_Boiga_irregularis_2_USGS_Photograph.jpg . Public Domain
6. Courtesy of Laurie Driver, U.S. Army Corps of Engineers. http://commons.wikimedia.org/wiki/File:Zebra_mussel_infestation_Ormond_Lock.jpg . Public Domain
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8. National Park Service. http://commons.wikimedia.org/wiki/File:Brown_tree_snake_Boiga_irregularis_2_USGS_Photograph.jpg;https://www.flickr.com/photos/wanderingseoul61/1503897694/in/photolist-3hTSoA-7x5ZxA-9Dvc1e-ph1dwn-74oBbv-fpLRzV-a16W4D-tdfXGw-p56eYi-jARvmo-HH38a-6S8Xdn-p5FcdJ-5Y1mxr-6mvhzP-fqjAPz-jEuSET-9futhb-6mzsgN-6mzrEb-6mvgUH-6mzpHf-6mzp4C-7eEmr1-8WXynB-8X1zb7-qNsmVr-8PJopF-8DNGbR-7Pv1sV-8vtfL9-3qaAqq-94f7sQ-9ww1cx-9ZKqjM-8QT5i7-aGXVj6-8SzxVu-jEu3Nn-9ah1WH-DYcJB-9f18hz-7ehNNi-9iA9HM-78U7Ru-3qaARy-kGnUpR-5Q7pL8-5RCgGX-9V2J3X . Public Domain
9. National Park Service. http://commons.wikimedia.org/wiki/File:Brown_tree_snake_Boiga_irregularis_2_USGS_Photograph.jpg . Public Domain
10. Courtesy of the US Geological Survey. http://en.wikipedia.org/wiki/Image:Pleistocene_north_ice_map.jpg . Public Domain
11. U Büntgen, C Raible, et al.. http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0025133 . CC BY 2.5
12. Courtesy of US National Oceanic and Atmospheric Administration. http://commons.wikimedia.org/wiki/File:Enso_normal.png . Public Domain
13. Courtesy of US National Oceanic and Atmospheric Administration. http://commons.wikimedia.org/wiki/File:Enso_elnino.png . Public Domain
14. Courtesy of US National Oceanic and Atmospheric Administration. http://commons.wikimedia.org/wiki/File:Enso_lanina.png . Public Domain
15. Courtesy of NOAA. http://www.noaanews.noaa.gov/stories2008/20080104_sunspot.html . Public Domain
16. Courtesy of Expedition 20 crew/NASA. http://earthobservatory.nasa.gov/IOTD/view.php?id=38985 . Public Domain
17. Tom Ruen. http://commons.wikimedia.org/wiki/File:Atmospheric_CO2_with_glaciers_cycles.gif . Public Domain
18. Scripps institution by Oceanography. https://scripps.ucsd.edu/programs/keelingcurve/wp-content/plugins/sio-bluemoon/graphs/mlo_full_record.png .
19. Courtesy of NASA. http://data.giss.nasa.gov/gistemp/graphs_v3/ . Public Domain
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47. Stephen Codrington;Courtesy of NOAA. http://commons.wikimedia.org/wiki/File:Obvious_water_pollution.jpeg;http://commons.wikimedia.org/wiki/File:Turtle_entangled_in_marine_debris_(ghost_net).jpg . CC BY 2.5
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CHAPTER 11 Ecology: Group Behavior and Survival

Chapter Outline

11.1 Animal Migration - Advanced

Learning Objectives

- Describe how and why migration occurs.

The Great Migration happens every year. Why?

Each year, around 1.5 million wildebeest and 300,000 zebra (along with other antelope) gather up their young and start their long trek north from Tanzania's Serengeti Plains to Kenya's Masai Mara National Reserve. They go in search of food and water. Their migration runs in a clockwise circle and the animals cover a distance of around 1800 miles. It's a tough journey, and every year an estimated 250,000 wildebeest don't survive.

Migration

In addition to reproductive cycles, animals have other behaviors that occur in regular cycles. One type of cyclic behavior is migration. Other cyclic behaviors are called circadian rhythms.

Migration usually refers to seasonal movements of animals from one area to another, typically over long distances. One area is often a breeding site. Migration occurs mainly in birds, fish, insects, and some ocean organisms, including whales. Migration is an innate behavior, but it generally occurs in response to predictable changes in the environment. For example, in the northern temperate zone, bald eagles, which prey on fish, migrate south when ponds and lakes freeze over in the winter.

Many other birds also migrate to milder climates from areas with harsh winters, where little food is available. Some species travel incredible distances during these migrations. **Figure** 11.1 shows migration routes of birds called bar-tailed godwits. These birds make both the longest nonstop flights of any bird and the longest journeys without food of any animal. Their migration routes are almost entirely over the Pacific Ocean. The birds fly from the Arctic or other areas in the far North (where they breed) to New Zealand or even farther south. They have been known to travel more than 11,000 kilometers (over 6,800 miles) in just nine days. How fast, on average, do they fly to cover this much distance in this amount of time?

FIGURE 11.1

This map shows the migration routes of birds called bar-tailed godwits. In their seasonal migration, they travel farther without feeding than any other species of animal. They also travel fast, given the distance and number of days they fly. For example, traveling over 6,800 miles in nine days requires an average speed of more than 31 miles per hour.

Some species of whales migrate seasonally as well. Gray whales have the longest known migration route of any whale or other mammal. In the summer, one group of gray whales lives in the Bering Sea near Alaska. Beginning in October, these whales head south, traveling along the western coast of both Canada and the United States. By mid-December, they can be seen off the California coast between Monterey and San Diego. By late December, the whales begin arriving at their destination: the warm waters near Mexico's Baja Peninsula. The entire trip covers about 10,000 kilometers (6,000 miles). The whales travel day and night and average almost 130 kilometers (80 miles) per day. Once they arrive at their destination, pregnant females give birth, and females that are not pregnant seek males for mating.

Migrating to and from areas that are thousands of kilometers apart requires several abilities. Animals must be able to determine their current location, the location of their destination, and how to get from one location to the other. Many species of migratory birds determine the direction in which to fly based on cues such as Earth's magnetic lines, the position of the sun, or the direction of prevailing winds. In addition to determining the correct direction, they must know how far or how long to travel in that direction. Other species of birds follow landmarks on Earth's surface, such as rivers, coastlines, or mountain ridges.

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Summary

- Migration occurs mainly in birds, fish, insects, and some ocean organisms, including whales.
- Migration is an innate behavior, but it generally occurs in response to predictable changes in the environment.
- Migrating to and from areas that are thousands of kilometers apart requires several abilities, including the ability to determine one's current location, the location of one's destination, and how to get from one location to the other.

Review

1. What are some common reasons for animal migration?
2. What animal takes the longest journey without food? What is the farthest mammalian migration?
3. How do migratory birds manage to determine their direction and how long they have traveled?

11.2 Reproductive Behavior

- Define courtship behavior.
- Explain the purpose of mating behavior.
- Describe how animals care for their young and defend their territory.

Why do these birds pair up?

These birds are pairing up so that they can produce offspring. Many birds are **monogamous**, keeping the same mate for an entire season. In some species, they even stay paired for their entire life.

Mating Behavior and Defending Territory

Some of the most important animal behaviors involve mating. **Mating** is the pairing of an adult male and female to produce young. Adults that are most successful at attracting a mate are most likely to have offspring. Traits that help animals attract a mate and have offspring increase their fitness. As the genes that encode these traits are passed to the next generation, the traits will become more common in the population.

Courtship Behaviors

In many species, females choose the male they will mate with. For their part, males try to be chosen as mates. They show females that they would be a better mate than the other males. To be chosen as a mate, males may perform **courtship behaviors**. These are special behaviors that help attract a mate. Male courtship behaviors get the attention of females and show off a male's traits. These behaviors are often observed as direct competition between males.

Different species have different courtship behaviors. One example is a peacock raising his tail feathers. The colorful peacock is trying to impress females of his species with his beautiful feathers. Another example of courtship behavior in birds is the blue-footed booby. He is doing a dance to attract a female for mating. During the dance, he spreads out his wings and stamps his feet on the ground. You can watch the following video of a blue-footed booby doing his courtship dance at: http://www.youtube.com/watch?v=oYmzdvMoUUA .

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Courtship behaviors occur in many other species. For example, males in some species of whales have special mating songs to attract females as mates. Frogs croak for the same reason. Male deer clash antlers to court females. Male jumping spiders jump from side to side to attract mates.

Courtship behaviors are one type of display behavior. A **display behavior** is a fixed set of actions that carries a specific message. Although many display behaviors are used to attract mates, some display behaviors have other purposes. For example, display behaviors may be used to warn other animals to stay away, as you will read below.

Caring for the Young

In most species of birds and mammals, one or both parents care for their offspring. Caring for the young may include making a nest or other shelter. It may also include feeding the young and protecting them from predators. Caring for offspring increases their chances of surviving. Birds called killdeers have an interesting way of protecting their chicks. When a predator gets too close to her nest, a mother killdeer pretends to have a broken wing. The mother walks away from the nest holding her wing as though it were injured (**Figure** 11.2). The predator thinks she is injured and will be easy prey. The mother leads the predator away from the nest and then flies away.

In most species of mammals, parents also teach their offspring important skills. For example, meerkat parents teach their pups how to eat scorpions without being stung. A scorpion sting can be deadly, so this is a very important skill. Teaching the young important skills makes it more likely that they will survive. Notice that, compared to other types of animals, birds and mammals have relatively few offspring.

FIGURE 11.2
This mother killdeer is pretending she has a broken wing. She is trying to attract a predator's attention in order to protect her chicks. This behavior puts her at risk of harm. How can it increase her fitness?

Defending Territory

Some species of animals are **territorial**. This means that they defend their area. The area they defend usually contains their nest and enough food for themselves and their offspring. A species is more likely to be territorial if there is not very much food in their area. Having a larger territory could mean more prey or food.

Animals generally do not defend their territory by fighting. Instead, they are more likely to use display behavior. The behavior tells other animals to stay away. It gets the message across without the need for fighting. Display behavior is generally safer and uses less energy than fighting. Male gorillas use display behavior to defend their territory. They pound on their chests and thump the ground with their hands to warn other male gorillas to keep away from their area. The robin displays his red breast to warn other robins to stay away (**Figure** 11.3).

Some animals deposit chemicals to mark the boundary of their territory. This is why dogs urinate on fire hydrants and other objects. Cats may also mark their territory by depositing chemicals. They have scent glands in their face. They deposit chemicals by rubbing their face against objects.

Summary

- Males of some species may perform courtship behaviors, special behaviors that help attract a mate.
- Some species of animals are territorial and defend their area.

Explore More

Use the resources below to answer the questions that follow.

Explore More I

- **Behavior on a Sage Grouse Lek** at http://www.youtube.com/watch?v=QYMHbFUTgAY (1:15)

FIGURE 11.3
The red breast of this male robin is easy to see. The robin displays his bright red chest to defend his territory. It warns other robins to keep out of his area.

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1. What is a lek? What sort of behavior is seen in a lek?
2. When do sage grouse (*Centrocercus urophasianus*) put on the most weight? How does this affect their reproductive success?

Explore More II

- **Elk Fighting in River** at http://www.youtube.com/watch?v=GUQcMZLZpx8 (2:45)

1. Notice the male elk (*Cervus canadensis*) which enters the video at the 2:05 mark. What do you think it is trying to do? Do you think its behavior helps or hurts the survival of elk in Yellowstone National Park?
2. What sort of behavior are the male elk displaying?

Review

1. What is a courtship behavior. Give an example.
2. Give an example of display behavior exhibited by a territorial animal.

11.3 Social Behavior

Learning Objectives

- Define social animals.
- Describe social behavior in animals.
- Explain and give examples of cooperation.

How are you social?

When you think about being social, do you think about hanging out and chatting with friends? Sending a text or posting to Facebook? Humans socialize in many ways. Social behavior is not limited to humans, however. Many animals are social.

Social Behavior

Why is animal communication important? Without it, animals would not be able to live together in groups. Animals that live in groups with other members of their species are called **social animals**. Social animals include many species of insects, birds, and mammals. Specific examples of social animals are ants, bees, crows, wolves, lions, and humans. To live together with one another, these animals must be able to share information.

Highly Social Animals

Some species of animals are very social. In these species, members of the group depend completely on one another. Different animals within the group have different jobs. Therefore, group members must work together for the good of all. Most species of ants and bees are highly social animals.

Ants live together in large groups called colonies (**Figure** 11.4). A colony may have millions of ants, making communication among the ants very important. All of the ants in the colony work together as a single unit. Each ant has a specific job, and most of the ants are workers. Their job is to build and repair the colony's nest. Worker ants also leave the nest to find food for themselves and other colony members. The workers care for the young as well. Other ants in the colony are soldiers. They defend the colony against predators. Each colony also has a queen. Her only job is to lay eggs. She may lay millions of eggs each month. A few ants in the colony are called drones. They are the only male ants in the colony. Their job is to mate with the queen.

FIGURE 11.4
The ants in this picture belong to the same colony. They have left the colony's nest to search for food.

Honeybees and bumblebees also live in colonies (**Figure** 11.5). Each bee in the colony has a particular job. Most of the bees are workers. Young worker bees clean the colony's hive and feed the young. Older worker bees build the waxy honeycomb or guard the hive. The oldest workers leave the hive to find food. Each colony usually has one queen that lays eggs. The colony also has a small number of male drones. They mate with the queen.

FIGURE 11.5
All the honeybees in this colony work together. Each bee has a certain job to perform. Notice the queen to the left. She is the largest bee in the colony.

Cooperation

Ants, bees, and other social animals must cooperate. **Cooperation** means working together with others. Members of the group may cooperate by sharing food. They may also cooperate by defending each other. Look at the ants pictured below (**Figure** 11.6). They show very clearly why cooperation is important. A single ant would not be able to carry this large bee back to the nest to feed the other ants. With cooperation, the job is easy.

FIGURE 11.6
These ants are cooperating. By working together, they are able to move this much larger insect prey back to their nest. At the nest, they will share the bee with other ants that do not leave the nest.

Animals in many other species cooperate. For example, lions live in groups called prides (**Figure** 11.7). All the lions in the pride cooperate, though there is still serious competition among the males. Male lions work together to defend the other lions in the pride. Female lions work together to hunt. Then, they share the meat with other pride members.

Another example of cooperation is seen with meerkats. Meerkats are small mammals that live in Africa. They also live in groups and cooperate with one another. For example, young female meerkats act as babysitters. They take care of the baby meerkats while their parents are away looking for food.

FIGURE 11.7
Members of this lion pride work together. Males cooperate by defending the pride. Females cooperate by hunting and sharing the food.

Summary

- Social animals, or animals that live in groups with other members of their species, include ants, bees, crows, wolves, and humans.

- Social animals must cooperate (work together) with others.

Explore More

Use the resource below to answer the questions that follow.

- **Wolf Hunting Tactics** at http://www.youtube.com/watch?v=2jXxtQRy47A (2:54)

MEDIA

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1. Observe the wolves (*Canis lupus*) in this video:
   a. Do you think they are displaying learned behavior, innate behavior, or both? Explain your reasoning fully.
   b. As social animals, which behavior do you think is most important to them? Explain your reasoning.
   c. Does your answer apply to all situations?

Review

1. What makes social animals unique?
2. Give three examples of social animals.
3. What is one example of how social animals cooperate?

11.4 References

1. . http://en.wikipedia.org/wiki/Image:Bar-tailed_Godwit_migration.jpg .
2. . http://en.wikipedia.org/wiki/Image:Bar-tailed_Godwit_migration.jpg . Public Domain
3. . . CC BY-NC
4. audreyjm529. http://www.flickr.com/photos/98799884@N00/3567167561/ . CC BY 2.0
5. Dwight Sipler. http://www.flickr.com/photos/photofarmer/5899245104/ . CC BY 2.0
6. Cat and mouse: Vorstius; Dog: Robin Taylor; Bird: Lilla Frerichs; Wasps: GanMed64; Lizard: Jimmy Harris; Rabbit: Lauris Rubenis. Cat and mouse: http://www.flickr.com/photos/48321643@N00/82027206/; Dog: http://www.flickr.com/photos/robinelaine/14160314/; Bird: http://www.publicdomainpictures.net/view-image.php?image=39654&picture=weaver-bird-weaving-nest-4; Wasps: http://www.flickr.com/photos/ganmed64/3884591759/; Lizard: http://www.flickr.com/photos/50216172@N00/3839707762/; Rabbit: http://www.flickr.com/photos/beardforgood/9186992422/ . Bird: Public Domain; Remaining images: CC BY 2.0
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CHAPTER 12 Genetics: Cell Division and Differentiation

Chapter Outline

12.1 Cell Cycle

Learning Objectives

- Define the cell cycle.
- List, in order, the phases of the cell cycle.
- Summarize the phases of the eukaryotic cell cycle.
- Explain control of the cell cycle.
- Define cancer.

What is a cell's life like?

The eukaryotic cell spends most of its "life" in interphase of the cell cycle, which can be subdivided into the three phases, G1, S and G2. During interphase, the cell does what it is supposed to do. Though cells have many common functions, such as DNA replication, they also have certain specific functions. That is, during the life of a heart cell, the cell would obviously perform certain different activities than a kidney cell or a liver cell.

The Cell Cycle

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

The Eukaryotic Cell Cycle

The diagram in **Figure** 12.1 represents the cell cycle of a eukaryotic cell. As you can see, the eukaryotic cell cycle has several phases. The **mitotic phase** (M) actually includes both mitosis and cytokinesis. This is when the nucleus and then the cytoplasm divide. The other three phases (G1, S, and G2) are generally grouped together as **interphase**. During interphase, the cell grows, performs routine life processes, and prepares to divide. These phases are discussed below.

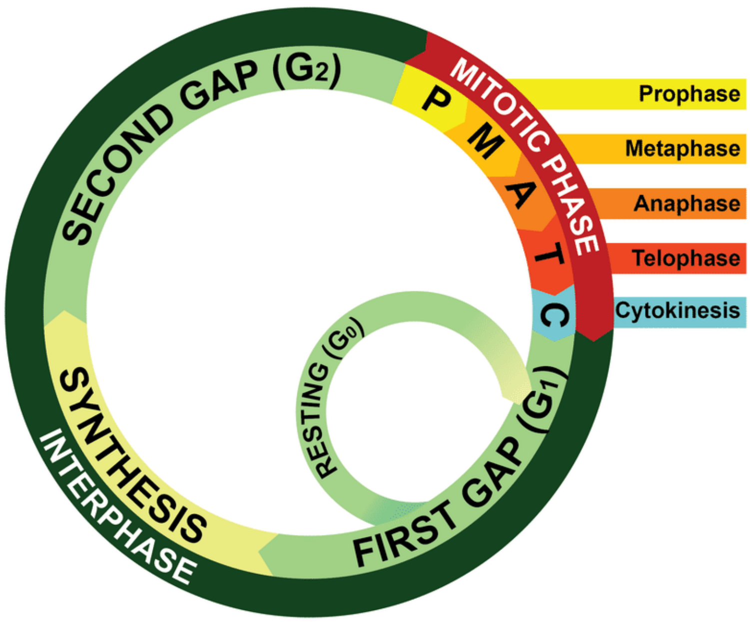


FIGURE 12.1

Eukaryotic Cell Cycle. This diagram represents the cell cycle in eukaryotes. The First Gap, Synthesis, and Second Gap phases make up interphase (I). The M (mitotic) phase includes mitosis and cytokinesis. After the M phase, two cells result.

Interphase

Interphase of the eukaryotic cell cycle can be subdivided into the following three phases, which are represented in **Figure** 12.1:

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

Control of the Cell Cycle

If the cell cycle occurred without regulation, cells might go from one phase to the next before they were ready. What controls the cell cycle? How does the cell know when to grow, synthesize DNA, and divide? The cell cycle is controlled mainly by regulatory proteins. These proteins control the cycle by signaling the cell to either start or delay the next phase of the cycle. They ensure that the cell completes the previous phase before moving on. Regulatory proteins control the cell cycle at key checkpoints, which are shown in **Figure** 12.2. There are a number of main checkpoints.

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

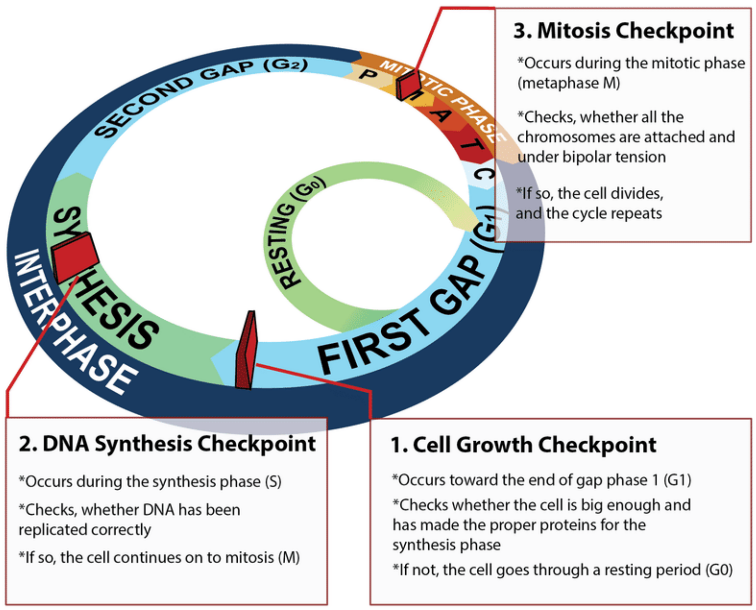
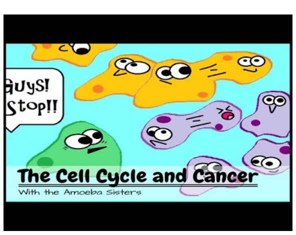


FIGURE 12.2
Checkpoints in the eukaryotic cell cycle ensure that the cell is ready to proceed before it moves on to the next phase of the cycle.

Cancer and the Cell Cycle

Cancer is a disease that occurs when the cell cycle is no longer regulated. This may happen because a cell's DNA becomes damaged. Damage can occur due to exposure to hazards such as radiation or toxic chemicals. Cancerous cells generally divide much faster than normal cells. They may form a mass of abnormal cells called a **tumor** (see **Figure** 12.3). The rapidly dividing cells take up nutrients and space that normal cells need. This can damage tissues and organs and eventually lead to death.



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Summary

- The cell cycle is a repeating series of events that cells go through. It includes growth, DNA synthesis, and cell division. In eukaryotic cells, there are two growth phases, and cell division includes mitosis.

FIGURE 12.3
These cells are cancer cells, growing out of control and forming a tumor.

- The cell cycle is controlled by regulatory proteins at three key checkpoints in the cycle. The proteins signal the cell to either start or delay the next phase of the cycle.
- Cancer is a disease that occurs when the cell cycle is no longer regulated. Cancer cells grow rapidly and may form a mass of abnormal cells called a tumor.

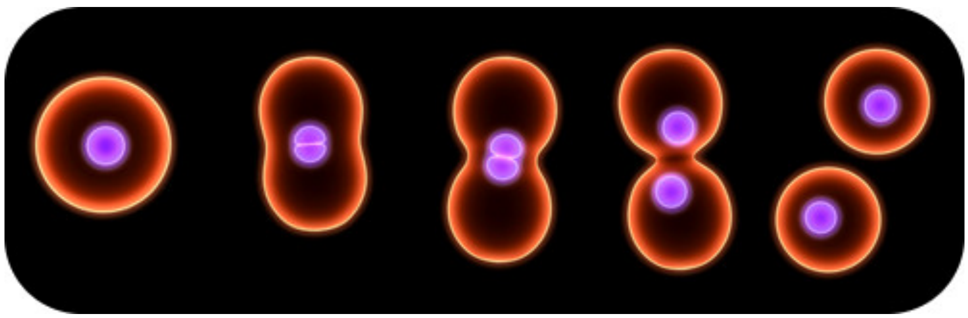
Review

1. Identify the phases of the eukaryotic cell cycle.
2. What happens during interphase?
3. Define cancer.
4. Cells go through a series of events that include growth, DNA synthesis, and cell division. Why are these events best represented by a cycle diagram?
5. Explain how the cell cycle is regulated.
6. Why is DNA replication essential to the cell cycle?

12.2 Cell Division

Learning Objectives

- Define cell division.
- Explain binary fission.
- Define mitosis and cytokinesis.
- Contrast cell division in prokaryotes and eukaryotes.



Where do cells come from?

No matter what the cell, all cells come from preexisting cells through the process of cell division. The cell may be the simplest bacterium or a complex muscle, bone, or blood cell. The cell may comprise the whole organism, or be just one cell of trillions.

Cell Division

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

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

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

Cell Division in Prokaryotes

Most prokaryotic cells divide by the process of **binary fission**. A bacterial cell dividing this way is depicted in **Figure** 12.4.

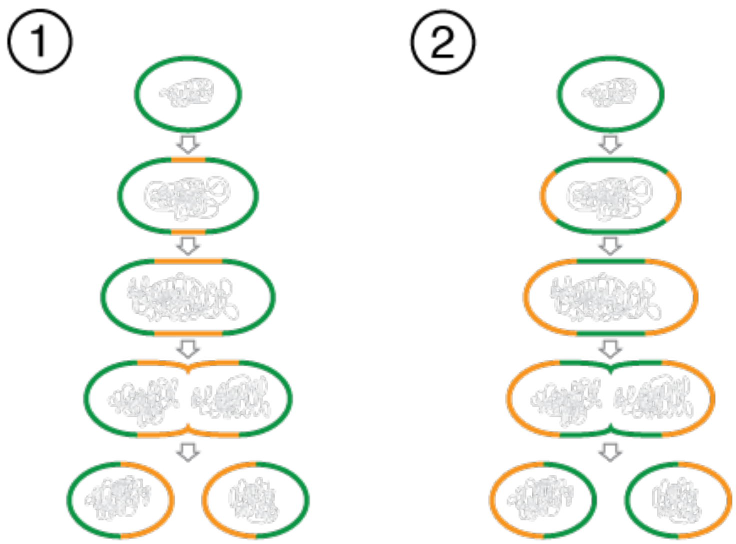


FIGURE 12.4

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

Binary fission can be described as a series of steps, although it is actually a continuous process. The steps are described below and also illustrated in **Figure** 12.5. They include DNA replication, chromosome segregation, and finally the separation into two daughter cells.

- Step 1: DNA Replication. Just before the cell divides, its DNA is copied in a process called DNA replication. This results in two identical chromosomes instead of just one. This step is necessary so that when the cell divides, each daughter cell will have its own chromosome.
- Step 2: Chromosome Segregation. The two chromosomes segregate, or separate, and move to opposite ends (known as "poles") of the cell. This occurs as each copy of DNA attaches to different parts of the cell membrane.
- Step 3: Separation. A new plasma membrane starts growing into the center of the cell, and the cytoplasm splits apart, forming two daughter cells. As the cell begins to pull apart, the new and the original chromosomes are separated. The two daughter cells that result are genetically identical to each other and to the parent cell. New cell wall must also form around the two cells.

Cell Division in Eukaryotes

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

1. The first step is **mitosis**, a multi-phase process in which the nucleus of the cell divides. During mitosis, the nuclear membrane breaks down and later reforms. The chromosomes are also sorted and separated to ensure that each daughter cell receives a diploid number (2 sets) of chromosomes. In humans, that number of chromosomes is 46 (23 pairs). Mitosis is described in greater detail in a subsequent concept.
2. The second major step is cytokinesis. As in prokaryotic cells, the cytoplasm must divide. Cytokinesis is the division of the cytoplasm in eukaryotic cells, resulting in two genetically identical daughter cells.

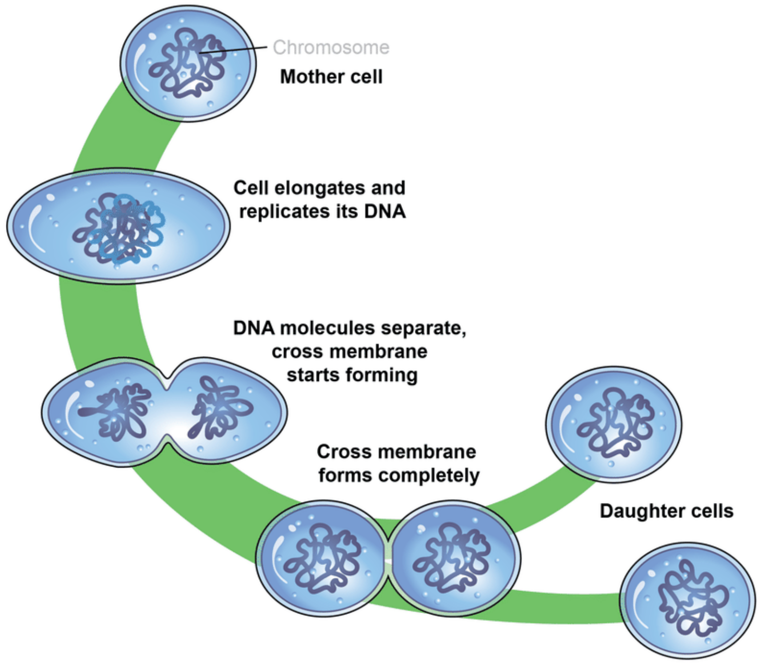
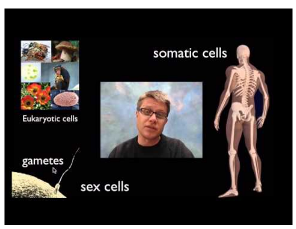


FIGURE 12.5
Steps of Binary Fission. Prokaryotic cells divide by binary fission. This is also how many single-celled organisms reproduce.



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Science Friday: The Axolotl: A Cut Above the Rest

The axolotl is an animal with the incredible ability to regenerate its legs. In this video by Science Friday, Dr. Susan Bryant discusses the research on how these animals are able to accomplish this amazing feat.

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Summary

- Cell division is part of the life cycle of virtually all cells. Cell division is the process in which one cell divides to form two new cells.
- Most prokaryotic cells divide by the process of binary fission.
- In eukaryotes, cell division occurs in two major steps: mitosis and cytokinesis.

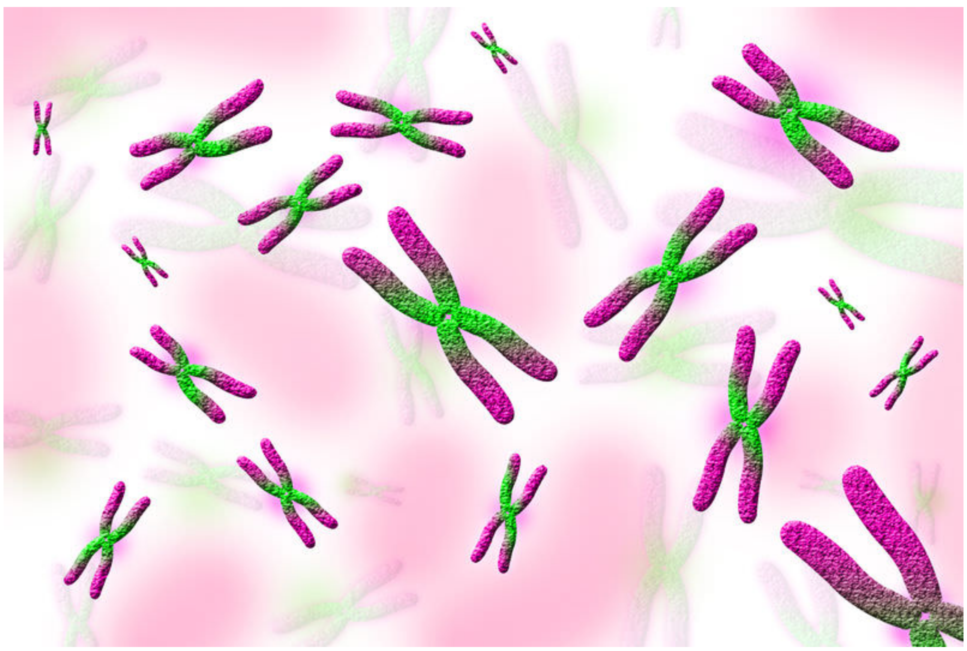
Review

1. Describe binary fission.
2. What is mitosis?
3. Contrast cell division in prokaryotes and eukaryotes. Why are the two types of cell division different?

12.3 Mitosis

Learning Objectives

- Explain the importance of mitosis.
- Explain chromosome structure.
- Define sister chromatids.
- List the phases of mitosis.
- Summarize the phases of mitosis.



How is your DNA organized?

Your DNA is organized into chromosomes, the pink structures pictured above. Your DNA doesn't always look so pretty, though. It only winds tightly into chromosomes when the cell is getting ready to divide. If your DNA wasn't organized into chromosomes, your DNA would look like a mass of strings and would be difficult to divide up!

Mitosis and Chromosomes

The genetic information of the cell, or DNA, is stored in the **nucleus**. During **mitosis**, two nuclei (plural for nucleus) must form, so that one nucleus can be in each of the new cells after the cell divides. In order to create two genetically identical nuclei, DNA inside of the nucleus must be copied or replicated. This occurs during the S phase of the cell cycle. During mitosis, the copied DNA is divided into two complete sets, so that after **cytokinesis**, each cell has a complete set of genetic instructions.

Chromosomes

To begin mitosis, the DNA in the nucleus wraps around proteins to form **chromosomes**. Each organism has a unique number of chromosomes. In human cells, our DNA is divided up into 23 pairs of chromosomes. Replicated DNA forms a chromosome made from two identical **sister chromatids**, forming an "X" shaped molecule (**Figure** 12.6). The two chromatids are held together on the chromosome by the **centromere**. The centromere is also where spindle fiber microtubules attach during mitosis. The **spindles** separate sister chromatids from each other.

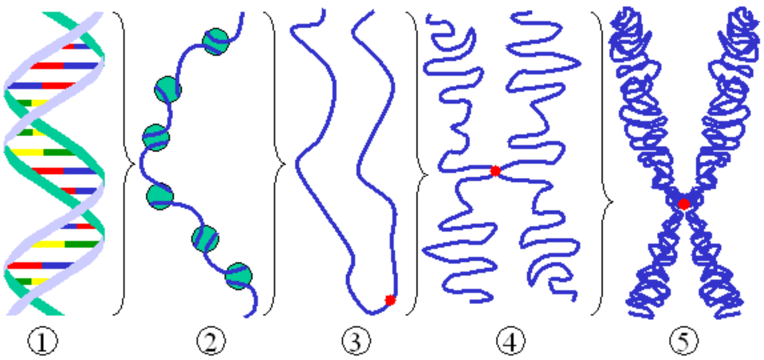


FIGURE 12.6

The DNA double helix wraps around proteins (2) and tightly coils a number of times to form a chromosome (5). This figure shows the complexity of the coiling process. The red dot shows the location of the centromere, which holds the sister chromatids together and is where the spindle microtubules attach during mitosis and meiosis. Notice that a chromosome resembles an "X."

Four Phases of Mitosis

During mitosis, the two sister chromatids must be divided. This is a precise process that has four individual phases to it. After the sister chromatids separate, each separate chromatid is now known as a chromosome. Each resulting chromosome is made of DNA from just one chromatid. So, each chromosome after this separation is made of "1/2 of the X." Through this process, each daughter cell receives one copy of each chromosome. The four phases of mitosis are prophase, metaphase, anaphase and telophase (**Figure** 12.7).

1. **Prophase**: The chromatin, which is unwound DNA, condenses forming chromosomes. The DNA becomes so tightly wound that you can see them under a microscope. The membrane around the nucleus, called the nuclear envelope, disappears. Spindles also form and attach to chromosomes to help them move.
2. **Metaphase**: The chromosomes line up in the center, or the equator, of the cell. The chromosomes line up in a row, one on top of the next.
3. **Anaphase**: The two sister chromatids of each chromosome separate as the spindles pull the chromatids apart, resulting in two sets of identical chromosomes.
4. **Telophase**: The spindle dissolves and nuclear envelopes form around the chromosomes in both cells.

After telophase, each new nucleus contains the exact same number and type of chromosomes as the original cell. The cell is now ready for cytokinesis, which literally means "cell movement." During cytokinesis, the cytoplasm divides and the parent cell separates, producing two genetically identical cells, each with its own nucleus. A new cell membrane forms and in plant cells, a cell wall forms as well. Below is a representation of dividing plant cells (**Figure** 12.8).

Summary

- The DNA in the nucleus wraps around proteins to form chromosomes.
- During mitosis, the newly duplicated chromosomes are divided into two daughter nuclei.

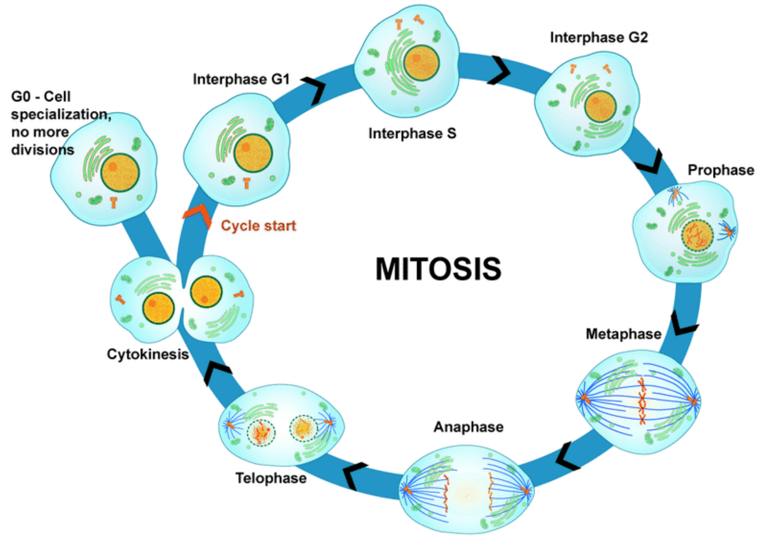


FIGURE 12.7
An overview of the cell cycle and mitosis: during prophase the chromosomes condense, during metaphase the chromosomes line up, during anaphase the sister chromatids are pulled to opposite sides of the cell, and during telophase the nuclear envelope forms.

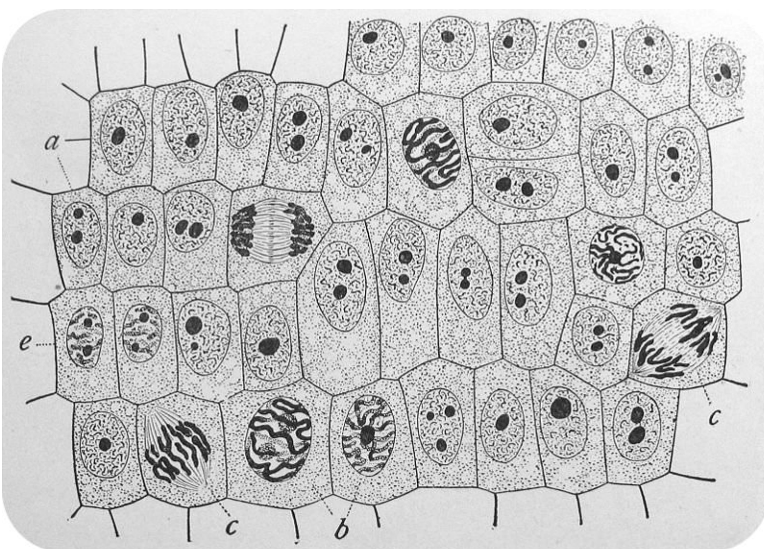


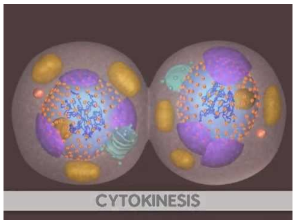
FIGURE 12.8
This is a representation of dividing plant cells. Cell division in plant cells differs slightly from animal cells as a cell wall must form. Note that most of the cells are in interphase. Can you find examples of the different stages of mitosis?

- Mitosis occurs in four phases, called prophase, metaphase, anaphase, and telophase.

Explore More

Use the resource below to answer the questions that follow.

- **Mitosis** by NDSU VCell Productions at http://www.youtube.com/watch?v=C6hn3sA0ip0 (6:10)



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1. When does the "classic" chromosome structure of DNA appear during mitosis?
2. What problems do you think might arise if the chromosomes did not align during metaphase?
3. When do the nuclear envelopes reform? What problems might arise if a cell started forming the nuclear envelopes earlier?
4. In what stage do cells spend most of their "life"?
5. How long does mitosis take in the typical eukaryotic cell?

Review

1. What are chromosomes?
2. What are the four phases of mitosis, in the correct order?
3. In what phase of mitosis are chromosomes moving toward opposite sides of the cell?
4. Compare the two nuclei that form as a result of mitosis?
5. What is cytokinesis, and when does it occur?

12.4 Carcinogens and Cancer

Learning Objectives

- Define cancer, mutation, and tumor.
- Describe causes of cancer.
- List warning signs of cancer.

Why is tanning bad for your health?

It might be fun to lay out in the sun like these two girls are doing. But getting too much sun can be very dangerous. Overexposure to sunlight raises your risk for skin cancer.

Cancer

Cancer is a disease that causes cells to divide out of control. Normally, the body has systems that prevent cells from dividing out of control. But in the case of cancer, these systems fail. Cancer is usually caused by mutations. **Mutations** are random errors in genes. Mutations that lead to cancer usually happen to genes that control the cell cycle. Because of the mutations, abnormal cells divide uncontrollably. This often leads to the development of a tumor. A **tumor** is a mass of abnormal tissue. As a tumor grows, it may harm normal tissues around it. Anything that can cause cancer is called a **carcinogen**. Carcinogens may be pathogens, chemicals, or radiation.

Pathogens

Pathogens that cause cancer include the human papilloma virus (HPV) (**Figure** 12.9) and the hepatitis B virus. HPV is spread through sexual contact. It can cause cancer of the reproductive system in females. The hepatitis B virus is spread through sexual contact or contact with blood containing the virus. It can cause cancer of the liver.

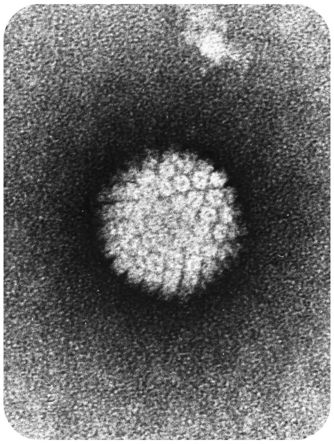

FIGURE 12.9
The mutations that cause cancer may occur when people are exposed to pathogens, such as the human papilloma virus (HPV), which is shown here.

Chemicals

Many different chemical substances cause cancer. Dozens of chemicals in tobacco smoke, including nicotine, have been shown to cause cancer (**Figure** 12.10). In fact, tobacco smoke is one of the main sources of chemical carcinogens. Smoking tobacco increases the risk of cancer of the lung, mouth, throat, and bladder. Using smokeless tobacco can also cause cancer. Other chemicals that cause cancer include asbestos, formaldehyde, benzene, cadmium, and nickel.

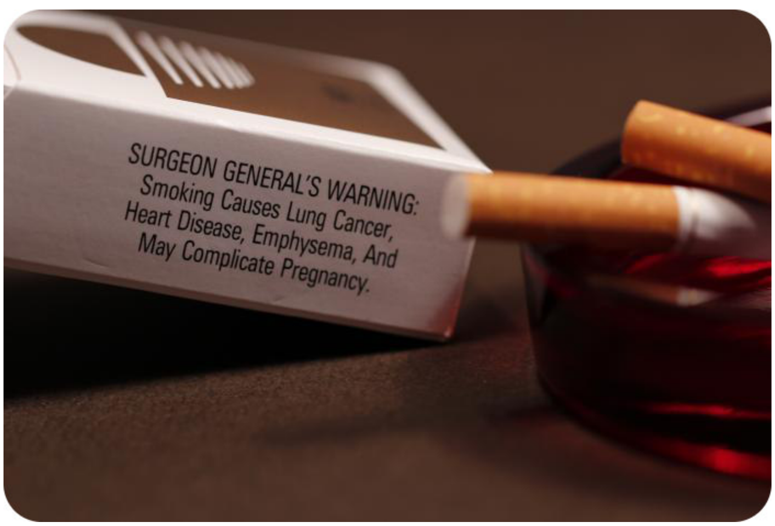

FIGURE 12.10
The mutations that cause cancer may occur when people are exposed to chemical carcinogens, such as those in cigarettes. It can be argued that tobacco smoke is the main source of chemical carcinogens.

Radiation

Forms of radiation that cause cancer include ultraviolet (UV) radiation and radon (**Figure** 12.11). **UV radiation** is part of sunlight. It is the leading cause of skin cancer. **Radon** is a natural radioactive gas that seeps into buildings from the ground. It can cause lung cancer.

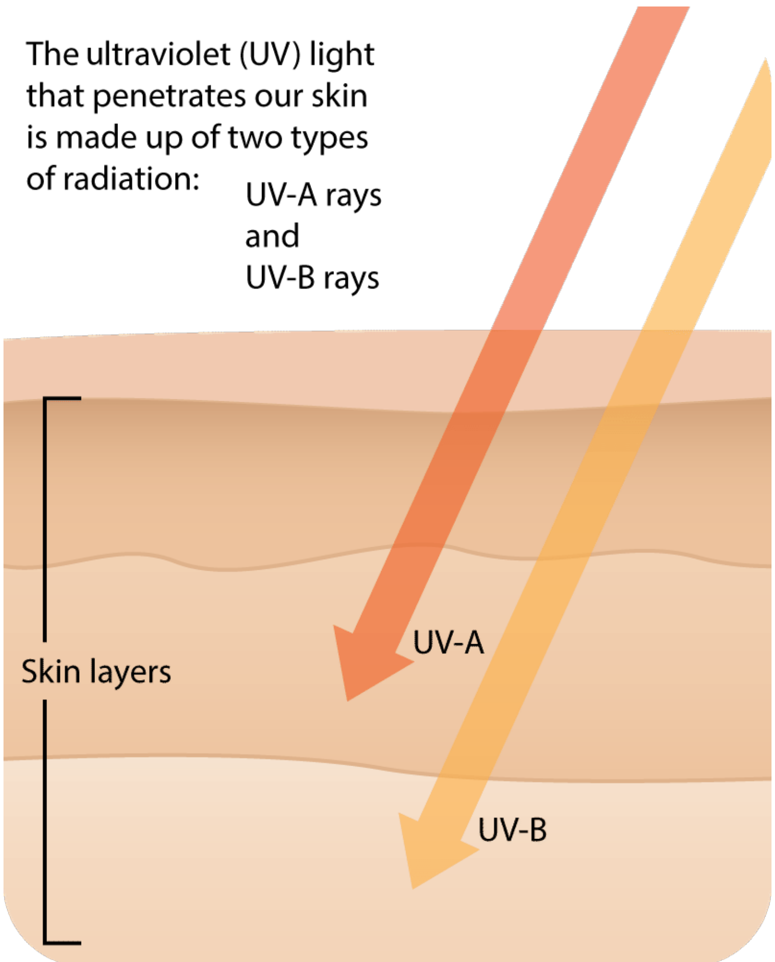

FIGURE 12.11
The mutations that cause cancer may occur when people are exposed to radiation, including the radiation from sunlight.

Common Types of Cancer

Cancer is usually found in adults, especially in adults over the age of 50. The most common type of cancer in adult males is cancer of the prostate gland. The prostate gland is part of the male reproductive system. Prostate cancer makes up about one third of all cancers in men. The most common type of cancer in adult females is breast cancer. It makes up about one third of all cancers in women. In both men and women, lung cancer is the second most common type of cancer. Most cases of lung cancer happen in people who smoke.

Cancer can also be found in children. But childhood cancer is rare. Leukemia is the main type of cancer in children. It makes up about one third of all childhood cancers. It happens when the body makes abnormal white blood cells.

Sometimes cancer cells break away from a tumor. If they enter the bloodstream, they are carried throughout the body. Then, the cells may start growing in other tissues. This is usually how cancer spreads from one part of the body to another. Once this happens, cancer is very hard to stop or control.

Treating Cancer

If leukemia is treated early, it usually can be cured. In fact, many cancers can be cured, which is known as remission, if treated early. Treatment of cancer often involves removing a tumor with surgery. This may be followed by other types of treatments. These treatments may include drugs (known as chemotherapy) and radiation therapy, which kill cancer cells.

The sooner cancer is treated, the greater the chances of a cure. This is why it is important to know the warning signs of cancer. Having warning signs does not mean that you have cancer. However, you should see a doctor to be sure. Everyone should know the warning signs of cancer. Detecting and treating cancer early can often lead to a cure. Some warning signs of cancer include:

- Change in bowel or bladder habits.
- Sores that do not heal.
- Unusual bleeding or discharge.
- Lump in the breast or elsewhere.
- Chronic indigestion.
- Difficulty swallowing.
- Obvious changes in a wart or mole.
- Persistent cough or hoarseness.

Summary

- Cancer is caused by mutations, which can be caused by pathogens, chemicals, or radiation.
- Cancer can be treated with surgery, drugs, and radiation.

Explore More

Use the resources below to answer the questions that follow.

Explore More I

- **How Cancer Cells Grow and Divide** at http://www.teachersdomain.org/asset/tdc02_vid_oncogene/

1. What is an oncogene?
2. How do receptors made by oncogenes differ from "normal" receptor cells?
3. How does cancer spread through the blood stream?

Explore More II

- **How Cancer Grows and Spreads** at http://www.pbs.org/wgbh/nova/body/how-cancer-grows.html

1. How are genetic mutations thought to affect the formation of cancer? What is the result of this process?
2. Cancer cells continuously divide. How does this affect the mutation rates of the cells?
3. What is angiogenesis? How does this help cancer spread?

Review

1. Define carcinogen and give three examples.
2. Explain how mutations can lead to cancer.
3. What type of cancers are associated with chemicals in cigarettes?
4. What type of cancer may be caused by UV radiation?
5. List four signs of cancer.

12.5 Carcinogens and Cancer

Learning Objectives

- Define cancer and carcinogen.
- Describe how carcinogens cause cancer.
- Distinguish between tumor-suppressor genes and proto-oncogenes.
- Distinguish between benign tumors and malignant tumors.
- Describe how cancer can be treated or prevented.

What's the worst thing you can do to hurt your health?

Besides pathogens, many other dangers in the environment may negatively affect human health. For example, air pollution can cause lung cancer. It can also make asthma and other diseases worse. Bioterrorism is another potential threat in the environment. It may poison large numbers of people or cause epidemics of deadly diseases. But the worst thing you can do to yourself is smoke cigarettes.

Carcinogens and Cancer

A **carcinogen** is anything that can cause cancer. **Cancer** is a disease in which cells divide out of control. Most carcinogens cause cancer by producing mutations in DNA.

Types of Carcinogens

There are several different types of carcinogens. They include pathogens, radiation, and chemicals. Some carcinogens occur naturally. Others are produced by human actions.

- Viruses cause about 15 percent of all human cancers. For example, the virus called hepatitis B causes liver cancer.
- UV radiation is the leading cause of skin cancer. The radioactive gas known as radon causes lung cancer.
- Tobacco smoke contains dozens of carcinogens, including nicotine and formaldehyde. Exposure to tobacco smoke is the leading cause of lung cancer.
- Some chemicals that were previously added to foods, such as certain dyes, are now known to cause cancer. Cooking foods at very high temperatures also causes carcinogens to form (see **Figure** 12.12).

FIGURE 12.12
Barbecued foods are cooked at very high temperatures. This may cause carcinogens to form.

How Cancer Occurs

Mutations that lead to cancer usually occur in genes that control the cell cycle. These include tumor-suppressor genes and proto-oncogenes.

- **Tumor-suppressor genes** normally prevent cells with damaged DNA from dividing. Mutations in these genes prevent them from functioning normally. As a result, cells with damaged DNA are allowed to divide.
- **Proto-oncogenes** normally help control cell division. Mutations in these genes turn them into oncogenes. **Oncogenes** promote the division of cells with damaged DNA.

Cells that divide uncontrollably may form a **tumor**, or abnormal mass of cells. Tumors may be benign or malignant. **Benign tumors** remain localized and generally do not harm health. **Malignant tumors** are cancerous. There are no limits to their growth, so they can invade and damage neighboring tissues. Cells from malignant tumors may also break away from the tumor and enter the bloodstream. They are carried to other parts of the body, where new tumors may form. The most common and the most deadly cancers for U.S. adults are listed in **Table** 12.1.

TABLE 12.1: Cancers in U.S. Adults

Gender	Most Common Types of Cancer after Skin Cancer (% of all cancers)	Most Common Causes of Cancer Deaths (% of all cancer deaths)
Males	prostate cancer (33%), lung cancer (13%)	lung cancer (31%), prostate cancer (10%)
Females	breast cancer (32%), lung cancer (12%)	lung cancer (27%), breast cancer (15%)

More cancer deaths in adult males and females are due to lung cancer than any other type of cancer. Lung cancer is most often caused by exposure to tobacco smoke. What might explain why lung cancer causes the most cancer deaths when it isn't the most common type of cancer?

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Cancer Treatment and Prevention

Most cancers can be treated, and some can be cured. The general goal of treatment is to remove the tumor without damaging other cells. A cancer patient is typically treated in more than one way. Possible treatments include surgery, drugs (**chemotherapy**), and radiation. Early diagnosis and treatment of cancer lead to the best chance for survival. That's why it's important to know the following warning signs of cancer:

- change in bowel or bladder habits
- sore that does not heal
- unusual bleeding or discharge
- lump in the breast or elsewhere
- chronic indigestion or difficulty swallowing
- obvious changes in a wart or mole
- persistent coughing or hoarseness

Having one or more warning signs does not mean you have cancer, but you should see a doctor to be sure. Getting routine tests for particular cancers can also help detect cancers early, when chances of a cure are greatest. For example, getting the skin checked regularly by a dermatologist is important for early detection of skin cancer (see **Figure** 12.13).

You can take steps to reduce your own risk of cancer. For example, you can avoid exposure to carcinogens such as tobacco smoke and UV light. You can also follow a healthy lifestyle. Being active, eating a low-fat diet, and maintaining a normal weight can help reduce your risk of cancer.

Summary

- A carcinogen is anything that causes cancer.
- Most carcinogens produce mutations in genes that control the cell cycle.

Review

1. What is a carcinogen? What is cancer?
2. How do most carcinogens cause cancer? Give two examples of carcinogens.
3. Describe tumor-suppressor genes and describe how they cause cancer.
4. Identify three ways cancer can be treated.

FIGURE 12.13
Regular checkups with a dermatologist can detect skin cancers early. Why is early detection important?

5. List four warning signs of cancer.
6. What might explain why lung cancer causes the most cancer deaths when it isn't the most common type of cancer?

12.6 Meiosis

Learning Objectives

- Give an overview of sexual reproduction.
- Summarize meiosis.
- Outline the stages of meiosis.
- Describe how chromosomes separate in meiosis I and meiosis II.

How do you make a cell with half the DNA?

Meiosis. This allows cells to have half the number of chromosomes, so two of these cells can come back together to form a new organism with the complete number of chromosomes. This process not only helps produce gametes, it also ensures genetic variation.

Meiosis

The process that produces haploid gametes is meiosis. **Meiosis** is a type of cell division in which the number of chromosomes is reduced by half. It occurs only in certain special cells of the organisms. During meiosis, homologous chromosomes separate, and **haploid** cells form that have only one chromosome from each pair. Two cell divisions occur during meiosis, and a total of four haploid cells are produced. The two cell divisions are called meiosis I and meiosis II. The overall process of meiosis is summarized in **Figure** 14.4.

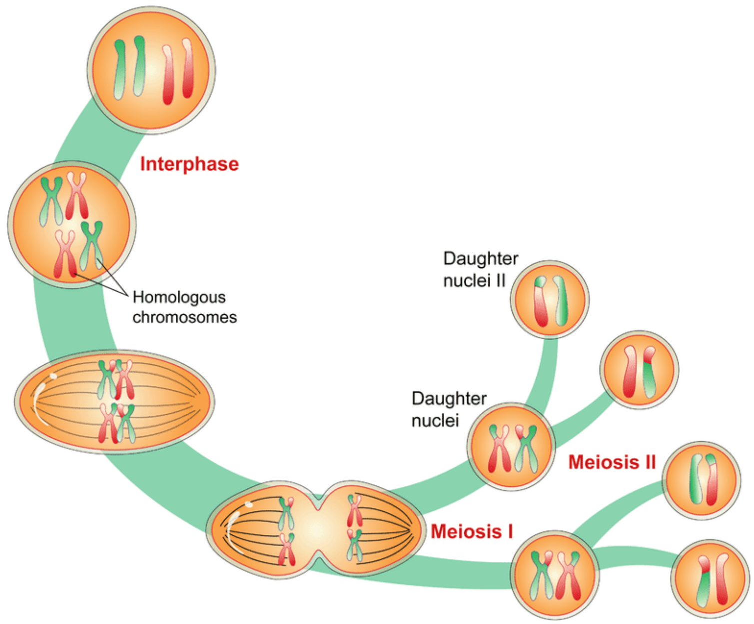

FIGURE 12.14

Overview of Meiosis. During meiosis, homologous chromosomes separate and go to different daughter cells. This diagram shows just the nuclei of the cells. Notice the exchange of genetic material that occurs prior to the first cell division.

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Phases of Meiosis

Meiosis I begins after DNA replicates during interphase of the cell cycle. In both meiosis I and meiosis II, cells go through the same four phases as mitosis - prophase, metaphase, anaphase and telophase. However, there are important differences between meiosis I and mitosis. The flowchart in **Figure** 14.5 shows what happens in both meiosis I and II.

Compare meiosis I in this flowchart with the figure from the *Mitosis and Cytokinesis* concept. How does meiosis I differ from mitosis? Notice at the beginning of meiosis (prophase I), homologous chromosomes exchange segments of DNA. This is known as **crossing-over**, and is unique to this phase of meiosis.

Meiosis I

1. Prophase I: The nuclear envelope begins to break down, and the chromosomes condense. Centrioles start moving to opposite poles of the cell, and a spindle begins to form. Importantly, **homologous chromosomes** pair up, which is unique to prophase I. In prophase of mitosis and meiosis II, homologous chromosomes do not form pairs in this way. Crossing-over occurs during this phase (see the *Genetic Variation* concept).
2. Metaphase I: Spindle fibers attach to the paired homologous chromosomes. The paired chromosomes line up along the equator (middle) of the cell. This occurs only in metaphase I. In metaphase of mitosis and meiosis II, it is sister chromatids that line up along the equator of the cell.

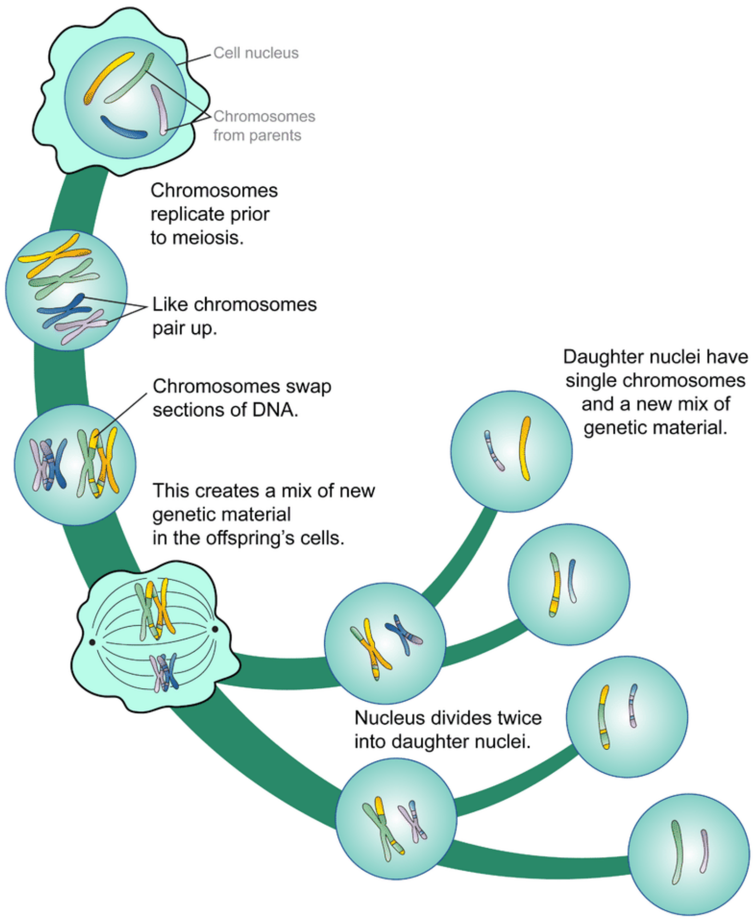


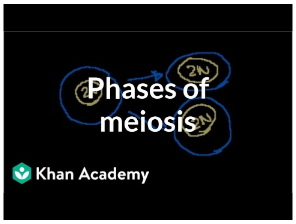
FIGURE 12.15

Phases of Meiosis. This flowchart of meiosis shows meiosis I in greater detail than meiosis II. Meiosis I—but not meiosis II—differs somewhat from mitosis. Compare meiosis I in this flowchart with the earlier figure featuring mitosis. How does meiosis I differ from mitosis?

3. Anaphase I: Spindle fibers shorten, and the chromosomes of each homologous pair start to separate from each other. One chromosome of each pair moves toward one pole of the cell, and the other chromosome moves toward the opposite pole.
4. Telophase I and Cytokinesis: The spindle breaks down, and new nuclear membranes form. The cytoplasm of the cell divides, and two haploid daughter cells result. The daughter cells each have a random assortment of chromosomes, with one from each homologous pair. Both daughter cells go on to meiosis II. The DNA does not replicate between meiosis I and meiosis II.

Meiosis II

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



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Summary

- Meiosis is the type of cell division that produces gametes.
- Meiosis involves two cell divisions and produces four haploid cells.
- Sexual reproduction has the potential to produce tremendous genetic variation in offspring. This is due in part to crossing-over during meiosis.

Review

1. What is meiosis?
2. Compare the events of metaphase I to metaphase II?
3. Create a diagram to show how crossing-over occurs and how it creates new gene combinations on each chromosome.
4. Explain why sexual reproduction results in genetically unique offspring.
5. Explain how meiosis I differs from mitosis.

12.7 References

1. Ed Uthman;User:Kelvinsong/Wikimedia Commons. http://web2.airmail.net/uthman/specimens/images/tvp.html;http://commons.wikimedia.org/wiki/File:Animal_cell_cycle.svg . Public Domain;CC BY-NC 3.0
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CHAPTER 13 Genetics: Role of DNA Inheritance

Chapter Outline

13.1 DNA

- Define transformation.
- Explain the work of Frederick Griffith that led to the discovery of transformation.
- Describe the work of Oswald Avery that helped explain the findings of Griffith.
- Summarize the findings of Alfred Hershey and Martha Chase that confirmed DNA is the genetic material.

The spiral structure in the picture is a large organic molecule. What type of organic molecule is it?

Here's a hint: molecules like this one determine who you are. They contain genetic information that controls your characteristics. They determine your eye color, facial features, and other physical attributes. What molecule is it?

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

DNA, the Genetic Material

DNA, deoxyribonucleic acid, is the genetic material in your cells. It was passed on to you from your parents and determines your characteristics. The discovery that DNA is the genetic material was another important milestone in molecular biology.

Griffith Searches for the Genetic Material

Many scientists contributed to the identification of DNA as the genetic material. In the 1920s, Frederick Griffith made an important discovery. He was studying two different strains of a bacterium, called R (rough) strain and S (smooth) strain. He injected the two strains into mice. The S strain killed (virulent) the mice, but the R strain did not (non-virulent) (see **Figure** 13.1). Griffith also injected mice with S-strain bacteria that had been killed by heat.

As expected, the killed bacteria did not harm the mice. However, when the dead S-strain bacteria were mixed with live R-strain bacteria and injected, the mice died.

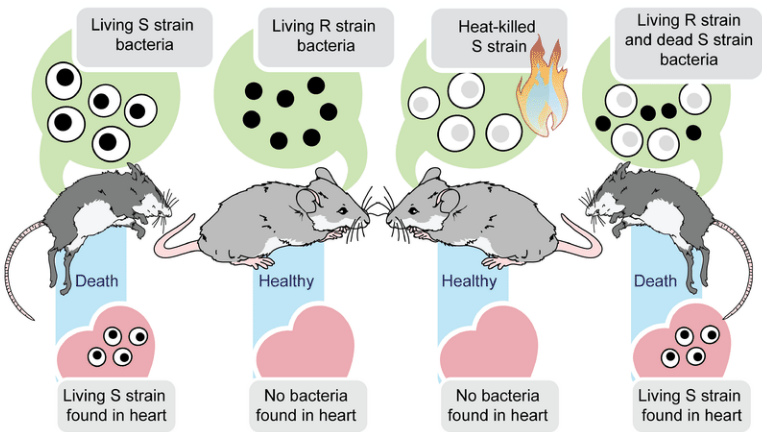


FIGURE 13.1
Griffith's Experimental Results. Griffith showed that a substance could be transferred to harmless bacteria and make them deadly.

Based on his observations, Griffith deduced that something in the killed S strain was transferred to the previously harmless R strain, making the R strain deadly. He called this process **transformation**, as something was "transforming" the bacteria from one strain into another strain. What was that something? What type of substance could change the characteristics of the organism that received it?

Avery's Team Makes a Major Contribution

In the early 1940s, a team of scientists led by Oswald Avery tried to answer the question raised by Griffith's results. They inactivated various substances in the S-strain bacteria. They then killed the S-strain bacteria and mixed the remains with live R-strain bacteria. (Keep in mind, the R-strain bacteria usually did not harm the mice.) When they inactivated proteins, the R-strain was deadly to the injected mice. This ruled out proteins as the genetic material. Why? Even without the S-strain proteins, the R strain was changed, or transformed, into the deadly strain. However, when the researchers inactivated DNA in the S strain, the R strain remained harmless. This led to the conclusion that DNA is the substance that controls the characteristics of organisms. In other words, DNA is the genetic material. You can watch an animation about the research of both Griffith and Avery at this link: http://www.dnalc.org/view/16375-Animation-17-A-gene-is-made-of-DNA-.html .

Hershey and Chase Seal the Deal

The conclusion that DNA is the genetic material was not widely accepted at first. It had to be confirmed by other research. In the 1950s, Alfred Hershey and Martha Chase did experiments with viruses and bacteria. **Viruses** are not made of cells. They are basically DNA inside a protein coat. To reproduce, a virus must insert its own genetic material into a cell (such as a bacterium). Then it uses the cell's machinery to make more viruses. The researchers used different radioactive elements to label the DNA and proteins in viruses. This allowed them to identify which molecule the viruses inserted into bacteria. DNA was the molecule they identified. This confirmed that DNA is the genetic material.

Summary

- The work of several researchers led to the discovery that DNA is the genetic material.

- Along the way, Griffith discovered the process of transformation.

Explore More

Explore More I

Use this resource to answer the questions that follow.

- **Bacteria and viruses have DNA too** at http://www.dnalc.org/resources/nobel/hershey.html

1. What is a bacteriophage?
2. How do phages reproduce?
3. Why was DNA labeled with radioactive phosphorus?
4. After the experiment, where was the radioactive phosphorus found?
5. What is the genetic material? Why?

Explore More II

- **A gene is made of DNA** at http://www.dnaftb.org/17/animation.html and http://www.dnaftb.org/17/problem.html .

Review

1. List the research that determined that DNA is the genetic material.
2. What is transformation?
3. What happened to the R-strain bacteria when Avery and his colleagues inactivated DNA in the S strain bacteria?

13.2 The DNA Double Helix - Advanced

Learning Objectives

- Explain Watson and Crick's double helix model of DNA.

How do sugars, phosphate groups and bases form DNA?

In an extremely elegant model, that's how. The base-pairing rules tell us that A always pairs with T, and G always pairs with C. But how does all this information, all these nucleotides, form the molecule known as DNA? It took the work of four distinguished scientists, three distinguished gentlemen one under-appreciated legendary woman, to solve this mystery.

The Double Helix

In the early 1950s, Rosalind Franklin started working on understanding the structure of DNA fibers. Franklin, together with Maurice Wilkins, used her expertise in x-ray diffraction photographic techniques to analyze the structure of DNA. In February 1953, Francis Crick and James D. Watson of the Cavendish Laboratory in Cambridge University had started to build a model of DNA. Watson and Crick indirectly obtained Franklin's DNA X-ray diffraction data demonstrating crucial information into the DNA structure. Francis Crick and James Watson (**Figure** 13.2) then published their double helical model of DNA in *Nature* on April 25th, 1953.

DNA has the shape of a **double helix**, just like a spiral staircase (**Figure** 13.3). As a nucleic acid, DNA is composed of **nucleotide** monomers, consisting of the deoxyribose sugar, a phosphate group, and a nitrogenous base (A, C, G or T). There are two sides to the double helix, called the **sugar-phosphate backbone**, as they are made from alternating phosphate groups and deoxyribose sugars. The "steps" of the double helix are made from the base pairs

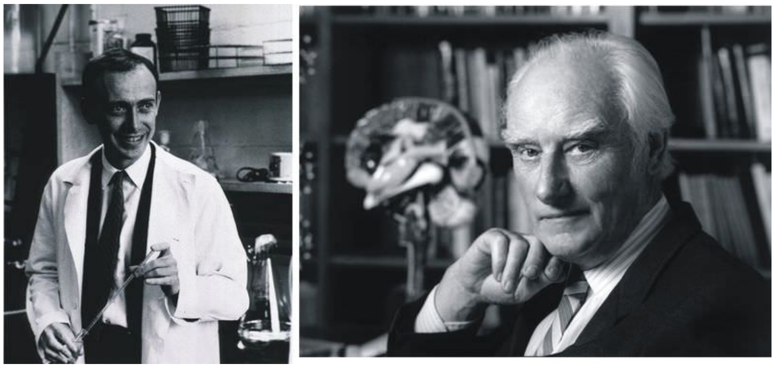


FIGURE 13.2
James Watson (left, about the time of the discovery of the double helix) and Francis Crick (right, photo taken many years later).

formed between the nitrogenous bases. The DNA double helix is held together by **hydrogen bonds** between the bases attached to the two strands.

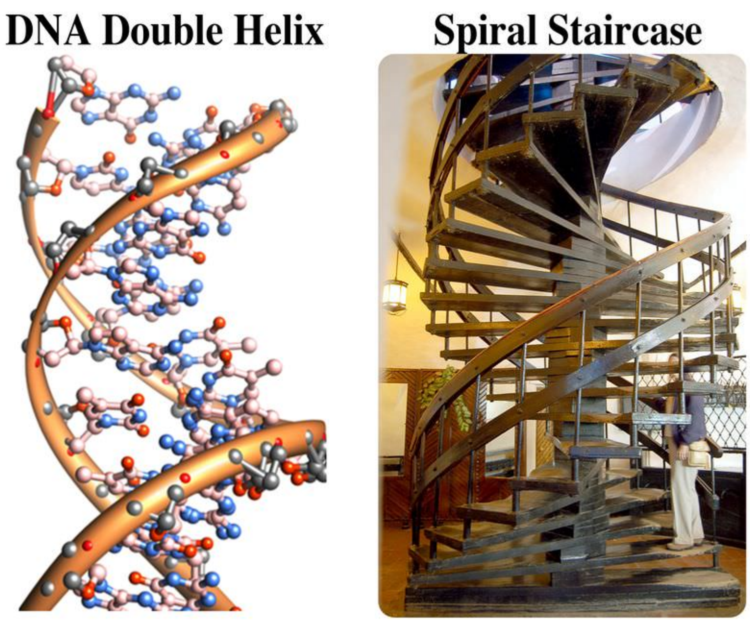


FIGURE 13.3
The DNA double helix. The two sides are the sugar-phosphate backbones, composed of alternating phosphate groups and deoxyribose sugars. The nitrogenous bases face the center of the double helix. As the base-pairing rules tell us, A always pairs with T, and G always pairs with C.

Complementary Base Pairs

The double helical nature of DNA, together with the findings of Chargaff, demonstrated the base-pairing nature of the bases. Adenine always pairs with thymine, and guanine always pairs with cytosine (**Figure** 13.4). Because of this complementary nature of DNA, the bases on one strand determine the bases on the other strand. These complementary base pairs explain why the amounts of guanine and cytosine are present in equal amounts, as are the amounts of adenine and thymine. Adenine and guanine are known as **purines**. These bases consist of two ring structures. Purines make up one of the two groups of nitrogenous bases. Thymine and cytosine are **pyrimidines**, which have just one ring structure. By having a purine always combine with a pyrimidine in the DNA double helix, the distance between the two sugar-phosphate backbones is constant, maintaining the uniform shape of the DNA molecule.

Anti-parallel Strands

The two strands in the DNA backbone run in "anti-parallel" directions to each other. That is, one of the DNA strands is built in the 5' → 3' direction, while the complementary strand is built in the 3' → 5' direction. In the DNA backbone, the sugars are joined together by phosphate groups that form bonds between the third and fifth carbon atoms of adjacent sugars. In a double helix, the direction of the nucleotides in one strand is opposite to their direction in the other strand. 5' and 3' each mark one end of a strand. A strand running in the 5' → 3' direction that has adenine will pair with base thymine on the complementary strand running in 3' → 5' direction.

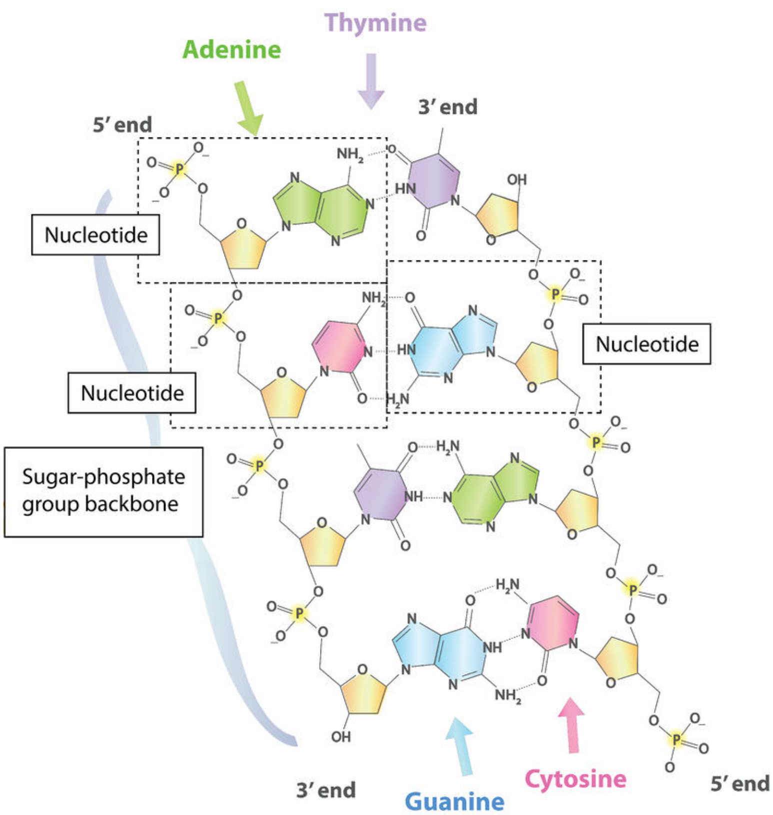


FIGURE 13.4

The base-pairing nature of DNA. Adenine always pairs with thymine, and they are held together with two hydrogen bonds. The guanine-cytosine base pair is held together with three hydrogen bonds. Note that one sugar-phosphate backbone is in the 5' → 3' direction, with the other strand in the opposite 3' → 5' orientation. Notice that the 5'-end begins with a free (not attached to the sugar of another nucleotide) phosphate group, while the 3'-end has a free (not attached to the phosphate group of another nucleotide) deoxyribose sugar.

Four Letter Code

DNA is made of a four letter code, made of just As, Cs, Gs, and Ts, that determines what the organism will become and what it will look like. How can these four bases carry so much information? This information results from the order of these four bases in the chromosomes. This sequence carries the unique genetic information for each species and each individual. Humans have about 3,000,000,000 bits of this information in each cell; 3 billion bases in the **genome**. A gorilla may also have close to that amount of information, but a slightly different sequence. For example, the sequence 5'-AGGTTTACCAGT-3' will have different information than 5'-CAAGGGATTACT-3'. The closer the evolutionary relationship is between two species, the more similar their DNA sequences will be. For example, the DNA sequences between two species of reptiles will be more similar than between a reptile and an elm tree.

DNA sequences can be used for scientific, medical, and forensic purposes. DNA sequences can be used to establish evolutionary relationships between species, to determine a person's susceptibility to inherit or develop a certain disease, or to identify crime suspects or victims. Of course, DNA analysis can be used for other purposes as well. So why is DNA so useful for these purposes? It is useful because every cell in an organism has the same DNA sequence. For this to occur, each cell must have a mechanism to copy its entire DNA. How can so much information be exactly copied in such a small amount of time?

Summary

- Watson and Crick demonstrated the double helix model of DNA.
- The two strands of the DNA double helix are complementary and run in anti-parallel directions.

Review

1. Explain Watson and Crick's double helix model of DNA.
2. Explain why complementary base pairing is necessary to maintain the double helix shape of the DNA molecule.
3. In what direction do the two strands in the DNA backbone run to each other?
4. What is the four letter code?

13.3 DNA - Advanced

Learning Objectives

- Describe the role of DNA.

What large organic molecule has a spiral shape, and may be the most important molecule to life?

Here's a hint: molecules like this one determine who you are. They contain genetic information that controls your characteristics. They determine your eye color, facial features, and other physical attributes. What molecule is it?

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

DNA and RNA

What tells the first cell of an organism what to do? How does that first cell know to divide and become two cells, then four cells, and so on? Does this cell have instructions? What are those instructions and what do they really do? What happens when those instructions don't work properly? Are the "instructions" the genetic material? Though today it seems completely obvious that deoxyribonucleic acid, or **DNA**, is the genetic material, this was not always known.

Practically everything a cell does, be it a liver cell, a skin cell, or a bone cell, it does because of proteins. It is your proteins that make a bone cell act like a bone cell, a liver cell act like a liver cell, or a skin cell act like a skin cell. It is the proteins that perform the functions of the cell, and of course, many of those functions are specific for the bone cell, liver cell, skin cell, or any other type of cell. In other words, it is the proteins that give an organism its traits. We know that it is your proteins that that make you tall or short, have light or dark skin, or have brown or blue eyes. But what tells those proteins how to act? It is the structure of the protein that determines its function. And it is the order and type of **amino acids** that determine the structure of the protein. And that order and type of amino acids that make up the protein are determined by your DNA sequence.

The relatively large chromosomes that never leave the nucleus are made of DNA. And, as proteins are made on the ribosomes in the cytoplasm, how does the information encoded in the DNA get to the site of protein synthesis? That's where **RNA** comes into this three-player act.

DNA $\rightarrow$ *RNA* $\rightarrow$ *Protein*

That's known as the **central dogma of molecular biology**. It states that "DNA makes RNA makes protein." Really it means that the genetic information within DNA is used to make smaller molecules of RNA, which leave the nucleus and then the genetic information in RNA is used to assemble amino acids into proteins. But this process does start with DNA. To understand the role of DNA in this process, it first had to be shown that DNA is the genetic material.

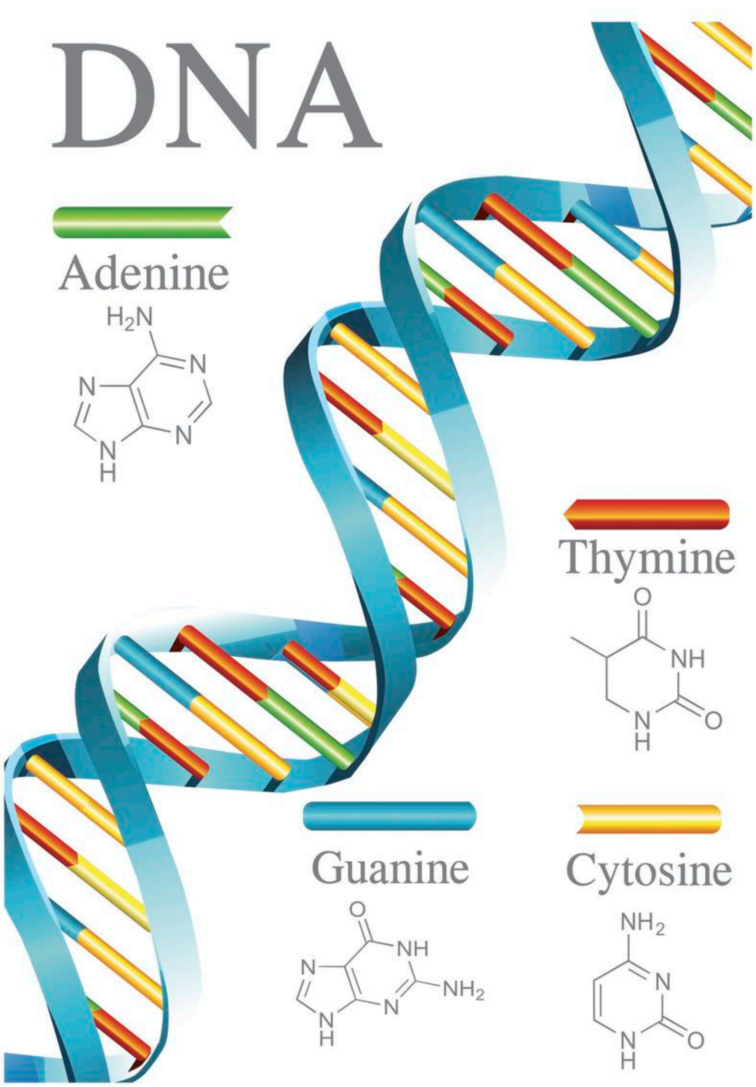


FIGURE 13.5

DNA winds into the familiar **double helix** configuration. However, it is the order of the four bases (adenine, guanine, cytosine and thymine) that provide the genetic information/instructions. These will be discussed in additional concepts.

Summary

- DNA is the genetic material.
- The central dogma of molecular biology states that DNA makes RNA makes protein.

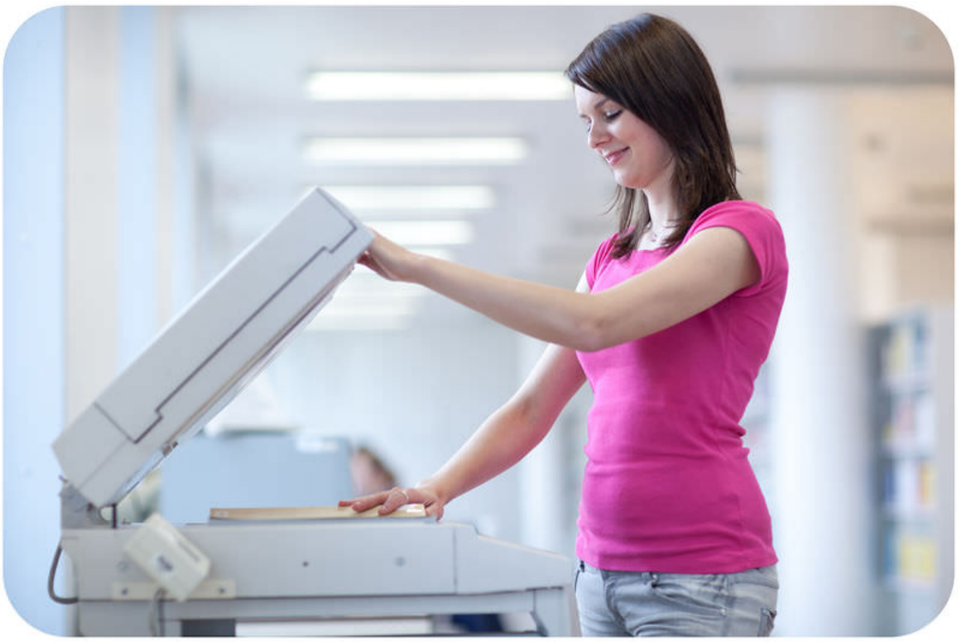
Review

1. What is DNA?
2. What is the central dogma of molecular biology?
3. Describe the relationship between DNA and protein function.

13.4 DNA Structure and Replication

Learning Objectives

- Explain why DNA must replicate itself.
- Describe the process of DNA replication.
- Explain the meaning of semiconservative replication.



Does DNA copy itself?

Yes, your DNA needs to copy itself every time a new cell is created. The new cell needs to have DNA exactly like the rest of your cells. Otherwise, that cell might malfunction. That's why it's important that the process of copying DNA, called DNA replication, is very accurate.

DNA Replication

DNA must replicate (copy) itself so that each resulting cell after mitosis and cell division has the same DNA as the parent cell. All these cells, the parent cell and the two new daughter cells, are genetically identical.

DNA replication occurs during the S phase (the Synthesis phase) of the cell cycle, before mitosis and cell division. The base pairing rules are crucial for the process of replication. DNA replication occurs when DNA is copied to form an identical molecule of DNA.

The general steps involved in DNA replication are as follows:

1. The DNA helix unwinds like a zipper as the bonds between the base pairs are broken. The enzyme DNA Helicase is involved in breaking these bonds.
2. The two single strands of DNA then each serve as a template for a new stand to be created. Using DNA as a template means that on the new strand, the bases are placed in the correct order because of the base pairing

rules. Recall that A and T are complementary bases, as are G and C. As a template strand is read, the new strand is created. If ATGCCA is on the "template strand," then TACGGT will be on the new DNA strand. The enzyme DNA Polymerase reads the template and builds the new strand of DNA.

3. The new set of nucleotides then join together to form a new strand of DNA. The process results in two DNA molecules, each with one old strand and one new strand of DNA.

This process is known as **semiconservative replication** because one strand is conserved (kept the same) in each new DNA molecule (**Figure** 13.6).

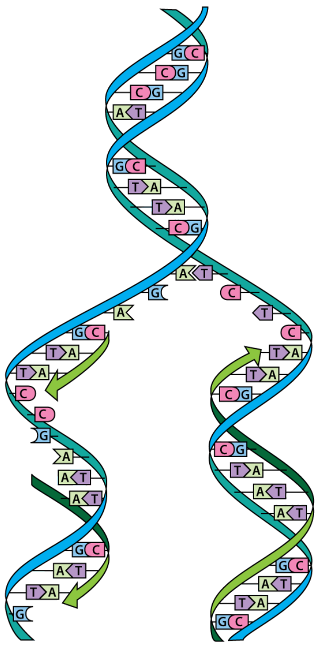


FIGURE 13.6

DNA replication occurs when the DNA strands "unzip," and the original strands of DNA serve as a template for new nucleotides to join and form a new strand.

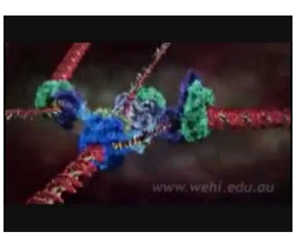
Summary

- During DNA replication, the DNA helix unwinds and the two single strands of DNA then each serve as a template for a new stand to be created.
- DNA replication is semi-conservative: the new DNA molecule consists of half of the parent DNA molecule.

Explore More

Use the resource below to answer the questions that follow.

- **DNA replication** at http://www.youtube.com/watch?v=yqESR7E4b_8 (7:47)



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1. What protein molecules does DNA wrap around to form a nucleosome?
2. What makes up chromatin?
3. When can you see chromosomes in a cell?
4. Are both strands of DNA copied continuously during replication? Explain your answer.

Review

1. Describe how DNA is replicated.
2. Explain why DNA replication is sometimes called semiconservative.

13.5 DNA Replication - Advanced

Learning Objectives

- Describe how DNA is replicated.
- Explain the importance of the fact that during DNA replication, each strand serves as a template to make a complementary DNA strand.

What do you need to copy?

Obviously, you need something to copy. The same is true for DNA. To copy or replicate DNA, you use both strands as templates.

DNA Replication

DNA replication is the process in which a cell's entire DNA is copied, or replicated. The identification of the structure of DNA suggested that each strand of the double helix would serve as a template for synthesis of a new strand. DNA replication process occurs during the Synthesis (S) phase of the eukaryotic cell cycle. As each DNA strand has the same genetic information, both strands of the double helix can serve as templates for the reproduction of a complementary new strand. The two resulting double helices, which each contain one "old" strand and one "new" strand of DNA, are identical to the initial double helix. DNA replication is said to be **semi-conservative** because of this process of replication, where the resulting double helix is composed of both an old strand and a new strand.

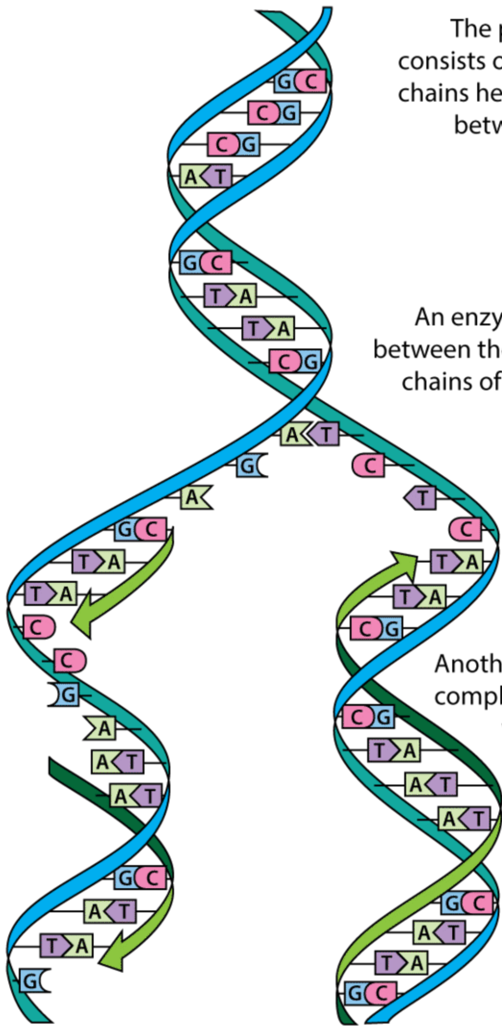

FIGURE 13.7

DNA replication occurs when the DNA strands "unzip", and the original strands of DNA serve as a template for new nucleotides to join and form a new strand. The replication fork is obvious at the point of separation of the double helix.

The semi-conservative mechanism of replication was one of three models originally proposed for DNA replication:

1. Semiconservative replication would produce two copies that each contained one of the original strands and one new strand.
2. Conservative replication would leave the two original template DNA strands together in a double helix, with the new DNA composed entirely of two new strands.
3. Dispersive replication would produce two copies of the DNA, both containing a mixture of old and new material.

Of these three models, the semi-conservative model seemed most reasonable since it would allow each new daughter strand to remain associated with its template strand. The semiconservative model was confirmed by the Meselson-Stahl experiment.

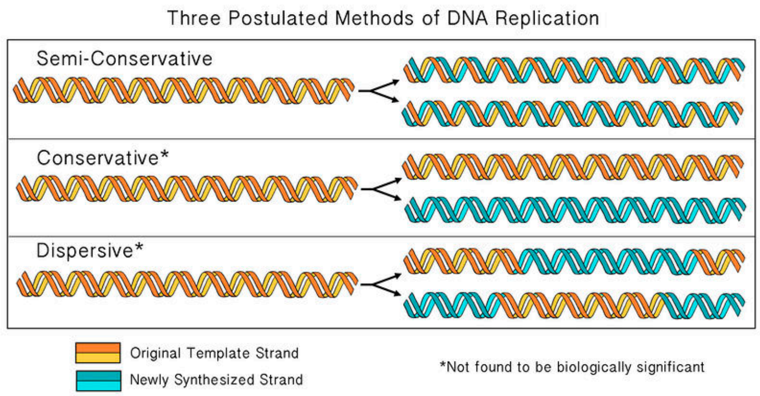

FIGURE 13.8

DNA replication is a semi-conservative process. Half of the parent DNA molecule is conserved in each of the two daughter DNA molecules.

The Meselson-Stahl Experiment

In 1958, Matthew Meselson and Franklin Stahl identified evidence that supported the hypothesis that DNA replication was semiconservative. The experiment took advantage of the fact that nitrogen is a major constituent of DNA, and that two forms of nitrogen are available: ^{14}N and a heavier isotope, ^{15}N. The DNA of cells grown in ^{15}N medium have a higher density than cells grown in normal ^{14}N medium. The experiment was performed as follows:

1. *E. coli* were grown for several generations in a medium with ^{15}N.
2. After that, *E. coli* cells with only ^{15}N in their DNA were transferred to a ^{14}N medium and were allowed to divide.
3. After one round of replication, DNA was isolated and was compared to pure ^{14}N DNA and ^{15}N DNA. After one round of DNA replication, the resulting DNA was found to have close to the intermediate density between ^{14}N labelled DNA and ^{15}N labelled DNA. Since conservative replication would result in equal amounts of DNA of the ^{15}N and ^{14}N densities, but no DNA of an intermediate density, the conservative replication model was excluded. However, this result was still consistent with both semiconservative and dispersive replication. Semiconservative replication would result in double-stranded DNA having an intermediate density, with one strand of ^{15}N DNA and one of ^{14}N DNA. Dispersive replication would result in double-stranded DNA also of an intermediate density, with both strands having mixtures of ^{15}N and ^{14}N DNA.
4. The cells were then allowed to progress through another round of DNA replication in the ^{14}N medium. DNA from cells after two replications had been completed was found to consist of equal amounts of DNA with both an intermediate density and a lower density. This was inconsistent with the dispersive replication model, which would have resulted in a single density, lower than the intermediate density of the one-replication cells, but still higher than cells grown only in ^{14}N DNA medium, as the original ^{15}N DNA would have been split evenly among all DNA strands. The result was consistent with the semiconservative replication hypothesis.

Helicase and Polymerase

DNA replication begins as an enzyme, **DNA helicase**, breaks the hydrogen bonds holding the two strands together and forms a **replication fork**. The resulting structure has two branching strands of DNA backbone with exposed bases. These exposed bases allow the DNA to be "read" by another enzyme, **DNA polymerase**, which then builds the complementary DNA strand. As DNA helicase continues to open the double helix, the replication fork grows.

5' → 3

The two new strands of DNA are "built" in opposite directions, through either a **leading strand** or a **lagging strand**. The leading strand is the DNA strand that DNA polymerase constructs in the 5' → 3' direction. This strand of DNA is made in a continuous manner, moving as the replication fork grows. The lagging strand is the DNA strand at the opposite side of the replication fork from the leading strand. It goes in the opposite direction, from 3' to 5'. DNA polymerase cannot build a strand in the 3' → 5' direction. Thus, this "lagging" strand is synthesized in short segments known as **Okazaki fragments**. On the lagging strand, an enzyme known as **primase** builds a short RNA primer. DNA polymerase is then able to use the free 3'-OH group on the RNA primer to make DNA in the 5' → 3' direction. The RNA fragments are then degraded and new DNA nucleotides are added to fill the gaps where the RNA was present. Another enzyme, **DNA ligase**, is then able to attach (ligate) the DNA nucleotides together, completing the synthesis of the lagging strand (**Figure** 13.9).

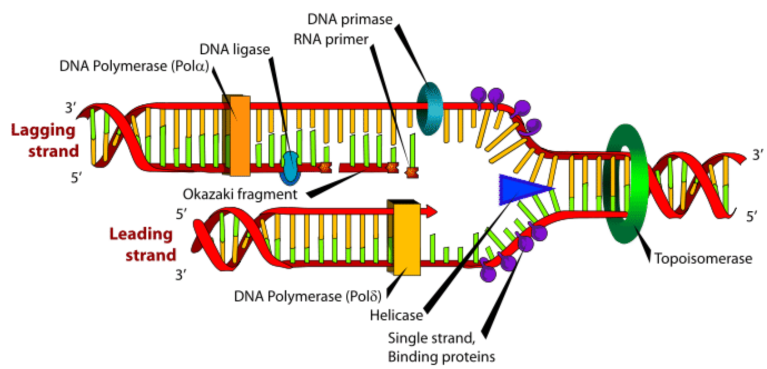

FIGURE 13.9

DNA replication. The two DNA strands are opened by helicase. The strands are held open by a single strand of binding proteins, preventing premature re-annealing. Topoisomerase solves the problem caused by tension generated by winding/unwinding of DNA. This enzyme wraps around DNA and makes a cut permitting the helix to spin and relax. Once DNA is relaxed, topoisomerase reconnects broken strands. DNA primase synthesizes a short RNA primer which initiates the Okazaki fragment. Okazaki fragments are attached by DNA ligase.

Many replication forks develop along a chromosome. This process continues until the replication forks meet, and the all of the DNA in a chromosome has been copied. Each new strand that has formed is complementary to the strand used as the template. Each resulting DNA molecule is identical to the original DNA molecule. During prophase of mitosis or prophase I of meiosis, these molecules of DNA condense into a chromosome made of two identical "sister" chromatids. This process ensures that cells that result from cell division have identical sets of genetic material, and that the DNA is an exact copy of the parent cell's DNA.

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Summary

- DNA replication is the semi-conservative process by which a cell's entire DNA is copied, or replicated.
- During DNA replication, the two new strands of DNA are "built" in opposite directions, starting at replication forks.

Review

1. How is DNA replicated?
2. What are the roles of the following enzymes?
   a. DNA polymerase
   b. DNA helicase
   c. DNA ligase
   d. primase
3. Why is DNA replication called a "semi-conservative" process?
4. Outline the Meselson-Stahl Experiment.

13.6 References

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CHAPTER 14 Genetics: Sources of Genetic Variation

Chapter Outline

14.1 Sources of Genetic Variation - Advanced

Learning Objectives

- Connect alleles to variations in traits.
- Distinguish environmental effects on gene expression from allelic variations in genes.
- Compare rates of mutation in microorganisms to those in multicellular organisms.
- Relate mutation and sexual reproduction to natural selection.
- Explain why populations, but not individuals, can evolve.

What makes things different?

With these dogs, it is their alleles that make them different. Mutations produce new and different alleles, which is the genetic variation that results in these different phenotypes.

Sources of Variation

Genetic variation results from the diversity of alleles. How do alleles form?

You may recall that **mutations** change the sequence of nucleotides in DNA. Mutations can alter single nucleotides or entire chromosomes (**Figure** 14.1), and they are the sole source of new alleles.

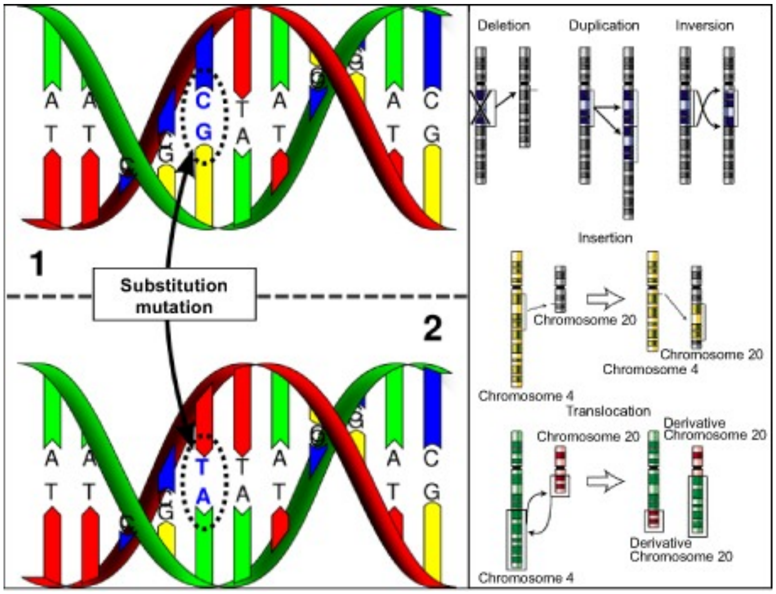

FIGURE 14.1

The ultimate source of genetic variation is random mutation - changes in nucleotide sequences of DNA. They may involve only a single base pair - as in (A), or many - as in chromosomal mutations (B).

Even a single nucleotide substitution can cause major changes in an organism; **Figure** 14.2 shows the molecular and cellular effects of the well-known substitution mutation which causes sickle-cell anemia in humans.

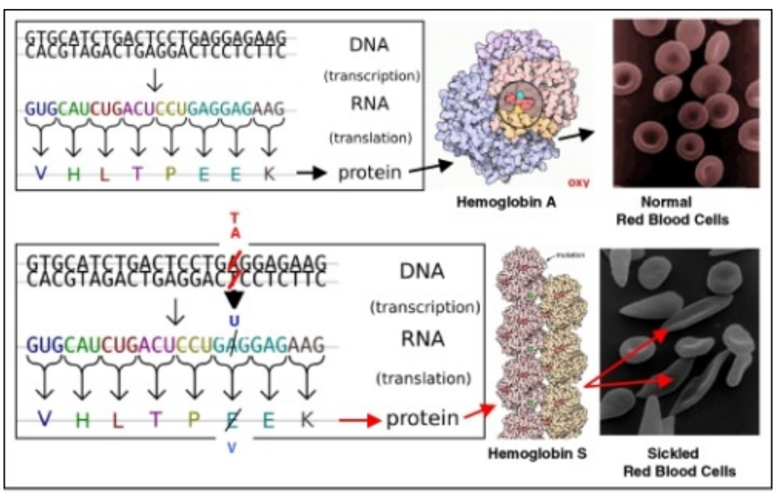

FIGURE 14.2

Mutations in DNA cause changes in the amino acid sequences of proteins, which in turn cause changes in traits. The disease Sickle Cell Anemia results from a single base-pair substitution in the gene for Hemoglobin. The single amino acid change dramatically alters the shape and function of the protein - and of red blood cells, which each contain 280,000 molecules of hemoglobin.

Ultraviolet or ionizing radiation, certain chemicals, or viruses can cause mutations to occur entirely by chance; they are not in any sense goal-directed. Usually, they reduce an organism's **fitness** - its ability to survive and reproduce. However, many mutations are neutral; they have no effect on an organism's fitness. A few may actually improve fitness. Sickle-cell hemoglobin (Hemoglobin S - see **Figure** 14.2) prevents malarial infection, so in equatorial environments where malaria is prevalent, one copy of the Hemoglobin-S allele increases chances of survival and reproduction.

New alleles arise only by chance mutations, yet without them, there would be no diversity and no evolution. Although they are rare (due to DNA repair mechanisms), mutations provide the creative potential for adaptation to environmental change.

Rates of mutation depend largely on reproductive rate and are highest in bacteria and viruses. HIV, for example, can produce over one trillion new viruses per day, and each replication of its genome provides an opportunity for mutation. Their high mutation rates explain why viruses and bacteria so often become resistant to drug treatments.

Mutations resulting in heritable variation for multicellular organisms happen constantly, but at a lower rate. In part, this is because mutations in body cells do not affect the DNA in eggs and sperm. While this prevents many damaging mutations from dooming offspring, it also reduces diversity and the potential for adaptation to changing environments. **Sexual reproduction**, however, compensates at least in part for this loss.

FIGURE 14.3

Sexual reproduction cannot produce new alleles, but it does shuffle alleles into unique combinations, adding to the raw material for natural selection.

Although sexual reproduction cannot produce new alleles, meiosis and fertilization shuffle alleles from past mutations into new combinations (**Figure** 14.3). As Mendel demonstrated, genes (which he called "factors") *segregate* and *sort independently* during the formation of eggs and sperm (return to the *Mendelian Genetics* concepts if needed), and fertilization is random. The result is that - by chance - each offspring has a unique combination of alleles - a tremendous source of variation and raw material for natural selection.

Summary

- Mutations are changes in single nucleotides or entire chromosomes and are the sole source of new alleles.
- Ultraviolet or ionizing radiation, chemicals, or viruses can cause mutations - in entirely random ways.
- Rates of mutation are high in rapidly reproducing viruses and bacteria, allowing them to adapt quickly to changing environments. An example is drug resistance.
- Rates of heritable mutations are lower in multicellular organisms because only germ cell mutations are passed on to offspring.
- Sexual reproduction recombines existing alleles through meiosis and random fertilization, so that each offspring is unique.
- Mutations and sexual reproduction provide the variety which is the raw material for natural selection.

Review

1. Describe the relationship between mutations, alleles, variation, natural selection, and chance.
2. Compare rates of mutation in microorganisms to those in multicellular organisms.

14.2 Meiosis

Learning Objectives

- Give an overview of sexual reproduction.
- Summarize meiosis.
- Outline the stages of meiosis.
- Describe how chromosomes separate in meiosis I and meiosis II.

How do you make a cell with half the DNA?

Meiosis. This allows cells to have half the number of chromosomes, so two of these cells can come back together to form a new organism with the complete number of chromosomes. This process not only helps produce gametes, it also ensures genetic variation.

Meiosis

The process that produces haploid gametes is meiosis. **Meiosis** is a type of cell division in which the number of chromosomes is reduced by half. It occurs only in certain special cells of the organisms. During meiosis, homologous chromosomes separate, and **haploid** cells form that have only one chromosome from each pair. Two cell divisions occur during meiosis, and a total of four haploid cells are produced. The two cell divisions are called meiosis I and meiosis II. The overall process of meiosis is summarized in **Figure** 14.4.

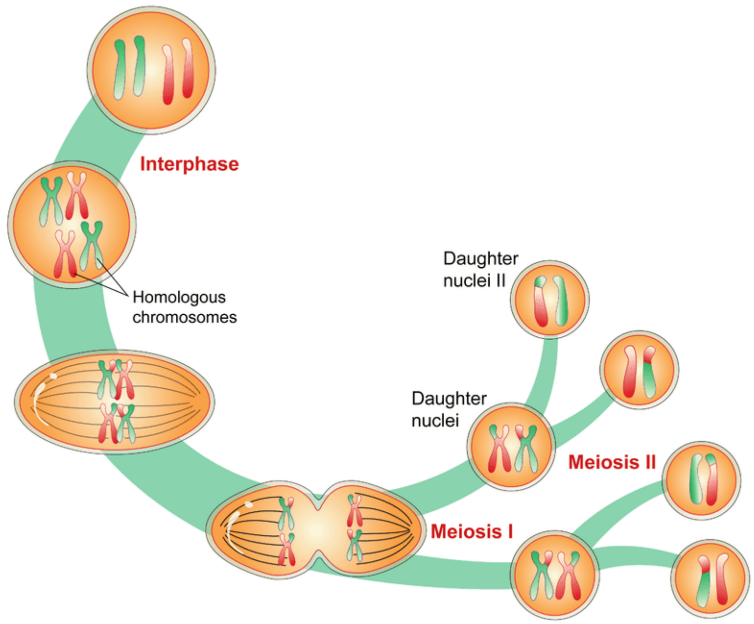

FIGURE 14.4
Overview of Meiosis. During meiosis, homologous chromosomes separate and go to different daughter cells. This diagram shows just the nuclei of the cells. Notice the exchange of genetic material that occurs prior to the first cell division.

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Phases of Meiosis

Meiosis I begins after DNA replicates during interphase of the cell cycle. In both meiosis I and meiosis II, cells go through the same four phases as mitosis - prophase, metaphase, anaphase and telophase. However, there are important differences between meiosis I and mitosis. The flowchart in **Figure** 14.5 shows what happens in both meiosis I and II.

Compare meiosis I in this flowchart with the figure from the *Mitosis and Cytokinesis* concept. How does meiosis I differ from mitosis? Notice at the beginning of meiosis (prophase I), homologous chromosomes exchange segments of DNA. This is known as **crossing-over**, and is unique to this phase of meiosis.

Meiosis I

1. Prophase I: The nuclear envelope begins to break down, and the chromosomes condense. Centrioles start moving to opposite poles of the cell, and a spindle begins to form. Importantly, **homologous chromosomes** pair up, which is unique to prophase I. In prophase of mitosis and meiosis II, homologous chromosomes do not form pairs in this way. Crossing-over occurs during this phase (see the *Genetic Variation* concept).
2. Metaphase I: Spindle fibers attach to the paired homologous chromosomes. The paired chromosomes line up along the equator (middle) of the cell. This occurs only in metaphase I. In metaphase of mitosis and meiosis II, it is sister chromatids that line up along the equator of the cell.

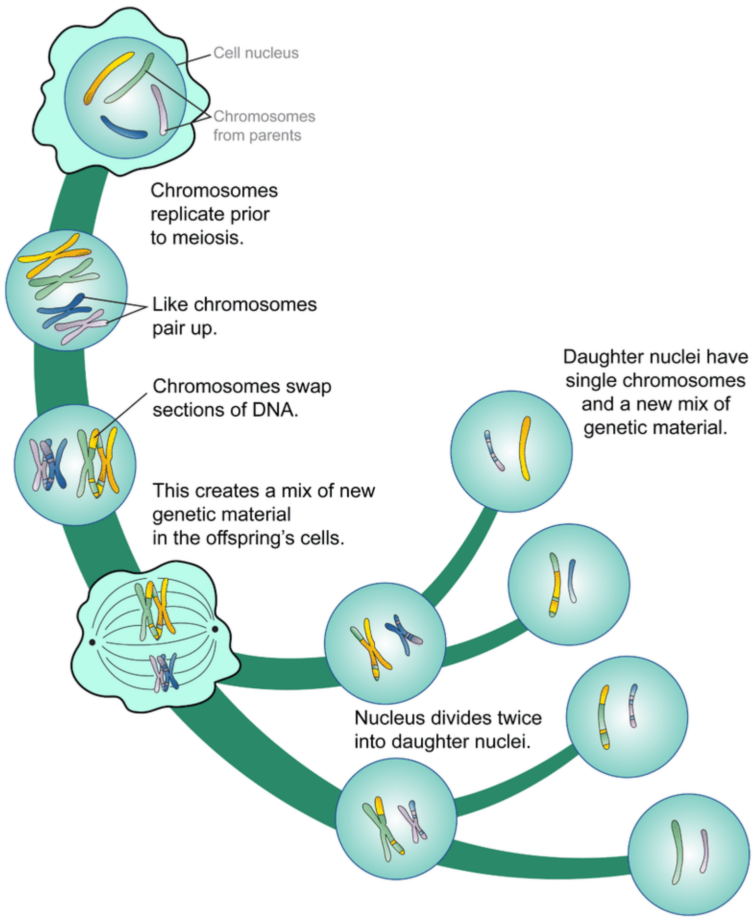


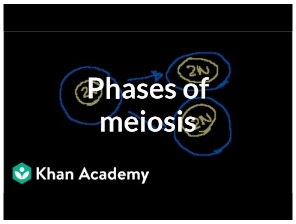
FIGURE 14.5

Phases of Meiosis. This flowchart of meiosis shows meiosis I in greater detail than meiosis II. Meiosis I—but not meiosis II—differs somewhat from mitosis. Compare meiosis I in this flowchart with the earlier figure featuring mitosis. How does meiosis I differ from mitosis?

3. Anaphase I: Spindle fibers shorten, and the chromosomes of each homologous pair start to separate from each other. One chromosome of each pair moves toward one pole of the cell, and the other chromosome moves toward the opposite pole.
4. Telophase I and Cytokinesis: The spindle breaks down, and new nuclear membranes form. The cytoplasm of the cell divides, and two haploid daughter cells result. The daughter cells each have a random assortment of chromosomes, with one from each homologous pair. Both daughter cells go on to meiosis II. The DNA does not replicate between meiosis I and meiosis II.

Meiosis II

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



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Summary

- Meiosis is the type of cell division that produces gametes.
- Meiosis involves two cell divisions and produces four haploid cells.
- Sexual reproduction has the potential to produce tremendous genetic variation in offspring. This is due in part to crossing-over during meiosis.

Review

1. What is meiosis?
2. Compare the events of metaphase I to metaphase II?
3. Create a diagram to show how crossing-over occurs and how it creates new gene combinations on each chromosome.
4. Explain why sexual reproduction results in genetically unique offspring.
5. Explain how meiosis I differs from mitosis.

14.3 Punnett Squares

Learning Objectives

- Explain a Punnett square.
- Describe how to use a Punnett square for a monohybrid and dihybrid cross.
- Predict genotypes of parents and offspring using a Punnett square.
- Determine phenotypes of offspring using a Punnett square.

What do you get when you cross an apple and an orange?

Though the above fruit may not result, it would be nice to scientifically predict what would result. Predicting the possible genotypes and phenotypes from a genetic cross is often aided by a Punnett square.

Punnett Squares

A **Punnett square** is a chart that allows you to easily determine the expected percentage of different genotypes in the offspring of two parents. An example of a Punnett square for pea plants is shown in **Figure** 16.2. In this example, both parents are **heterozygous** for flower color (*Bb*). The **gametes** produced by the male parent are at the top of the chart, and the gametes produced by the female parent are along the side. The different possible combinations of **alleles** in their offspring are determined by filling in the cells of the Punnett square with the correct letters (alleles).

Predicting Offspring Genotypes

In the cross shown in **Figure** 16.2, you can see that one out of four offspring (25 percent) has the **genotype** *BB*, one out of four (25 percent) has the genotype *bb*, and two out of four (50 percent) have the genotype *Bb*. These percentages of genotypes are what you would expect in any cross between two heterozygous parents. Of course, when just four offspring are produced, the actual percentages of genotypes may vary by chance from the expected percentages. However, if you considered hundreds of such crosses and thousands of offspring, you would get very close to the expected results, just like tossing a coin.

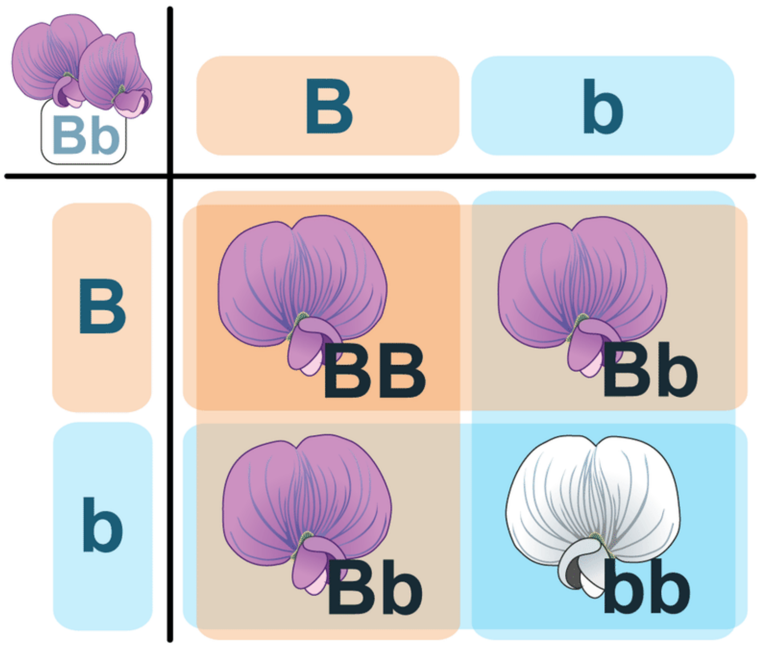

FIGURE 14.6
This Punnett square shows a cross between two heterozygotes, Bb. Do you know where each letter (allele) in all four cells comes from? Two pea plants, both heterozygous for flower color, are crossed. The offspring will show the dominant purple coloration in a 3:1 ratio. Or, about 75% of the offspring will be purple.

Predicting Offspring Phenotypes

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

Determining Missing Genotypes

A Punnett square can also be used to determine a missing genotype based on the other genotypes involved in a cross. Suppose you have a parent plant with purple flowers and a parent plant with white flowers. Because the *b* allele is recessive, you know that the white-flowered parent must have the genotype *bb*. The purple-flowered parent, on the other hand, could have either the *BB* or the *Bb* genotype. The Punnett square in **Figure** 16.3 shows this cross. The question marks (?) in the chart could be either *B* or *b* alleles.

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

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

FIGURE 14.7

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

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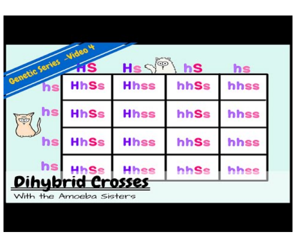
Punnett Square for Two Characteristics

When you consider more than one characteristic at a time, using a Punnett square is more complicated. This is because many more combinations of alleles are possible. For example, with two genes each having two alleles, an individual has four alleles, and these four alleles can occur in 16 different combinations. This is illustrated for pea plants in **Figure** 16.4. In this cross, known as a **dihybrid cross**, both parents are heterozygous for pod color (*Gg*) and pod form (*Ff*).



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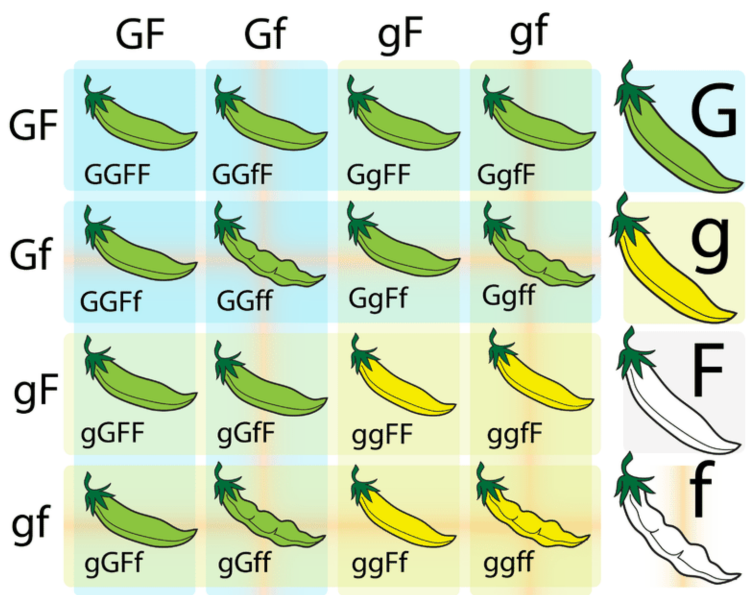


FIGURE 14.8
Punnett Square for Two Characteristics. This Punnett square represents a cross between two pea plants that are heterozygous for two characteristics. G represents the dominant allele for green pod color, and g represents the recessive allele for yellow pod color. F represents the dominant allele for full pod form, and f represents the recessive allele for constricted pod form.

Summary

- A Punnett square is a chart that allows you to determine the expected percentages of different genotypes in the offspring of two parents.
- A Punnett square allows the prediction of the percentages of phenotypes in the offspring of a cross from known genotypes.
- A Punnett square can be used to determine a missing genotype based on the other genotypes involved in a cross.

Review

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

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

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

	A	A
?	A?	Aa
?	Aa	A?

4. How do the Punnett squares for a monohybrid cross and a dihybrid cross differ?

5. What are the genotypes of gametes of a AaBb self-pollination?

6. Mendel carried out a dihybrid cross to examine the inheritance of the characteristics for seed color and seed shape. The dominant allele for yellow seed color is *Y*, and the recessive allele for green color is *y*. The dominant allele for round seeds is *R*, and the recessive allele for a wrinkled shape is *r*. The two plants that were crossed were

F1 dihybrids *RrYy*. Identify the ratios of traits that Mendel observed in the F2 generation. Create a Punnett square to help you answer the question.

14.4 Genetic Variation

Learning Objectives

- Explain why sexual reproduction leads to variation in offspring.
- Define crossing-over.
- Summarize the process of crossing-over.
- Explain the importance of independent assortment and random fertilization.

What helps ensure the survival of a species?

Genetic variation. It is this variation that is the essence of evolution. Without genetic differences among individuals, "survival of the fittest" would not be likely. Either all survive, or all perish.

Genetic Variation

Sexual reproduction results in infinite possibilities of genetic variation. In other words, sexual reproduction results in offspring that are genetically unique. They differ from both parents and also from each other. This occurs for a number of reasons.

- When homologous chromosomes form pairs during prophase I of meiosis I, crossing-over can occur. **Crossing-over** is the exchange of genetic material between homologous chromosomes. It results in new combinations of genes on each chromosome.
- When cells divide during meiosis, homologous chromosomes are randomly distributed to daughter cells, and different chromosomes segregate independently of each other. This called is called **independent assortment**. It results in gametes that have unique combinations of chromosomes.

- In sexual reproduction, two gametes unite to produce an offspring. But which two of the millions of possible gametes will it be? This is likely to be a matter of chance. It is obviously another source of genetic variation in offspring. This is known as **random fertilization.**

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

Crossing-Over

Crossing-over occurs during prophase I, and it is the exchange of genetic material between non-sister chromatids of homologous chromosomes. Recall during prophase I, homologous chromosomes line up in pairs, gene-for-gene down their entire length, forming a configuration with four chromatids, known as a **tetrad**. At this point, the chromatids are very close to each other and some material from two chromatids switch chromosomes, that is, the material breaks off and reattaches at the same position on the homologous chromosome (**Figure** 14.9). This exchange of genetic material can happen many times within the same pair of homologous chromosomes, creating unique combinations of genes. This process is also known as **recombination**.

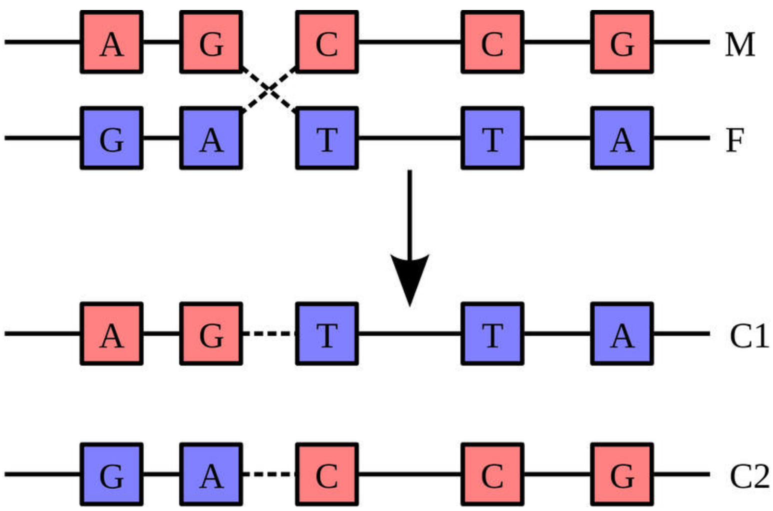
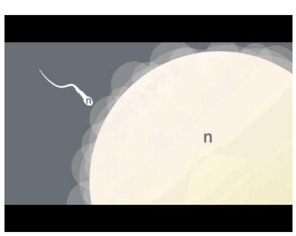


FIGURE 14.9

Crossing-over. A maternal strand of DNA is shown in red. A paternal strand of DNA is shown in blue. Crossing over produces two chromosomes that have not previously existed. The process of recombination involves the breakage and rejoining of parental chromosomes (M, F). This results in the generation of novel chromosomes (C1, C2) that share DNA from both parents.



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Independent Assortment and Random Fertilization

In humans, there are over 8 million configurations in which the chromosomes can line up during metaphase I of meiosis. It is the specific processes of meiosis, resulting in four unique haploid cells, that result in these many combinations. This independent assortment, in which the chromosome inherited from either the father or mother can sort into any gamete, produces the potential for tremendous genetic variation. Together with random fertilization, more possibilities for genetic variation exist between any two people than the number of individuals alive today. Sexual reproduction is the random fertilization of a gamete from the female using a gamete from the male. In humans, over 8 million (2^{23}) chromosome combinations exist in the production of gametes in both the male and female. A sperm cell, with over 8 million chromosome combinations, fertilizes an egg cell, which also has over 8 million chromosome combinations. That is over 64 trillion unique combinations, not counting the unique combinations produced by crossing-over. In other words, each human couple could produce a child with over 64 trillion unique chromosome combinations!

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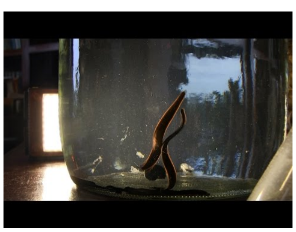
Science Friday: True BloodSuckers - Leeches

Leeches seem like disgusting creatures with little intelligence. But, in this video by Science Friday, Dr. Mark Siddall discusses his research on leeches and some of their interesting properties.



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Summary

- Sexual reproduction has the potential to produce tremendous genetic variation in offspring.
- This variation is due to independent assortment and crossing-over during meiosis, and random union of gametes during fertilization.

Review

1. What is crossing-over and when does it occur?

2. Describe how crossing-over, independent assortment, and random fertilization lead to genetic variation.
3. How many combinations of chromosomes are possible from sexual reproduction in humans?
4. Create a diagram to show how crossing-over occurs and how it creates new gene combinations on each chromosome.

14.5 Mutation and Gene Flow - Advanced

Learning Objectives

- Predict the possible effects of mutation, and analyze the probability of each type of effect.
- Contrast mutation in microorganisms to mutation in multicellular organisms.
- Define gene flow.
- Describe two possible effects of gene flow on the genetics of a population.

How do a population's genes change?

Remember, without change, there cannot be evolution. Together, the forces that change a population's gene frequencies are the driving mechanisms behind evolution.

Causes of Microevolution: Mutation and Gene Flow

As discussed previously, **mutations** - random, accidental changes in the sequence of nucleotides in DNA - are the original sources of genetic variation. Only mutations can create new **alleles** - new raw material for natural selection. UV or ionizing radiation, chemicals, and viruses constantly generate mutations in a gene pool, destabilizing genetic equilibrium and creating the potential for adaptation to changing environments. However, both rates of mutation and their effects on the fitness of the organism vary.

In multicellular organisms, most mutations occur in body cells and do not affect eggs and sperm; these are lost when the individual dies and usually do not affect evolution. Only mutations in gamete-producing cells can become part of the gene pool. The rate at which mutations enter the gene pool is low, due to DNA "proofreading" and repair enzymes - and the extensive amount of DNA which does not code for protein. Mutations which do change nucleotide sequences in functional genes may also have no effect (because the Genetic Code is redundant - multiple codons code for the same amino acid), or very little effect, if the amino acid is not located in a critical part of the protein.

Occasionally, however, a single nucleotide substitution can have a major effect on a protein - as we previously saw with sickle-cell anemia. Usually, the effect of a mutation on a protein is harmful; rarely is it helpful. In the case of sickle-cell anemia, it is both - depending on the environment. Sickled cells carry oxygen much less efficiently, but prevent malaria infections. Overall, the chance that a single mutation will increase the fitness of a multicellular organism is extremely low. If the environment changes, however, the adaptive value of a new allele may change as well. Over time, mutations accumulate, providing the variation needed for natural selection.

For the small genomes of viruses and bacteria, mutations affect genes directly and generation times are short, so rates of mutation are much higher. For an HIV population in one AIDS patient, rates of viral mutation and replication are so high that in a single day, every site in the HIV genome may have experienced mutation (**Figure** 17.22). This rapid generation of new alleles challenges our best efforts at drug treatment and explains the evolution of antibiotic resistance. Because of the abundance of random, spontaneous mutations, HIV generates a large amount of raw material for natural selection and readily evolves resistance to new "environments" created by single drugs (**Figure** 17.23). Drug "cocktails," which contain multiple anti-viral chemicals, are our effort to change the "environment" and keep up with mutation in the human-HIV evolutionary race. For microorganisms, mutation is a strong force for evolution.

For all organisms, mutations are the ultimate source of genetic variation. For a population, however, the immigration or emigration of individuals or gametes may also add to or subtract from a gene pool - a process known as **gene flow**. For example, wind or animals can carry pollen or seeds from one plant population to another. In baboon troops or wolf packs (**Figure** 17.24), juvenile males may leave the group to find mates and establish separate populations. Human history includes countless migrations; gene flow continues to mix gene pools and cause microevolutionary changes.

Gene flow can bring new alleles into a population which occurred by chance and were successful in other populations. In this way, it can accelerate microevolution. However, if exchange between populations is frequent, it reduces differences between populations, in effect increasing population size. In this case, gene flow tends to maintain separate populations as one species, reducing speciation, if not microevolution.

Mutations, together with recombination of existing alleles by sexual reproduction, provide the diversity which is the raw material for natural selection and evolution. Gene flow can accelerate the spread of alleles or reduce the differences between populations. Both can contribute significantly to microevolution. However, many biologists consider the major causes of microevolutionary change to be genetic drift and natural selection.

Summary

- Random, spontaneous mutations constantly generate new alleles in a gene pool, destabilizing genetic equilibrium and creating the potential for adaptation to changing environments.
- In multicellular organisms, only mutations that affect germ cells become part of the gene pool.
- Because of extensive "junk" DNA, repair enzymes, and multicellularity, many mutations do not reach the gene pool.
- Many mutations are harmful, disrupting protein function.
- Because the genetic code is redundant and some amino-acid substitutions may not change protein function, many mutations have no effect on an organism's fitness.

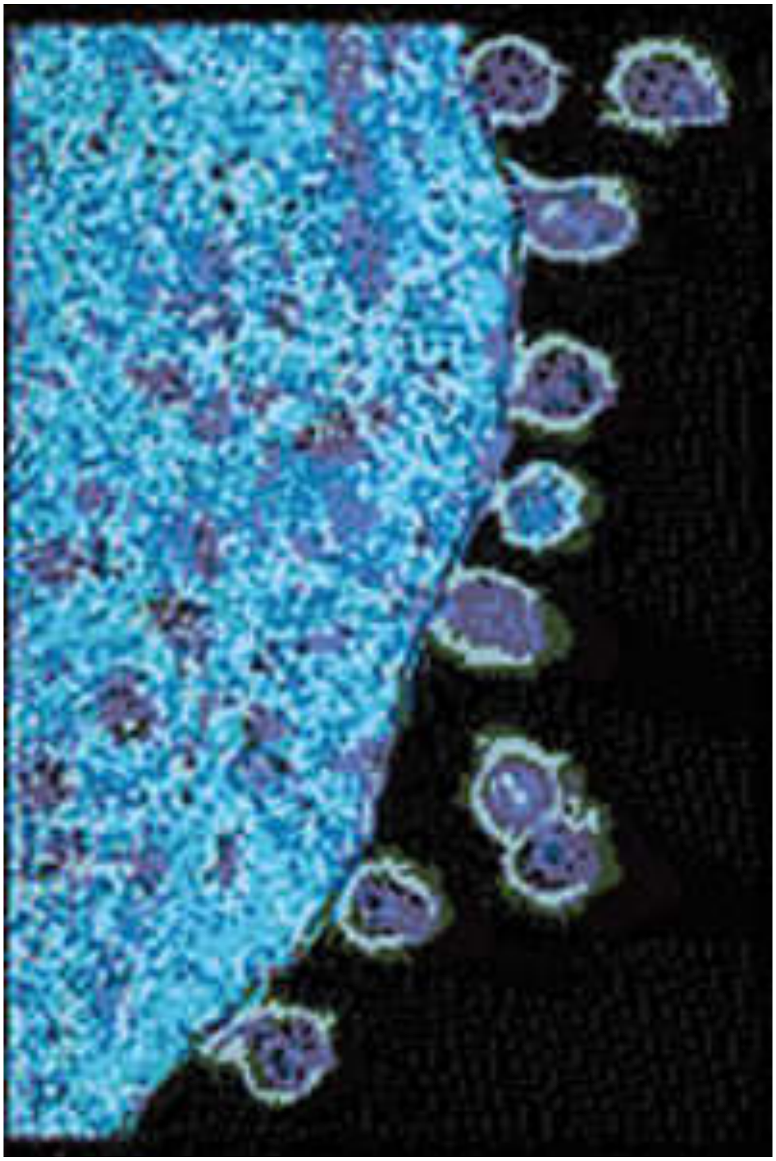


FIGURE 14.10
HIV daughter particles are shed from an infected human T-cell host. Both HIV replication and mutation rates are so high that during a single day, the HIV population in one AIDS patient generates mutations at every site in the HIV genome. New alleles provide the potential for extremely rapid evolution, including the development of resistance to drugs.

- Even neutral mutations hold potential for future selection if the environment changes.
- A few mutations may be advantageous, improving or changing protein function.
- In microorganisms mutation rates are much higher due to rapid reproduction and small genomes.
- Mutation, together with recombination of existing alleles provides the diversity which is the raw material for natural selection and evolution.
- The movement of genes from one population to another (gene flow) can change allele frequencies.
- Gene flow can accelerate the spread of successful alleles or reduce differences between populations.

Review

1. Analyze the possible effects of mutations and the probability and importance of each type of mutation.
2. Describe two possible effects of gene flow on the genetics of a population.

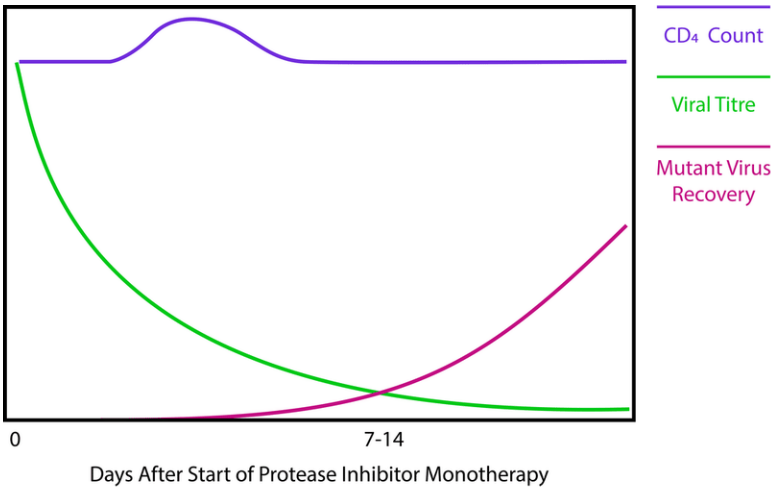


FIGURE 14.11

Extremely high HIV mutation rates provide many new alleles - the raw material for natural selection - in AIDS patients. This variation allows at least some mutant viruses to survive and reproduce in the changing "environments" of new drug therapies. The graph shows the effects of one type of drug: an initial decrease in the HIV population and a temporary rise in the number of human host (CD4) cells. Before long, however, mutants with alleles conferring drug resistance appear and begin to reproduce, which leads to a recovery in the HIV population. This change in allele frequencies is microevolution, caused by mutation and natural selection.

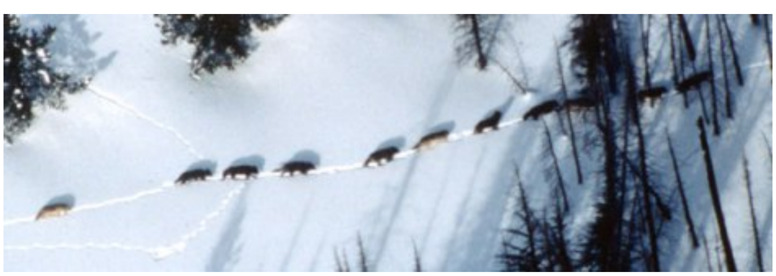


FIGURE 14.12

Dominant alpha wolves lead their pack in Yellowstone National Park. The lowest ranking omega individual, in the rear, may eventually leave the pack to find a mate and establish his own territory and pack. He would carry some of the genes from his pack to the new one - a form of gene flow which seems built into wolves' social organization.

14.6 Effect of Environment on Genetics - Advanced

Learning Objectives

- Outline how heredity and environment can interact to affect phenotype.

What do these twins have in common?

Almost all their DNA. In fact, all their nuclear DNA. Some of their mitochondrial DNA may have slight variations. So that would mean that genetic studies involving twins can be potentially very rewarding.

Effects of Environment on Phenotype

Genes play an important part in influencing phenotype, but genes are not the only influence. Environmental conditions, such as temperature and availability of nutrients can affect phenotypes. For example, temperature affects coat color in Siamese cats.

The pointed pattern is a form of partial albinism, which results from a mutation in an enzyme that is involved in melanin production. The mutated enzyme is heat-sensitive; it fails to work at normal body temperatures. However, it is active in cooler areas of the skin. This results in dark coloration in the coolest parts of the cat's body, such as the lower limbs and the face, as shown in **Figure** 16.7. The cat's face is cooled by the passage of air through the nose. Generally adult Siamese cats living in warm climates have lighter coats than those in cooler climates.

Height in humans is a complex phenotype influenced by many genes, but it is also influenced by nutrition. A person who eats a diet poor in nutrients will not grow as tall as they would have had they eaten a more nutritious diet.

Environmental Trigger

Does everyone who smokes develop lung cancer? No, of course not. Is it possible to get lung cancer without smoking? Sadly, yes it is. That's not to say there is no relationship between the two: smoking is still the leading

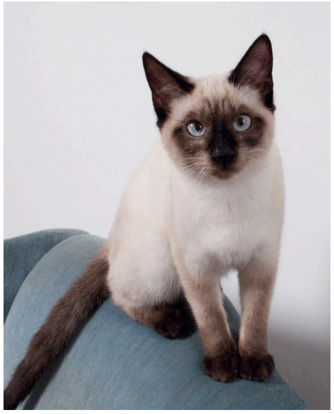


FIGURE 14.13
The dark "points" on this Siamese cat are caused by a gene that codes for a temperature-sensitive enzyme. The enzyme, which causes a darkening of the cat's fur, is active only in the cooler parts of the body such as the tail, feet, ears, and area around the nose.

cause of lung cancer. But it does suggest that a person's genetic background has a role in this process. Apart form true single gene disorders, environmental factors, or **environmental triggers**, may determine the development of disease in individuals genetically predisposed to a particular condition. Environmental triggers may include stress, physical and mental abuse, diet, exposure to toxins, pathogens, and radiation. Many cancers are thought to have an environmental component. It has been suggested that environmental factors play a role in autism as well. Asthma is obviously triggered under certain environmental conditions.

Twin Studies

The classical twin design compares the similarity of identical and fraternal twins.

Scientists often study the effects of environment on phenotype by studying identical twins. Identical twins have the same genes, so phenotypic differences between twins often have an environmental cause. **Twin studies** help understand the relative importance of environmental and genetic influences on individual traits and behaviors. Twins are a valuable source of information concerning the relationship between genes and environment. As **monozygotic twins** (identical) share their nuclear DNA, their **polymorphisms**, the nucleotide differences that make their DNA unique, are common to the two individuals. This means that any phenotypic variation, such as in height, intelligence, or any other measurable trait, is due to the environment. What is different about the experiences of the twins? What unique experiences might one twin have that the other twin did not have? By comparing phenotypes of hundreds of twins, researchers can understand the roles of genetics, shared environment and unique experiences in the formation and development of specific traits.

Dizygotic twins (fraternal or non-identical) share only about half of their polymorphisms. These twins are helpful to study as they tend to share many aspects of their environment. As they are born in the same place, usually within a few minutes of each other, they share many environmental conditions. They had the same *in utero* environment, they usually have a similar or the same parenting style during their childhood, and a similar or the same education. Similarities during childhood usually occur with wealth, culture, and their community.

Modern twin studies have shown that almost all human traits are at least partly influenced by genetic differences. Some characteristics, such as height, show a strong genetic influence, while other characteristics have an intermediate level of genetic influence, such as with intelligence. Some characteristics have a much more complex genetic relationship, with evidence for different genes affecting different aspects of the trait. Autism, with its wide spectrum of severity, is such an example.

FIGURE 14.14

Autism has a wide phenotypic spectrum of disability. Twin studies have been instrumental in demonstrating an environmental component in autism.

Summary

- An organism's phenotype can be influenced by environmental conditions.
- Environmental triggers play a role in the development of disease in individuals genetically predisposed to that disease.
- Twin studies help scientists understand the relative importance of environmental and genetic influences on individual traits and behaviors.

Review

1. Outline the relationship between environment and phenotype.
2. What is an environmental trigger? Give an example.
3. What do twin studies provide?
4. What is the difference between monozygotic twins and dizygotic twins?

14.7 Mutation

Learning Objectives

- Define mutation.
- Distinguish between point mutations and chromosomal mutations.
- Explain the outcome from a frameshift mutation.
- Describe the types of chromosomal mutations.
- Explain how mutations occur.

Would a mutation make you a superhero?

In the comic books, a mutation can give a person superpowers. Do you think this really happens? In real life, a mutation can be beneficial, or it can harm an organism. For example, beneficial mutations lead to evolution, and harmful mutations can lead to diseases like cancer. A mutation, however, is not going to turn you into a superhero!

Mutations

The process of DNA replication is not always 100% accurate. Sometimes the wrong base is inserted in the new strand of DNA. This wrong base could become permanent. A permanent change in the sequence of DNA is known as a **mutation**. Small changes in the DNA sequence are usually **point mutations**, which is a change in a single nucleotide. Once DNA has a mutation, that mutation will be copied each time the DNA replicates. After cell division, each resulting cell will carry the mutation.

A mutation may have no effect. However, sometimes a mutation can cause a protein to be made incorrectly. A defect in the protein can affect how well the protein works, or whether it works at all. Usually the loss of a protein function is detrimental to the organism.

In rare circumstances, though, the mutation can be beneficial. Mutations are a mechanism for how species evolve. For example, suppose a mutation in an animal's DNA causes the loss of an enzyme that makes a dark pigment in the animal's skin. If the population of animals has moved to a light colored environment, the animals with the mutant gene would have a lighter skin color and be better camouflaged. So in this case, the mutation is beneficial.

Point Mutations

If a single base is deleted (called a deletion, which is also a point mutation), there can be huge effects on the organism, because this may cause a **frameshift mutation**. Remember that the bases in the mRNA are read in groups of three by the tRNA. If the reading frame is off by even one base, the resulting sequence will consist of an entirely different set of codons.

The reading of an mRNA is like reading three-letter words of a sentence. Imagine the sentence: "The big dog ate the red cat." If you take out the second letter from "big," the frame will be shifted so now it will read: "The bgd oga tet her edc at." One single deletion makes the whole "sentence" impossible to read. A point mutation that adds a base (known as an insertion) would also result in a frameshift.

Chromosomal Mutations

Mutations may also occur in chromosomes (**Figure** 14.15). These mutations are going to be fairly large mutations, possible affecting many genes. Possible types of mutations in chromosomes include:

1. Deletion: When a segment of DNA is lost, so there is a missing segment in the chromosome. These usually result in many genes missing from the chromosome.
2. Duplication: When a segment of DNA is repeated, creating a longer chromosome. These usually result in multiple copies of genes in the chromosome.
3. Inversion: When a segment of DNA is flipped and then reattached to the same chromosome.
4. Insertion: When a segment of DNA from one chromosome is added to another, unrelated chromosome.
5. Translocation: When two segments from different chromosomes change positions.

Causes of Mutations

Many mutations are not caused by errors in replication. Mutations can happen spontaneously, and they can be caused by **mutagens** in the environment. Some chemicals, such as those found in tobacco smoke, can be mutagens. Sometimes mutagens can also cause cancer. Tobacco smoke, for example, is often linked to lung cancer.

Summary

- A mutation is a permanent change in the sequence of bases in DNA.

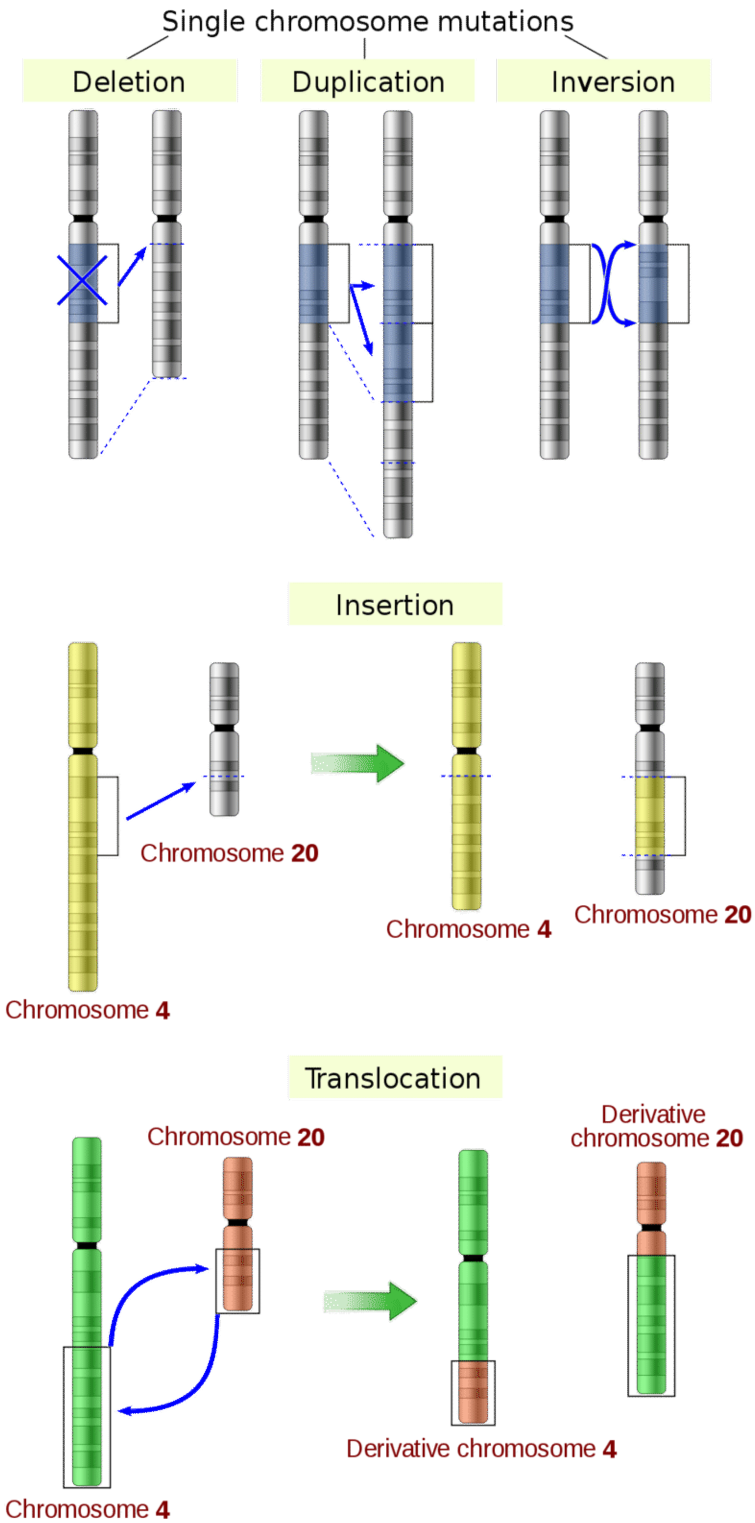


FIGURE 14.15
Mutations can arise in DNA through deletion, duplication, inversion, insertion, and translocation within the chromosome.

- Mutations occur in the DNA through deletion, duplication, inversion, insertion, and translocation within the chromosome.
- Mutations can occur due to errors during DNA replication or by mutagens in the environment.

Explore More

Use the resources below to answer the questions that follow.

Explore More I

- **Types of Mutations - Understanding Evolution** at http://evolution.berkeley.edu/evolibrary/article/mutations_03

1. What is an example of a genetic disorder caused by a substitution mutation?
2. How can a substitution mutation change a protein?
3. Explain a frameshift mutation.
4. What can cause a frameshift mutation?

Explore More II

- **Gene Regulation** at http://www.teachersdomain.org/asset/novat10_int_evodevo/

Go to this link to see how mutations affect gene regulation. Make sure you make more than one animal and see the effects of more than one mutation occurring at a time.

1. How do mutations in a part of DNA not associated with a gene generally affect the expression of that gene?
2. What do transcription factor proteins do in an organism?

Review

1. Are mutations typically beneficial to the organism?
2. What can cause DNA to mutate?
3. What is a frameshift mutation?
4. Describe two types of chromosomal mutations.

14.8 Mutation Causes

Learning Objectives

- Define mutagen.
- Identify causes of mutation.
- Give examples of spontaneous mutations.

What does radiation contamination do?

It mutates DNA. The Chernobyl disaster was a nuclear accident that occurred on April 26, 1986. It is considered the worst nuclear power plant accident in history. A Russian publication concludes that 985,000 excess cancers occurred between 1986 and 2004 as a result of radioactive contamination. The 2011 report of the European Committee on Radiation Risk calculates a total of 1.4 million excess cancers occurred as a result of this contamination.

Causes of Mutation

Mutations have many possible causes. Some mutations seem to happen spontaneously without any outside influence. They can occur when mistakes are made during DNA replication or transcription. Other mutations are caused by environmental factors. Anything in the environment that can cause a mutation is known as a **mutagen**. Examples of mutagens are pictured in **Figure** 14.16.

Spontaneous Mutations

There are five common types of spontaneous mutations. These are described in the **Table** 14.1.

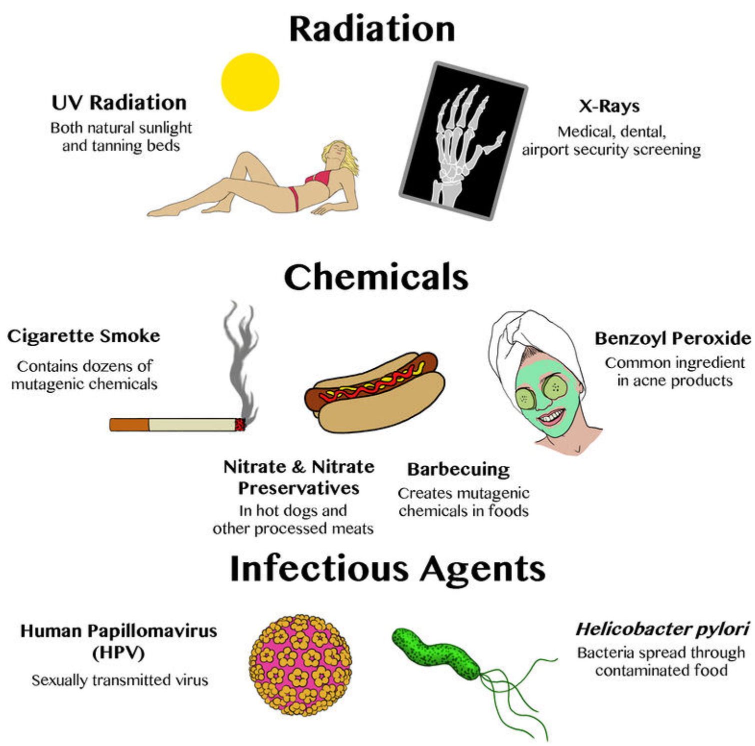


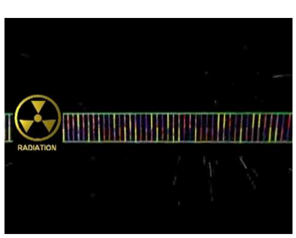
FIGURE 14.16
Examples of Mutagens. Types of mutagens include radiation, chemicals, and infectious agents. Do you know of other examples of each type of mutagen shown here?

TABLE 14.1: Common Spontaneous Mutations

Mutation	Description
Tautomerism	a base is changed by the repositioning of a hydrogen atom
Depurination	loss of a purine base (A or G)
Deamination	spontaneous deamination of 5-methycytosine
Transition	a purine to purine (A to G, G to A), or a pyrimidine to pyrimidine (C to T, T to C) change
Transversion	a purine becomes a pyrimidine, or vice versa

The Chernobyl Disaster: Follow-up

Though the area immediately around the Chernobyl disaster may not be safe for human life for thousands of years, the *Exclusion Zone* around the Chernobyl nuclear power station has become a haven for wildlife. As humans were evacuated from the area 25 years ago, existing animal populations multiplied and rare species not seen for centuries have returned or have been reintroduced, for example lynx, wild boar, wolf, Eurasian brown bear, European bison, Przewalski's horse, and eagle owl. The Exclusion Zone is so lush with wildlife and greenery that in 2007 the Ukrainian government designated it a wildlife sanctuary. It is now one of the largest wildlife sanctuaries in Europe.



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14.9 References

1. David Hall; Courtesy of the NIH;Amanda Champ. http://commons.wikimedia.org/wiki/File:Dna-SNP.svg; http://commons.wikimedia.org/wiki/File:Types-of-mutation.png;http://www.flickr.com/photos/amandachamp/8065699360 . CC BY 2.5; Public Domain;CC BY 2.0
2. Amanda Champ. http://commons.wikimedia.org/wiki/Image:Genetic_code.svg http://commons.wikimedia.org/wiki/Image:Hb-animation2.gif http://commons.wikimedia.org/wiki/Image:Redbloodcells.jpg http://commons.wikimedia.org/wiki/Image:Sickle_cell_hemoglobin.png http://commons.wikimedia.org/wiki/Image:Sicklecells.jpg;http://www.flickr.com/photos/amandachamp/8065699360 . CC-BY-SA-2.5,2.0,1.0, Public Domain;CC BY 2.0
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CHAPTER 15 Genetics: Protein Systhesis

Chapter Outline

15.1 RNA

Learning Objectives

- Distinguish between DNA and RNA.
- Name the three types of RNA.
- Explain the functions of each type of RNA.

How does your DNA send a message?

DNA is the blueprint that provides the directions on how to build all the proteins your body needs to function. However, DNA is confined to the nucleus and, therefore, isn't involved directly in the process of actually making the proteins. So how does DNA tell the rest of the cell what to do? It sends a message! The messengers consist of a special type of RNA.

Three RNAs

DNA contains the instructions to create proteins, but it does not make proteins itself. DNA is located in the nucleus, which it never leaves, while proteins are made on ribosomes in the cytoplasm. So DNA needs a messenger to bring its instructions to a ribosome located outside of the nucleus. DNA sends out a message, in the form of **RNA** (ribonucleic acid), describing how to make the protein.

There are three types of RNA directly involved in protein synthesis:

- Messenger RNA (**mRNA**) carries the instructions from the nucleus to the cytoplasm. mRNA is produced in the nucleus, as are all RNAs.

- The other two forms of RNA, ribosomal RNA (**rRNA**) and transfer RNA (**tRNA**), are involved in the process of ordering the amino acids to make the protein. rRNA becomes part of the ribosome, which is the site of protein synthesis, and tRNA brings an amino acid to the ribosome so it can be added to a growing chain during protein synthesis. There are numerous tRNAs, as each tRNA is specific for an amino acid. The amino acid actually attaches to the tRNA during this process. More about RNAs will be discussed during the *Transcription* and *Translation* Concepts.

All three RNAs are nucleic acids, made of nucleotides, similar to DNA (**Figure** 15.1). The RNA nucleotide is different from the DNA nucleotide in the following ways:

- RNA contains a different kind of sugar, called ribose.
- In RNA, the base uracil (U) replaces the thymine (T) found in DNA.
- RNA is a single strand molecule.

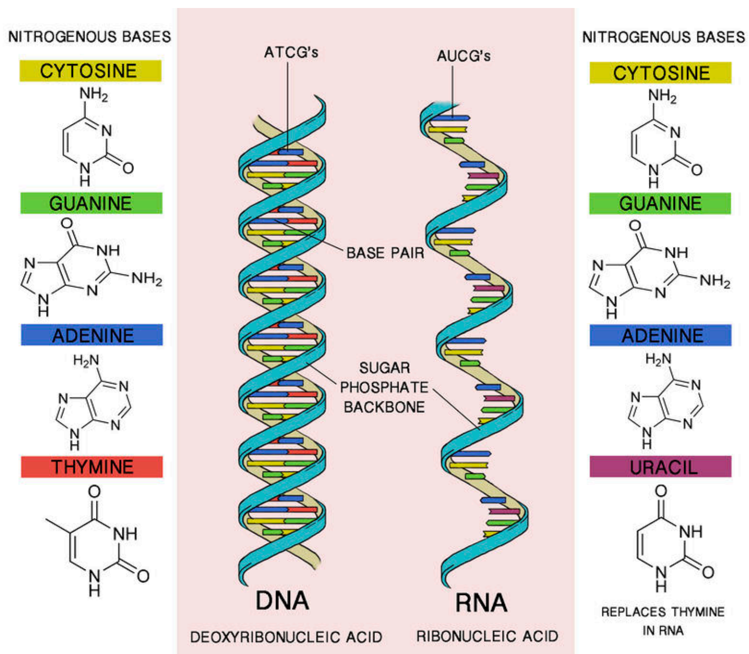


FIGURE 15.1
A comparison of DNA and RNA, with the bases of each shown. Notice that in RNA, uracil replaces thymine.

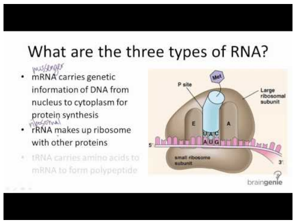
Summary

- Messenger RNA (mRNA) carries the instructions from the nucleus to the cytoplasm.
- The other two forms of RNA, ribosomal RNA (rRNA) and transfer RNA (tRNA), are involved in the process of ordering the amino acids to make proteins.
- RNA is a nucleic acid, like DNA, but differs slightly in its structure.

Explore More

Use the resource below to answer the questions that follow.

- **Three types of RNA** at http://www.youtube.com/watch?v=Kf5NeG97-38 (1:13)



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1. What does mRNA do? Where does it do this?
2. What does tRNA do? Where does it do this?
3. What does rRNA do? Where does it do this?
4. Describe the structure of the ribosome.

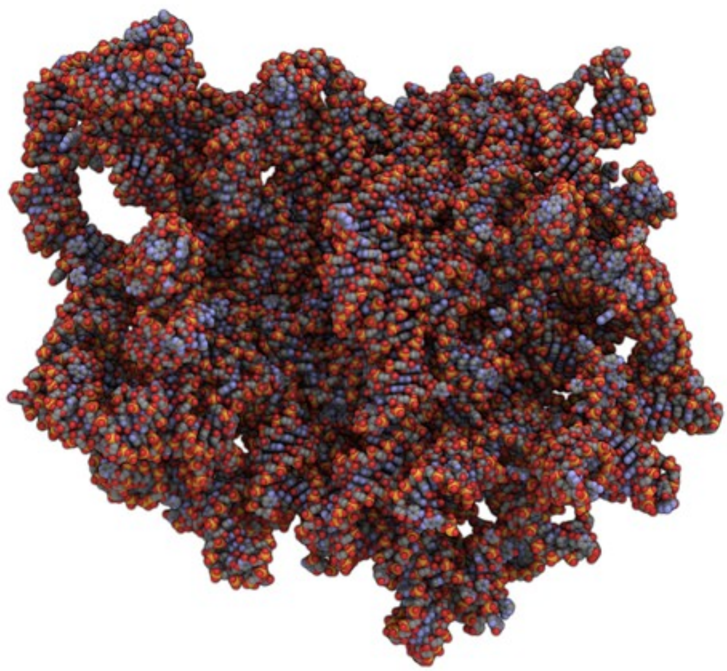
Review

1. What is the role of the mRNA in the cell?
2. Compare and contrast the composition of DNA and RNA.
3. What are the roles of tRNA and rRNA?

15.2 RNA Structure - Advanced

Learning Objectives

- Describe the structure and function of RNA.



Protein or RNA molecule?

Actually both. This represents the chemical structure of the ribosome of Baker's yeast, *Saccharomyces cerevisiae*. It is made of both protein and RNA. The RNA in this ribosome, though, has protein-like properties. RNAs are able to fold back onto themselves, folding into three-dimensional structures with functional properties. Sometimes these are enzymatic properties, such as those found in the ribosome.

RNA Structure

RNA structure differs from DNA structure in three specific ways. Both are nucleic acids and made out of **nucleotides**; however, RNA is single stranded while DNA is double stranded. RNA nucleotides, like those from DNA, have three parts: a 5-carbon sugar, a phosphate group and a base. RNA contains the 5-carbon sugar **ribose**, whereas in DNA, the sugar is deoxyribose. The difference between ribose and deoxyribose is the lack of a hydroxyl group attached to the pentose ring in the 2' position of deoxyribose.

Though both RNA and DNA contain the nitrogenous bases adenine, guanine and cytosine, RNA contains the nitrogenous base **uracil** instead of thymine. Uracil pairs with adenine in RNA, just as thymine pairs with adenine in

DNA. Uracil and thymine have very similar structures; uracil is an unmethylated form of thymine.

The nucleotide sequence of RNA, which is complementary to the DNA sequence, allows RNA to encode genetic information. RNA though carries the genetic information of just one gene. Hence, compared to DNA, RNA molecules are relatively small.

A comparison of RNA and DNA is shown in **Table** 15.1.

TABLE 15.1: short caption

	RNA	DNA
	single stranded	double stranded
Specific Base	contains uracil	contains thymine
Sugar	ribose	deoxyribose
Size	relatively small	big (chromosomes)
Location	moves to cytoplasm	stays in nucleus
Types	3 types: mRNA, tRNA, rRNA	generally 1 type

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RNA Activity

Analysis of RNAs has revealed that they are highly structured. Unlike DNA, most RNAs, though single-stranded, do form specific secondary structures. Like proteins, the folded structure of the RNA is specific and gives the RNA functional properties. Some RNAs contain self-complementary sequences that allow parts of the RNA to fold and pair with itself to form double helices. RNA nucleotides base-pair like DNA nucleotides, however in DNA, this base-pairing is necessary to form the double helix structure uniform to all DNA. In RNA, the base pairs would be A-U and G-C pairings. The base pairing in RNA is unique to each molecule of RNA and results in a three-dimensional structure that gives each molecule functional properties. Unlike DNA, their structures do not consist of long double helices but rather collections of short helices combined into a functional molecule. Because of the structure of RNA, the RNA molecule can achieve biochemical catalysis, similar to that of enzymes. For instance, the structure of the ribosome allows peptide bond formation during **protein synthesis.** The active site of the ribosome is composed entirely of RNA.

Summary

- RNA is a single-stranded nucleic acid.
- RNA contains the nitrogenous base uracil.
- RNA can fold into three-dimensional structures with functional properties.

Review

1. Describe the differences between DNA and RNA.
2. How does RNA have functional properties?
3. What is the structural difference between uracil and thymine?

15.3 Transcription

Learning Objectives

- Define transcription.
- Explain the relationship between a codon and the mRNA.
- Describe how mRNA is created from DNA.

How does DNA write its message?

The process of DNA sending a message to the cytoplasm is called transcription. Transcription means "a written copy." However, DNA can't get out a pen and write a message. It creates an mRNA molecule to carry the message.

Transcription

DNA is located in the nucleus. Proteins are made on ribosomes in the cytoplasm. Remember that information in a **gene** is converted into **mRNA**, which carries the information to the ribosome. In the nucleus, mRNA is created by using the DNA in a gene as a template. A **template** is a model provided for others to copy.

The process of constructing an mRNA molecule from DNA is known as **transcription** (**Figure** 15.2 and **Figure** 15.3). Transcription is similar to DNA replication, except in transcription, single stranded RNA is produced instead of double stranded DNA. In transcription, only one strand of DNA is used as a template. First, the double helix of DNA unwinds and an enzyme, RNA Polymerase, builds the mRNA using the DNA as a template. The nucleotides follow basically the same base pairing rules as in DNA to form the correct sequence in the mRNA. This time, however, uracil (U) pairs with each adenine (A) in the DNA.

For example, a DNA sequence ACGGGTAAGG will be transcribed into the mRNA sequence UGCCCAUUCC. In this manner, the information of the DNA is passed on to the mRNA. The mRNA will carry this code to the ribosomes to tell them how to make a protein.

As not all genes are used in every cell, a gene must be "turned on" or expressed when the gene product is needed by the cell. Only the information in a gene that is being expressed is transcribed into an mRNA.

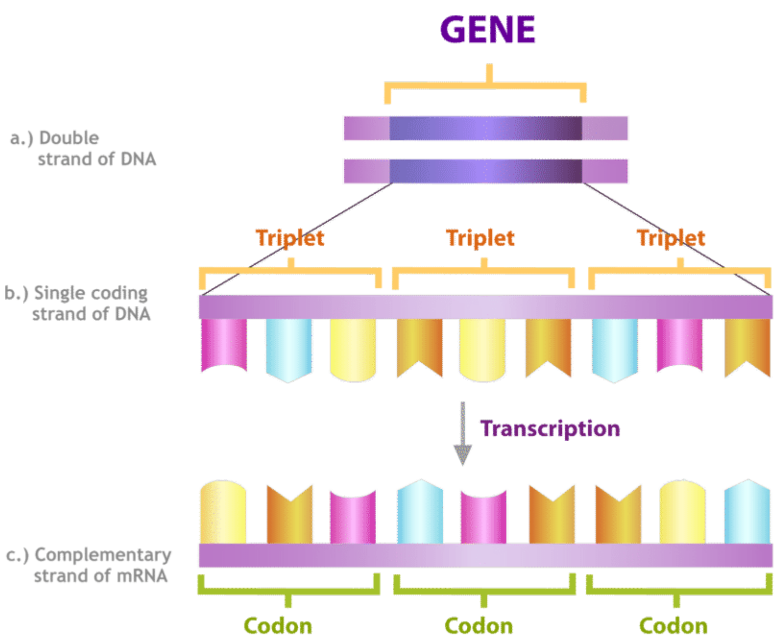

FIGURE 15.2
Transcription is when RNA is created from a DNA template. Each gene (a) contains triplets of bases (b) that are transcribed into RNA (c). Every triplet in the DNA, or **codon** in the mRNA, encodes for a unique amino acid.

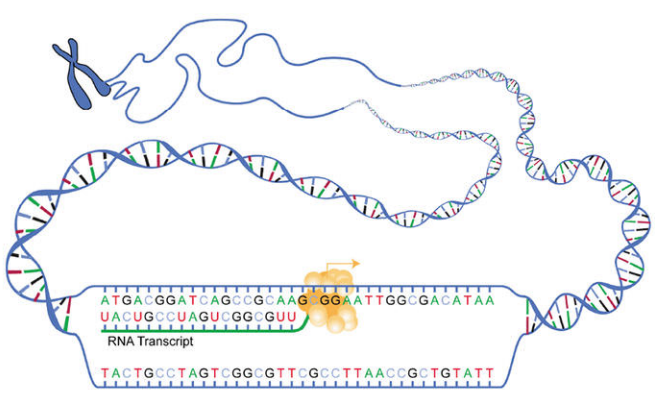

FIGURE 15.3
Base-pairing ensures the accuracy of transcription. Notice how the helix must unwind for transcription to take place. The new mRNA is shown in green.

Summary

- The process of constructing an mRNA molecule from DNA is known as transcription.
- The base pairing rules ensure that the DNA code is conserved in the sequence in the mRNA.

Explore More

Use the resources below to answer the questions that follow.

Explore More I

- **Transcription and Translation** at http://www.youtube.com/watch?v=41_Ne5mS2ls (4:06)

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Click image to the left or use the URL below.

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1. How is RNA different from DNA? Do you think this difference is important? Why?
2. Where is the mRNA made?
3. Where does the mRNA go after it is produced?

Explore More II

- **Cell Transcription** at http://www.pbslearningmedia.org/asset/lsps07_int_celltrans/

1. How many regions of a gene are there? What are they called? What is the function of each region?
2. Imagine one of these three regions was deleted by a mutation. What would happen during transcription? Explain your answer for each separate region.
3. What is the function of RNA polymerase? What kind of molecule is RNA polymerase?

Review

1. What is the final product of transcription?
2. How does the genetic code in the DNA get passed on to the mRNA?
3. What will be the mRNA sequence transcribed from a TTAAACGGCCTA template?

15.4 Translation

- Define translation.
- Explain the relationship between the tRNA, anticodon, codon, and mRNA.
- Describe the process of translation.
- Explain the role of the genetic code.

How does the cell translate a message?

The mRNA is the message sent from the nucleus to the ribosome, the organelle of protein synthesis. Like a foreign language, the genetic code of the mRNA message must then be translated so that the ribosomes make the correct protein. The process of reading the code of a mRNA to make a protein is called translation.

Translation

The mRNA, which is transcribed from the DNA in the nucleus, carries the directions for the protein-making process. mRNA tells the **ribosome** (**Figure** 15.4) how to create a specific protein.

The process of reading the mRNA code in the ribosome to make a protein is called **translation** (**Figure** 15.5): the mRNA is translated from the language of nucleic acids (nucleotides) to the language of proteins (amino acids). Sets of three bases, called **codons**, are read in the ribosome, the organelle responsible for making proteins.

The following are the steps involved in translation:

- mRNA travels to the ribosome from the nucleus.

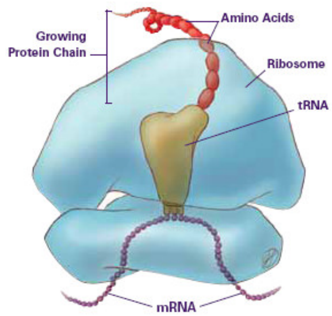


FIGURE 15.4
Ribosomes translate RNA into a protein with a specific amino acid sequence. The tRNA binds and brings to the ribosome the amino acid encoded by the mRNA.

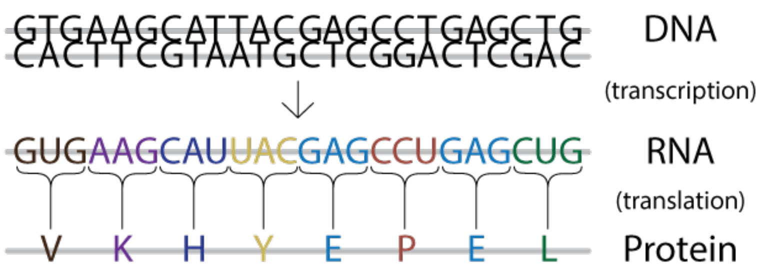


FIGURE 15.5
This summary of how genes are expressed shows that DNA is transcribed into RNA, which is translated, in turn, to protein. The one letter code represents amino acids.

The following steps occur in the ribosome:

- The base code in the mRNA determines the order of the amino acids in the protein. The genetic code in mRNA is read in "words" of three letters (triplets), called codons. Each codon codes for an amino acid. There are 20 amino acids used to make proteins, and different codons code for different amino acids. For example, GGU codes for the amino acid glycine, while GUC codes for valine.
- tRNA reads the mRNA code and brings a specific amino acid to attach to the growing chain of amino acids. The **anticodon** on the tRNA binds to the codon on the mRNA. Each tRNA carries only one type of amino acid and only recognizes one specific codon. For example, a GGC anticodon will bind to a CCG codon, and a CGA anticodon will bind to a GCU codon.
- tRNA is released from the amino acid.
- Three codons, UGA, UAA, and UAG, indicate that the protein should stop adding amino acids. They are called **stop codons** and do not code for an amino acid. Once tRNA comes to a stop codon, the protein is set free from the ribosome.

The following chart (**Figure** 15.6) is used to determine which amino acids correspond to which codons.

Summary

- Translation is the process of reading the mRNA code in the ribosome to make a protein.
- Sets of three bases on the mRNA, called codons, are read in order to select the correct amino acid for building a protein.

Explore More

1. What reads the sequence of the mRNA? What are three nucleotides that code for an amino acid called?

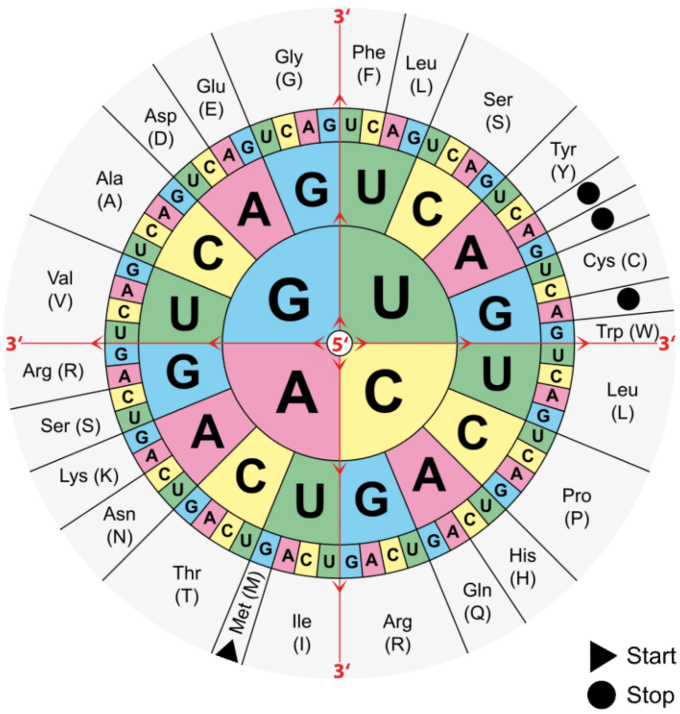


FIGURE 15.6

This chart shows the genetic code used by all organisms. For example, an RNA codon reading GUU would encode for a valine (Val) according to this chart. Start at the center for the first base of the three base codon, and work your way out. Notice that more than one codon may encode for a single amino acid. For example, glycine (Gly) is encoded by a GGG, GGA, GGC, and GGU. Notice there are 64 codons. Of the 64 codons, three are stop codons.

2. What brings amino acids to the translation site?
3. What is an anticodon? Where are they found? What is their function?
4. About how many amino acids are present in your average protein?
5. How many ribosomes read a single mRNA molecule at the same time? How is this beneficial to the organism?

Explore More II

1. What is the start code for translating an mRNA molecule?
2. How many stop codes are there from translating mRNA? What are they?
3. How many different amino acids are used to make proteins?

Review

1. What is translation?
2. What is a codon?
3. What is a stop codon?
4. What would happen if the stop codon was mutated to encode for another amino acid?
5. Given the DNA sequence, ATGTTAGCCGTATGC, what is the mRNA sequence? What is the amino acid sequence?

15.5 Proteins

Learning Objectives

- Describe the composition of a protein.
- Distinguish between the four levels of protein structure.
- Summarize significant protein functions.

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

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

Proteins

A **protein** is an organic compound made up of small molecules called **amino acids**. There are 20 different amino acids commonly found in the proteins of living organisms. Small proteins may contain just a few hundred amino acids, whereas large proteins may contain thousands of amino acids. The largest known proteins are titins, found in muscle, which are composed from over 27,000 amino acids.

Protein Structure

When amino acids bind together, they form a long chain called a **polypeptide**. A protein consists of one or more polypeptide chains. A protein may have up to four levels of structure. The lowest level, a protein's primary structure,

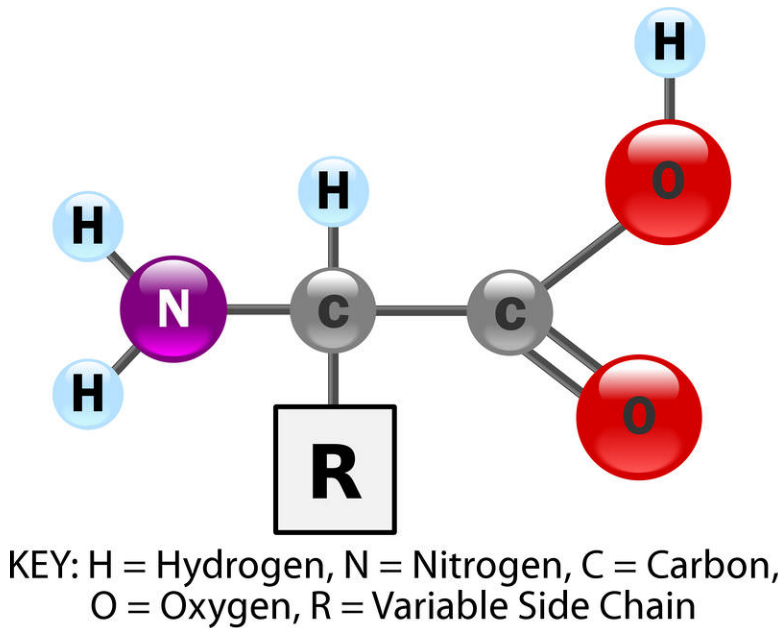


FIGURE 15.7
General Structure of Amino Acids. This model shows the general structure of all amino acids. Only the side chain, R, varies from one amino acid to another. For example, in the amino acid glycine, the side chain is simply hydrogen (H). In glutamic acid, in contrast, the side chain is CH_2CH_2COOH. Variable side chains give amino acids different chemical properties. The order of amino acids, together with the properties of the amino acids, determines the shape of the protein, and the shape of the protein determines the function of the protein. KEY: H = hydrogen, N = nitrogen, C = carbon, O = oxygen, R = variable side chain

is its sequence of amino acids. Higher levels of protein structure are described in **Figure** 15.8. The complex structures of different proteins give them unique properties, which they need to carry out their various jobs in living organisms.

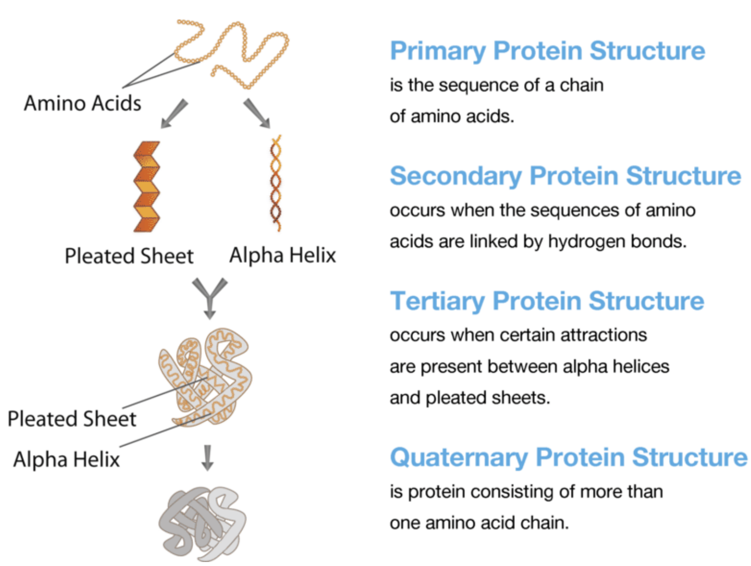


FIGURE 15.8
Protein Structure. The structure of a protein starts with its sequence of amino acids. What determines the secondary structure of a protein? What are two types of secondary protein structure?

Functions of Proteins

Proteins play many important roles in living things. Some proteins help cells keep their shape (structural proteins), some, such as connective and motor proteins, make up muscle tissues, and some transport items in and out of cells (transport proteins). Some proteins act as signals, and other proteins receive those signals. **Enzymes** are proteins that speed up chemical reactions in cells. Other proteins are **antibodies**, which bind to foreign substances such as bacteria and target them for destruction. Still other proteins carry messages or transport materials. For example, human red blood cells contain a protein called **hemoglobin**, which binds with oxygen. Hemoglobin allows the blood to carry oxygen from the lungs to cells throughout the body. A model of the hemoglobin molecule is shown in **Figure** 15.9.

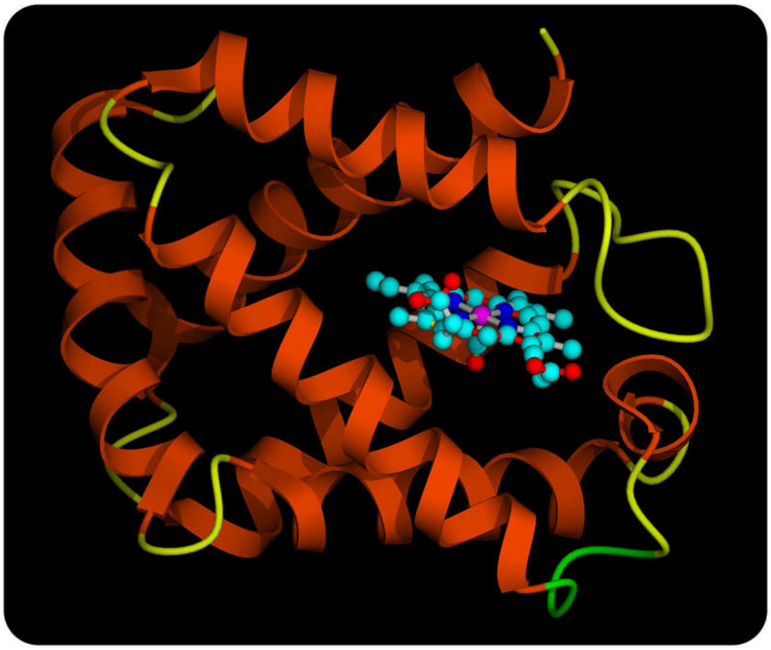
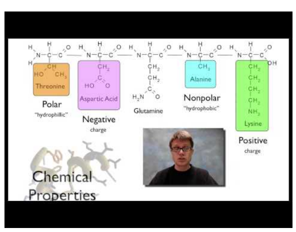


FIGURE 15.9

Hemoglobin Molecule. This model represents the protein hemoglobin. The purple part of the molecule contains iron. The iron binds with oxygen molecules.



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Proteins and Diet

Proteins in the diet are necessary for life. Dietary proteins are broken down into their component amino acids when food is digested. Cells can then use the components to build new proteins. Humans are able to synthesize all but eight of the twenty common amino acids. These eight amino acids, called **essential amino acids**, must be consumed in foods. Like dietary carbohydrates and lipids, dietary proteins can also be broken down to provide cells with energy.

Science Friday: The Medical Wonders of Worm Spit

How useful is worm spit? It turns out that worm spit, also known as silk, is a very useful material in medicine. In this video by Science Friday, Dr. David Kaplan describes how silk is used in a variety of medical applications.

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Summary

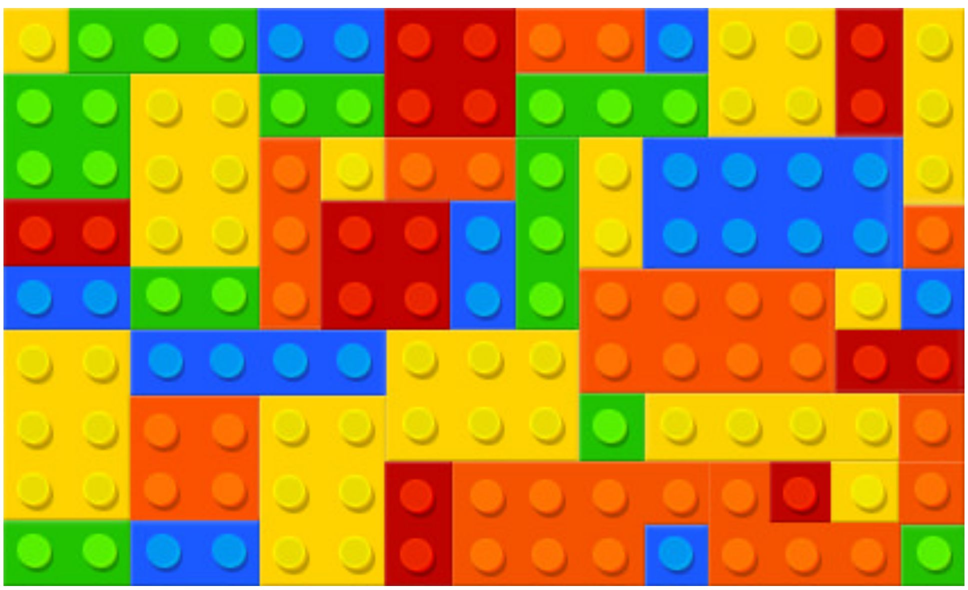
- Proteins are organic compounds made up of amino acids.
- A protein may have up to four levels of structure. The complex structures of different proteins give them unique properties.
- Enzymes are proteins that speed up biochemical reactions in cells. Antibodies are proteins that target pathogens for destruction.

Review

1. Proteins are made out of _____________.
2. What determines the primary structure of a protein?
3. State two functions of proteins.
4. What are enzymes?
5. Describe the role of hemoglobin.

15.6 Protein Synthesis

- Define gene.
- Describe the purpose of protein synthesis.
- Explain the meaning of gene expression.
- Summarize the relationship between DNA, amino acids, and proteins.



How do you build a protein?

Your body needs proteins to create muscles, regulate chemical reactions, transport oxygen, and perform other important tasks in your body. But how are these proteins built? They are made up of units called amino acids. Just like there are only a few types of blocks in a set, there are a limited number of amino acids. But there are many different ways in which they can be combined.

Introduction to Protein Synthesis

A monomer is a molecule that can bind to other monomers to form a polymer. **Amino acids** are the monomers of a protein. The DNA sequence contains the instructions to place amino acids into a specific order.

When the amino acid monomers are assembled in that specific order, proteins are made, a process called **protein synthesis.** In short, DNA contains the instructions to create proteins. But DNA does not directly make the proteins. Proteins are made on the ribosomes in the cytoplasm, and DNA (in an eukaryotic cell) is in the nucleus. So the cell uses an RNA intermediate to produce proteins.

Each strand of DNA has many separate sequences that code for a specific protein. Insulin is an example of a protein made by your cells (**Figure** 15.10). Units of DNA that contain code for the creation of a protein are called **genes**.

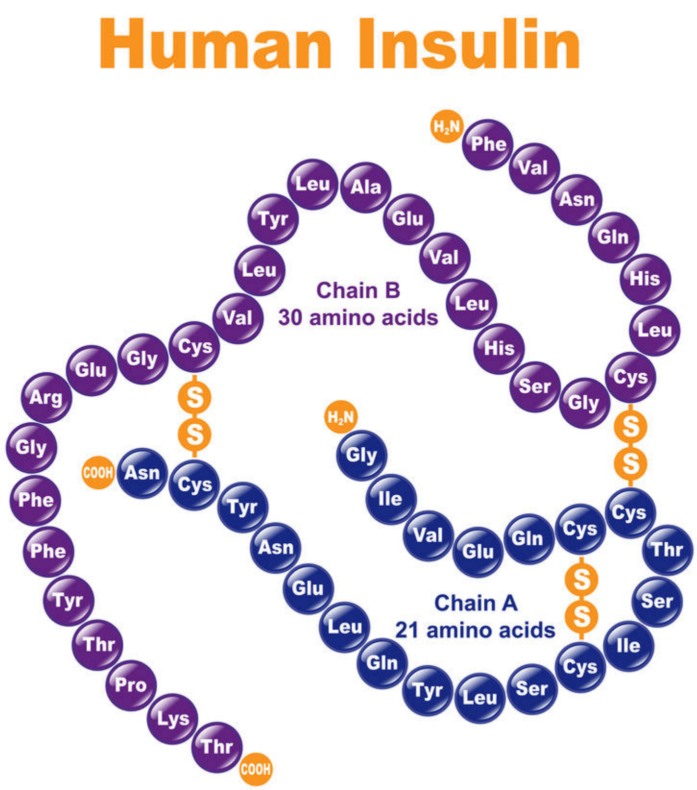


FIGURE 15.10
Insulin. Each blue or purple bead represents a different amino acid. Just 20 different amino acids are arranged in many different combinations to make thousands of proteins.

Cells Can Turn Genes On or Off

There are about 22,000 genes in every human cell. Does every human cell have the same genes? Yes. Does every human cell make the same proteins? No. In a multicellular organism, such as us, cells have specific functions because they have different proteins. They have different proteins because different genes are expressed in different cell types (which is known as **gene expression**).

Imagine that all of your genes are "turned off." Each cell type only "turns on" (or expresses) the genes that have the code for the proteins it needs to use. So different cell types "turn on" different genes, allowing different proteins to be made. This gives different cell types different functions.

Once a gene is expressed, the protein product of that gene is usually made. For this reason, gene expression and protein synthesis are often considered the same process.

Summary

- DNA contains the instructions to assemble amino acids in a specific order to make protein.
- Each cell type only "turns on" (or expresses) the genes that have the code for the proteins it needs to use.
- Gene expression and protein synthesis are usually considered the same molecular process.

Explore More

1. What is the cell structure used in the assembly of proteins?
2. What is the molecule that delivers the amino acids?
3. What ends protein synthesis?

Review

1. What is a gene?
2. What is an amino acid?
3. If every human cell has the same genes, how can they look and function so differently?
4. What is the relationship between DNA and proteins?

15.7 References

1. Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
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3. National Human Genome Research Institute. http://commons.wikimedia.org/wiki/Image:DNA_transcription.gif . Public Domain
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CHAPTER 16 Genetics: Population Genetics

Chapter Outline

16.1 Mendel's Laws

Learning Objectives

- Distinguish between dominant and recessive traits.
- Explain the law of segregation.

What does it mean to be dominant?

The most powerful or influential individual in a group is sometimes called dominant. In genetics, a dominant trait means nearly the same thing. A dominant trait is the most influential trait and masks the other trait.

Dominance

Do you remember what happened when Mendel crossed purple flowered-plants and white flowered-plants? All the offspring had purple flowers. There was no blending of traits in any of Mendel's experiments. Mendel had to come up with a theory of inheritance to explain his results. He developed a theory called the **law of segregation**.

The Law of Segregation

Mendel proposed that each pea plant had two hereditary factors for each trait. There were two possibilities for each hereditary factor, such as a purple factor or white factor. One factor is **dominant** to the other. The other trait that is masked is called the **recessive** factor, meaning that when both factors are present, only the effects of the dominant factor are noticeable (**Figure** 16.1). Although you have two hereditary factors for each trait, each parent can only pass on one of these factors to the offspring. When the sex cells, or **gametes** (sperm or egg), form, the heredity factors must separate, so there is only one factor per gamete. In other words, the factors are "segregated" in each gamete. Mendel's law of segregation states that the two hereditary factors separate when gametes are formed. When fertilization occurs, the offspring receive one hereditary factor from each gamete, so the resulting offspring have two factors.

The law of segregation predates our understanding or meiosis. Mendel developed his theories without an understanding of DNA, or even the knowledge that DNA existed. Quite a remarkable feat!

FIGURE 16.1

In peas, purple flowers are dominant to white. If one of these purple flowers is crossed with a white flower, all the offspring will have purple flowers.

Example Cross

This law explains what Mendel had seen in the F1 generation when a tall plant was crossed with a short plant. The two heredity factors in this case were the short and tall factors. Each individual in the F1 would have one of each factor, and as the tall factor is dominant to the short factor (the recessive factor), all the plants appeared tall.

In describing genetic crosses, letters are used. The dominant factor is represented with a capital letter (T for tall) while the recessive factor is represented by a lowercase letter (t). For the T and t factors, three combinations are possible: TT, Tt, and tt. TT plants will be tall, while plants with tt will be short. Since T is dominant to t, plants that are Tt will be tall because the dominant factor masks the recessive factor.

In this example, we are crossing a TT tall plant with a tt short plant. As each parent gives one factor to the F1 generation, all of the F1 generation will be Tt tall plants.

When the F1 generation (Tt) is allowed to self-pollinate, each parent will give one factor (T or t) to the F2 generation. So the F2 offspring will have four possible combinations of factors: TT, Tt, tT, or tt. According to the laws of probability, 25% of the offspring would be tt, so they would appear short. And 75% would have at least one T factor and would be tall.

Summary

- One hereditary factor is dominant to the other. The dominant trait masks the recessive factor, so that when both factors are present, only the effects of the dominant factor are noticeable.
- According to Mendel's law of segregation, there are two hereditary factors for each trait that must segregate during gamete (egg and sperm) production. As a result, offspring receive one factor from each parent, resulting in two factors for each trait in the offspring.

Explore More

Use the resource below to answer the questions that follow.

- **Mendel's Experiment** at http://www.sumanasinc.com/webcontent/animations/content/mendel/mendel.html

1. In Mendel's experiments, did it matter if the dominant trait came from the seed plant or the pollen plant?
2. Yellow is a dominant trait in peas. You breed two plants with yellow peas, and some of the offspring's peas are green? How can this be? Explain your answer fully.
3. For some of his experiments Mendel saw a 9:3:3:1 ratio, consisting of 9 yellow/smooth, 3 yellow/wrinkled, 3 green/smooth, and 1 green/wrinkled. What did he conclude from this ratio? Explain where these ratios came from.

Review

1. What is the difference between a dominant trait and a recessive trait?
2. Explain the law of segregation.
3. When Mendel crossed a *TT* tall plant with a *tt* short plant, what did he observe in the F1 generation? Why?
4. If *PP* purple plants are crossed with *pp* white plants, what will be the possible combinations of factors if the F1 generation is allowed to self-pollinate?

16.2 Population Genetics

Learning Objectives

- Distinguish between microevolution and macroevolution.
- Define gene pool.
- Explain how to calculate allele frequencies.

Jeans vs. Genes. What's the difference?

Plenty. One you have for life, the other just lasts a few years. One is the basis for the passing of traits from one generation to the next. Some jeans you change frequently. But what happens when you change a gene's frequency? Essentially, evolution is a change in gene frequencies within a population.

Genes in Populations

Darwin knew that heritable variations are needed for evolution to occur. However, he knew nothing about Mendel's laws of genetics. Mendel's laws were rediscovered in the early 1900s. Only then could scientists fully understand the process of evolution. We now know that variations of traits are heritable. These variations are determined by different **alleles**. We also know that evolution is due to a change in alleles over time. How long a time? That depends on the scale of evolution.

- **Microevolution** occurs over a relatively short period of time within a population or species. The Grants observed this level of evolution in Darwin's finches (see the "Biogeography" concept).
- **Macroevolution** occurs over geologic time above the level of the species. The fossil record reflects this level of evolution. It results from microevolution taking place over many generations.

Remember that individuals do not evolve. Their **genes** do not change over time. The unit of evolution is the population. A **population** consists of organisms of the same species that live in the same area. In terms of evolution, the population is assumed to be a relatively closed group. This means that most mating takes place within the population. The science that focuses on evolution within populations is **population genetics**. It is a combination of evolutionary theory and Mendelian genetics.

Gene Pool

The genetic makeup of an individual is the individual's **genotype**. A population consists of many genotypes. Altogether, they make up the population's gene pool. The **gene pool** consists of all the genes of all the members of the population. For each gene, the gene pool includes all the different alleles for the gene that exist in the population. For a given gene, the population is characterized by the frequency of the different alleles in the gene pool.

Allele Frequencies

Allele frequency is how often an allele occurs in a gene pool relative to the other alleles for that gene. Look at the example in the **Table** 17.2. The population in the table has 100 members. In a sexually reproducing species, each member of the population has two copies of each gene. Therefore, the total number of copies of each gene in the gene pool is 200. The gene in the example exists in the gene pool in two forms, alleles *A* and *a*. Knowing the genotypes of each population member, we can count the number of alleles of each type in the gene pool. The table shows how this is done.

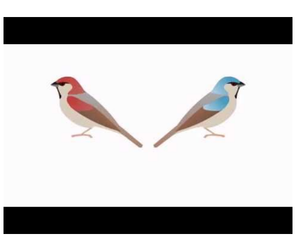
TABLE 16.1: Number of Alleles in a Gene Pool

Genotype	**Number of Individuals in the Population with that Genotype**	**Number of Allele *A* Contributed to the Gene Pool by that Genotype**	**Number of Allele *a* Contributed to the Gene Pool by that Genotype**
AA	50	$50 \times 2 = 100$	$50 \times 0 = 0$
Aa	40	$40 \times 1 = 40$	$40 \times 1 = 40$
aa	10	$10 \times 0 = 0$	$10 \times 2 = 20$
Totals	100	140	60

Let the letter p stand for the frequency of allele A. Let the letter q stand for the frequency of allele a. We can calculate p and q as follows:

- p = number of A alleles/total number of alleles = 140/200 = 0.7
- q = number of a alleles/total number of alleles = 60/200 = 0.3
- Notice that $p + q = 1$.

Evolution occurs in a population when allele frequencies change over time. What causes allele frequencies to change? That question was answered by Godfrey Hardy and Wilhelm Weinberg in 1908 (see the *Hardy-Weinberg Theorem* concept).



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Summary

- Microevolution occurs over a short period of time in a population or species. Macroevolution occurs over geologic time above the level of the species.
- The population is the unit of evolution.
- A population's gene pool consists of all the genes of all the members of the population.
- For a given gene, the population is characterized by the frequency of different alleles in the gene pool.

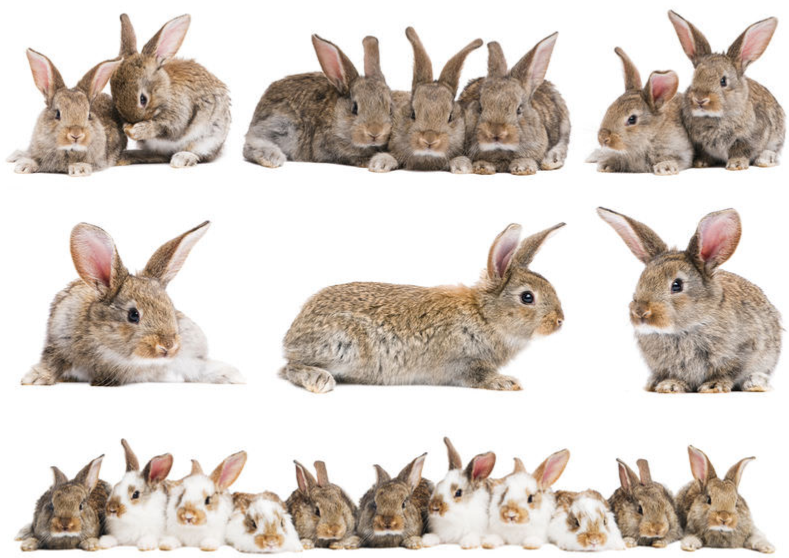
Review

1. Compare microevolution to macroevolution.
2. Why are populations, rather than individuals, the units of evolution?
3. What is a gene pool?
4. Assume that a population of 50 individuals has the following numbers of genotypes for a gene with two alleles, *B* and *b*: *BB* = 30, *Bb* = 10, and *bb* = 10. Calculate the frequencies of the two alleles in the population's gene pool.

16.3 Allele Frequencies - Advanced

Learning Objectives

- Explain how to determine allele frequencies.
- Define evolution in terms of allele frequencies.
- Discuss what is meant by a population which is fixed for a certain gene.



Why are some rabbits lighter in color?

Because of the frequency of the alleles in the population's gene pool. Allele frequency, or how often an allele is found in a gene pool, is related to the expression of that allele.

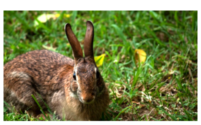
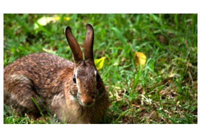
Allele Frequencies

Our analysis of the rabbit populations (**Table** 17.3) showed that the relative numbers of various **alleles** are the best measure of variability in a gene pool (or a population). Population geneticists calculate the proportions, or frequencies, of each allele in order to study changes in populations. In fact, a change in **allele frequency** is the most precise measure of the process of **evolution.** Recall that genetic variability, as seen through numerous alleles, is the fundamental component for natural selection to occur. Without this variability, evolution cannot happen.

TABLE 16.2: Table of Phenotypes and Genotypes in Two Rabbit Populations

Phenotypes	Number of each phenotype	Genotypes	Number of each genotype	Alleles contributed to gene pool	Total gene pool

TABLE 16.2: (continued)

Phenotypes	Number of each phenotype	Genotypes	Number of each genotype	Alleles contributed to gene pool	Total gene pool
Rabbit Population #1 	90 *brown*	*BB*	50	$100B$	$140B$
		*Bb*	40	$40B+40b$	
	10 *albino*	*bb*	10	$20b$	$60b$
Rabbit Population #2 	90 *brown*	*BB*	70	$140B$	$160B$
		*Bb*	20	$20B+20b$	
	10 *albino*	*bb*	10	$20b$	$40b$

An allele's frequency is the fraction (expressed as a decimal) of a population's gene pool made up of that particular allele. In rabbit population #1 above, the gene pool for coat color included 200 alleles, 140 of which were *B*. The frequency of allele *B* for population #1 is 140/200 = 0.7. Because frequencies must total 1.0, and the only other allele is *b,* the frequency of allele *b* is 0.3. (Alternatively, we can calculate the frequency of allele *b* by dividing the number of this allele by the total number of alleles: 60/200 is again 0.3.) In population #2, 160 of 200 alleles are *B,* so the frequency of allele *B* is 0.8, and the frequency of allele *b* is 0.2. What would change if albino rabbits comprised 20% of the population?

If all the members of a rabbit population (#3) are homozygous brown, the frequency of *B* is 1.0, the frequency of *b* is 0, and there is no diversity. Allele *B* is said to be *fixed*, and until a mutation occurs, no possibility for evolution (with respect to this particular gene) exists. A population with frequencies of 0.5 for *B* and 0.5 for *b* would have maximum diversity for this two-gene system. Any change in those frequencies across generations would reflect evolution of the population.

Summary

- Changes in allele frequency measure the process of evolution.
- Allele frequency is the decimal fraction of a population's gene pool made up of that particular allele.
- A gene pool containing only one type of allele is fixed; it lacks variation and potential for evolution, at least until mutation occurs.
- For a gene with two alleles, allele frequencies of 0.5 indicate maximum variation.
- Any change in allele frequency reflects evolution of a population.

Review

1. Explain how to determine allele frequencies.
2. Evaluate phenotype, genotype, and allele frequencies as measures of variation, as raw material for evolution, and as a measure of evolution.

16.4 Punnett Squares

Learning Objectives

- Explain a Punnett square.
- Describe how to use a Punnett square for a monohybrid and dihybrid cross.
- Predict genotypes of parents and offspring using a Punnett square.
- Determine phenotypes of offspring using a Punnett square.

What do you get when you cross an apple and an orange?

Though the above fruit may not result, it would be nice to scientifically predict what would result. Predicting the possible genotypes and phenotypes from a genetic cross is often aided by a Punnett square.

Punnett Squares

A **Punnett square** is a chart that allows you to easily determine the expected percentage of different genotypes in the offspring of two parents. An example of a Punnett square for pea plants is shown in **Figure** 16.2. In this example, both parents are **heterozygous** for flower color (*Bb*). The **gametes** produced by the male parent are at the top of the chart, and the gametes produced by the female parent are along the side. The different possible combinations of **alleles** in their offspring are determined by filling in the cells of the Punnett square with the correct letters (alleles).

Predicting Offspring Genotypes

In the cross shown in **Figure** 16.2, you can see that one out of four offspring (25 percent) has the **genotype** *BB*, one out of four (25 percent) has the genotype *bb*, and two out of four (50 percent) have the genotype *Bb*. These percentages of genotypes are what you would expect in any cross between two heterozygous parents. Of course, when just four offspring are produced, the actual percentages of genotypes may vary by chance from the expected percentages. However, if you considered hundreds of such crosses and thousands of offspring, you would get very close to the expected results, just like tossing a coin.

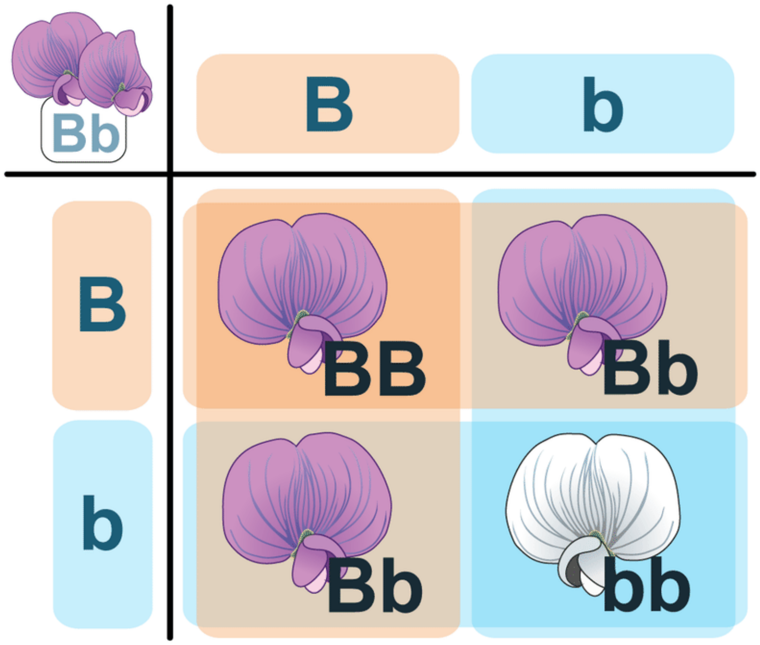


FIGURE 16.2

This Punnett square shows a cross between two heterozygotes, Bb. Do you know where each letter (allele) in all four cells comes from? Two pea plants, both heterozygous for flower color, are crossed. The offspring will show the dominant purple coloration in a 3:1 ratio. Or, about 75% of the offspring will be purple.

Predicting Offspring Phenotypes

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

Determining Missing Genotypes

A Punnett square can also be used to determine a missing genotype based on the other genotypes involved in a cross. Suppose you have a parent plant with purple flowers and a parent plant with white flowers. Because the *b* allele is recessive, you know that the white-flowered parent must have the genotype *bb*. The purple-flowered parent, on the other hand, could have either the *BB* or the *Bb* genotype. The Punnett square in **Figure** 16.3 shows this cross. The question marks (?) in the chart could be either *B* or *b* alleles.

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

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

FIGURE 16.3

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

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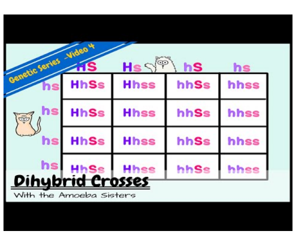
Punnett Square for Two Characteristics

When you consider more than one characteristic at a time, using a Punnett square is more complicated. This is because many more combinations of alleles are possible. For example, with two genes each having two alleles, an individual has four alleles, and these four alleles can occur in 16 different combinations. This is illustrated for pea plants in **Figure** 16.4. In this cross, known as a **dihybrid cross**, both parents are heterozygous for pod color (*Gg*) and pod form (*Ff*).



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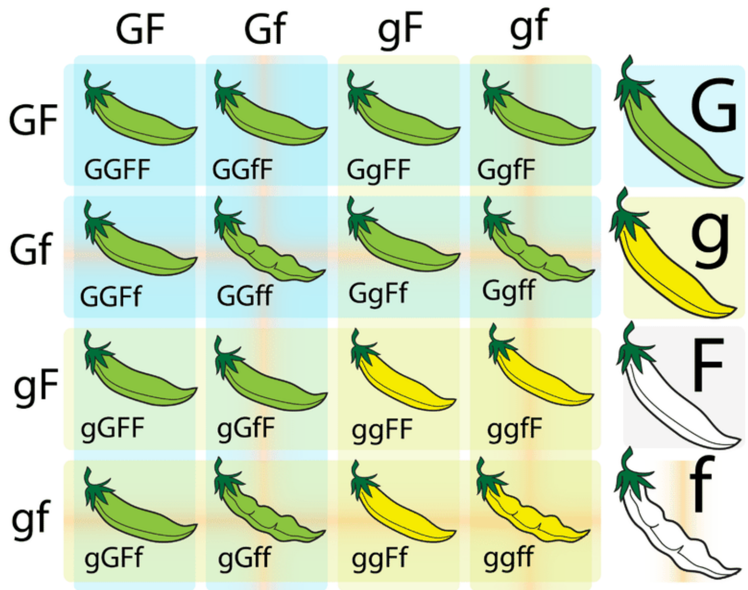

FIGURE 16.4

Punnett Square for Two Characteristics. This Punnett square represents a cross between two pea plants that are heterozygous for two characteristics. G represents the dominant allele for green pod color, and g represents the recessive allele for yellow pod color. F represents the dominant allele for full pod form, and f represents the recessive allele for constricted pod form.

Summary

- A Punnett square is a chart that allows you to determine the expected percentages of different genotypes in the offspring of two parents.
- A Punnett square allows the prediction of the percentages of phenotypes in the offspring of a cross from known genotypes.
- A Punnett square can be used to determine a missing genotype based on the other genotypes involved in a cross.

Review

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

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

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

	A	A
?	A?	Aa
?	Aa	A?

4. How do the Punnett squares for a monohybrid cross and a dihybrid cross differ?

5. What are the genotypes of gametes of a AaBb self-pollination?

6. Mendel carried out a dihybrid cross to examine the inheritance of the characteristics for seed color and seed shape. The dominant allele for yellow seed color is *Y*, and the recessive allele for green color is *y*. The dominant allele for round seeds is *R*, and the recessive allele for a wrinkled shape is *r*. The two plants that were crossed were

F1 dihybrids *RrYy*. Identify the ratios of traits that Mendel observed in the F2 generation. Create a Punnett square to help you answer the question.

16.5 Probability

Learning Objectives

- Explain how probability is related to inheritance.
- Describe the relationship of probability to gamete formation and fertilization.

What are the odds of landing on 25 again?

Not as high as inheriting an allele from a parent. Probability plays a big role in determining the chance of inheriting an allele from a parent. It is similar to tossing a coin. What's the chance of the coin landing on heads?

Probability

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

Probability is the likelihood, or chance, that a certain event will occur. The easiest way to understand probability is with coin tosses (see **Figure** 16.5). When you toss a coin, the chance of a head turning up is 50 percent. This is because a coin has only two sides, so there is an equal chance of a head or tail turning up on any given toss.

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

FIGURE 16.5

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

closer you will get to 50 percent heads. For example, if you tossed a coin 1000 times, you might get 510 heads and 490 tails.

Probability and Inheritance

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

Probability and Gamete Formation

How is gamete formation like tossing a coin? Consider Mendel's purple-flowered pea plants again. Assume that a plant is heterozygous for the flower-color allele, so it has the genotype *Bb* (see **Figure** 16.6). During meiosis, homologous chromosomes, and the alleles they carry, segregate and go to different gametes. Therefore, when the *Bb* pea plant forms gametes, the *B* and *b* alleles segregate and go to different gametes. As a result, half the gametes produced by the *Bb* parent will have the *B* allele and half will have the *b* allele. Based on the rules of probability, any given gamete of this parent has a 50 percent chance of having the *B* allele and a 50 percent chance of having the *b* allele.

Probability and Fertilization

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

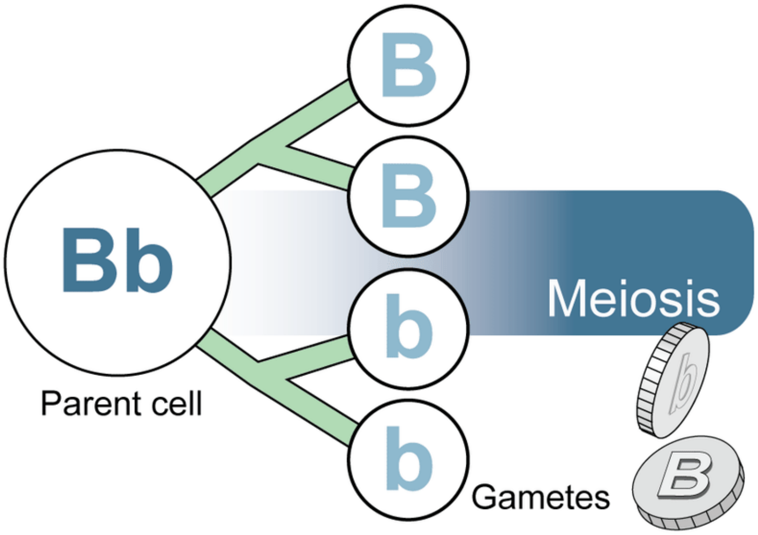

FIGURE 16.6
Formation of gametes by meiosis. Paired alleles always separate and go to different gametes during meiosis.

Summary

- Probability is the chance that a certain event will occur. For example, the probability of a head turning up on any given coin toss is 50 percent.
- Probability can be used to predict the chance of gametes and offspring having certain alleles.

Review

1. Define probability. Apply the term to a coin toss.
2. How is gamete formation like tossing a coin?
3. With a BB homozygote, what is the chance of a gamete having the B allele? The b allele?

16.6 Effect of Environment on Genetics - Advanced

Learning Objectives

- Outline how heredity and environment can interact to affect phenotype.

What do these twins have in common?

Almost all their DNA. In fact, all their nuclear DNA. Some of their mitochondrial DNA may have slight variations. So that would mean that genetic studies involving twins can be potentially very rewarding.

Effects of Environment on Phenotype

Genes play an important part in influencing phenotype, but genes are not the only influence. Environmental conditions, such as temperature and availability of nutrients can affect phenotypes. For example, temperature affects coat color in Siamese cats.

The pointed pattern is a form of partial albinism, which results from a mutation in an enzyme that is involved in melanin production. The mutated enzyme is heat-sensitive; it fails to work at normal body temperatures. However, it is active in cooler areas of the skin. This results in dark coloration in the coolest parts of the cat's body, such as the lower limbs and the face, as shown in **Figure** 16.7. The cat's face is cooled by the passage of air through the nose. Generally adult Siamese cats living in warm climates have lighter coats than those in cooler climates.

Height in humans is a complex phenotype influenced by many genes, but it is also influenced by nutrition. A person who eats a diet poor in nutrients will not grow as tall as they would have had they eaten a more nutritious diet.

Environmental Trigger

Does everyone who smokes develop lung cancer? No, of course not. Is it possible to get lung cancer without smoking? Sadly, yes it is. That's not to say there is no relationship between the two: smoking is still the leading

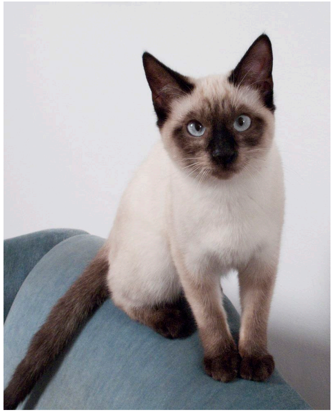

FIGURE 16.7
The dark "points" on this Siamese cat are caused by a gene that codes for a temperature-sensitive enzyme. The enzyme, which causes a darkening of the cat's fur, is active only in the cooler parts of the body such as the tail, feet, ears, and area around the nose.

cause of lung cancer. But it does suggest that a person's genetic background has a role in this process. Apart form true single gene disorders, environmental factors, or **environmental triggers**, may determine the development of disease in individuals genetically predisposed to a particular condition. Environmental triggers may include stress, physical and mental abuse, diet, exposure to toxins, pathogens, and radiation. Many cancers are thought to have an environmental component. It has been suggested that environmental factors play a role in autism as well. Asthma is obviously triggered under certain environmental conditions.

Twin Studies

The classical twin design compares the similarity of identical and fraternal twins.

Scientists often study the effects of environment on phenotype by studying identical twins. Identical twins have the same genes, so phenotypic differences between twins often have an environmental cause. **Twin studies** help understand the relative importance of environmental and genetic influences on individual traits and behaviors. Twins are a valuable source of information concerning the relationship between genes and environment. As **monozygotic twins** (identical) share their nuclear DNA, their **polymorphisms**, the nucleotide differences that make their DNA unique, are common to the two individuals. This means that any phenotypic variation, such as in height, intelligence, or any other measurable trait, is due to the environment. What is different about the experiences of the twins? What unique experiences might one twin have that the other twin did not have? By comparing phenotypes of hundreds of twins, researchers can understand the roles of genetics, shared environment and unique experiences in the formation and development of specific traits.

Dizygotic twins (fraternal or non-identical) share only about half of their polymorphisms. These twins are helpful to study as they tend to share many aspects of their environment. As they are born in the same place, usually within a few minutes of each other, they share many environmental conditions. They had the same *in utero* environment, they usually have a similar or the same parenting style during their childhood, and a similar or the same education. Similarities during childhood usually occur with wealth, culture, and their community.

Modern twin studies have shown that almost all human traits are at least partly influenced by genetic differences. Some characteristics, such as height, show a strong genetic influence, while other characteristics have an intermediate level of genetic influence, such as with intelligence. Some characteristics have a much more complex genetic relationship, with evidence for different genes affecting different aspects of the trait. Autism, with its wide spectrum of severity, is such an example.

FIGURE 16.8

Autism has a wide phenotypic spectrum of disability. Twin studies have been instrumental in demonstrating an environmental component in autism.

Summary

- An organism's phenotype can be influenced by environmental conditions.
- Environmental triggers play a role in the development of disease in individuals genetically predisposed to that disease.
- Twin studies help scientists understand the relative importance of environmental and genetic influences on individual traits and behaviors.

Review

1. Outline the relationship between environment and phenotype.
2. What is an environmental trigger? Give an example.
3. What do twin studies provide?
4. What is the difference between monozygotic twins and dizygotic twins?

16.7 References

1. Miguelferig;Forest and Kim Starr/Starr Environmental;Jodi So. http://commons.wikimedia.org/wiki/File:Mendel_3b_miguelferig.png;http://www.flickr.com/photos/starr-environmental/9196383877/;CK-12 Foundation . public domain;CC BY 2.0
2. Forest and Kim Starr/Starr Environmental;Miguelferig;Zachary Wilson. http://www.flickr.com/photos/starr-environmental/9196383877/;http://commons.wikimedia.org/wiki/File:Mendel_3b_miguelferig.png;CK-12 Foundation . CC BY 2.0;public domain;CC BY-NC 3.0
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CHAPTER 17 Evolution: Theory of Evolution by Natural Selection & Adaptation

Chapter Outline

17.1 Theory of Evolution

- Define evolution.
- Describe the significance of the voyage of the *HMS Beagle.*
- Summarize Darwin's finding on the Galápagos Islands.

Where in the world is this?

This picture was taken in the Galápagos Islands, which is off the west coast of South America. The Galápagos Islands are home to many unique organisms, such as these tree-like cacti. Darwin's observations on these islands led to his development of the theory of evolution.

Darwin's Theory of Evolution

Do you ever wonder why some birds are big like ostriches and some birds are small like robins? Or why a lion has a mane while a leopard has spots? In the 19th century, an English natural scientist named **Charles Darwin** (**Figure** 17.1) was also fascinated by the diversity of life on Earth.

He set out to answer the following questions:

- Why are organisms different?
- Why are organisms similar?
- Why are there so many different types of organisms?

To answer his questions, he developed what we now call "the theory of evolution by natural selection." This theory is one of the most important theories in the field of life science. In everyday English, "evolution" simply means "change." In biology, **evolution** states that all living organisms came from earlier forms of life. The theory of evolution by natural selection explains why evolution occurs. Darwin spent over 20 years traveling around the world and making observations before he fully developed his theory.

FIGURE 17.1
Charles Darwin was one of the most influential scientists who has ever lived. Darwin introduced the world to the theory of evolution by natural selection, which laid the foundation for how we understand the living world today.

Voyage of the

In 1859, Charles Darwin published his book, *On the Origin of Species by Means of Natural Selection* (often known as *The Origin of Species*). His book describes the observations and evidence that he collected more than 20 years of research, beginning with a five-year voyage around the world on a British research ship, the ***HMS Beagle***. During the voyage (**Figure** 17.2), Darwin made observations about plants and animals around the world. He also collected specimens to study for when he returned to England.

Each time the *HMS Beagle* stopped at a port, Darwin went on land to explore and look at the local plants, animals, and fossils. One of the most important things Darwin did was keep a diary. He took detailed notes and made drawings of his observations.

FIGURE 17.2
Charles Darwin's famous five year voyage was aboard the *HMS Beagle* from 1831-1836.

The Galápagos Islands

While the crew of the *HMS Beagle* mapped the coastline of South America, they traveled to a group of islands called the Galápagos. The Galápagos are a group of 16 volcanic islands near the equator, about 600 miles from the west coast of South America. Darwin spent months on foot exploring the islands. The specimens he collected from the Galápagos and sent back to England greatly influenced his ideas of evolution (**Figure** 17.3).

FIGURE 17.3
The Galápagos Islands are a group of 16 volcanic islands 600 miles off the west coast of South America. The islands are famous for their many species found nowhere else. It was on these islands where Darwin began to develop his theory of evolution.

On the Galápagos, Darwin observed that the same kind of animal differed from one island to another. For example, the iguanas (large lizards) differed between islands (**Figure** 17.4). The members of one iguana species spent most of their time in the ocean, swimming and diving underwater for seaweed, while those of another iguana species lived on land and ate cactus. Darwin wondered why there were two species of iguanas on the same set of islands that were so different from one another. What do you think?

FIGURE 17.4
The Galápagos iguanas are among the signature animals of the Galápagos Islands. Here both a land iguana and a marine iguana are shown.

Giant Tortoises

Darwin also observed giant tortoises on the Galápagos (**Figure** 17.5). These tortoises were so large that two people could ride on them. Darwin noticed that different tortoise species lived on islands with different environments. He realized that the tortoises had traits that allowed them to live in their particular environments. For example, tortoises that ate plants near the ground had rounded shells and shorter necks. Tortoises on islands with tall shrubs had longer necks and shells that bent upward, allowing them to stretch their necks (**Figure** 17.5). Darwin began to hypothesize that organisms developed traits over time because of differences in their environments. Darwin began to think that organisms evolved **adaptations** that allowed them to live in their environment. These adaptations were beneficial traits for their environment.

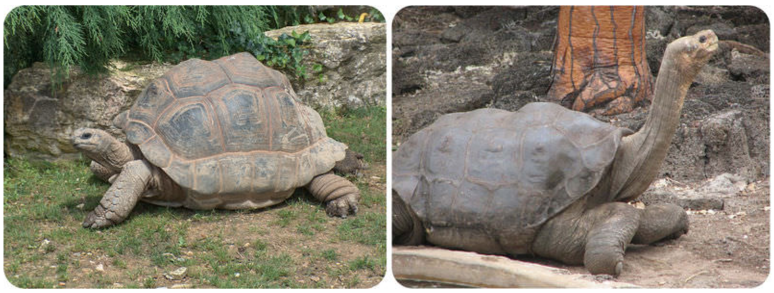

FIGURE 17.5

The name "Galápagos" means "giant tortoise." When Darwin arrived on the Galápagos Islands, he was amazed by the size and variety of shapes of these animals. The giant tortoise (left) is a unique animal found only in the Galápagos Islands. There are only about 200 tortoises remaining on these islands. This Pinta Island tortoise (right) is able to reach leaves high in shrubs with its long neck and curved shell.

Darwin's Finches

The most studied animals on the Galápagos are finches, a type of bird (**Figure** 17.6). When Darwin first observed finches on the islands, he did not even realize they were all finches. But when he studied them further, he realized they were related to each other. Each island had its own distinct species of finch. The birds on different islands had many similarities, but their beaks differed in size and shape.

In his diary, Darwin pointed out how each animal is well-suited for its particular environment. The shapes of the finch beaks on each island were well-matched with the seeds available on that island, but not the seeds on other islands. For example, a larger and stronger beak was needed to break open large seeds on one island, and a small beak was needed to eat the small seeds on a different island.

Summary

- Charles Darwin developed what we now call "the theory of evolution by natural selection."
- Darwin's observations on the Galápagos Islands suggested that animals are well-suited for their specific environments.

Explore More

1. How long was the voyage of the *HMS Beagle*?
2. Did Charles Darwin conceive of natural selection on this voyage? Explain your answer.
3. What was wrong with Darwin's collection of finches from the Galápagos Islands? How was this mistake in collection corrected?
4. What did Darwin notice about the flora (plants) and fauna (animals) of Ecuador compared to the flora and fauna of the Galápagos Islands?
5. How does the distance of an island group from the mainland affect gene flow between that island group and the mainland?

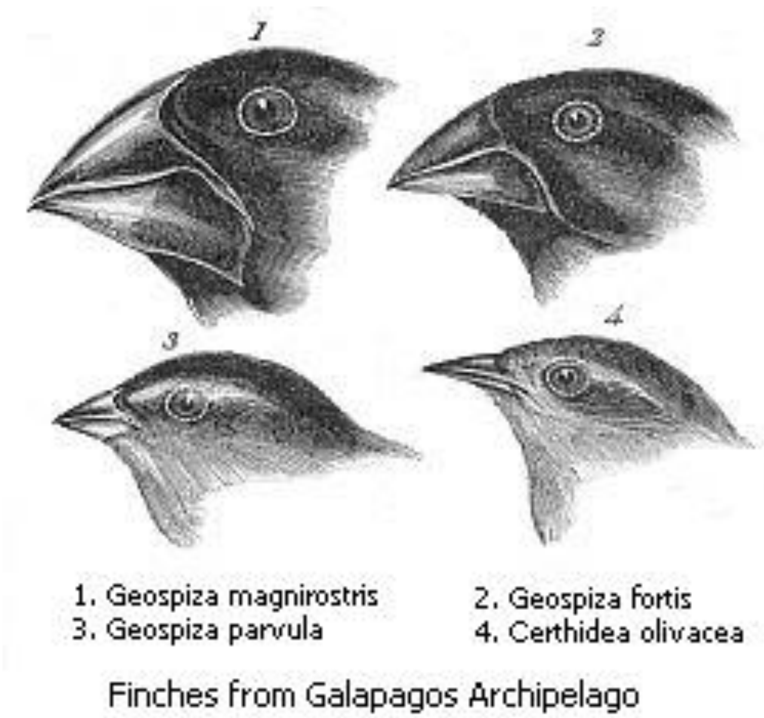

FIGURE 17.6
Four of Darwin's finch species from the Galápagos Islands. The birds came from the same finch ancestor. They evolved as they adapted to different food resources on different islands. The first bird uses its large beak to crack open and eat large seeds. Bird #3 is able to pull small seeds out of small spaces.

Review

1. Define biological evolution.
2. Who was Charles Darwin?
3. What is special about the Galápagos islands?
4. Name an example of how animals were adapted for their specific environments on the Galápagos Islands.

17.2 Natural Selection

Learning Objectives

- Describe natural selection.
- Explain how new species may originate.
- Discuss how natural selection can keep a harmful allele in a gene pool.
- Summarize natural selection for polygenic traits.
- Distinguish stabilizing selection from directional selection and from disruptive selection.

What is fitness?

Does this type of fitness have anything to do with natural selection? Usually not. There are countless ways in which an organism can be more "fit," or better adapted to its habitat. And we probably do not know about most of these adaptations.

Natural Selection

Natural selection occurs when there are differences in fitness among members of a population. As a result, some individuals pass more genes to the next generation. This causes allele frequencies to change.

Sickle Cell and Natural Selection

The example of sickle-cell anemia is described in the **Figure** 17.7 and **Table** 17.1. It shows how natural selection can keep a harmful allele in a gene pool.

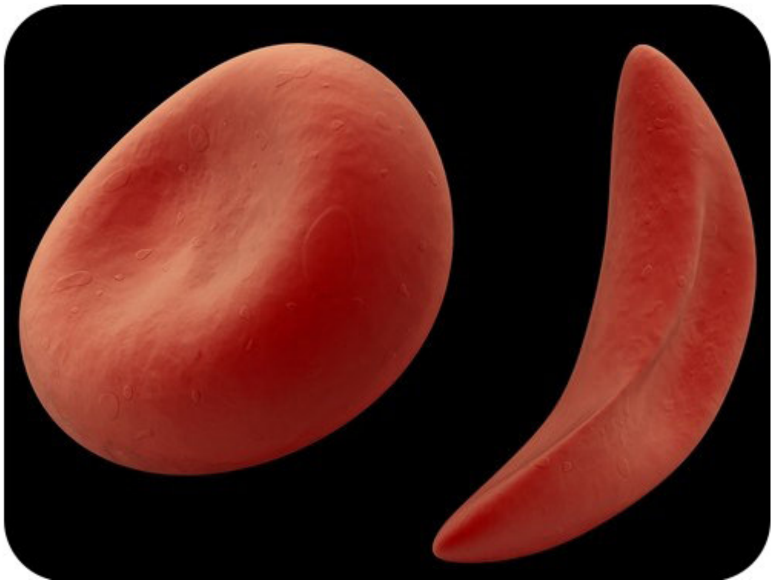

FIGURE 17.7
Sickle Cell and Natural Selection. Notice the normal-shaped red blood cell on the left, and the sickle-shaped cell on the right.

TABLE 17.1: Sickle Cell and Natural Selection

Genotype	Phenotype	Fitness
AA	100% normal hemoglobin	Somewhat reduced fitness because of no resistance to malaria
AS	Enough normal hemoglobin to prevent sickle-cell anemia	Highest fitness because of resistance to malaria
SS	100% abnormal hemoglobin, causing sickle-cell anemia	Greatly reduced fitness because of sickle-cell anemia

Here's how natural selection can keep a harmful allele in a gene pool:

- The allele (*S*) for sickle-cell anemia is a harmful autosomal recessive. It is caused by a mutation in the normal allele (*A*) for hemoglobin (a protein on red blood cells).
- Malaria is a deadly tropical disease. It is common in many African populations.
- Heterozygotes (*AS*) with the sickle-cell allele are resistant to malaria. Therefore, they are more likely to survive and reproduce. This keeps the *S* allele in the gene pool.

The sickle-cell example shows that fitness depends on phenotypes. It also shows that fitness may depend on the environment. What do you think might happen if malaria was eliminated in an African population with a relatively high frequency of the *S* allele? How might the fitness of the different genotypes change? How might this affect the frequency of the *S* allele?

Natural Selection and Polygenic Traits

Sickle-cell trait is controlled by a single gene. Natural selection for polygenic traits is more complex, unless you just look at phenotypes. Three ways that natural selection can affect phenotypes are shown in **Figure** 17.8.

1. **Stabilizing selection** occurs when phenotypes at both extremes of the phenotypic distribution are selected against. This narrows the range of variation. An example is human birth weight. Babies that are very large or very small at birth are less likely to survive. This keeps birth weight within a relatively narrow range.
2. **Directional selection** occurs when one of two extreme phenotypes is selected for. This shifts the distribution toward that extreme. This is the type of natural selection that the Grants observed in the beak size of Galápagos finches.

3. **Disruptive selection** occurs when phenotypes in the middle of the range are selected against. This results

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Summary

- Natural selection occurs when there are differences in fitness among members of a population.
- Natural selection for a polygenic trait changes the distribution of phenotypes. It may have a stabilizing, directional, or disruptive effect on the phenotype distribution.

Review

1. What is natural selection and what are its effects on allele frequencies?
2. Describe three types of natural selection for a polygenic trait.
3. How does the recessive sickle-cell allele stay in the gene pool?

17.3 Natural Selection and Populations - Advanced

Learning Objectives

- Discuss natural selection and evolution in terms of phenotypes and allele frequencies.
- Explain the distribution of phenotypes for a trait whose genetic basis is polygenic.
- Using a normal distribution of phenotypic variation, interpret directional, disruptive, and stabilizing patterns of selection.
- Describe how natural selection can sometimes lead to the persistence of harmful or even lethal alleles.
- Analyze the logic of kin selection.

What's fitness?

Does this type of fitness have anything to do with natural selection? Usually not. There are countless ways in which an organism can be more "fit," or better adapted to its habitat. And we probably do not know about most of these adaptations.

Natural Selection

While genetic drift, including the bottleneck and founder effects, can cause microevolution (generational change in allele frequencies), its effects are mostly random. The results of genetic drift may include enhanced capabilities, but more often, they are neutral or deleterious. **Natural selection** depends not on chance, but on differential survival determined by an individual's traits. Even though the variations are due to chance, the products of natural selection are usually organisms well-suited to their environment.

Recall that Hardy-Weinberg equilibrium requires that all individuals in a population are equal in their ability to survive and successfully reproduce. As Darwin noted, however, overproduction of offspring and variation among individuals often lead to differential survival and reproduction - in other words, natural selection (**Figure** 17.9). We discussed natural selection as a part of Darwin's theory of evolution in other concepts, but in this section, we will go deeper than Darwin could. We will explore natural selection at the level of populations - in terms of allele, genotype, and phenotype frequencies.

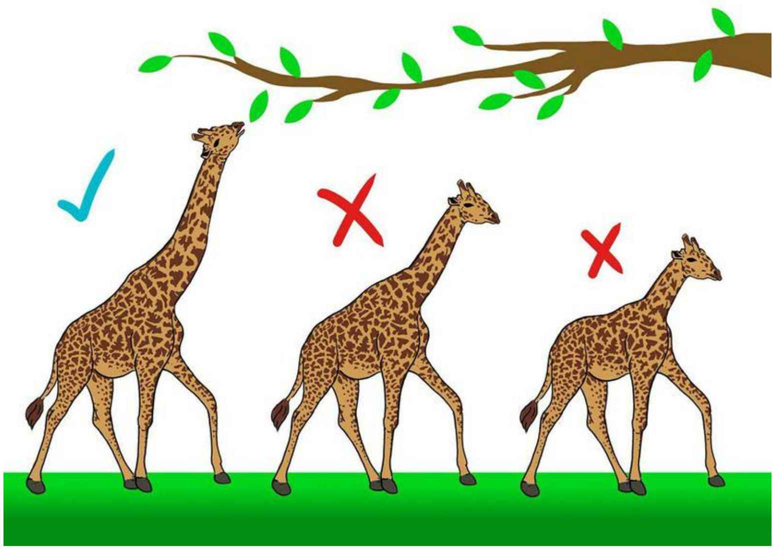


FIGURE 17.9

Natural selection involves (1) heritable variation (here, giraffe neck length), (2) overproduction of offspring (3 giraffes born, not all can survive), (3) differential survival and reproduction (not enough food for all giraffes; those with shorter necks starve), and (4) gradual change in traits in the population (long-necked giraffes survive and reproduce, so their genes for long necks increase in frequency in the next generation).

Acting on an Organism's Phenotype

Natural selection acts on an organism's phenotype (appearance), which is a product of genotype and any environmental influences on gene expression. By selecting *for* alleles which improve survival and/or reproduction and selecting *against* harmful alleles, natural selection changes the proportion of alleles from one generation to the next - causing microevolution. Let's return once more to our rabbit population. If a predator such as a hawk can see white rabbits (genotype ***bb***) more easily than brown rabbits (***BB*** and ***Bb***), brown rabbits are more likely than white rabbits to survive hawk predation. Because more brown rabbits will survive to reproduce, the next generation will probably contain a higher frequency of ***B*** alleles. Note, however, that the recessive ***b*** alleles are unlikely to disappear completely, because they can "hide" from the hawks in heterozygous brown rabbits. This is a good reminder that natural selection acts on phenotypes, rather than genotypes. The hawk - or natural selection - is unable to distinguish a ***BB*** rabbit from a ***Bb*** rabbit. The hawk is only able to distinguish a brown rabbit from a white rabbit, demonstrating how natural selection acts on the phenotype rather than the genotype of an organism.

Consider a different example, which emphasizes reproduction rather than survival: If both brown and white rabbits preferred to mate with white rabbits, the next generation's gene pool would probably show an increase in the frequency of the ***b*** allele, because white rabbits would be more likely to reproduce successfully.

Although some traits are determined by a single gene, many are influenced by more than one gene (polygenic). The result of polygenic inheritance is a continuum of phenotypic values which often show a bell curve pattern of variation. **Figure** 17.10 shows the effect of three genes, each having two alleles, on human skin color; the result is a normal distribution ranging from very dark to very light, with a peak near the middle. You can demonstrate polygenic inheritance (probably with some environmental influence) for height, ear length, or handspan by measuring your classmates and graphing the data in a similar fashion. Some curves will be flat, and others sharp - but most will resemble the normal "bell" shape.

Given this pattern of phenotypic variation, natural selection can take three forms (**Figure** 17.10). We will use the theoretical human skin color distribution (**Figure** 17.10) to illustrate the three types of selection. **Directional**

selection shifts the frequency curve away from the average by favoring individuals with an extreme form of the variation. The skin of early humans living in sun-rich Africa received high levels of UV radiation, which destroys vitamin B (folate) and leads to severe birth defects such as spina bifida. Selection, then, favored darker-skinned individuals, and the frequency of the darker alleles increased. After several generations, the curve would still be bell-shaped, but it would have shifted to the right, in the direction of the darker alleles. The average individual would have had darker skin as result of this microevolutionary change.

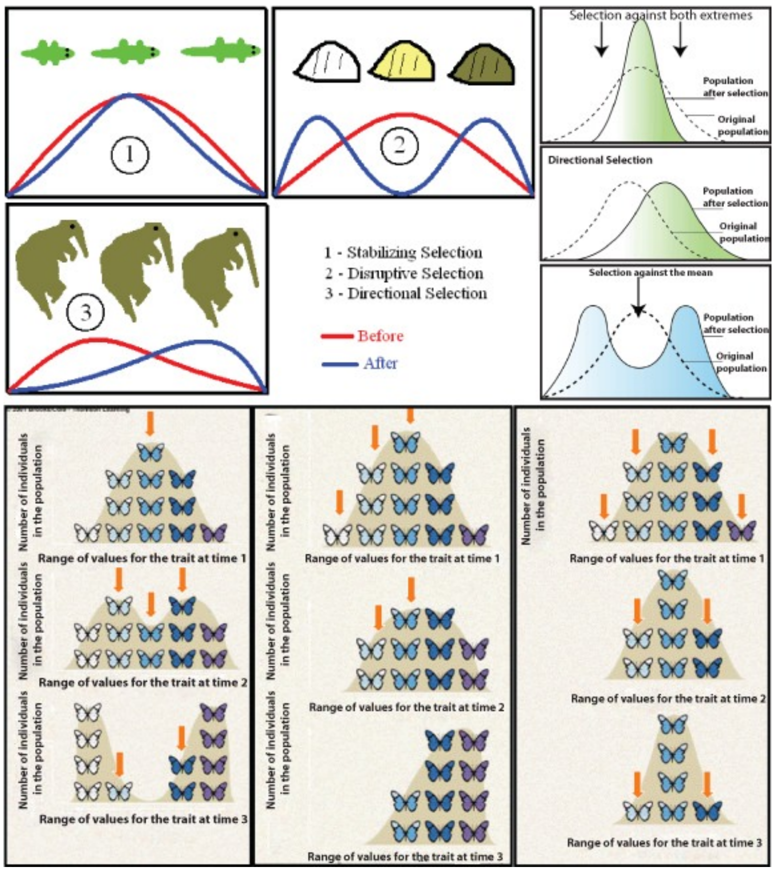


FIGURE 17.10

Three types of selection can alter allele frequencies, causing microevolution. The effect of stabilizing selection (1) is to reduce variation. Disruptive selection (2) results in two different populations, which may eventually become isolated from one another. Directional selection (3) enhances or reduces a single characteristic, such as trunk or snout length in the above example.

Natural Selection and Human Migration

As humans migrated into the northern hemisphere, excessive UV radiation was no longer a problem, but the relative lack of sunlight led to lower levels of vitamin D_3, normally synthesized in the skin and necessary for calcium absorption and bone growth. Thus, selection in the north favored lighter-skinned individuals - another example of directional selection. However, if we consider the human population as a whole at that time, **disruptive selection** would describe the microevolution taking place. In northern climates, alleles for light skin would be favored, and in southern climates alleles for dark skin would be favored, resulting in two distinct peaks in the distribution of skin color phenotypes and their corresponding genotypes. Keep in mind that the "three gene - dark/light" model is an oversimplification of the genetics underlying skin color, but the adaptive values are real, and the model allows us to illustrate how microevolution works. Note that a map of human skin colors supports this type of selection to some extent (**Figure** 17.11).

Today, extensive migration, mobility, and intermarriage in the human population may be changing selective pressures on skin color once again. For the sake of argument, let's make the somewhat unrealistic assumption that mixing becomes complete and that all people will be sufficiently mobile that they experience intermediate levels of sunlight. These conditions would select against both extremely dark skin (too little vitamin D_3) and extremely light skin (too

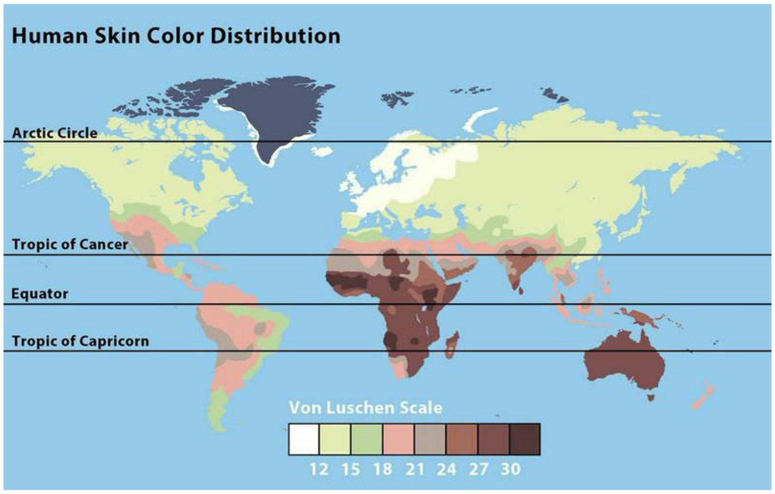


FIGURE 17.11
The distribution of skin colors at least partially supports disruptive selection - for lighter skin in the north, to allow sunlight to form vitamin D_3 in the skin, and for darker skin toward the equator to prevent UV radiation from breaking down vitamin B-folate.

little vitamin B-folate). The result would be a taller, narrower distribution - less diversity - about the same mean, a phenomenon known as **stabilizing selection**. Although our example is perhaps unrealistic, stabilizing selection is probably the most common form of natural selection, preventing form and function from straying away from a "proven" norm.

Stabilizing Selection

Stabilizing selection can lead to the preservation of harmful alleles. A famous example, which we considered in earlier lessons, is sickle-cell anemia (**Figure** 17.12). The gene for Beta-hemoglobin - half of the oxygen-carrying protein in our blood - has two alleles, which we will call Hgb-A and Hgb-S. Individuals having two copies of the Hgb-S allele suffer from sickle-cell anemia, a potentially lethal disease in which sickled cells clog capillaries and cannot carry oxygen efficiently. In equatorial regions, individuals with two copies of Hgb-A become infected with *Plasmodium* parasites and often die from malaria. However, individuals with one copy of each allele (the heterozygous genotype) escape both causes of death; although they may experience slight sickling at high altitudes, they do not suffer from full-blown anemia, and malaria parasites cannot infect their red blood cells. Stabilizing selection has maintained the frequencies of both alleles, even though each is potentially lethal in the homozygous state.

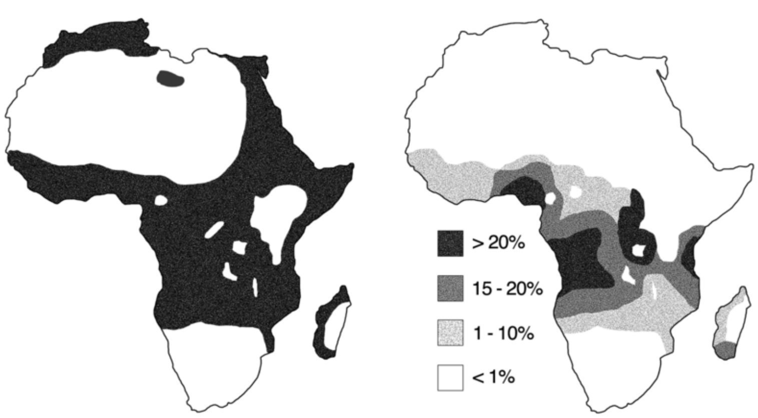


FIGURE 17.12
The distribution of malaria (left) correlates closely with the distribution of the sickle-cell allele (right). Because the heterozygous genotype confers immunity to malaria, this allele, which is lethal in the homozygous condition, persists in environments where malaria is common. Thus, natural selection can occasionally result in persistence of harmful alleles.

Selection for a particular trait may also select for other traits which do not directly affect fitness - if, for example, genes are linked, or if a single gene influences several different traits.

Fitness

Another way to look at natural selection is in terms of **fitness** - the ability of an organism with a certain genotype to reproduce. Fitness can be measured as the proportion of that organism's genes in all of the next generation's genes. When differences in individual genotypes affect fitness, the genotypes with higher fitness become more common. This change in genotype frequencies is natural selection.

Kin Selection

An intriguing corollary of genotype selection is **kin selection.** Behaviors which sacrifice reproductive success or even survival can actually increase fitness if they promote the survival and reproduction of close relatives who share a significant proportion of the same genes. Examples include subordinate male turkeys, who help their dominant brothers display to potential mates (**Figure** 17.13), and honeybee workers, who spend their lives collecting pollen and raising young to ensure that their mother, the queen, reproduces successfully (**Figure** 17.14).

FIGURE 17.13

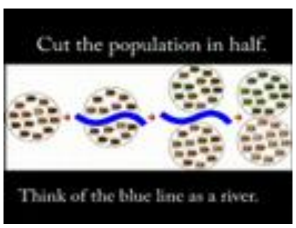
Wild turkeys display in groups of closely related individuals, but only alpha males eventually mate. Subordinate males sacrifice their chance to reproduce, even chasing away other males to promote their dominant brothers' success, because this behavior increases the chance that the genes they share will be represented in the next generation. This means of increasing gene frequency is kin selection.

We have looked carefully at equilibrium populations and at possible disruptions of equilibrium which cause microevolution - a generational change in a population's allele frequencies:

- Mutations, together with sexual reproduction, are the ultimate sources of variation, and are important causes of microevolution in microorganisms.
- Gene flow can accelerate microevolution by importing new, already successful alleles into the population.
- Genetic drift can increase the effect of chance variations in small populations.
- Natural selection can be directional, disruptive, or stabilizing.
- Specialized types of selection, such as mate selection and kin selection, can cause microevolution.

Evolutionary biologists are not yet in agreement regarding the relative importance of each type of selection to the history of life, although most would agree that natural selection is the primary force in microevolution. In the next lesson, we will apply our understanding of microevolutionary processes to that "mystery of mysteries," as Darwin and Herschel called it: the origin of species.

FIGURE 17.14
Many social insects also illustrate kin selection. These honeybee workers are sterile. They spend their lives collecting pollen, feeding larvae, and cleaning and defending the hive. With no chance of reproductive success of their own, they dedicate their lives to the reproductive success of the hive's queen - their mother - who shares 50% of her genes with each of them.



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Summary

- Natural selection occurs in populations of any size and results are more likely to adapt a population to its environment.
- Natural selection acts on phenotypic variations; some phenotypic variations may include environmental effects which are not heritable.
- Evolution is a result of natural selection and is measured as a change in allele frequencies.
- For a trait whose genetic basis is polygenic, the pattern of phenotypic variation usually forms a bell curve about an average value.
- Directional selection results in a shift of allele frequencies toward one extreme.
- Disruptive selection favors both extremes over the average phenotypic value.
- Stabilizing selection maintains or narrows existing variation in phenotype.
- Fitness is the ability of an organism with a certain genotype to reproduce successfully.
- Because alleles often affect more than one trait in different ways, or have different effects in different environments, natural selection can sometimes lead to the persistence of harmful or even lethal alleles.
- Kin selection involves the sacrifice an individual's own reproductive potential in order to help a close relative reproduce successfully.

Review

1. Use the distribution of phenotypes for a trait whose genetic basis is polygenic to interpret directional, disruptive, and stabilizing patterns of selection.
2. Describe how natural selection can sometimes lead to the persistence of harmful or even lethal alleles. Include an example.
3. Describe kin selection. Give an example.

17.4 Artificial Selection and Coevolution - Advanced

Learning Objectives

- Recognize that the process of evolution by natural selection continues to change our world and ourselves, both despite and because of our best efforts to control it.
- Understand that we have added direct observation of natural selection to the evidence for evolution.
- Evaluate the importance of artificial selection to human life.
- Discuss our use of hybridization to improve yield and to adapt crops to many climates.
- Explain how cloning contradicts the principles of natural selection.

How can a predator, such as a wolf, influence evolution?

Wolves hunt caribou, chasing them down to capture them. The slower caribou are more likely to become lunch or dinner, leaving the faster individuals to reproduce. The resulting faster offspring will be even more difficult for the wolves to catch, and only the fastest wolves - or perhaps the wolves who are genetically capable of developing methods to hunt very fast prey - will get enough food to survive. This is coevolution in action.

Artificial Selection or Coevolution?

Much of the immediate success of Darwin's theory was due to his careful comparison of his new idea of natural selection to the well-known breeding of animals. Darwin was especially interested in pigeons, and his observations of their many varieties inspired his own early thinking. Humans have relied on **artificial selection** ever since we first put seeds in the ground some ten thousand years ago. Today, our continuing efforts to develop crops and animals for food, work, and companions have expanded beyond breeding to include **genetic engineering**. Dismay about our effects on the environment is encouraging us to see ourselves more as a part of nature, rather than above it; perhaps we will eventually abandon Darwin's term "artificial selection" in favor of **coevolution**.

Evolution by natural selection is not just an explanation of the history of life. The process of Darwin's theory clearly continues, changing our world and ourselves, both despite and because of our best efforts to control it. And we have reached beyond Darwin's wildest expectations; we now have direct observations of **natural selection** to add to the overwhelming evidence for evolution.

The range of variations artificially induced in relatively short periods of time by animal breeders convinced Darwin that natural selection across **geologic time** could have produced the great diversity of present life. Domestication of animals has resulted in the remarkable variety of dogs (**Figure** 17.15) from wolves, as well as cattle, horses, llamas, camels, and a few evolutionary dead-ends, such as the donkey.

FIGURE 17.15

Selective breeding has led to dramatic differences among breeds in a relatively short time, yet dogs are still able to interbreed with wolves - the wild species from which they originated. Darwin used his observations of artificial selection, as he called it, to derive and promote his theory of evolution by natural selection.

However, artificial selection has resulted in an achievement that extends far beyond our immediate, intentional goals. Our initial cultivation of plants such as corn (**Figure** 17.16) played a role in the eventual development of human civilization.

Hybridization

Since Darwin's time, selective breeding and **hybridization** - the mixing of separate species - has become even more sophisticated. We have further hybridized high-yield hybrids with local varieties throughout the world, intentionally adapting them to local climates and pests. Unfortunately, our widespread destruction of habitat is eroding the species and genetic diversity which provides the raw material for such efforts. Moreover, against our intent, our hybrids sometimes interbreed with natural varieties in the wild, leading to what some call **genetic pollution**. An example is a tiger, thought to be pure Bengal but actually a Bengal-Siberian hybrid, released in India to demonstrate the survival abilities of captive-raised tigers. The tiger did survive - to pollute the genetically pure Bengal population in a national park with northern-adapted Siberian genes (**Figure** 17.17).

Dolly

The new field of biotechnology has dramatically changed our quest to improve upon natural selection. Ironically, one new development actually undermines the very foundation of Darwin's theory. As the first mammal to be cloned, a sheep name Dolly showed animal breeders, from farms to racetracks, that they could copy "ideal" individuals without the bothersome variation which accompanies sexual reproduction (**Figure** 17.18). A **clone** is a genetically identical copy; **genetic variation** has been eliminated. Many people hope that future decisions about cloning will consider Darwin's lessons about the value of variation in unpredictable, changing environments.

FIGURE 17.16

Over time, selective breeding has modified teosinte's few fruitcases (left) into modern corn's rows of exposed kernels (right). Cultivation of crops such as corn and wheat gave early humans the freedom to develop civilizations.

FIGURE 17.17

The natural genes which adapted the Indian Bengal tiger (*Panthera tigris tigris*, right) and the Russian Siberian tiger (*Panthera tigris altaica*, left) to their unique habitats were mixed or "polluted" when a captive hybrid was released into a national park in India. The "escape" of non-native genes into a wild population is *genetic pollution*.

FIGURE 17.18
Dolly, the first cloned mammal, is preserved for public display after six years of public life. Cloning can copy animals we believe are superior, but it denies the importance of genetic variation to survival of species, a point made clear in Darwin's ideas about natural selection.

Genetic Engineering

Another contribution of biotechnology is genetic engineering, the transfer of a gene from one organism to another. First, scientists inserted the human gene for insulin into bacteria, which read the DNA and produced the human protein for use by diabetics (this was possible because all life - including both bacteria and mammals - use the same universal Genetic Code). Many more cost-saving and designer medical advances have followed:

- Production of clotting factors for hemophiliacs.
- Vaccines for devastating diseases such as hepatitis B.
- A breast cancer "designer drug," Herceptin.
- The potential for cheap, effective vaccines in fruits such as bananas.

Scientists have extended genetic engineering to agriculture, improving range, nutrition, resistance to disease, and other aspects of life. **Transgenic animals**, which possess genes from another species, now produce vaccines and hormones, serve in scientific research, and entertain us as pets. However, as for traditional agriculture, fears surround potential cross-pollination and interbreeding with wild populations. Modified genes have been found in plants up to 21 km (13 miles) away from their source. If such transfers spread resistance to herbicides or pesticides to wild populations, they will have defeated their intended purpose.

In his book, *The Botany of Desire*, Michael Pollan questions our feelings of superiority over our domesticated plants and animals. Discussing our domestication of the apple for its sugar, the tulip for its beauty, marijuana for its psychogenic effects, and the potato for its food value, Pollan takes the plants' view of the evolving relationships. Could it not be that, as we have selected and modified these plants, they have also selected us for our powers to ensure their survival and reproduction - and changed us in the process? Are domestication of animals, cultivation of plants, and selective breeding actually forms of coevolution? Pollan's delightful yet sobering treatise may reflect a growing realization that we humans are as much a part of nature as any other species. Yes, we can influence evolution in a number of ways. However, we remain subject to natural selection, and every choice we make has effects on evolution - including our own. As we have already seen, and will see again in the next topic, our choices often have unintended effects.

Coevolution

Evolution occurs in response to a change in the environment. Darwin made this point a central theme of his theory. Environmental change often affects numerous species of organisms. In fact, species in symbiotic relationships tend to evolve together in response to such change. This is called coevolution. As one species changes, the other species must also change in order to adapt.

One example of coevolution occurs in flowering plants and the species that pollinate them. The flower and bird in **Figure** 17.19 are a good example. They have evolved matching structures, allowing both to survive.

FIGURE 17.19

Results of Coevolution in a flower and its pollinator. The very long mouth part of this hummingbird has coevolved with the tubular flower it pollinates. Only this species of bird can reach the nectar deep in the flower. What might happen to the flower if the bird species went extinct?

In coevolution, relationships may be positive for one species, positive for both, or may be an evolutionary arms race between predator and prey. Flowering plants depend on insects for pollination, so have evolved colors, shapes, scents, and even food supplies that are attractive to certain insect species. Insects, in turn, have evolved mouthparts, senses, and flight patterns that allow them to respond to and benefit from specific floral offerings, as shown in **Figure** 17.20.

The **endosymbiotic theory** describes a special form of coevolution: mitochondria and chloroplasts evolve within eukaryote cells, yet because these organelles have their own DNA sequence, different from that of the nucleus in the "host" cell, the organelle and host cell evolve in tandem - each influences the evolution of the other.

FIGURE 17.20
Impressive proboscis and vivid colors! Hawk moths and the zinneas influence each other's evolution, because the flower depends on the moth for pollination, and the moth feeds on the flower.

Summary

- The process of evolution by natural selection continues to change our world and ourselves, both despite and because of our best efforts to control it.
- Humans have designed and produced crops, work animals, and companions through artificial selection.
- Cloning has the potential to reproduce exact copies of selected individuals, but it goes against the principles which govern natural selection.
- Genetic engineering, like traditional methods of breeding and domestication, designs medicines, plants, and animals to suit our goals.
- Products of genetic engineering include insulin and growth hormone, vaccines in milk and bananas, and produce with longer growing seasons, longer shelf lives, and more nutrition.
- Coevolution occurs when species evolve together. Coevolution often happens in species that have symbiotic relationships. Examples include flowering plants and their pollinators.

Review

1. List the ways in which we have directly observed evidence for evolution and/or natural selection.
2. Describe the importance of artificial selection to human life.
3. What is genetic pollution and why does it matter?
4. Compare cloning to natural selection.
5. Give examples of useful products of genetic engineering.
6. Explain Michael Pollan's ideas about our relationship with our domesticated crops, animals, and pets, and give your opinion about them, using examples from your own experience.

Explore More

Use this resource to answer the questions that follow.

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1. What is coevolution?
2. What are the benefits of coevolution?
3. What is not coevolution? Give examples.
4. Give examples of coevolution.

17.5 Population Genetics

Learning Objectives

- Distinguish between microevolution and macroevolution.
- Define gene pool.
- Explain how to calculate allele frequencies.

Jeans vs. Genes. What's the difference?

Plenty. One you have for life, the other just lasts a few years. One is the basis for the passing of traits from one generation to the next. Some jeans you change frequently. But what happens when you change a gene's frequency? Essentially, evolution is a change in gene frequencies within a population.

Genes in Populations

Darwin knew that heritable variations are needed for evolution to occur. However, he knew nothing about Mendel's laws of genetics. Mendel's laws were rediscovered in the early 1900s. Only then could scientists fully understand the process of evolution. We now know that variations of traits are heritable. These variations are determined by different **alleles**. We also know that evolution is due to a change in alleles over time. How long a time? That depends on the scale of evolution.

- **Microevolution** occurs over a relatively short period of time within a population or species. The Grants observed this level of evolution in Darwin's finches (see the "Biogeography" concept).
- **Macroevolution** occurs over geologic time above the level of the species. The fossil record reflects this level of evolution. It results from microevolution taking place over many generations.

Remember that individuals do not evolve. Their **genes** do not change over time. The unit of evolution is the population. A **population** consists of organisms of the same species that live in the same area. In terms of evolution, the population is assumed to be a relatively closed group. This means that most mating takes place within the population. The science that focuses on evolution within populations is **population genetics**. It is a combination of evolutionary theory and Mendelian genetics.

Gene Pool

The genetic makeup of an individual is the individual's **genotype**. A population consists of many genotypes. Altogether, they make up the population's gene pool. The **gene pool** consists of all the genes of all the members of the population. For each gene, the gene pool includes all the different alleles for the gene that exist in the population. For a given gene, the population is characterized by the frequency of the different alleles in the gene pool.

Allele Frequencies

Allele frequency is how often an allele occurs in a gene pool relative to the other alleles for that gene. Look at the example in the **Table** 17.2. The population in the table has 100 members. In a sexually reproducing species, each member of the population has two copies of each gene. Therefore, the total number of copies of each gene in the gene pool is 200. The gene in the example exists in the gene pool in two forms, alleles A and a. Knowing the genotypes of each population member, we can count the number of alleles of each type in the gene pool. The table shows how this is done.

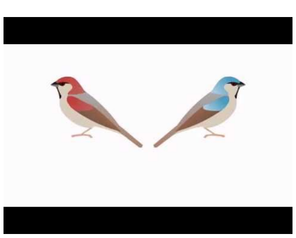
TABLE 17.2: Number of Alleles in a Gene Pool

Genotype	Number of Individuals in the Population with that Genotype	Number of Allele A Contributed to the Gene Pool by that Genotype	Number of Allele a Contributed to the Gene Pool by that Genotype
AA	50	$50 \times 2 = 100$	$50 \times 0 = 0$
Aa	40	$40 \times 1 = 40$	$40 \times 1 = 40$
aa	10	$10 \times 0 = 0$	$10 \times 2 = 20$
Totals	100	140	60

Let the letter p stand for the frequency of allele A. Let the letter q stand for the frequency of allele a. We can calculate p and q as follows:

- p = number of A alleles/total number of alleles = 140/200 = 0.7
- q = number of a alleles/total number of alleles = 60/200 = 0.3
- Notice that $p + q = 1$.

Evolution occurs in a population when allele frequencies change over time. What causes allele frequencies to change? That question was answered by Godfrey Hardy and Wilhelm Weinberg in 1908 (see the *Hardy-Weinberg Theorem* concept).



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Summary

- Microevolution occurs over a short period of time in a population or species. Macroevolution occurs over geologic time above the level of the species.
- The population is the unit of evolution.
- A population's gene pool consists of all the genes of all the members of the population.
- For a given gene, the population is characterized by the frequency of different alleles in the gene pool.

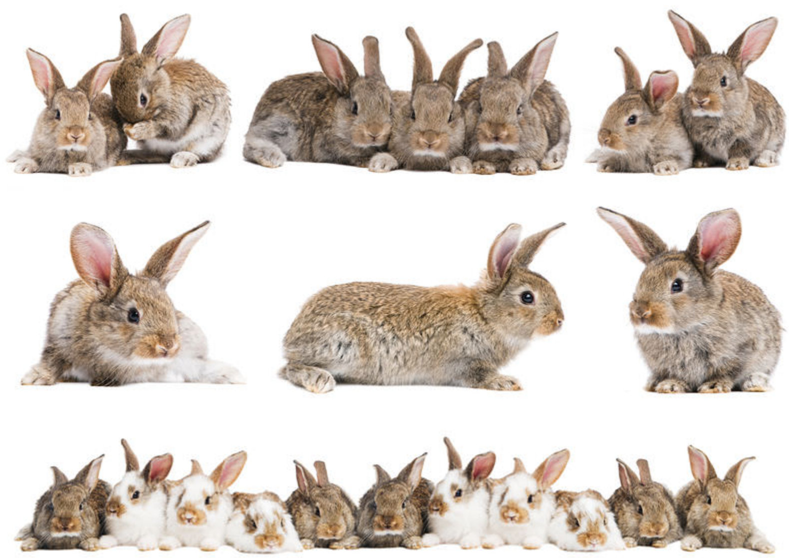
Review

1. Compare microevolution to macroevolution.
2. Why are populations, rather than individuals, the units of evolution?
3. What is a gene pool?
4. Assume that a population of 50 individuals has the following numbers of genotypes for a gene with two alleles, *B* and *b*: *BB* = 30, *Bb* = 10, and *bb* = 10. Calculate the frequencies of the two alleles in the population's gene pool.

17.6 Allele Frequencies - Advanced

Learning Objectives

- Explain how to determine allele frequencies.
- Define evolution in terms of allele frequencies.
- Discuss what is meant by a population which is fixed for a certain gene.



Why are some rabbits lighter in color?

Because of the frequency of the alleles in the population's gene pool. Allele frequency, or how often an allele is found in a gene pool, is related to the expression of that allele.

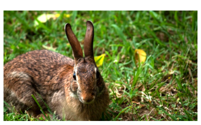
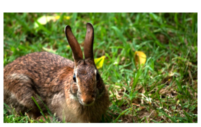
Allele Frequencies

Our analysis of the rabbit populations (**Table** 17.3) showed that the relative numbers of various **alleles** are the best measure of variability in a gene pool (or a population). Population geneticists calculate the proportions, or frequencies, of each allele in order to study changes in populations. In fact, a change in **allele frequency** is the most precise measure of the process of **evolution.** Recall that genetic variability, as seen through numerous alleles, is the fundamental component for natural selection to occur. Without this variability, evolution cannot happen.

TABLE 17.3: Table of Phenotypes and Genotypes in Two Rabbit Populations

Phenotypes	Number of each phenotype	Genotypes	Number of each genotype	Alleles contributed to gene pool	Total gene pool

TABLE 17.3: (continued)

Phenotypes	Number of each phenotype	Genotypes	Number of each genotype	Alleles contributed to gene pool	Total gene pool
Rabbit Population #1 	90 *brown*	*BB*	50	100*B*	140*B*
		*Bb*	40	$40B+40b$	
	10 *albino*	*bb*	10	20*b*	60*b*
Rabbit Population #2 	90 *brown*	*BB*	70	140*B*	160*B*
		*Bb*	20	$20B+20b$	
	10 *albino*	*bb*	10	20*b*	40*b*

An allele's frequency is the fraction (expressed as a decimal) of a population's gene pool made up of that particular allele. In rabbit population #1 above, the gene pool for coat color included 200 alleles, 140 of which were *B*. The frequency of allele *B* for population #1 is 140/200 = 0.7. Because frequencies must total 1.0, and the only other allele is *b,* the frequency of allele *b* is 0.3. (Alternatively, we can calculate the frequency of allele *b* by dividing the number of this allele by the total number of alleles: 60/200 is again 0.3.) In population #2, 160 of 200 alleles are *B,* so the frequency of allele *B* is 0.8, and the frequency of allele *b* is 0.2. What would change if albino rabbits comprised 20% of the population?

If all the members of a rabbit population (#3) are homozygous brown, the frequency of *B* is 1.0, the frequency of *b* is 0, and there is no diversity. Allele *B* is said to be *fixed*, and until a mutation occurs, no possibility for evolution (with respect to this particular gene) exists. A population with frequencies of 0.5 for *B* and 0.5 for *b* would have maximum diversity for this two-gene system. Any change in those frequencies across generations would reflect evolution of the population.

Summary

- Changes in allele frequency measure the process of evolution.
- Allele frequency is the decimal fraction of a population's gene pool made up of that particular allele.
- A gene pool containing only one type of allele is fixed; it lacks variation and potential for evolution, at least until mutation occurs.
- For a gene with two alleles, allele frequencies of 0.5 indicate maximum variation.
- Any change in allele frequency reflects evolution of a population.

Review

1. Explain how to determine allele frequencies.
2. Evaluate phenotype, genotype, and allele frequencies as measures of variation, as raw material for evolution, and as a measure of evolution.

17.7 Microevolution - Advanced

Learning Objectives

- Compare and relate macroevolution to microevolution.
- Define microevolution in terms of allele frequencies.
- Define genetic equilibrium for a population.

Why do humans vary in skin color?

Is this the results of a change in allele frequencies? Is this an example of evolution within a species? The answer to both these questions is yes. And this is an example of microevolution.

Microevolution

- How many people in the United States carry the recessive **allele** for the lethal genetic disease, cystic fibrosis?
- Why must we treat AIDS patients with multi-drug "cocktails?"
- Why do we consider Northern Elephant seals endangered, even though their population has risen to 100,000 individuals?
- Why don't South African Cheetahs reject skin grafts from unrelated individuals?
- What were the probable effects on human evolution of the six years of "volcanic winter" caused by the "megacollosal" eruption of Mt. Toba 70,000 years ago?
- Why doesn't natural selection eliminate certain lethal genes?
- Why do humans vary in skin color?

This concept will introduce you to our current understanding of the causes of evolution and show you how scientists use this understanding to solve problems and answer puzzling questions like those above.

In an earlier concept, we defined **microevolution** as evolution within a species or population, and **macroevolution** was defined as evolution at or above the level of species. The differences between the two are time and scale.

Microevolution can refer to changes as small as a shift in **allele frequencies** for a single gene from one generation to the next. In contrast, macroevolution describes changes in species over geologic time. Many biologists consider evolution to be a single process; they regard macroevolution as the cumulative effects of microevolution. The *History of Life* concepts discussed patterns and processes of macroevolution; this lesson will focus on genetic changes within populations and species. At this level, we can see how evolution really works - a view that Darwin never had.

A change in allele frequencies within a population from one generation to the next - even if it involves only a single gene - is evolution. Biologists refer to this change in the gene pool as microevolution because it is evolution on the smallest scale. For our rabbit population from the previous lesson, a generation-to-generation increase in the frequency of the albino allele, *b,* from 0.3 to 0.4 (and the corresponding decrease in the frequency of allele *B* from 0.7 to 0.6) would be microevolution. The changes in Galapagos finch beak size, documented by Peter and Rosemary Grant, and the color changes of peppered moths will undoubtedly show corresponding changes in allele frequencies once we identify the responsible genes and alleles. Resistance to antibiotics in bacteria and the appearance of new strains of influenza viruses and HIV (**Figure** 17.21) also involve changes in allele frequencies. Each of these are examples of microevolution.

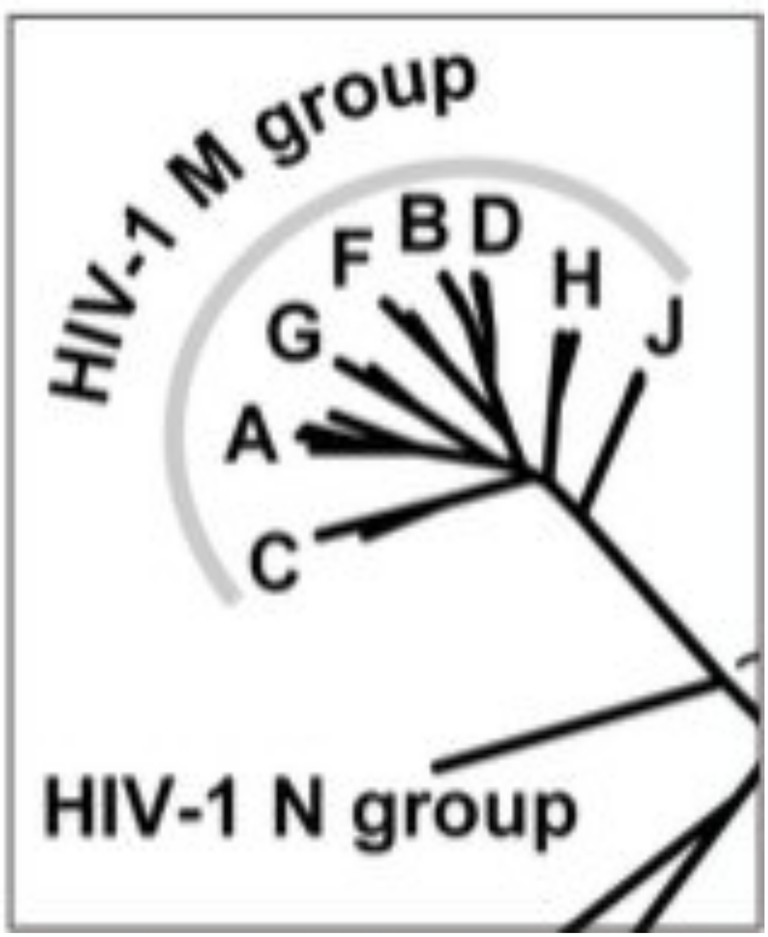


FIGURE 17.21

This portion of the evolutionary tree for Human Immunodeficiency Virus (HIV) shows 8 or more strains of the HIV-1 M (Main) group and a single strain of the HIV-1 N (Not Main/Not Outlier) group. The complete tree includes strains of SIV (Simian Immunodeficiency Virus). Each strain represents a change in allele frequencies.

What forces cause changes in allele frequencies? What mechanisms determine how microevolution happens? Before we tackle these questions, we will examine a population at equilibrium - a population which is *not* evolving.

Summary

- Macroevolution is the change in species over geologic time; it is the cumulative effect of microevolution.

- Microevolution is evolution within species or populations; it can be measured as a generation-to-generation change in allele frequencies.

Review

1. Compare microevolution to macroevolution.
2. Define microevolution in terms of allele frequencies.

17.8 Mutation and Gene Flow - Advanced

Learning Objectives

- Predict the possible effects of mutation, and analyze the probability of each type of effect.
- Contrast mutation in microorganisms to mutation in multicellular organisms.
- Define gene flow.
- Describe two possible effects of gene flow on the genetics of a population.

How do a population's genes change?

Remember, without change, there cannot be evolution. Together, the forces that change a population's gene frequencies are the driving mechanisms behind evolution.

Causes of Microevolution: Mutation and Gene Flow

As discussed previously, **mutations** - random, accidental changes in the sequence of nucleotides in DNA - are the original sources of genetic variation. Only mutations can create new **alleles** - new raw material for natural selection. UV or ionizing radiation, chemicals, and viruses constantly generate mutations in a gene pool, destabilizing genetic equilibrium and creating the potential for adaptation to changing environments. However, both rates of mutation and their effects on the fitness of the organism vary.

In multicellular organisms, most mutations occur in body cells and do not affect eggs and sperm; these are lost when the individual dies and usually do not affect evolution. Only mutations in gamete-producing cells can become part of the gene pool. The rate at which mutations enter the gene pool is low, due to DNA "proofreading" and repair enzymes - and the extensive amount of DNA which does not code for protein. Mutations which do change nucleotide sequences in functional genes may also have no effect (because the Genetic Code is redundant - multiple codons code for the same amino acid), or very little effect, if the amino acid is not located in a critical part of the protein.

Occasionally, however, a single nucleotide substitution can have a major effect on a protein - as we previously saw with sickle-cell anemia. Usually, the effect of a mutation on a protein is harmful; rarely is it helpful. In the case of sickle-cell anemia, it is both - depending on the environment. Sickled cells carry oxygen much less efficiently, but prevent malaria infections. Overall, the chance that a single mutation will increase the fitness of a multicellular organism is extremely low. If the environment changes, however, the adaptive value of a new allele may change as well. Over time, mutations accumulate, providing the variation needed for natural selection.

For the small genomes of viruses and bacteria, mutations affect genes directly and generation times are short, so rates of mutation are much higher. For an HIV population in one AIDS patient, rates of viral mutation and replication are so high that in a single day, every site in the HIV genome may have experienced mutation (**Figure** 17.22). This rapid generation of new alleles challenges our best efforts at drug treatment and explains the evolution of antibiotic resistance. Because of the abundance of random, spontaneous mutations, HIV generates a large amount of raw material for natural selection and readily evolves resistance to new "environments" created by single drugs (**Figure** 17.23). Drug "cocktails," which contain multiple anti-viral chemicals, are our effort to change the "environment" and keep up with mutation in the human-HIV evolutionary race. For microorganisms, mutation is a strong force for evolution.

For all organisms, mutations are the ultimate source of genetic variation. For a population, however, the immigration or emigration of individuals or gametes may also add to or subtract from a gene pool - a process known as **gene flow**. For example, wind or animals can carry pollen or seeds from one plant population to another. In baboon troops or wolf packs (**Figure** 17.24), juvenile males may leave the group to find mates and establish separate populations. Human history includes countless migrations; gene flow continues to mix gene pools and cause microevolutionary changes.

Gene flow can bring new alleles into a population which occurred by chance and were successful in other populations. In this way, it can accelerate microevolution. However, if exchange between populations is frequent, it reduces differences between populations, in effect increasing population size. In this case, gene flow tends to maintain separate populations as one species, reducing speciation, if not microevolution.

Mutations, together with recombination of existing alleles by sexual reproduction, provide the diversity which is the raw material for natural selection and evolution. Gene flow can accelerate the spread of alleles or reduce the differences between populations. Both can contribute significantly to microevolution. However, many biologists consider the major causes of microevolutionary change to be genetic drift and natural selection.

Summary

- Random, spontaneous mutations constantly generate new alleles in a gene pool, destabilizing genetic equilibrium and creating the potential for adaptation to changing environments.
- In multicellular organisms, only mutations that affect germ cells become part of the gene pool.
- Because of extensive "junk" DNA, repair enzymes, and multicellularity, many mutations do not reach the gene pool.
- Many mutations are harmful, disrupting protein function.
- Because the genetic code is redundant and some amino-acid substitutions may not change protein function, many mutations have no effect on an organism's fitness.

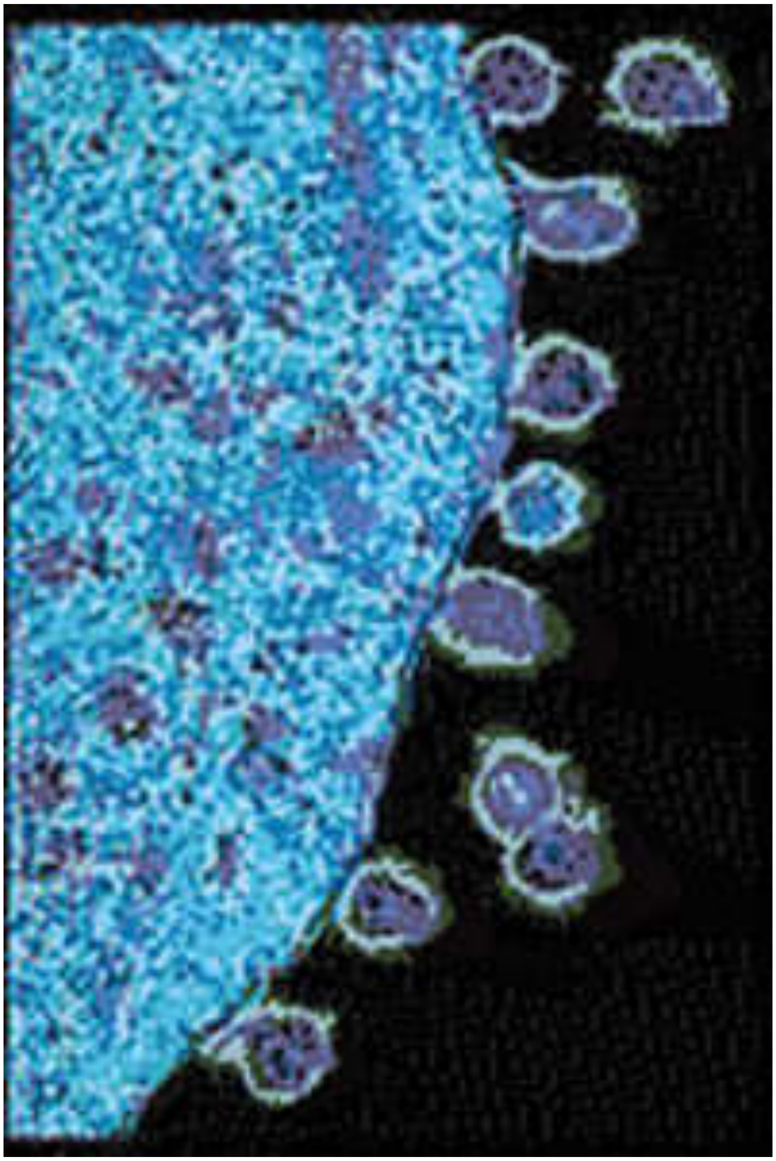


FIGURE 17.22
HIV daughter particles are shed from an infected human T-cell host. Both HIV replication and mutation rates are so high that during a single day, the HIV population in one AIDS patient generates mutations at every site in the HIV genome. New alleles provide the potential for extremely rapid evolution, including the development of resistance to drugs.

- Even neutral mutations hold potential for future selection if the environment changes.
- A few mutations may be advantageous, improving or changing protein function.
- In microorganisms mutation rates are much higher due to rapid reproduction and small genomes.
- Mutation, together with recombination of existing alleles provides the diversity which is the raw material for natural selection and evolution.
- The movement of genes from one population to another (gene flow) can change allele frequencies.
- Gene flow can accelerate the spread of successful alleles or reduce differences between populations.

Review

1. Analyze the possible effects of mutations and the probability and importance of each type of mutation.
2. Describe two possible effects of gene flow on the genetics of a population.

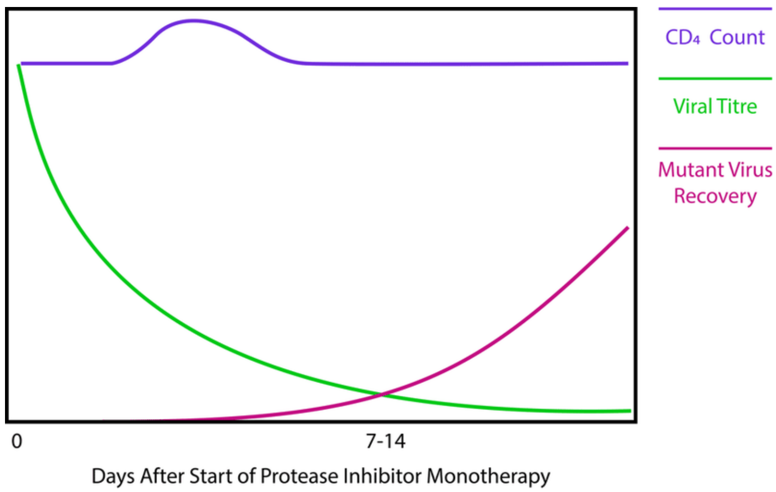


FIGURE 17.23

Extremely high HIV mutation rates provide many new alleles - the raw material for natural selection - in AIDS patients. This variation allows at least some mutant viruses to survive and reproduce in the changing "environments" of new drug therapies. The graph shows the effects of one type of drug: an initial decrease in the HIV population and a temporary rise in the number of human host (CD4) cells. Before long, however, mutants with alleles conferring drug resistance appear and begin to reproduce, which leads to a recovery in the HIV population. This change in allele frequencies is microevolution, caused by mutation and natural selection.

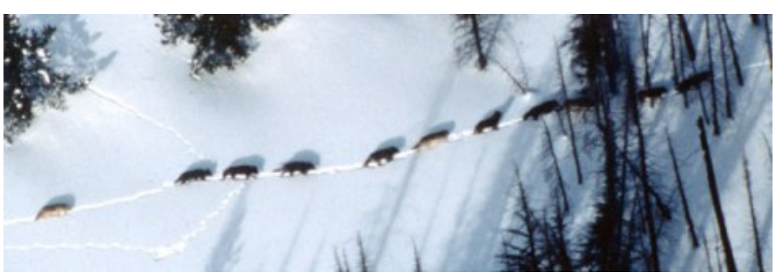


FIGURE 17.24

Dominant alpha wolves lead their pack in Yellowstone National Park. The lowest ranking omega individual, in the rear, may eventually leave the pack to find a mate and establish his own territory and pack. He would carry some of the genes from his pack to the new one - a form of gene flow which seems built into wolves' social organization.

17.9 Population Size and Genetic Drift - Advanced

Learning Objectives

- Define genetic drift.
- Describe three possible effects of genetic drift on populations and/or specific alleles.
- Clarify and give an example of the concepts of the bottleneck and founder effects.

What does it mean to drift?

To drift means to be carried along by currents of air or water. A snowdrift is a deposit of snow sculpted by wind into a mound during a snowstorm. With a genetic drift, allele frequencies can change as they *drift* just by random chance.

Causes of Microevolution: Population Size and Genetic Drift

Recall that the third requirement for Hardy-Weinberg equilibrium is a very large population size. This is because chance variations in allele frequencies are minimal in large populations. In small populations, random variations in allele frequencies can significantly influence the "survival" of any allele, regardless of its adaptive value. Random changes in allele frequencies in small populations are known as **genetic drift**. Many biologists think that genetic drift is a major cause of microevolution.

You see the effects of chance when you flip a coin. If you flipped a penny 4 times, you would not be too surprised if it came up heads 4 times and tails not at all. If you tossed it 100 times, you would be very surprised if the results were 100 heads and no tails. The larger the "population" of coin tosses, the lower the effects of chance, and the closer the results should match the expected 50-50 ratio. The same is true for populations. If we imagine a rabbit population with a very small gene pool of just 2 ***B*** alleles and 2 ***b*** alleles, it is not difficult to understand that occasionally, chance alone would result in no albino offspring (only genotypes ***BB*** or ***Bb***) - or even no brown offspring (only genotype

bb). However, a gene pool of 100 ***B*** alleles and 100 ***b*** alleles would be very unlikely to produce a generation of offspring entirely lacking one allele or the other, despite having identical initial allele frequencies of 0.5.

Because chance governs meiosis and fertilization, random variations can influence allele frequencies, especially for small populations. Note that these chance variations can increase the frequency of alleles which have no adaptive advantages or disadvantages - or decrease the frequency of alleles which do have adaptive value. Genetic drift can result in extinction of an allele or an entire population - or rapid evolution (**Figure** 17.25). Two sets of circumstances can create small populations for which genetic drift can have major consequences: the **bottleneck effect** and the **founder effect.**

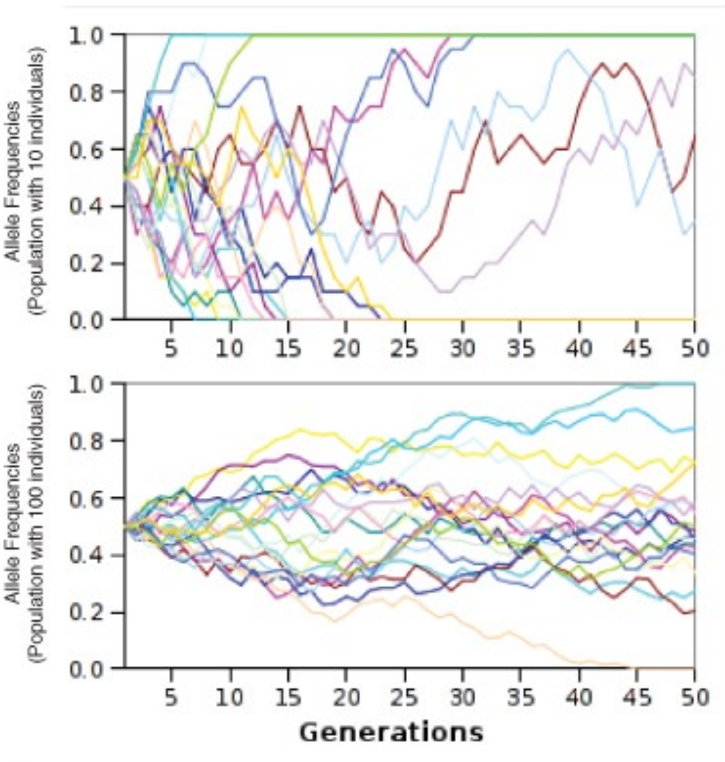


FIGURE 17.25

Computer models show that the effect of small population size on allele frequencies is a significant increase in variation due to chance. Each line depicts a different allele. In the small population (above), most of the 20 alleles beginning at frequencies of 0.5 become either "fixed" (frequency = 1.0) or extinct (frequency = 0) within 5 - 25 generations. In the larger population (below), only one pair of alleles shows fixation/extinction - and that occurs only after 45 generations. Note that these variations are independent of natural selection; they do not necessary help fit the organism to its environment.

The Bottleneck Effect

Natural catastrophes such as earthquakes, floods, fires, or droughts can drastically reduce population size - usually without respect to allele frequencies. As a result of the disaster, some alleles may be lost entirely and others may be present in frequencies which differ from those of the original population. The smaller population is then subject to genetic drift, which may further reduce diversity within the population. The loss of diversity resulting from a drastic reduction in population size and subsequent genetic drift is the bottleneck effect (**Figure** 17.26). Much of our concern for endangered species derives from our understanding of the way in which small population size can reduce diversity by increasing genetic drift. We will look at two examples of the bottleneck effect - one caused by humans and the other probably experienced by our human ancestors.

During the 19th century, overhunting reduced the worldwide population of Northern Elephant Seals (**Figure** 17.27) to fewer than 100 individuals. Because an alpha bull typically mates with a "harem" of 30-100 females, it is possible that just a single male fathered all the seals which exist today! After legal protection, their numbers have rebounded to 100,000. However, the effects of the past bottleneck - significant loss of genetic variability - remain. Reduced genetic diversity means that today's seals are more susceptible to disease and weather. Effects of genetic drift on the

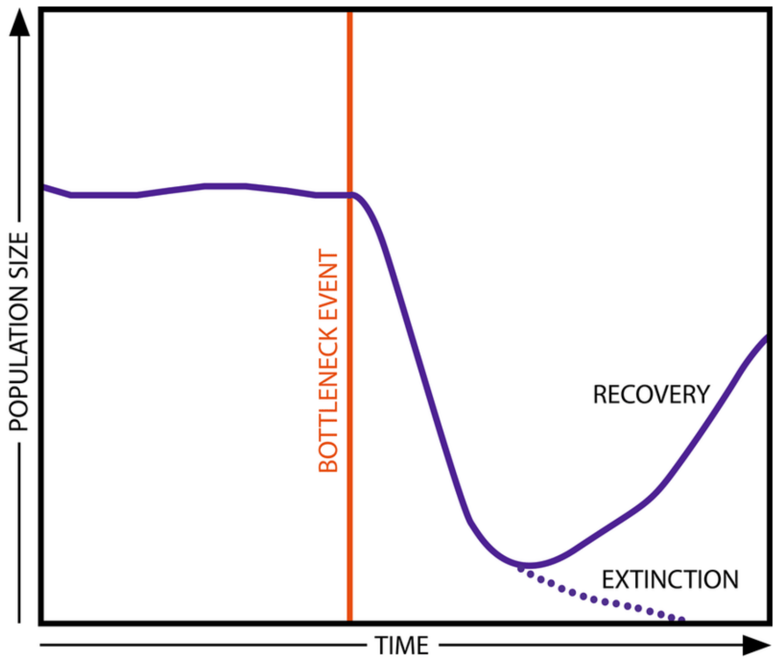


FIGURE 17.26

A random but major catastrophe which causes a sudden, severe reduction in population size can lead to a bottleneck effect. The reduction in gene pool size - and often diversity - leaves populations subject to genetic drift; chance variations can cause extinction - or accelerated evolution leading to recovery. Even if recovery occurs, genetic diversity remains low.

gene pool may have contributed to the loss of 80% of pups during the El Nino year of 1997-98.

FIGURE 17.27

The Northern Elephant Seal population fell to fewer than 100 individuals due to overhunting during the 19th century. Although their numbers have recovered, the bottleneck effect of reduced genetic variation limits their potential to adapt to future environmental changes.

Although the exact cause is unknown, a bottleneck effect for South African Cheetahs (**Figure** 17.28) during the last ice age, about 10,000 years ago, has apparently led to extremely low genetic variability. Genetic variation among cheetahs has been compared to that of highly inbred varieties of laboratory mice; skin grafts between unrelated individuals are not rejected. These animals also suffer from low sperm counts. Like many endangered species, cheetahs are threatened not only by habitat loss, but also by reduced genetic diversity, which reduces their potential to adapt to changing environments.

We humans may have experienced a population bottleneck between 70,000 and 75,000 years ago, when supervolcano Mount Toba exploded with category 8 (“megacolossal!”) force in Sumatra. According to anthropologist Stanley Ambrose’s theory, global temperature dropped as much as 5 degrees Celsius for several years, possibly leading to

FIGURE 17.28
Although the cause is unknown, South African Cheetahs apparently experienced a population bottleneck effect 10,000 years ago. Their current genetic uniformity is remarkable; skin grafts between even unrelated individuals do not elicit rejection responses.

an ice age. Ambrose believes that the environmental effects ("six years of relentless volcanic winter") reduced the total human population to less than 10,000. Isolated individual populations would have experienced genetic drift and rapid evolution or extinction.

The Founder Effect

Whereas a drastic reduction in population size causes the bottleneck effect, a form of population expansion leads to the founder effect. If a small group of individuals (the founders) breaks off from a larger population to colonize a distant area, they will probably carry with them only a limited amount of the genetic diversity of the original population (**Figure** 17.29). For this reason, the new population they establish may differ significantly in genotype and phenotype. Inevitably, it will also be small and therefore subject to genetic drift.

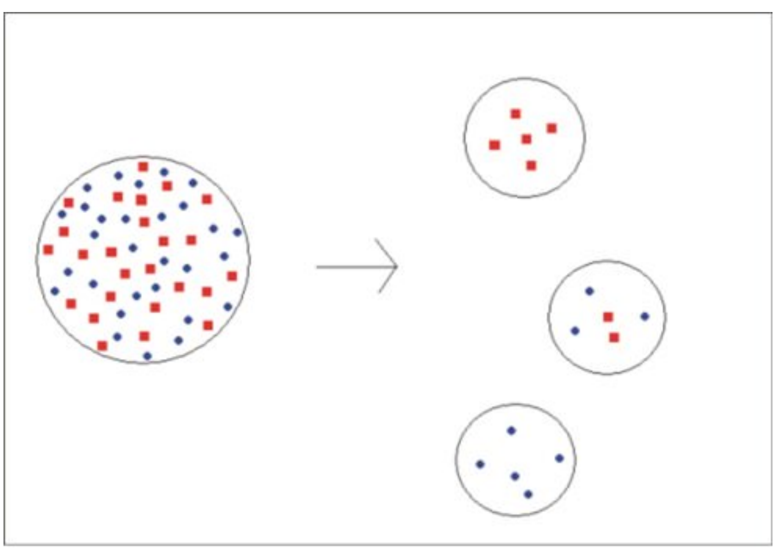


FIGURE 17.29
In this diagram, the red squares and blue dots represent individuals with different alleles. Small groups of individuals (see the right three circles) which leave a larger population (left) to colonize a new area carry with them smaller gene pools, with allele frequencies which may differ significantly from that of the parent population - due to chance. The effects of chance in these new populations become more important; genetic drift may result in extinction or rapid evolution.

On newly formed islands, such as the Galapagos, Hawaii, and more recently Surtsey, Iceland, founder populations are often the only source of life on the island. Many founder populations probably become extinct, but others evolve rapidly, due to genetic drift. Some may diverge rapidly to occupy many available ecological niches - a process known as **adaptive radiation.** As we have discussed in past chapters, Galapagos finches and Hawaiian honeycreepers probably each evolved from small populations of a single ancestral finch-like species (see the previous chapter on *Evolutionary Theory*).

Historically and even today, human populations have experienced founder effects. In some cases, migration and colonization are the cause. Quebec was founded by a group of no more than 2,600 people, ancestors of today's more than 7 million Quebecois, who show remarkable genetic similarity and a number of heritable diseases, well studied by geneticists.

Cultural isolation, as well as colonization, can result in founder effects. Amish populations in the United States have grown from an initial group of about 200 immigrants, dating back to the mid-1700s. Because they have remained culturally and reproductively isolated from non-Amish Americans, they show considerable uniformity. The Amish today are often studied for their genetic uniformity, as well as certain recessive conditions. Geneticists believe that just one or two of the initial 200 Amish carried a recessive allele for Ellis-van Creveld syndrome (short limbs, extra fingers, and heart anomalies), yet through genetic drift, the isolated Amish population now has the highest incidence of this syndrome in the world (**Figure** 17.30).

FIGURE 17.30

Polydactyly (extra digits) and short limbs are characteristics of Ellis-van Creveld syndrome, a genetic disease which is rare worldwide but more common in the Amish population. Because the Amish population began with just 200 immigrants and has remained isolated, their high incidence of this syndrome may be a result of the founder effect.

Summary

- In small populations, random variations in allele frequencies can significantly influence the "survival" of any allele, regardless of its adaptive value; this phenomenon is genetic drift.
- Genetic drift can result in the extinction of an allele or an entire population.
- Alternatively, genetic drift can lead to the rapid evolution of a population.
- In the bottleneck effect, a catastrophe, disease, or overhunting can dramatically reduce a population's size and genetic variation, increasing its susceptibility to the effects of genetic drift.
- In the founder effect, a small group leaves a larger population to colonize a new area. Again, genetic drift may lead to loss of genetic diversity, extinction, or rapid evolution.
- Genetic drift leads to evolution in populations of small size, but results are mostly due to chance.

Review

1. Describe three possible effects of genetic drift on populations and/or specific alleles.

2. Why do we consider Northern Elephant seals endangered, even though their population has risen to 100,000 individuals?

17.10 References

1. John Gould. https://flic.kr/p/85vm16;http://commons.wikimedia.org/wiki/File:Darwin%27s_finches.jpeg . Public Domain;Public Domain; CC-BY 2.0
2. George Richmond;John Gould. http://commons.wikimedia.org/wiki/File:Charles_Darwin_by_G._Richmond.jpg;http://commons.wikimedia.org/wiki/File:Darwin%27s_finches.jpeg . Public Domain
3. Christopher Auyeung;John Gould. CK-12 Foundation;http://commons.wikimedia.org/wiki/File:Darwin%27s_finches.jpeg . CC BY-NC 3.0;Public Domain
4. Courtesy of NASA, labeled by User:Storpilot/Wikimedia Commons;John Gould. http://commons.wikimedia.org/wiki/File:Galapagos-satellite-esislandnames.jpg;http://commons.wikimedia.org/wiki/File:Darwin%27s_-finches.jpeg . Public Domain
5. Leland Jackson; Leon Brocard;John Gould. http://www.flickr.com/photos/dianaandleland/9010234532/; http://www.flickr.com/photos/acme/3247645396/;http://commons.wikimedia.org/wiki/File:Darwin%27s_finches.jpeg . CC BY 2.0;Public Domain
6. Yotcmdr; Mike Weston;John Gould. http://commons.wikimedia.org/wiki/File:Giant_Tortoise.JPG; http://commons.wikimedia.org/wiki/File:Lonesome_George_in_profile.png;http://commons.wikimedia.org/wiki/File:Darwin%27s_finches.jpeg . Public Domain; CC-BY 2.0;Public Domain
7. John Gould;Hana Zavadska;U.S. Fish and Wildlife Service. http://commons.wikimedia.org/wiki/File:Darwin%27s_finches.jpeg;CK-12 Foundation;http://commons.wikimedia.org/wiki/File:Arctic_Hare.jpg . Public Domain;CC BY-NC 3.0
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12. User Toony, GFDL. . CK-12 Foundation
13. User: The Prophet Tiresias. http://en.wikipedia.org/wiki/Image:Selection_Chart.png . Public Domain
14. Laura Guerin. . CK-12 Foundation
15. Anthony Allison. http://commons.wikimedia.org/wiki/File:Malaria_versus_sickle-cell_trait_distributions.png . Public Domain
16. Maureen. http://www.flickr.com/photos/amerune/302221440/ . CC BY 2.0
17. Maja Dumat. http://www.flickr.com/photos/blumenbiene/4592507080 . CC BY 2.0
18. Colin and Sarah Northway. https://www.flickr.com/photos/apes_abroad/4822043093 . CC BY 2.0
19. Kris Herbert; Jamie McCaffrey; Jon Hurd;Kris Herbert; Jamie McCaffrey; Jon Hurd Wolf:. Wolf: http://www.flickr.com/photos/kristiherbert/355647915/; Chihuahua: http://www.flickr.com/photos/15609463@N03/8749843808/; Great Dane: http://www.flickr.com/photos/jonhurd/3408125576/;http://www.flickr.com/photos/kristiherbert/355647915/; Chihuahua: http://www.flickr.com/photos/15609463@N03/8749843808/; Great Dane: http://www.flickr.com/photos/jonhurd/3408125576/ . CC BY 2.0
20. John Doebley. http://commons.wikimedia.org/wiki/File:Teosinte.png . CC BY 2.5
21. Dave Pape; Wilfred Hdez. http://commons.wikimedia.org/wiki/File:Panthera_tigris_altaica_13_-_Buffalo_Zoo.jpg; http://www.flickr.com/photos/wilfred_hdez/12982749544/ . Public Domain; CC BY 2.0
22. Colin and Sarah Northway. https://www.flickr.com/photos/apes_abroad/4822043093 . CC BY 2.0
23. marksontok. http://www.flickr.com/photos/mark233/6338067876 . CC BY 2.0
24. Michal Maňas. http://commons.wikimedia.org/wiki/File:Macroglossum_stellatarum.jpg . CC BY 2.5

25. . . CC BY-NC
26. Theoretical Biology and Biophysics Group, Los Alamos National Laboratory: C. Kuiken, B. Foley, B. Hahn, P. Marx, F. McCutchan, J. Mellors, J. W. Mullins, B. Korber. http://commons.wikimedia.org/wiki/File:HIV-SIV-phylogenetic-tree.png . Public Domain
27. National Park Service. http://commons.wikimedia.org/wiki/File:Wolf_pack_in_Yellowstone_NP.jpg . Public Domain
28. National Institutes of Health, Department of Health and Human Services. http://commons.wikimedia.org/wiki/File:HIV_Daughter_Particles.jpg . Public Domain
29. Laura Guerin. . CK-12 Foundation
30. National Park Service. http://commons.wikimedia.org/wiki/File:Wolf_pack_in_Yellowstone_NP.jpg . Public Domain
31. Geneviève Baujat and Martine Le Merrer Ellis-Van, Creveld Syndrome, Orphanet Journal of Rare Diseases, 2007. http://commons.wikimedia.org/wiki/File:Polydactyly_ECS.jpg . CC BY 2.0
32. . http://commons.wikimedia.org/wiki/Image:Allele-frequency-fr.png . GNU-FDL
33. Laura Guerin. . CK-12 Foundation
34. Jan Roletto. http://commons.wikimedia.org/wiki/File:See_elefanten.jpg . Public Domain
35. B. Pavacic. http://commons.wikimedia.org/wiki/File:MasaiMaraCheetahs01.jpg . Public Domain
36. Kazulanth. http://commons.wikimedia.org/wiki/File:Founder_effect.png . Public Domain
37. Geneviève Baujat and Martine Le Merrer Ellis-Van, Creveld Syndrome, Orphanet Journal of Rare Diseases, 2007. http://commons.wikimedia.org/wiki/File:Polydactyly_ECS.jpg . CC BY 2.0

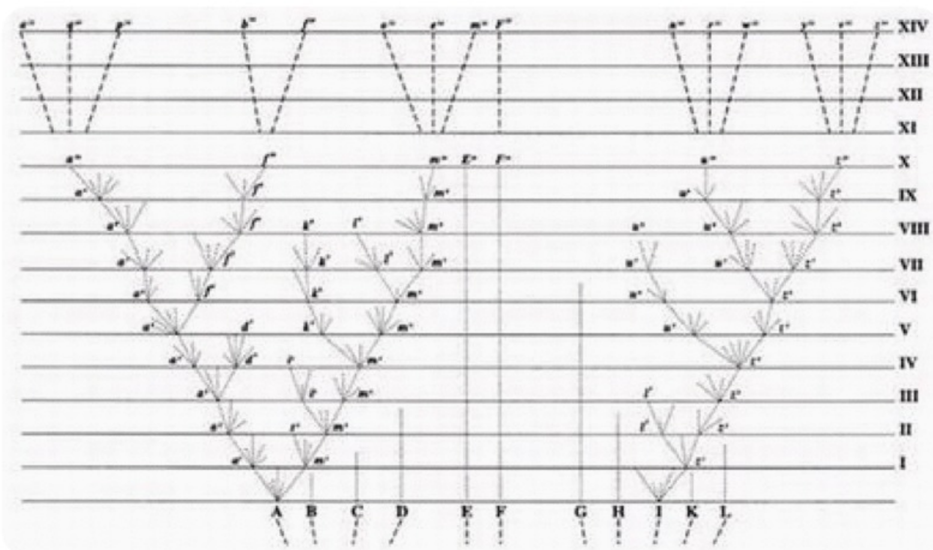
Chapter 18 Evolution: Evidence for Evolution

Chapter Outline

18.1 Theory of Evolution

Learning Objectives

- Define fitness and natural selection.
- Summarize Darwin's reasoning.
- Explain how a species can evolve through natural selection.



How do new species form?

This is the only illustration in Charles Darwin's 1859 book *On the Origin of Species*, showing his ideas describing the divergence of species from common ancestors.

Darwin's Theory of Evolution by Natural Selection

Darwin spent many years thinking about the work of Lamarck, Lyell, and Malthus, what he had seen on his voyage, and artificial selection. What did all this mean? How did it all fit together? It fits together in Darwin's theory of evolution by natural selection. It's easy to see how all of these influences helped shape Darwin's ideas.

Evolution of Darwin's Theory

It took Darwin years to form his theory of evolution by natural selection. His reasoning went like this:

1. Like Lamarck, Darwin assumed that species can change over time. The fossils he found helped convince him of that.
2. From Lyell, Darwin saw that Earth and its life were very old. Thus, there had been enough time for evolution to produce the great diversity of life Darwin had observed.

3. From Malthus, Darwin knew that populations could grow faster than their resources. This "overproduction of offspring" led to a "struggle for existence," in Darwin's words.
4. From artificial selection, Darwin knew that some offspring have variations that occur by chance, and that can be inherited. In nature, offspring with certain variations might be more likely to survive the "struggle for existence" and reproduce. If so, they would pass their favorable variations to their offspring.
5. Darwin coined the term **fitness** to refer to an organism's relative ability to survive and produce fertile offspring. Nature selects the variations that are most useful. Therefore, he called this type of selection **natural selection**.
6. Darwin knew artificial selection could change domestic species over time. He inferred that natural selection could also change species over time. In fact, he thought that if a species changed enough, it might evolve into a new species.

Wallace's paper not only confirmed Darwin's ideas. It also pushed him to finish his book, *On the Origin of Species*. Published in 1859, this book changed science forever. It clearly spelled out Darwin's theory of evolution by natural selection and provided convincing arguments and evidence to support it.

Applying Darwin's Theory

The following example applies Darwin's theory. It explains how giraffes came to have such long necks (see **Figure** 18.1).

- In the past, giraffes had short necks. But there was chance variation in neck length. Some giraffes had necks a little longer than the average.
- Then, as now, giraffes fed on tree leaves. Perhaps the environment changed, and leaves became scarcer. There would be more giraffes than the trees could support. Thus, there would be a "struggle for existence."
- Giraffes with longer necks had an advantage. They could reach leaves other giraffes could not. Therefore, the long-necked giraffes were more likely to survive and reproduce. They had greater fitness.
- These giraffes passed the long-neck trait to their offspring. Each generation, the population contained more long-necked giraffes. Eventually, all giraffes had long necks.

FIGURE 18.1

Giraffes feed on leaves high in trees. Their long necks allow them to reach leaves that other ground animals cannot.

As this example shows, chance variations may help a species survive if the environment changes. Variation among species helps ensure that at least one will be able to survive environmental change.

KQED: Chasing Beetles, Finding Darwin

It's been over 150 years since Charles Darwin published *On the Origin of Species*. Yet his ideas remain as central to scientific exploration as ever, and has been called the unifying concept of all biology. Is evolution continuing today? Of course it is.

QUEST follows researchers who are still unlocking the mysteries of evolution, including entomologist David Kavanaugh of the California Academy of Sciences, who predicted that a new beetle species would be found on the Trinity Alps of Northern California.

It's rare for a biologist to predict the discovery of a new species. For his prediction, Kavanaugh drew inspiration from Darwin's own 1862 prediction. When Darwin observed an orchid from Madagascar with a foot-long nectar, he predicted that a pollinator would be found with a tongue long enough to reach the nectar inside the orchid's very thin, elongated nectar "pouch", though he had never seen such a bird or insect. Darwin's prediction was based on his finding that all species are related to each other and that some of them evolve together, developing similar **adaptations**. Darwin's prediction came true in 1903, when a moth was discovered in Madagascar with a long, thin proboscis, which it uncurls to reach the nectar in the orchid's nectar. In the process of feeding from the orchid, the moth serves as its pollinator. The moth was given the scientific name *Xanthopan morganii praedicta*, in honor of Darwin's prediction.

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As you view *Chasing Beetles, Finding Darwin,* focus on the following concepts:

1. the relationship between studying beetles and evolution,
2. the development of new species,
3. the relationship between genetic make-up of an organism and evolution,
4. the role of *beneficial* mutations,
5. the role of "habitat islands",
6. the selection for certain traits among breeders, such as pigeon breeders,
7. the importance of identifying new species.

Science Friday: Sex, Lies and Orchids

Orchids utilize a wide variety of techniques to manipulate other species into becoming their pollinators. In this video by Science Friday, curator Marc Hachadourian describes some of these deceptive methods.

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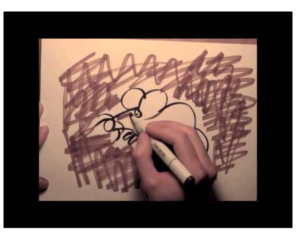
Summary

- Darwin's book *On the Origin of Species* clearly spells out his theory.
- Darwin's book also provides evidence and logic to support that evolution occurs and that it occurs by natural selection.

Review

1. Define fitness.
2. Apply Darwin's theory of evolution by natural selection to a specific case. For example, explain how Galápagos tortoises could have evolved saddle-shaped shells.
3. Explain how the writings of Charles Lyell and Thomas Malthus helped Darwin develop his theory of evolution by natural selection.
4. Discuss the role artificial selection had on Darwin's theory.

Resources



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18.2 Summary of Evolution - Advanced

Learning Objectives

- Describe the evidence for natural selection among Darwin's finches documented by the Grants.

How can one bird supply so much information?

By its beak. This is a Galápagos finch, one of the birds studied by Charles Darwin. This species and all the other finch species of the Galápagos Islands provided Darwin with valuable evidence for his theory.

Evolution: A Summary

Altogether, the fossil record, homologies, analogies, vestigial structures, molecular uniformity and diversity, and biogeography provide powerful scientific evidence for the descent of today's species from common ancestors. Some details of natural selection have been and are still being modified. However, the remarkable biological discoveries of the 150 years since Darwin published *On the Origin of Species* have dramatically strengthened support for his theory. Moreover, Darwin's theory continues to enlighten new discoveries. Prominent geneticist and evolutionary biologist Theodosius Dobzhansky said, "Nothing in biology makes sense except in the light of evolution." Perhaps we could paraphrase Dobzhansky: *Everything in biology makes sense in the light of evolution.*

At that time, the only piece still missing from the evidence puzzle is direct observation of the process itself. Darwin thought that humans could never witness evolution in action because of the vast time periods required. For once, however, he was mistaken; evolution in action can and has been observed.

Evolution Continues and We "Catch it in the Act"

Much more passively and with a clear understanding of our lack of control, humans have watched viruses rapidly evolve through mutation to cause frightening worldwide epidemics, or **pandemics** - including the 1918 "Spanish flu", Severe Acute Respiratory Syndrome (SARS), West Nile virus, the "avian flu" (caused by a highly pathogenic viral subtype of influenza A, known as H5N1), and the 2009 "swine flu" (caused by the H1N1 influenza virus). **Figure** 18.2 shows the increase in human infections and deaths from H5N1. Mutations have adapted it for life in both birds and humans and for transmission from bird to bird and bird to human. If a future mutation adapts it for effective transmission from human to human, a serious epidemic could result. If, as some argue, influenza pandemics occur in cycles, we are overdue for a dramatic demonstration of evolution and natural selection.

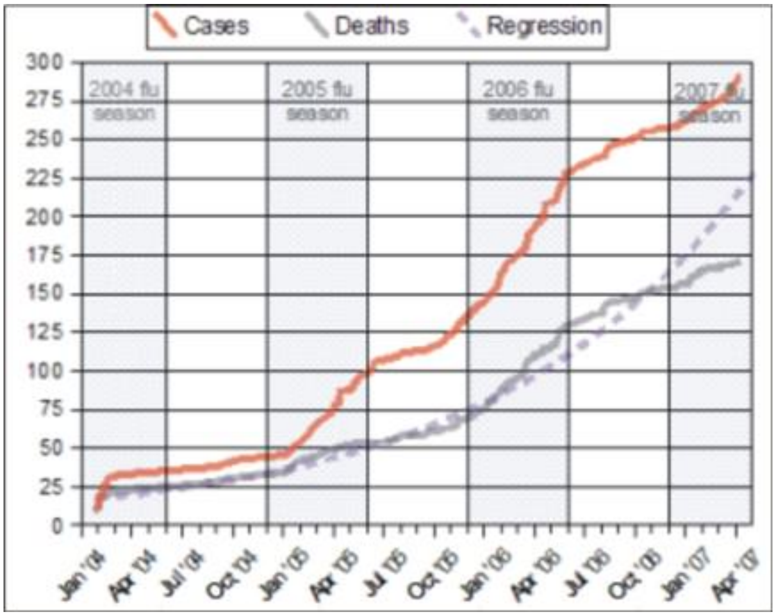


FIGURE 18.2

Human infections and deaths from avian flu, caused by the H5N1 subtype of influenza A virus, are clearly increasing. Mutations have adapted the virus for life in both birds and humans and for transmission from birds to birds and from birds to humans. Some scientists think the probability is high that the virus will also evolve the means for effective transmission between humans and cause a serious pandemic.

The Peppered Moth

Peppered moths (**Figure** 18.3) are mostly white with black specks; this color pattern hid them for centuries from predatory birds, as the moths rest against lichen covered tree trunks. However, soot from the **Industrial Revolution** darkened the trees and destroyed their camouflage, selecting instead for the dark mutants which occasionally appeared. Gradually the population shifted to the dark color, an instance of natural selection that was directly observed by Englishmen of the time. Subsequent improvements in air pollution control have cleaned up the environment, and the English now note a new change: the trees have lightened, and moth populations are returning to their original coloration. These direct observations of natural selection would have delighted Darwin (except perhaps for the pollution) just a few years earlier.

The Galápagos Finches

Much more intentionally, biologists Peter and Rosemary Grant (introduced in the *Evolution: Biogeography (Advanced)* concept) have devoted more than 30 years to a study of two species of Darwin's finches on one of the Galápagos islands (**Figure** 18.4). Catching, weighing, and recording the seed species eaten by hundreds of these birds, they have witnessed changes in beak size which clearly correlate with changes in weather and availability of food. A severe drought and food shortage in 1977 led to a significant change. Birds whose small beaks could not crack the tough remaining seeds died, and the larger-beaked individuals who survived reproduced. The following year, offspring were larger bodied and larger-beaked, showing that natural selection led to evolution. A rainy winter in 1984-1985 reversed the trend; more soft seeds were produced, and the smaller beaked finches survived to reproduce in greater numbers than their large-beaked cousins.

FIGURE 18.3

The peppered moth population changed from mostly light (left) to mostly dark (right) as the lichen-covered trees in England's forests absorbed soot from the Industrial Revolution. Now, as pollution is being cleaned up, the moth population is returning to its former proportion of light moths. These changes illustrate what famous idea?

FIGURE 18.4

A large cactus ground finch crushes a seed on the island of Española in the Galápagos archipelago. Peter and Rosemary Grant studied two closely related species of Darwin's finches and recorded changes in beak size and body size, which paralleled changes in weather. How fitting that they should demonstrate natural selection in action - something Darwin did not think possible - using one of the species he made famous!

Jonathan Winter eloquently describes the Grants' work and discoveries in his Pulitzer Prize-winning *The Beak of the Finch, A story of Evolution in our Time.* His words urge us to see evolution as ongoing for all life, making a fitting conclusion to this lesson and chapter:

"For all species, including our own, the true figure of life is a perching bird, a passerine, alert and nervous in every part, ready to dart off in an instant. Life is always poised for flight. From a distance it looks still, silhouetted against the bright sky or the dark ground; but up close it is flitting this way and that, as if displaying to the world at every moment its perpetual readiness to take off in any of a thousand directions." —*The Beak of the Finch: A Story of Evolution in Our Time,* Jonathan Weiner, 1995.

Summary

- Viral epidemics occur when chance viral mutations adapt the virus to new hosts or new methods of transmission.
- Peppered moth populations changed color as the Industrial revolution changed the color of their habitat.
- Peter and Rosemary Grant studied two closely related species of Darwin's finches and recorded changes in beak size and body size, which paralleled changes in weather.

Review

1. In what way do viral epidemics demonstrate evolution?
2. Describe the findings of Peter and Rosemary Grant.

18.3 Fossils

Learning Objectives

- Define fossil.
- Describe how fossils help us understand the past.

Would this be evidence of evolution?

Fossils, like this dinosaur fossil, provide evidence of species that lived in the past and have since gone extinct. In other words, these fossils are evidence of evolution.

Fossil Evidence

In his book *On the Origin of Species*, Darwin included evidence to show that evolution had taken place. He also made logical arguments to support his theory that evolution occurs by natural selection. Since Darwin's time, much more evidence has been gathered. The evidence includes a huge number of fossils. It also includes more detailed knowledge of living things, right down to their DNA.

Fossils are a window into the past. They provide clear evidence that evolution has occurred. Scientists who find and study fossils are called **paleontologists**. How do they use fossils to understand the past? Consider the example of the horse, shown in the **Figure** 18.5. The fossil record shows how the horse evolved.

The oldest horse fossils show what the earliest horses were like. They were about the size of a fox, and they had four long toes. Other evidence shows they lived in wooded marshlands, where they probably ate soft leaves. Through time, the climate became drier, and grasslands slowly replaced the marshes. Later fossils show that horses changed as well.

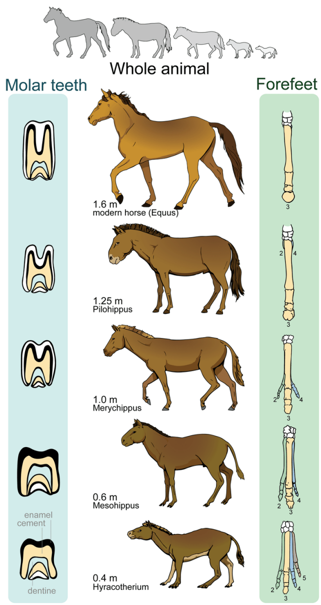
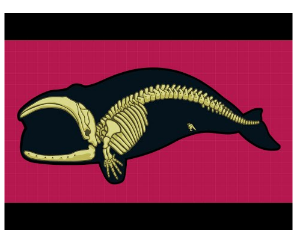


FIGURE 18.5
Evolution of the horse. Fossil evidence, depicted by the skeletal fragments, demonstrates evolutionary milestones in this process. Notice the 57 million year evolution of the horse leg bones and teeth. Especially obvious is the transformation of the leg bones from having four distinct digits to that of today's horse.

- They became taller, which would help them see predators while they fed in tall grasses.
- They evolved a single large toe that eventually became a hoof. This would help them run swiftly and escape predators.
- Their molars (back teeth) became longer and covered with cement. This would allow them to grind tough grasses and grass seeds without wearing out their teeth.

Similar fossil evidence demonstrates the evolution of the whale, moving from the land into the sea.



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Science Friday: Millions of Fossils Can't Be Wrong

What's in a tar pit? In this video by Science Friday, Dr. John Harris describes how the La Brea Tar Pit has come to accumulate so many fossils.

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Summary

- Fossils provide a window into the past. They are evidence for evolution.
- Scientists who find and study fossils are called paleontologists.

Review

1. What is a fossil?
2. How do paleontologists learn about evolution?
3. Describe what fossils reveal about the evolution of the horse.

18.4 Comparative Anatomy

Learning Objectives

- Explain the significance of homologous structures, analogous structures, and vestigial structures.
- Describe the meaning of similar DNA sequences between two species.

Is this evidence of evolution?

Take a close look at this gorilla hand. The similarities to a human hand are remarkable. Comparing anatomy, and characterizing the similarities and differences, provides evidence of evolution.

Evidence from Living Species

Just as Darwin did many years ago, today's scientists study living species to learn about evolution. They compare the anatomy, embryos, and DNA of modern organisms to understand how they evolved.

Comparative Anatomy

Comparative anatomy is the study of the similarities and differences in the structures of different species. Similar body parts may be homologies or analogies. Both provide evidence for evolution.

Homologous structures are structures that are similar in related organisms because they were inherited from a common ancestor. These structures may or may not have the same function in the descendants. **Figure** 18.6 shows the hands of several different mammals. They all have the same basic pattern of bones. They inherited this pattern from a common ancestor. However, their forelimbs now have different functions.

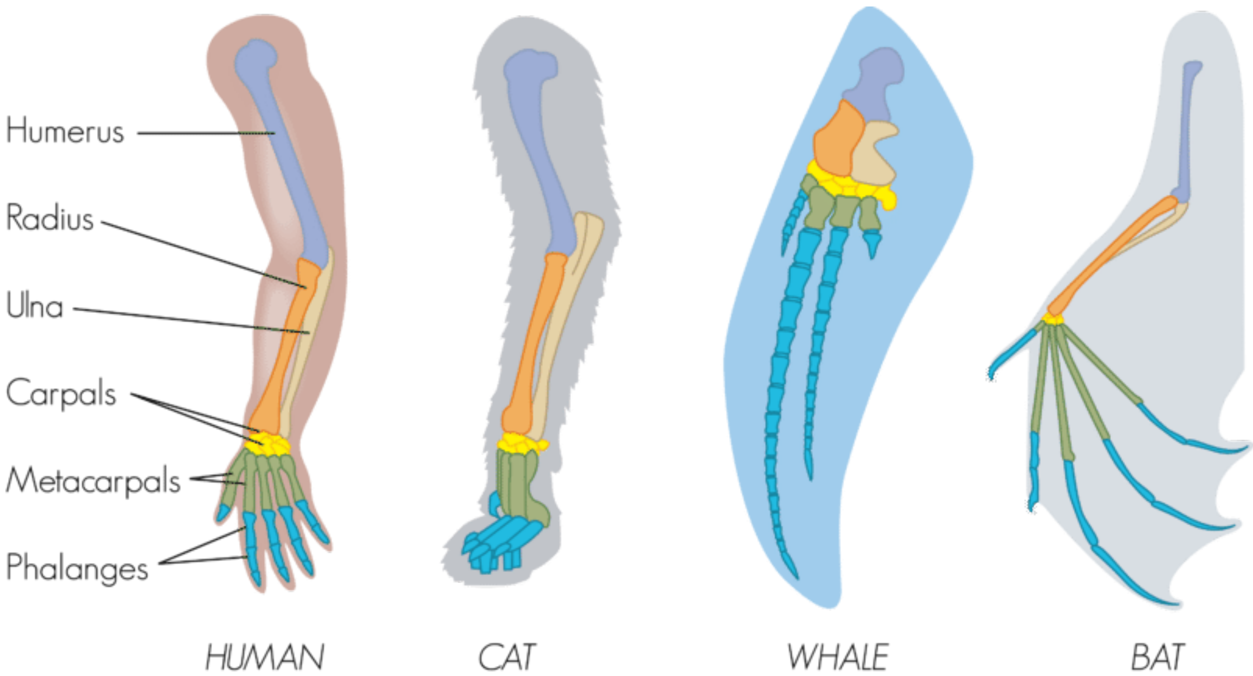
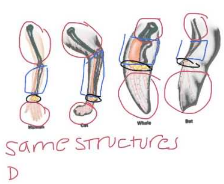


FIGURE 18.6
The forelimbs of all mammals have the same basic bone structure.



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Analogous structures are structures that are similar in unrelated organisms. The structures are similar because they evolved to do the same job, not because they were inherited from a common ancestor. For example, the wings of bats and birds, shown in **Figure** 18.7, look similar on the outside. They also have the same function. However, wings evolved independently in the two groups of animals. This is apparent when you compare the pattern of bones inside the wings.

Comparative Embryology

Comparative embryology is the study of the similarities and differences in the embryos of different species. Similarities in embryos are evidence of common ancestry. All vertebrate embryos, for example, have gill slits and tails. Most vertebrates, except for fish, lose their gill slits by adulthood. Some of them also lose their tail. In humans, the tail is reduced to the tail bone. Thus, similarities organisms share as embryos may be gone by adulthood.

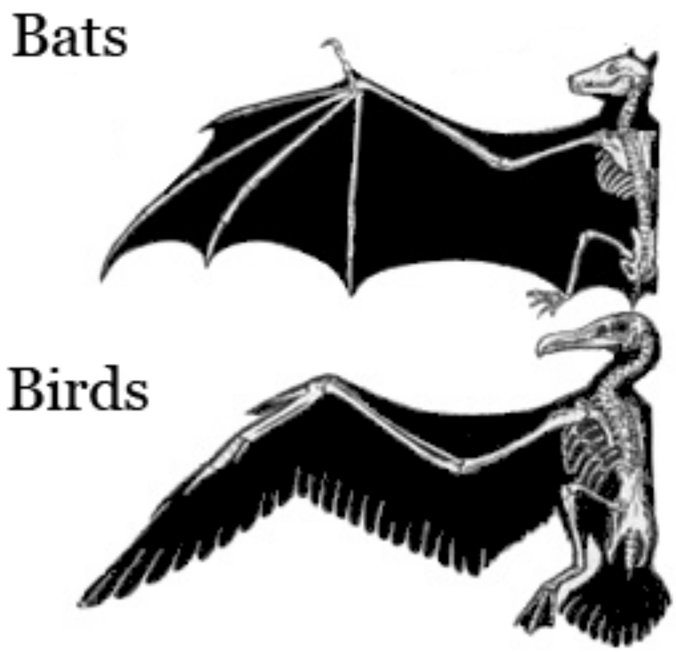
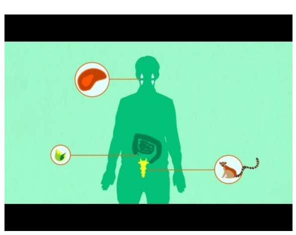


FIGURE 18.7
Wings of bats and birds serve the same function. Look closely at the bones inside the wings. The differences show they developed from different ancestors.

This is why it is valuable to compare organisms in the embryonic stage.

Vestigial Structures

Structures like the human tail bone and whale pelvis are called **vestigial structures**. Evolution has reduced their size because the structures are no longer used. The human appendix is another example of a vestigial structure. It is a tiny remnant of a once-larger organ. In a distant ancestor, it was needed to digest food. It serves no purpose in humans today. Why do you think structures that are no longer used shrink in size? Why might a full-sized, unused structure reduce an organism's fitness?



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Comparing DNA

Darwin could compare only the anatomy and embryos of living things. Today, scientists can compare their DNA. Similar DNA sequences are the strongest evidence for evolution from a common ancestor. More similarities in the

DNA sequence is evidence for a closer evolutionary relationship. Look at the cladogram in the **Figure** 18.8. It shows how humans and apes are related based on their DNA sequences.

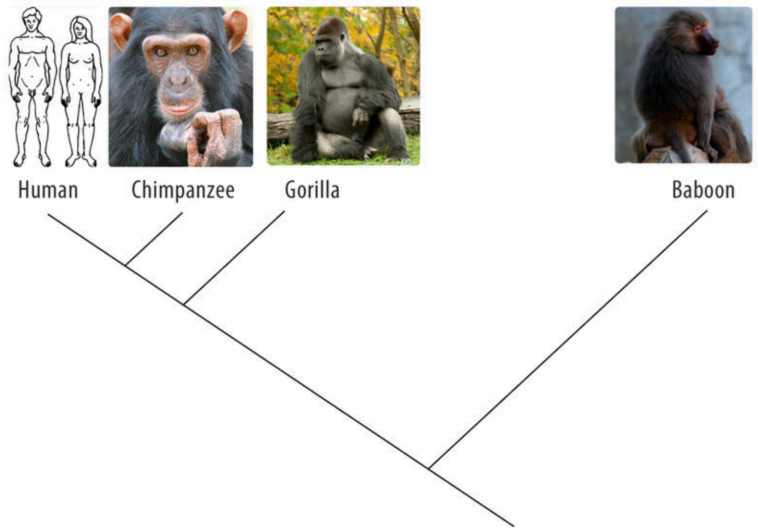

FIGURE 18.8
Cladogram of Humans and Apes. This cladogram is based on DNA comparisons. It shows how humans are related to apes by descent from common ancestors.

Summary

- Scientists compare the anatomy, embryos, and DNA of living things to understand how they evolved.
- Evidence for evolution is provided by homologous structures. These are structures shared by related organisms that were inherited from a common ancestor.
- Other evidence for evolution is provided by analogous structures. These are structures that unrelated organisms share because they evolved to do the same job.
- Comparing DNA sequences provided some of the strongest evidence of evolutionary relationships.

Review

1. What are vestigial structures? Give an example.
2. Compare homologous and analogous structures.
3. Why do vertebrate embryos show similarities between organisms that do not appear in the adults?
4. Humans and apes have five fingers they can use to grasp objects. Do you think these are analogous or homologous structures? Explain.
5. What is the strongest evidence of evolution from a common ancestor?

18.5 Biogeography

Learning Objectives

- Define biogeography.
- Describe how biogeography relates to evolutionary change.
- Discuss the work of Peter and Rosemary Grant.

Why would geography have anything to do with evolution?

Similar to "how did the chicken cross the road?" but on a much grander scale. How did the animal cross Europe and into Asia? Or Asia into America? How did anything get into Australia?

Evidence from Biogeography

Biogeography is the study of how and why plants and animals live where they do. It provides more evidence for evolution. Let's consider the camel family as an example.

Biogeography of Camels: An Example

Today, the camel family includes different types of camels. They are shown in **Figure** 18.9. All of today's camels are descended from the same camel ancestors. These ancestors lived in North America about a million years ago.

Early North American camels migrated to other places. Some went to East Asia. They crossed a land bridge during the last ice age. A few of them made it all the way to Africa. Others went to South America. They crossed the Isthmus of Panama. Once camels reached these different places, they evolved independently. They evolved adaptations that suited them for the particular environment where they lived. Through natural selection, descendants of the original camel ancestors evolved the diversity they have today.

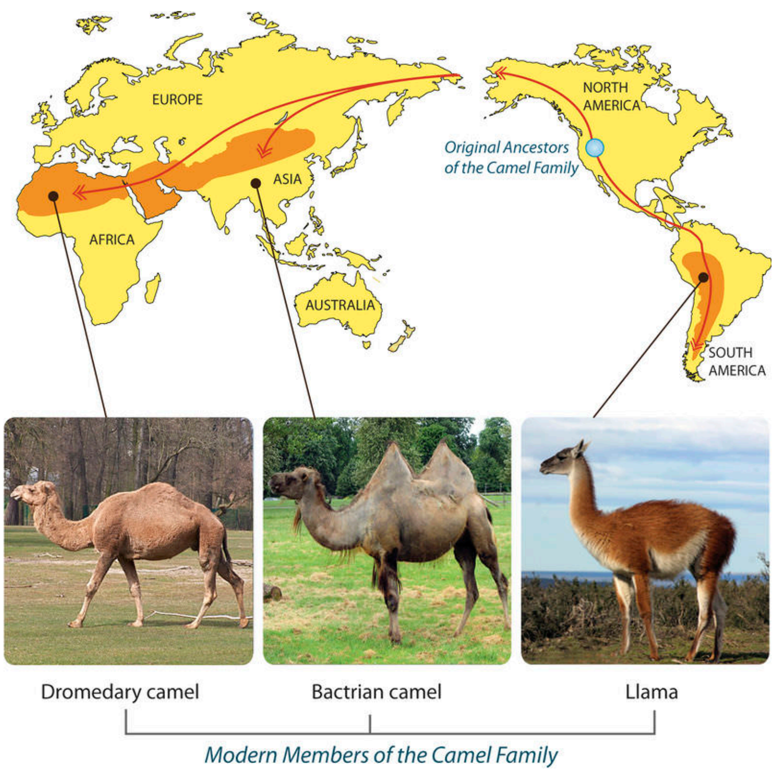

FIGURE 18.9

Camel Migrations and Present-Day Variation. Members of the camel family now live in different parts of the world. They differ from one another in a number of traits. However, they share basic similarities. This is because they all evolved from a common ancestor. What differences and similarities do you see?

Island Biogeography

The biogeography of islands yields some of the best evidence for evolution. Consider the birds called finches that Darwin studied on the Galápagos Islands (see **Figure** 18.10). All of the finches probably descended from one bird that arrived on the islands from South America. Until the first bird arrived, there had never been birds on the islands. The first bird was a seed eater. It evolved into many finch species. Each species was adapted for a different type of food. This is an example of **adaptive radiation**. This is the process by which a single species evolves into many new species to fill available niches.

Eyewitness to Evolution

In the 1970s, biologists Peter and Rosemary Grant went to the Galápagos Islands. They wanted to re-study Darwin's finches. They spent more than 30 years on the project. Their efforts paid off. They were able to observe evolution by natural selection actually taking place.

While the Grants were on the Galápagos, a drought occurred. As a result, fewer seeds were available for finches to eat. Birds with smaller beaks could crack open and eat only the smaller seeds. Birds with bigger beaks could crack and eat seeds of all sizes. As a result, many of the small-beaked birds died in the drought. Birds with bigger beaks survived and reproduced (see **Figure** 18.11). Within 2 years, the average beak size in the finch population increased. Evolution by natural selection had occurred.

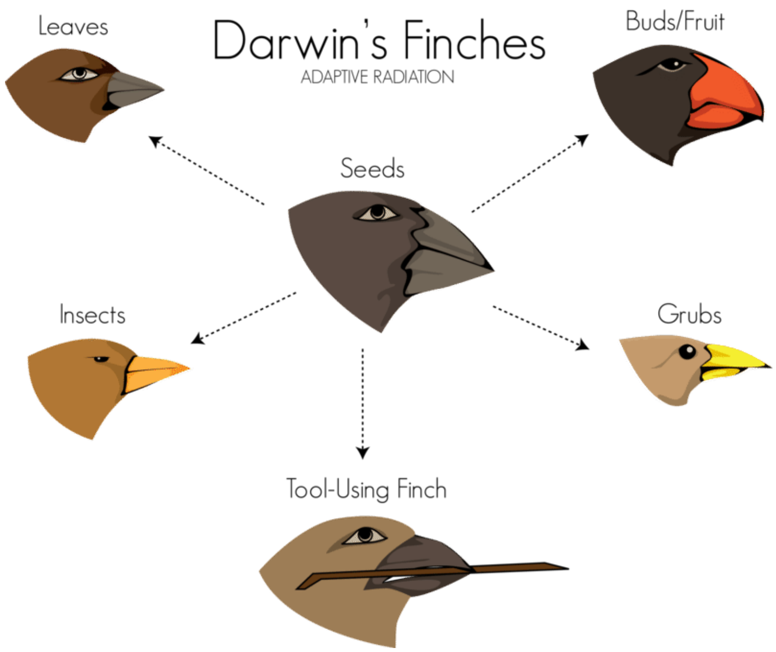

FIGURE 18.10
Galápagos finches differ in beak size and shape, depending on the type of food they eat.

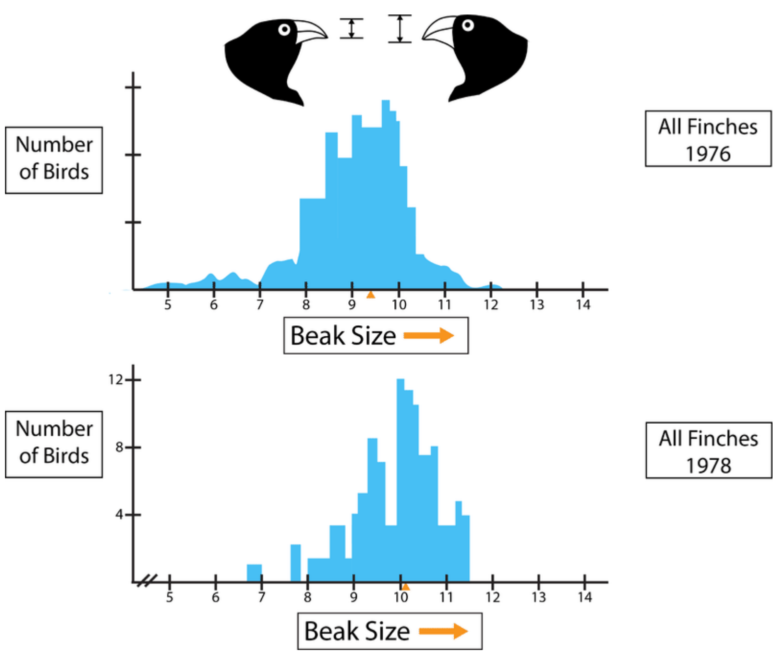

FIGURE 18.11
Evolution of Beak Size in Galápagos Finches. The top graph shows the beak sizes of the entire finch population studied by the Grants in 1976. The bottom graph shows the beak sizes of the survivors in 1978. In just 2 years, beak size increased.

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Summary

- Biogeography is the study of how and why plants and animals live where they do. It also provides evidence for evolution.
- On island chains, such as the Galápagos, one species may evolve into many new species to fill available niches. This is called adaptive radiation.

Review

1. Define biogeography.
2. Describe an example of island biogeography that provides evidence of evolution.
3. Describe the effects of the drought on the Galápagos Islands observed by the Grants.

18.6 Evolution Evidence

Learning Objectives

- Explain the evolutionary meaning of having a common ancestor.
- Discuss how vestigial structures and embryology support evolution theory.

Why do you have a tail bone?

If you look closely at a skeleton, you might notice a triangular bone at the end of the spinal column. This is your tailbone. Why would you have a tailbone when you don't have a tail? You have a tailbone because your ancient ancestors *did* have a tail. These sorts of "left-over" structures support the theory of evolution.

Structural Evidence

Even though two different species may not look similar, they may have similar internal structures that suggest they have a **common ancestor**. That means both evolved from the same ancestor organism a long time ago. Common ancestry can also be determined by looking at the structure of the organism as it first develops.

Vestigial Structures

Some of the most interesting kinds of evidence for evolution are body parts that have lost their use through evolution (**Figure** 18.12). For example, most birds need their wings to fly. But the wings of an ostrich have lost their original use. Structures that have lost their use through evolution are called **vestigial structures**. They provide evidence for evolution because they suggest that an organism changed from using the structure to not using the structure, or using it for a different purpose.

Penguins do not use their wings, known as flippers, to fly in the air. However, they do use them to move in the water. The theory of evolution suggests that penguins evolved to use their wings for a different purpose. A whale's pelvic bones, which were once attached to legs, are also vestigial structures. Whales are descended from land-dwelling ancestors that had legs.

Homologous structures are structures that have a common function and suggest common ancestry. For example, homologous structures include the limbs of mammals, such as bats, lions, whales, and humans, which all have a common ancestor. Different mammals may use their limbs for walking, running, swimming or flying. The method the mammal uses to move is considered a common function.

FIGURE 18.12
Moles live underground where they do not need eyes to find their way around. This mole's eyes are covered by skin. Body parts that do not serve their original function are vestigial structures.

Similar Embryos

Some of the oldest evidence of evolution comes from **embryology**, the study of how organisms develop. An embryo is an animal or plant in its earliest stages of development. This means looking at a plant or animal before it is born or hatched. Centuries ago, people recognized that the embryos of many different species have similar appearances.

The embryos of some species are even difficult to tell apart. Many of these animals do not differ much in appearance until they develop further.

Some unexpected traits can appear in animal embryos. For example, human embryos have gill slits just like fish! In fish they develop into gills, but in humans they disappear before birth. The presence of the gill slits suggests that a long time ago humans and fish shared a common ancestor.

The similarities between embryos suggests that these animals are related and have common ancestors. For example, humans did not evolve from chimpanzees. But the similarities between the embryos of both species suggest that we have an ancestor in common with chimpanzees. As our common ancestor evolved, humans and chimpanzees went down different evolutionary paths and developed different traits.

Summary

- Vestigial structures, or structures that have lost their use through evolution, are important evidence of evolution.
- Studying the embryos of organisms also provides evidence that two very different animals could have descended from a common ancestor.

Explore More

Use the resource below to answer the questions that follow.

- **Richard Dawkins Vestigial Organs The Wings of the Flightless Cormorant** at https://www.youtube.com/watch?v=3e5cs0PtuA4 .

1. Are all cormorants flightless?
2. What is the vestigial trait most obvious in the flightless cormorant?
3. How have these birds compensated for their inability to fly?

Review

1. What is a vestigial structure? Give an example.
2. How does embryology provide evidence for evolution?
3. Given an example of a structure that is present in human embryos, but has disappeared by birth.

18.7 Molecular Evidence

- Describe molecular clocks.
- Explain the molecular evidence for evolution.

How similar are you to a chimpanzee?

Chimpanzees and humans turn out to be very similar—if you look at their DNA. When scientists determined the entire genetic code of both humans and chimpanzees, they found that we have over 98% identical DNA.

Molecular Evidence

Arguably, some of the best evidence of evolution comes from examining the molecules and DNA found in all living things.

Beginning in the 1940s, scientists studying molecules and DNA have confirmed conclusions about evolution drawn from other forms of evidence. **Molecular clocks** are used to determine how closely two species are related by calculating the number of differences between the species' DNA sequences or amino acid sequences. These clocks are sometimes called gene clocks or evolutionary clocks. The fewer the differences, the less time since the species split from each other and began to evolve into different species (**Figure** 18.13).

A chicken and a gorilla will have more differences between their DNA and amino acid sequences than a gorilla and an orangutan. That means the chicken and gorilla had a common ancestor a very long time ago, while the gorilla and orangutan shared a more recent common ancestor. This provides additional evidence that the gorilla and orangutan are more closely related than the gorilla and the chicken. Which pair of organisms would have more molecular differences, a mammal and a bird, a mammal and a frog, or a mammal and a fish?

On the other hand, animals may look similar but can have very different DNA sequences and evolutionary ancestry. Which would have more DNA sequences in common, a whale and a horse, or a whale and a shark?

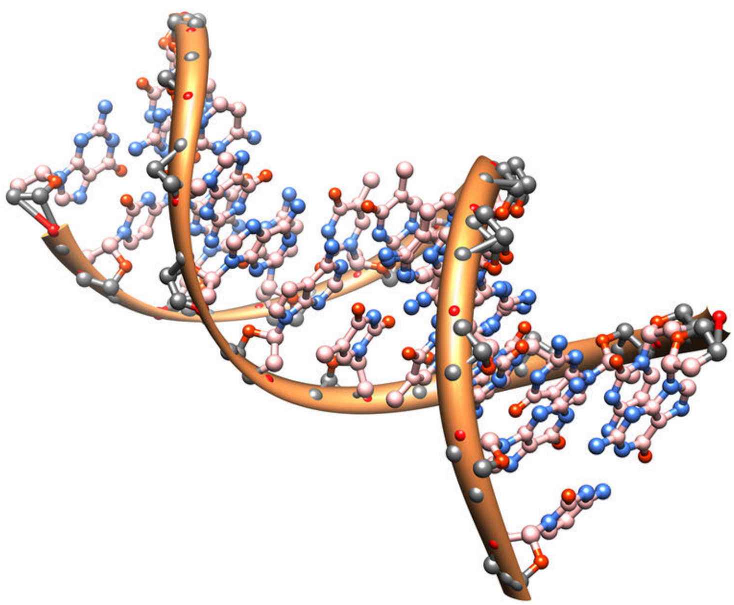


FIGURE 18.13
Almost all organisms are made from DNA with the same building blocks. The genomes (all of the genes in an organism) of all mammals are almost identical.

The **genomes**, or all the DNA sequences of all the genes of an organism, have been determined for many different organisms. The comparison of genomes provides new information about the relationships among species and how evolution occurs (**Figure** 18.14).

Molecular evidence for evolution also includes:

1. The same biochemical building blocks, such as amino acids and nucleotides, are found in all organisms, from bacteria to plants and animals. Recall that amino acids are the building blocks of proteins, and nucleotides are the building blocks of DNA and RNA.
2. DNA and RNA determine the development of all organisms.
3. The similarities and differences between the genomes confirm patterns of evolution.

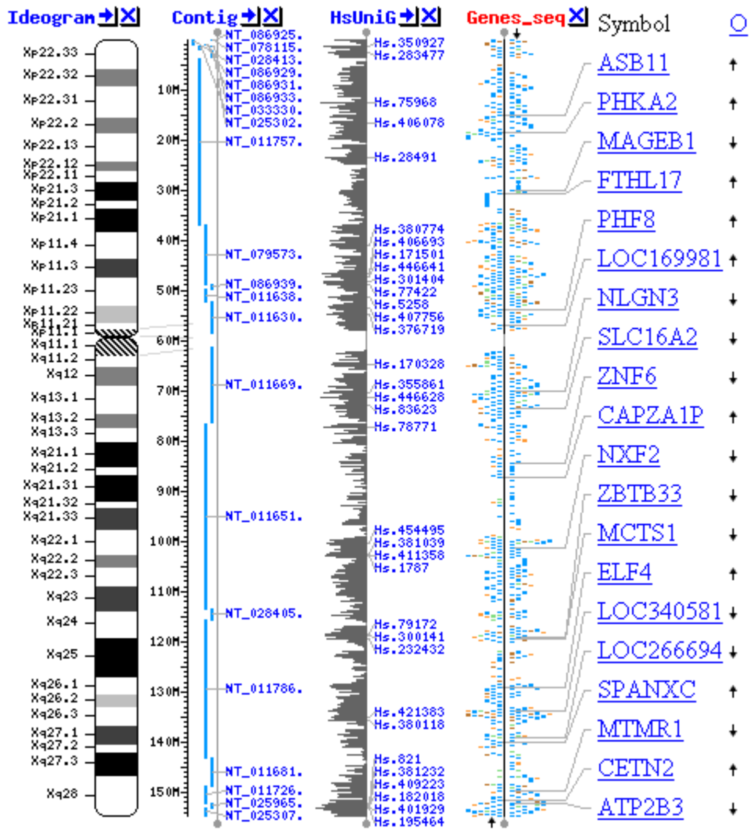


FIGURE 18.14

This is a map of the genes on just one of the 46 human chromosomes. How does this region of a chromosome compare to similar regions in other species? Similarities and differences between the genomes (the genetic makeup) of different organisms reveal the relationships between the species.

Summary

- Molecular clocks are used to determine how closely two species are related by calculating the number of differences between the species' DNA sequences or amino acid sequences.
- Molecular evidence for evolution includes that all living things share the same biochemical building blocks.

Explore More

Use the resources below to answer the questions that follow.

Explore More I

- **Genes Tell Us About Evolution - Shape of Life**

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/57488

1. How is the genetic sequence of an organism like a blueprint of that organism?
2. If two organisms have almost identical sequences for the same gene, are they considered closely related?
3. What type of animal have scientists long thought was basal to all other animals? How has genetic analysis affected this view?
4. How has genetic analysis become quicker than it once was? How has that greatly helped with the search for a basal organism?

Explore More II

- **How Genes Direct Development - Shape of Life**

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/57489

1. What is a regulatory gene? How might they explain differences between organisms?
2. What are "hox genes"? What phase of development are they a part of? What organisms have hox genes?
3. If you find a fly with a leg coming out of its head and can identify what happened genetically to cause this, what have you discovered?

Review

1. Explain how scientists use a molecular clock to determine relationships between species.
2. What is a genome?
3. What two species from the following should have the fewest differences in their genomes: chicken, mouse, duck, gorilla?
4. What two species from the following should have the most differences in their genomes: frog, mouse, cow, human?

18.8 Molecular Biology and Evolution - Advanced

Learning Objectives

- Discuss the molecular similarities found in all species of organisms.
- Describe how evolution explains the remarkable molecular similarities among diverse species.
- Analyze the relationship between Darwin's Theory of Evolution and more recent discoveries such as Mendel's work in genetics and the molecular biology of DNA and protein.

Your genes are over 95% identical to those of the great apes. What does this mean?

The closer genes from two species are to each other, the closer they are related evolutionarily. Molecular biology has played a significant role in determining these relationships.

Molecular Biology

Did you know that your genes may be 50% the same as those of a banana?

Unknown in Darwin's time, the "comparative anatomy" of the molecules which make up life has added an even more convincing set of homologies to the evidence for evolution. All living organisms have genes made of DNA. The order of nucleotides - As, Ts, Cs, and Gs - in each gene codes for a protein, which does the work or builds the structures of life. Proteins govern the traits chosen (or not) in natural selection. For all organisms, a single Genetic Code translates the sequence of nucleotides in a gene into a corresponding chain of 20 amino acids. By itself, the universality of DNA genes and their code for proteins is strong evidence for common ancestry. Yet there is still more.

If we compare the sequence of nucleotides in the DNA of one organism to the sequence in another, we see remarkable similarities. For example, human DNA sequences are 98-99% the same as those of chimpanzees, and 50% the same as a banana's! These similarities reflect similar metabolisms. All organisms have genes for DNA replication, protein synthesis, and processes such as cellular respiration. Although metabolic processes do not leave fossils, similar DNA sequences among existing organisms provide excellent evidence for common ancestry.

The differences in DNA sequences are even more intriguing. Many are single base substitutions resulting from mutations accumulated through time. Assuming mutations occur randomly, the number of differences in bases between any two species measures the time elapsed since two organisms shared a common ancestor. This type of **molecular clock** has confirmed traditional classification based on anatomy. Most scientists consider it sufficiently powerful to clarify or correct our understanding of evolutionary history. For example, human DNA differs 1.2% from chimpanzees, 1.6% from gorillas, and 6.6% from baboons; we can infer from this data that humans and chimpanzees share a relatively recent common ancestor, and that the common ancestor we share with gorillas lived much longer ago. **Figure** 18.15 shows a **cladogram** depicting hypothetical evolutionary relationships constructed with this data. Similarities and differences in the sequences of amino acids in proteins support common ancestry in the same way, because they are determined by DNA. See the *History of Life: Molecular Clocks (Advanced)* concept for additional information on molecular clocks.

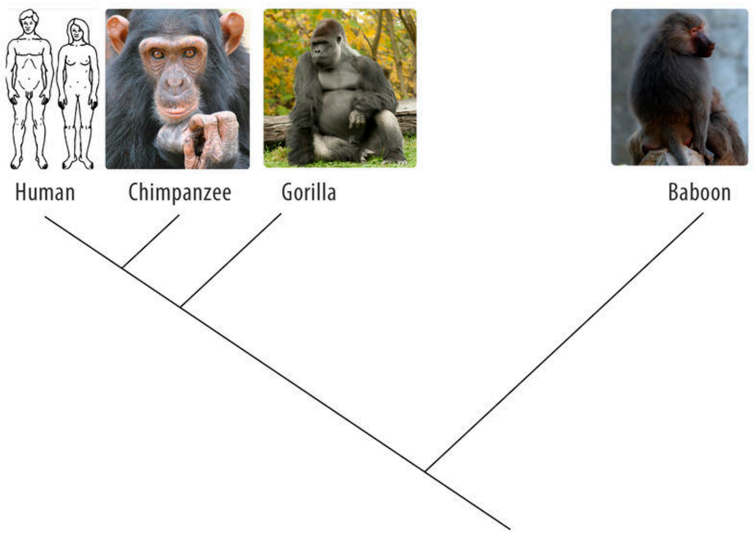


FIGURE 18.15

Cladograms use comparison data to construct diagrams showing evolutionary relationships. This cladogram uses comparisons of DNA sequences to reveal patterns of descent from common ancestors. Molecular biology has supported and extended our understanding of evolutionary relationships based on traditional anatomy.

Heritability and variation in traits are essential parts of Darwin's theory of evolution by natural selection. Since he published *On the Origin of Species,* the rediscovery of Mendel's identification of genes and how they are inherited has confirmed Darwin's ideas. Molecular biology has clarified the nature of genes and the sources of variation. Comparative analysis of DNA and proteins continues to give us an exquisitely detailed view of patterns of variation, common ancestry, and how evolution works.

The Reverse Evolution Machine

In search of the common ancestor of all mammals, the University of California, Santa Cruz's scientist David Haussler is pulling a complete reversal. He is trying to understand the DNA of extinct creatures and determine how that DNA changed over millions of years. Instead of studying fossils, he's comparing the genomes of living mammals to understand the DNA of our common ancestors, focusing on conserved regions among many or all mammalian species. His technique holds promise for providing a better picture of how life evolved.

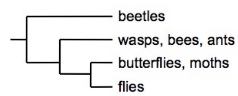
Summary

- The universality of DNA for genes, use of amino acids to build protein enzymes, and the Genetic Code are all strong pieces of evidence for common ancestry.
- Similarities in metabolic pathways such as DNA replication, transcription, and cellular respiration are further pieces of evidence for common ancestry.

- Within these similarities are differences in the sequence of As, Ts, Cs, and Gs due to the accumulation of mutations.
- Comparison of DNA sequences supports descent with modification and can be used to clarify evolutionary relationships.
- A Cladogram is a tree-like diagram showing evolutionary relationships which can be constructed from one or multiple kinds of comparison data; DNA sequence comparisons are often used.
- Darwin's Theory of Evolution is strongly supported and also helps to explain many more recent discoveries, such Mendel's work in genetics and the molecular biology of both DNA and proteins.

Review

1. List the molecular similarities found in all species of organisms, which support common ancestry.
2. Interpret the following cladogram in terms of evolutionary relationships and the DNA data which could have been used to construct it.



18.9 References

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CHAPTER 19 Evolution: Speciation

Chapter Outline

19.1 What is a Species? - Advanced

Learning Objectives

- Explain the concept of a species.
- Compare the biological species concept to morphological, genealogical, and ecological concepts.
- Analyze the reasons why biologists consider all humans to be members of the same species.

What is a Species?

Shown here are various species of the genus Musa, including the common banana. In fact, these are all "bananas." The phenotypic variations are due to genetic differences.

What is a Species?

Darwin avoided the use of the word evolution in his major work about evolution. The word "evolve" appears once, at the very end. He titled his work *The Origin of Species* - a process or group of processes now called **speciation.** What exactly is a species? How did the millions of species which exist on earth today arise? Will they (we!) continue to change? How quickly? These are questions Darwin sought to answer - and the questions we will explore in this lesson on evolution. Darwin's work opened the door to life's history. This lesson will look at both the details of and modifications to his ideas, which research has made clear in the 150 years since he published *The Origin*.

A toddler readily recognizes that she/he is surrounded by distinct groups of individuals which we call "kinds" of plants and animals. Biologists refer to kinds of living things as a **species** - groups of individual organisms which are very similar. If we look closely, however, variations make it quite difficult to decide where to draw the lines between species. For example, are a St. Bernard and a Chihuahua similar enough to group within the same species? Just how similar must two organisms be for biologists to decide they are members of the same species? The answer to this question is not clear, even to biologists who specialize in classification. We will explore several, because how we define a species can help to clarify how species develop.

The Biological Species Concept

A widely used definition of species is the **biological species concept** (**Figure** 19.1), first proposed by evolutionary biologist Ernst Mayr in 1942. Mayr's concept begins with the idea that members of a species must be *similar enough that they could interbreed*. Because all dogs - from a St. Bernard to a Chihuahua - are capable of interbreeding, biologists consider all dogs to be members of the same species. If you are familiar with mules, however, you know that this definition needs clarification. If horses and donkeys mate, they produce mules, but mules are sterile and cannot continue to interbreed. Therefore, the biological species concept becomes *organisms similar enough to interbreed and produce fertile offspring*. Horses and donkeys, therefore, are not members of the same species. As you may know, wolves and dogs can interbreed to produce viable hybrids with fertile offspring; surely, wolves and dogs are not members of the same species? The last part of the definition addresses this problem, and the complete definition becomes:

A **biological species** is a group of organisms similar enough that they could interbreed and produce fertile offspring under natural conditions.

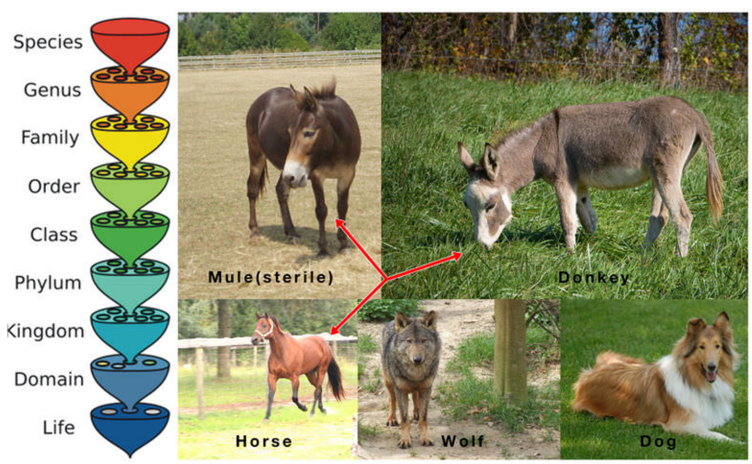

FIGURE 19.1
The species is the smallest group or level used to classify living things. As for all levels, the goal of classification is to show evolutionary relationships. A biological species is defined as a group of organisms similar enough to reproduce and have fertile offspring under natural conditions. A mating between a horse and a donkey produces a mule, but the mule is sterile, so the horse and donkey are not considered members of the same species. On the other hand, dogs and wolves can interbreed successfully, but because they do not do so in nature, they are not classified as members of the same species.

This definition serves the goal of defining members of a species as individuals which are still undergoing evolution - they form a distinct yet potentially common gene pool. You will learn much more about classification in the other concepts, but here it is important to realize that one of the primary goals of classification is to show evolutionary history - patterns of common ancestry. This makes the biological species - a functionally reproducing unit - an important foundation of classification. Closely related species descended from relatively recent common ancestors, and distantly related species descended from more distant common ancestors. The emphasis the biological species concept places on successful reproduction fits this goal of classification quite well.

Another advantage of the biological concept is that it has the potential to explain how speciation occurred - that is, how two closely related groups of organisms became different species through **reproductive isolation**. Members of two species may appear very similar, yet fail to interbreed because of **reproductive barriers**. Barriers to reproduction may either prevent mating, or prevent development of a fertilized egg after mating. Elaborate courtship behaviors, including the blinking pattern of fireflies or the songs of birds, are often required to elicit mating behavior - and limit mating to members of a species (**Figure** 19.2). Different breeding seasons, such as flowering dates, can also prevent interbreeding. Molecular differences between even closely related species may prevent sperm or pollen from actually fertilizing eggs. Once the eggs are fertilized, chromosomes may be so incompatible that mitosis and meiosis cannot proceed normally; if the zygote cannot develop, offspring do not survive. All of these barriers between species work to ensure successful reproduction within species, keeping specific, useful adaptations "in the family;" thus, they are a logical way for us to distinguish members of one species from members of another.

FIGURE 19.2

The Western Meadowlark (left) and the Eastern Meadowlark (right) appear morphologically identical. However, geography and songs serve as reproductive barriers to interbreeding, so the two are considered to be separate species.

Although the biological species concept is extremely helpful in evolutionary thinking it has serious limitations for practical use. For organisms that reproduce asexually - including all bacteria and viruses - the definition is entirely unworkable. Nor can we detect whether or not fossil organisms would have been able to interbreed - whether or not they coexisted. Biologists must rely on structure and (if available) biochemical similarities to classify fossils and most microorganisms.

The Morphological Species Concept

Alternatives to the biological species concept emphasize the characteristics and processes which unite, rather than divide (reproductive barriers), species. We will look at just a few in order to gain insight into evolutionary thought. A much more practical definition is the **morphological species concept**, which groups organisms based on structural and biochemical similarities. Recent advances in molecular biology, such as DNA comparison, have strengthened this means of clarifying evolutionary relationships. Biologists probably use this method more than any other to differentiate species in nature, despite its limitations in confirming the potential for interbreeding.

The Ecological Species Concept

The **ecological species concept** focuses on a group's common **ecological niche** - the set of environmental conditions and resources used or required by the group. This concept is based on the idea that ecological and evolutionary processes divide resources in such a way that *individuals can most efficiently adapt* to use those resources *as a group*. All members of a species, then, have a unique set of adaptations to a particular set of environmental conditions. Note that both the morphological and ecological definitions "work" for asexually reproducing organisms and many fossils. However, they do not help to explain *how* two closely related groups became different species, as the biological definition does.

The Evolutionary Species Concept

The last concept we will consider has the potential to clarify the path of speciation, or evolutionary history - that primary goal of classification. The **genealogical** or **evolutionary species concept** defines a species as a group of organisms with a unique genetic history - a group which shares common ancestry without divergence. A species, according to this concept, is a group which forms one tip on the branching tree of life's history. Modern technology which compares DNA and protein sequences makes this definition workable, but still, the mechanism of speciation is not defined.

Ideally, all of these ways of determining exactly which individuals make up a species would merge; all make valid points about the idea of a species, and all seek the common goal of defining a new, unique unit of life in space and time. Practically, however, each has its own usefulness for different purposes. If we were working in the field, we would undoubtedly use the morphological concept. However, as we explore the idea of speciation mentally and through lab models, we will adopt the biological species concept as our working definition.

Humans, One Species?

What about humans? Are we all members of the same species? According to the biological species concept, the answer is a resounding yes. Despite our differences in appearance, culture, and location on planet Earth, any human female is capable of producing fertile offspring with any human male. Therefore, all humans are members of the same biological species. In contrast, humans and chimpanzees do not interbreed even when they share the same territory, so biologists consider chimpanzees to be a distinct species. Before we leave the "species problem" and *Homo sapiens*, it is worth noting that *all* of the various definitions of species confirm the unity of the human species. DNA sequences, cell chemistry, anatomy, ecological resources, and reproductive ability all reveal similarities which unite us as a single species with common ancestry. In fact, the most recent and precise method of comparison - DNA sequences - shows that somewhere between 1 in 100 and 1 in 1,000 base pairs differ, on average, between one human and the next. Based on this analysis, we humans are 99.9% identical. The differences which seem so great to us (skin color, facial features, build, personality) are important for recognition of individuals, and a few may adapt us to particular regions of the Earth, but overall, we are vastly more similar to than different from each other; we are one species.

Although we may not learn exactly how we came to be a separate species, we can gain some insight by looking closely at what is known of the process of speciation. What do we know now - that Darwin did not know - about "the origin of species?"

Summary

- Ever since Darwin's publication of *The Origin of Species*, biologists have continued to work out the details of how species originate - the foundation of evolutionary process.
- A species is the smallest group of organisms into which biologists classify living things.
- A biological species is a group of organisms that can interbreed to produce fertile offspring under natural conditions. This is probably the most widely accepted definition of a species.
- A morphological species groups organisms based on extensive structural and biochemical similarities. This is probably the most practical definition for use in the field.
- A genealogical or evolutionary species includes organisms which share a recent, unique common ancestor. This is the goal of all classification; the only question is how to recognize members.
- An ecological species groups organisms together if they share a unique set of adaptations to a particular set of environmental conditions.
- Ideally, all four definitions would merge to recognize a true species.
- All humans are members of the same biological species because all races and cultures can and do intermarry and our DNA is 99.9% identical.

Review

1. Define the biological species concept and analyze its usefulness.
2. Compare the biological species concept to morphological, genealogical, and ecological concepts.
3. Analyze the reasons why biologists consider all humans to be members of the same species.

19.2 Origin of Species

Learning Objectives

- Define speciation.
- Compare and contrast allopatric and sympatric speciation.

How can a river influence evolution?

Imagine a group of small organisms, such as mice, that become separated by a mighty river. This group has now become isolated, and formed two separate groups. The groups are obviously no longer able to breed together. Over many generations, each group will evolve separately, eventually forming two completely new species of mice.

Origin of Species

Macroevolution is evolution over geologic time above the level of the species. One of the main topics in macroevolution is how new species arise. The process by which a new species evolves is called **speciation**. How does speciation occur? How does one species evolve into two or more new species?

To understand how a new species forms, it's important to review what a species is. A **species** is a group of organisms that can breed and produce fertile offspring together in nature. For a new species to arise, some members of a species must become reproductively isolated from the rest of the species. This means they can no longer interbreed with other members of the species. How does this happen? Usually they become geographically isolated first.

Allopatric Speciation

Assume that some members of a species become geographically separated from the rest of the species. If they remain separated long enough, they may evolve genetic differences. If the differences prevent them from interbreeding with members of the original species, they have evolved into a new species. Speciation that occurs in this way is called **allopatric speciation**. An example is described in the **Figure** 19.3.

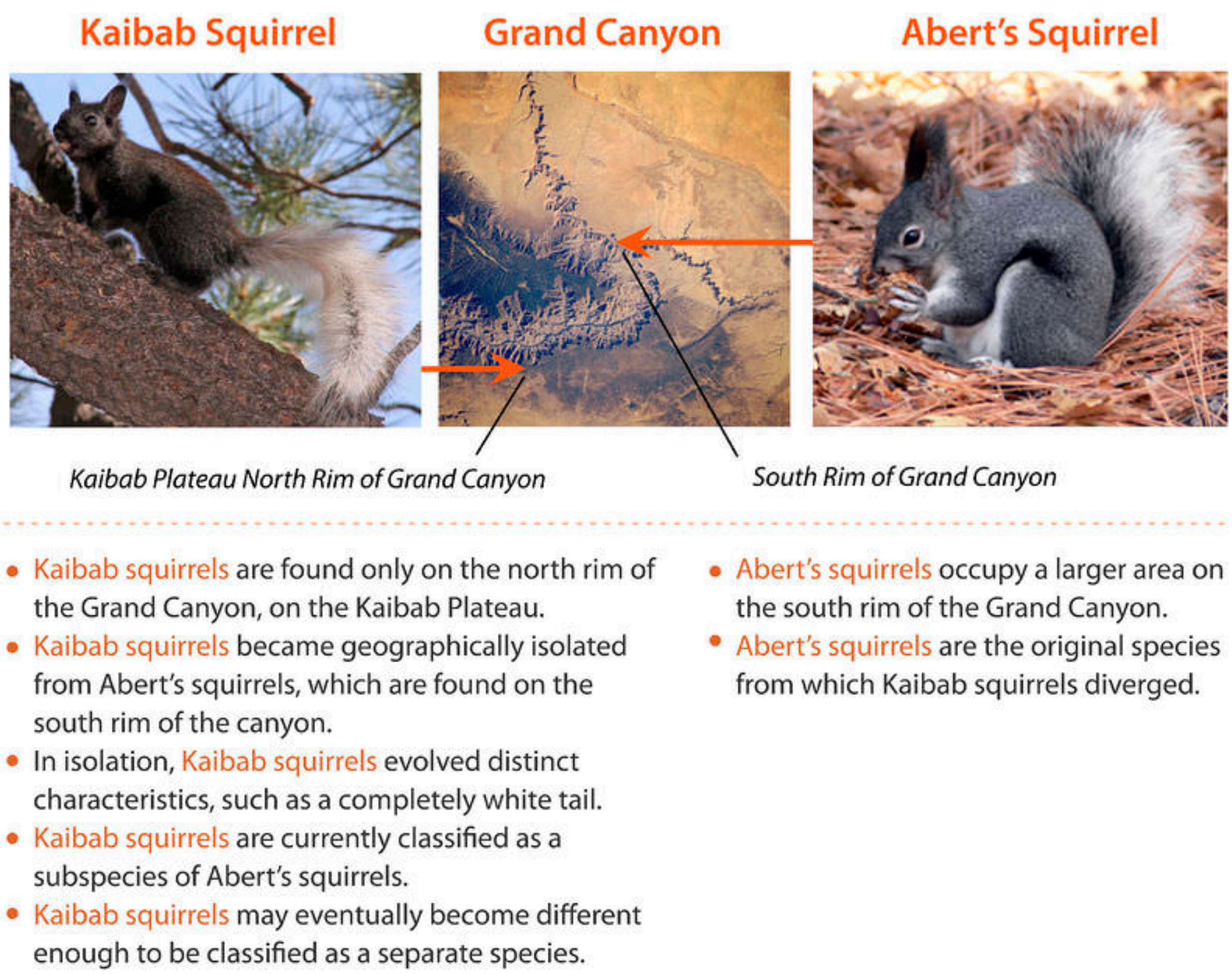

FIGURE 19.3
Allopatric Speciation in the Kaibab Squirrel. The Kaibab squirrel is in the process of becoming a new species.

Sympatric Speciation

Less often, a new species arises without geographic separation. This is called **sympatric speciation**. The following example shows one way this can occur.

1. Hawthorn flies lay eggs in hawthorn trees (see **Figure** 19.9). The eggs hatch into larvae that feed on hawthorn fruits. Both the flies and trees are native to the U.S.
2. Apple trees were introduced to the U.S. and often grow near hawthorn trees. Some hawthorn flies started to lay eggs in nearby apple trees. When the eggs hatched, the larvae fed on apples.
3. Over time, the two fly populations—those that fed on hawthorn trees and those that preferred apple trees—evolved reproductive isolation. Now they are reproductively isolated because they breed at different times. Their breeding season matches the season when the apple or hawthorn fruits mature.
4. Because they rarely interbreed, the two populations of flies are evolving other genetic differences. They appear to be in the process of becoming separate species.

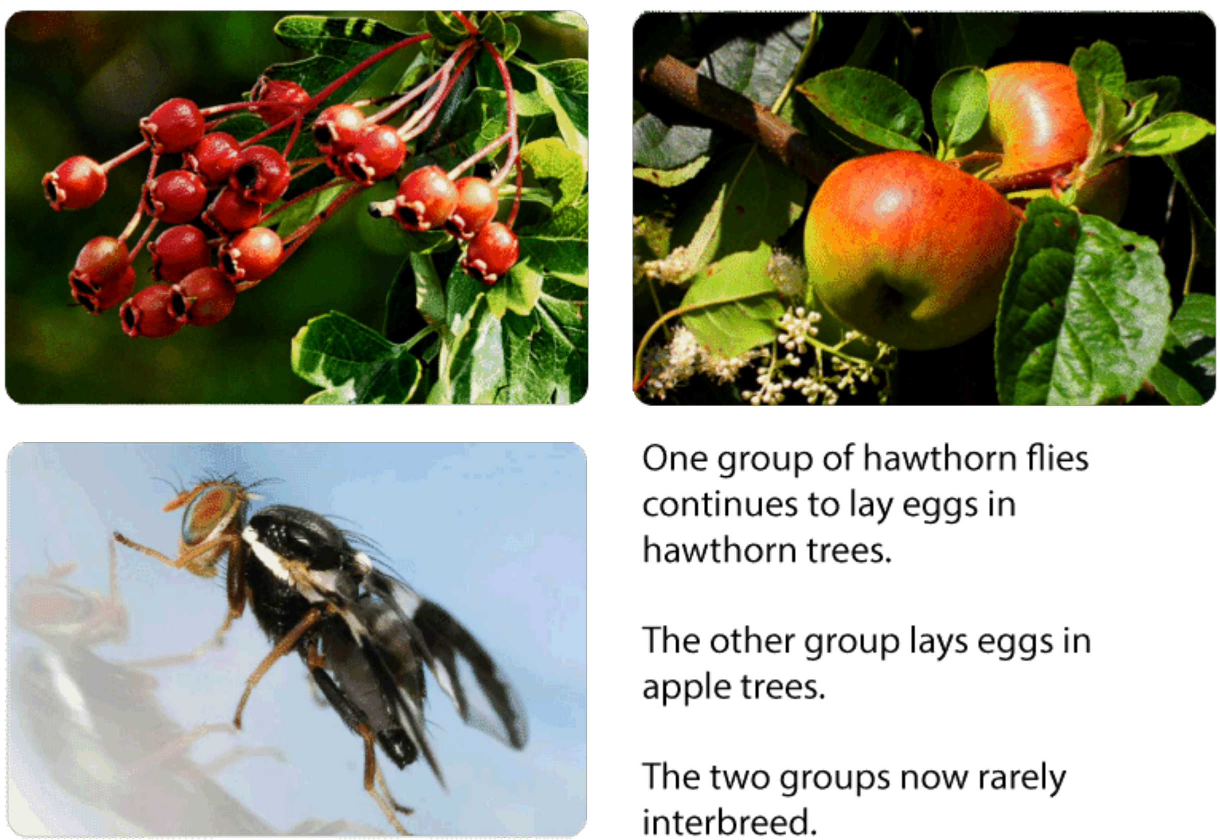

FIGURE 19.4
Sympatric Speciation in Hawthorn Flies. Hawthorn flies are diverging from one species into two. As this example shows, behaviors as well as physical traits may evolve and lead to speciation.

MEDIA

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Summary

- New species arise in the process of speciation.
- Allopatric speciation occurs when some members of a species become geographically separated. They then evolve genetic differences. If the differences prevent them from interbreeding with the original species, a new species has evolved.
- Sympatric speciation occurs without geographic separation.

Review

1. Define speciation.
2. Describe how allopatric speciation occurs.
3. Why is sympatric speciation less likely to occur than allopatric speciation?

19.3 Extinction and Radiation of Life

Learning Objectives

- Define extinction and explain why it occurs.
- Define adaptive radiation, and explain its relationship to extinction.

Should this pterodactyl be concerned? Should you?

When the dinosaurs were wiped out by an asteroid impact, the mammals were waiting to take over their niches. Could this happen again? Are there other ways species could go extinct and leave open niches for new organisms to fill?

Extinction

Most of the species that have lived have also gone extinct. There are two ways to go extinct: besides the obvious way of dying out completely, a species goes extinct if it evolves into a different species. Extinction is a normal part of Earth's history.

But sometimes large numbers of species go extinct in a short amount of time. This is a **mass extinction**. The causes of different mass extinctions are different: collisions with comets or asteroids, massive volcanic eruptions, or rapidly changing climate are all possible causes of some of these disasters (**Figure** 19.5).

FIGURE 19.5
An extinct *Tyrannosaurus rex*. This fossil resembles a living organism.

Adaptive Radiation

After a mass extinction, many habitats are no longer inhabited by organisms because they have gone extinct. With new habitats available, some species will adapt to the new environments. Evolutionary processes act rapidly during these times and many new species evolve to fill those available habitats. The process in which many new species evolve in a short period of time to fill available niches is called **adaptive radiation**. At the end of this period of rapid evolution the life forms do not look much like the ones that were around before the mass extinction. For example, after the extinction of the dinosaurs, mammals underwent adaptive radiation and became the dominant life form.

Summary

- Species go extinct when all of the individuals die out or evolve into a different species.
- Many species go extinct at roughly the same time during a mass extinction.
- New habitats become available and species evolve to fill them so that biodiversity increases during adaptive radiation.

Review

1. Why is extinction considered a normal part of Earth's history?
2. What are some of the possible causes of mass extinctions?
3. Why do many new species evolve after a mass extinction?

Explore More

Use this resource to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

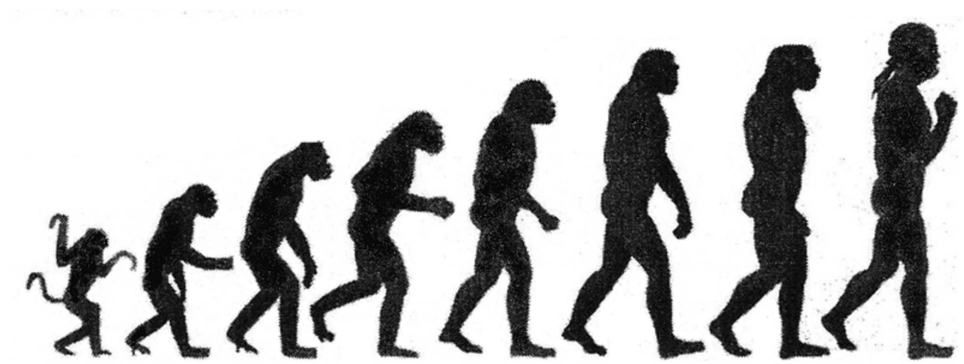
URL: http://www.ck12.org/flx/render/embeddedobject/178261

1. What does a branch on a phylogenetic tree indicate?
2. What two things could have happened when a species disappears?
3. What is necessary regarding ability to mate for one species to become two different species?
4. What two things might a changing environment force to happen? What do each of these to things do to biodiversity?
5. How did natural selection take place in three-spined stickelbacks at Loberg Lake in Alaska? How is this an example of speciation?
6. Under what conditions does adaptive radiation take place? How are honeycreepers in Hawaii an example?
7. How many species that ever existed are now extinct?
8. How many mass extinctions have been identified according to the teacher? What is a mass extinction?
9. What is the K-T (Cretaceous-Tertiary) boundary?
10. What is found at the K-T boundary? What could that mean?

19.4 Tracing Evolution

Learning Objectives

- Explain the rate of evolution.
- Describe an evolutionary tree.



Can you watch evolution happening?

Usually evolutionary changes occur at a very slow pace. Human evolution took millions of years. However, sometimes evolution can also happen quite quickly.

Tracing Evolution

How fast is evolution? Can you actually see evolution happening within your lifetime? Usually evolution takes a long time. So how can we visualize how it has happened?

Rates of Evolution

How long did it take for the giraffe to develop a long neck? How long did it take for the Galápagos finches to evolve? How long did it take for whales to evolve from land mammals? These, and other questions about the rate of evolution, are difficult to answer.

The **rate of evolution** depends on how many of an organism's genes have changed over a period of time. Evolution is usually so gradual that we do not see the change for many, many generations. The rate of evolution also depends on the generation time of a particular species.

Not all organisms evolve at the same rate. Humans took millions of years to evolve from a mammal that is now extinct. It is very difficult to observe evolution in humans. However, there are organisms that are evolving so fast that you can observe evolution! A human takes about 22 years to go through one generation. But some bacteria go through over a thousand generations in less than two months. Some bacteria go through many generations in a few days. And sometimes a bacterial generation is as fast as 20 minutes! We can actually trace their evolution as it is happening.

Evolutionary Trees

If evolution can take a very long time, how can we visualize how it happens? Charles Darwin came up with the idea of an **evolutionary tree** to represent the relationships between different species and their common ancestors (**Figure** 19.6). The base of the tree represents the ancient ancestors of all life. The separation into large branches shows where these original species evolved into new species.

The branches keep splitting into smaller and smaller branches as species continue to evolve into more and more species. Some species are represented by short twigs spurting out of the tree, then stopping. These are species that went extinct before evolving into new species. Other "Trees of Life" have been created by other scientists (**Figure** 19.6). If the evolutionary tree went back far enough to begin with the first living organism, what type of organism would that be? Animal, plant, fungi protist, or none of those?

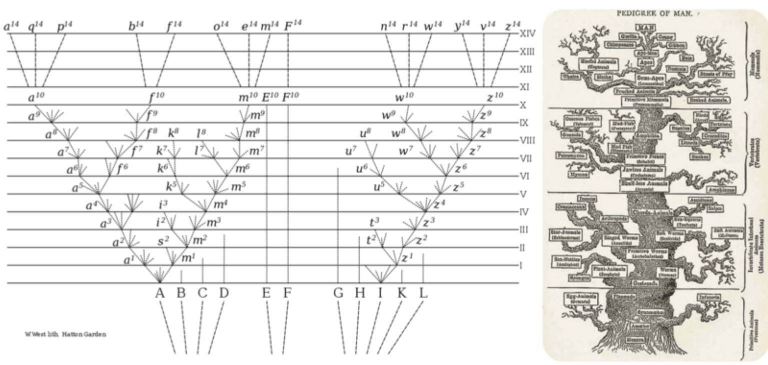


FIGURE 19.6

Darwin drew this version of the "Tree of Life" on the left to represent how species evolve and diverge into separate directions. Each point on the tree where one branch splits off from another represents the common ancestor of the species on the separate branches. Scientists have drawn many different versions of the "Tree of Life" to show different features of evolution. The Tree of Life on the right was made by Ernst Haeckel in 1879.

Summary

- Evolution is usually so gradual that we do not see the change for many, many generations.
- An evolutionary tree can be drawn to visualize the relationships between different species and their common ancestors.

Explore More

Use the resource below to answer the following questions.

- **Richard Dawkins: Why are there still Chimpanzees?** at http://www.youtube.com/watch?v=wh0F4FBLJRE (1:47)

1. Are we descended from chimpanzees? Explain your answer.
2. When reading an evolutionary tree, what does it mean if two species are very close on the tree?
3. What does it mean if two species are very far apart on a tree?
4. What five species comprise the Great Apes?

Review

1. How fast is evolution?

2. What is the purpose of an evolutionary tree?
3. Who came up with the idea for the evolutionary tree?

19.5 Isolating Mechanisms and Speciation - Advanced

Learning Objectives

- Distinguish allopatric from sympatric speciation.
- Describe two general types of reproductive isolation.
- Explain how polyploidy can result in sympatric speciation.
- Analyze the importance of environmental complexity to sympatric speciation for animals.

How did the mouse cross the river?

Chances are, with a river like this, it didn't. If a population of mice becomes divided into two as a river forms or some other geographic division occurs, will that population eventually become two distinct populations and two separate species?

Isolating Mechanisms

Biologists today divide isolating mechanisms into two major categories based on whether they happen in different locations (*allopatric* = "other fatherland") or a single location (*sympatric* = "same fatherland") (**Figure** 19.7).

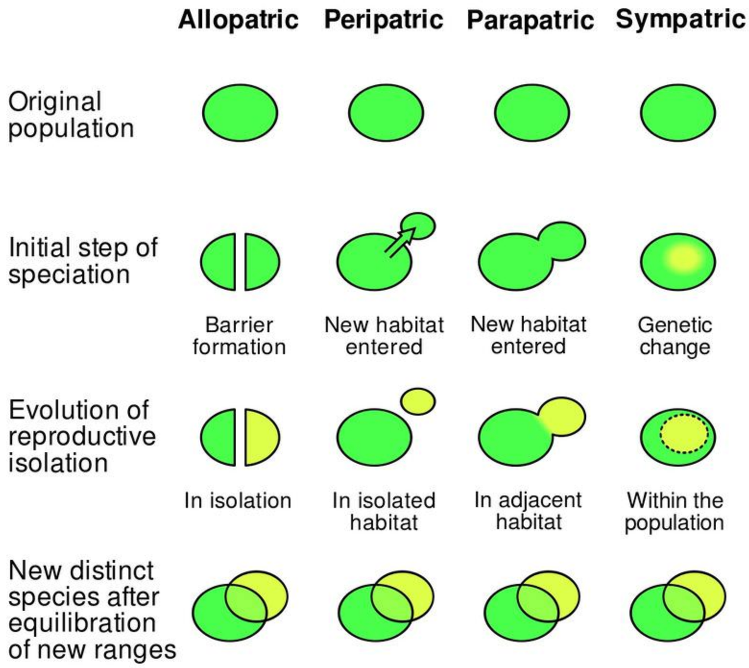


FIGURE 19.7

Two mechanisms of speciation are allopatric ("other fatherland") and sympatric ("together in the fatherland") forms. In both cases, a single population divides into two, and heritable differences eventually prevent gene flow between the two through reproductive isolation.

Allopatric Speciation

Allopatric speciation involves geographic barriers, which physically isolate populations. Formation of a land bridge such as the Isthmus of Panama, for example, could separate members of a marine population into two groups. Emergence of a mountain range could separate members of a lowland species. According to the fossil record, the rifting of continents divided populations of terrestrial animals and plants. In these cases, dramatic changes in landforms lead to geographic isolation; however, movements of animals and plants can also result in physical isolation. Single individuals or small groups of individuals may move away from a parent population to colonize a new area, and the new colony could be isolated from its parent population. Such movements are not always intentional; a storm apparently carried a small flock of finches from the coast of South America to the Galapagos Islands. In each case, geographic barriers (the land bridge, the ocean) isolate the two populations so that gene flow stops and genetic divergence can proceed. Natural selection may lead each population to adapt to its own unique environment, or genetic drift may lead to chance differences in gene pools. If genetic divergence results in reproductive incompatibility, the two populations have become two separate species.

Diane Dodd, working with a laboratory population of fruit flies (**Figure** 19.8), experimentally verified the idea that physical isolation can lead to reproductive isolation and speciation. Dodd split the population into two groups, and fed maltose to one group and starch to the other. She observed that each new environment selected for improved efficiency in digesting the available food molecule. After eight or more generations of isolation, the two populations were recombined. After isolation, "starch" flies preferred to mate with other "starch" flies, and "maltose" flies preferred "maltose" mates. Although the preferences were not absolute, they did demonstrate at least initial formation of a reproductive barrier.

Sympatric Speciation

Sympatric speciation involves the emergence of a new species within the geographic range of the parent population. In the absence of geographic isolation, reproductive barriers must arise in different ways in order for new species to form. Some biologists doubt the relative importance of sympatric speciation to evolutionary change, but several

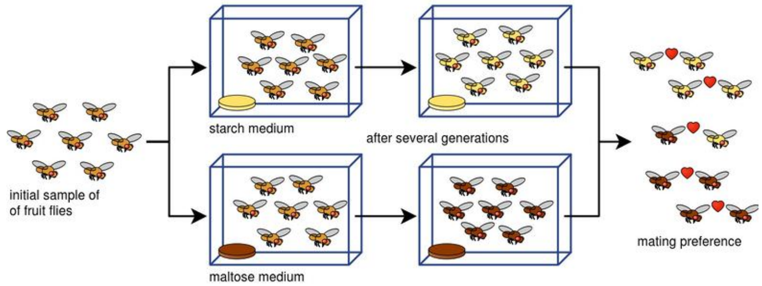


FIGURE 19.8
If a single population of fruit flies is divided and the two subpopulations are separated for at least eight generations and fed different foods, members of the subgroups prefer to mate with individuals from their own feeding group. Although this behavioral reproductive barrier was not complete, Diane Dodd's data supports the hypothesis that geographic isolation can lead to heritable reproductive isolation.

examples demonstrate the potential for this mechanism of evolution.

The following example shows one way sympatric speciation can occur:

1. Hawthorn flies lay eggs in hawthorn trees (see **Figure** 19.9). The eggs hatch into larvae that feed on hawthorn fruits. Both the flies and trees are native to the U.S.
2. Apple trees were introduced to the U.S. and often grow near hawthorn trees. Some hawthorn flies started to lay eggs in nearby apple trees. When the eggs hatched, the larvae fed on apples.
3. Over time, the two fly populations—those that fed on hawthorn trees and those that preferred apple trees—evolved reproductive isolation. Now they are reproductively isolated because they breed at different times. Their breeding season matches the season when the apple or hawthorn fruits mature.
4. Because they rarely interbreed, the two populations of flies are evolving other genetic differences. They appear to be in the process of becoming separate species.

Polyploidy

In plants, new species occasionally arise by duplication of chromosomes - a condition known as **polyploidy** (**Figure** 19.10). Recall that our human body cells are diploid and that egg and sperm cells are haploid. If meiosis fails to reduce the number of chromosomes, diploid sex cells result. In plants, which can self-pollinate, diploid pollen may fertilize a diploid egg, resulting in a tetraploid offspring. Although tetraploids may self-pollinate or interbreed with other tetraploids, they cannot successfully reproduce with their parents, because three sets of chromosomes (two from the tetraploid parent and one from the "normal" diploid parent) cannot successfully perform the intricate dance of meiosis. Peanuts, potatoes, and cotton are familiar crops that are tetraploid. Strawberries and sugarcane are octaploid (eight sets of chromosomes in each cell, compared to our two). Polyploidy is a common form of speciation in plants in nature, as well as in agriculture.

Two species of plants may *hybridize* - often forming unusually vigorous **hybrid** offspring. Unfortunately, despite their vigor, these offspring are often infertile due to chromosome incompatibility. However, if polyploidy occurs within the offspring, each of the previously unmatched chromosomes has a partner, offspring fertility is restored, and a new species is formed. Triticale (**Figure** 19.11), a hexaploid hybrid of wheat and rye, was produced in the laboratory in this manner. Combining the high yield and quality of wheat with the disease-resistance of rye, triticale is now a successful grain crop in Europe, China, and Australia.

Polyploidy is less common in animals, perhaps because they less frequently self-fertilize. Some salamanders are polyploid, but offspring are usually sterile and "species" reproduce by parthenogenesis (development from unfertilized eggs). Human and other mammalian livers often contain many polyploid cells.

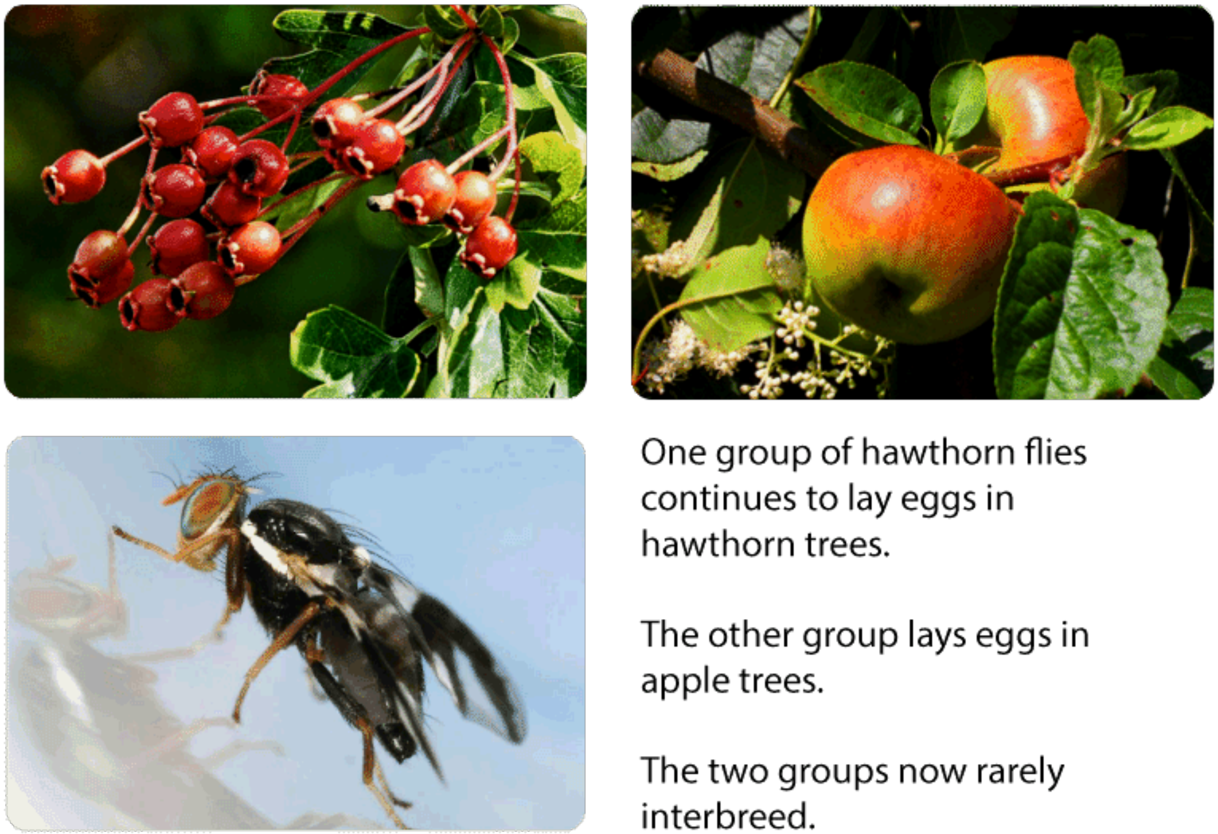


FIGURE 19.9
Sympatric Speciation in Hawthorn Flies. Hawthorn flies are diverging from one species into two. As this example shows, behaviors as well as physical traits may evolve and lead to speciation.

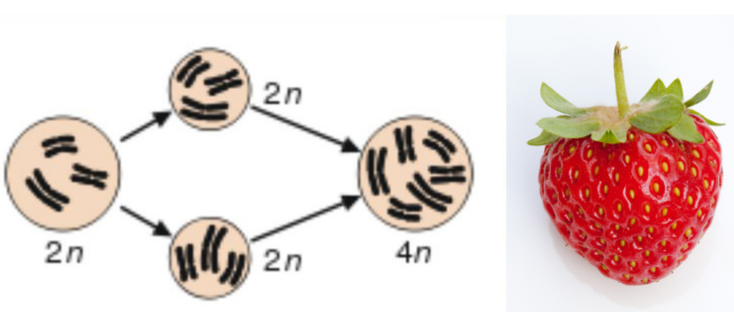


FIGURE 19.10
One way in which polyploidy can arise is for meiosis to produce diploid (2n), rather than haploid (1n) gametes by nondisjunction. Self-fertilization results in tetraploid (4n) offspring. Strawberries (right) probably experienced two episodes of polyploidy; they are octaploid!

Although polyploidy is rare among animals, other zoological modes of sympatric speciation exist. For example, environmental change within a population's range may lead to two habitats in which genetic divergence may take place. Our hypothetical rabbit example, discussed in the *Population Genetics* concepts, is an example of this type of sympatric speciation. A field example involves the hawthorn fly discussed above (**Figure** 19.12), whose larval maggot stage feeds on hawthorn fruit. Apple trees, introduced to the US, often grow near hawthorns, and some

FIGURE 19.11
Triticale (large photo, right) is a new crop species formed by hybridizing wheat (top left) and rye (middle left). Reproduction of offspring for the new species was not possible until after polyploidy. The "final" species is hexaploid.

hawthorn flies have begun to feed on apples. The two populations, although sympatric, have developed significant genetic differences and, at least in the wild, no longer tend to interbreed. This apparent reproductive isolation involves both temporal divergence (apples and hawthorns and their respective fly populations mature in slightly different seasons) and mating and egg-laying preferences (which link larval fruit to adult behavior). Many biologists consider these flies to be an example of sympatric speciation in progress. This environmental complexity has led to speciation as distinct groups of what was once the same population occupy different niches.

Cichlid fish in East Africa's Lake Victoria illustrate both allopatric and sympatric speciation (**Figure** 19.13). Less than a million years old, the Lake harbors nearly 200 closely related cichlid species. Biologists conclude that adaptive radiation by a small group of colonizers into available niches explains the diversity of feeding specializations among these closely related species, much like Darwin's finches in the Galapagos. Because the various habitats in the huge Lake (or islands in the oceans) isolate populations, adaptive radiation is often considered a type of allopatric speciation. However, nonrandom mating may have led to at least one more recent sympatric speciation. Females of two closely related species appear to select mates based on differing, brightly colored backs. Although the two color variations can still interbreed in the lab, they do not appear to do so in nature.

Summary

- Allopatric speciation involves geographic barriers, which physically isolate populations.
- Barriers to mating and barriers to development of zygotes can both cause reproductive isolation.
- Experiments with fruit flies support the possibility that geographic isolation can lead to reproductive isolation.
- Sympatric speciation involves the emergence of a new species within the geographic range of the parent population.
- In plants, polyploidy is a common sympatric form of "instant speciation."
- Hybridization and polyploidy have formed many vigorous crop species.
- In animals, environmental complexity may lead to sympatric speciation.
- Cichlid fish in Lake Victoria illustrate both adaptive radiation - a form of allopatric speciation - and more recent sympatric speciation due to heritable changes in mating preference.

FIGURE 19.12
The hawthorn fly (A) appears to be undergoing sympatric speciation. Traditionally, the species laid eggs on hawthorn (upper right), and the larvae (E) fed on the fruits. After the introduction of apples (lower right) to many of the same habitats, some hawthorn flies have begun laying eggs (B) on this species, and the maggots develop normally in the fruit. The two populations have diverged genetically and no longer interbreed in the wild.

FIGURE 19.13
Cichlids appear to have undergone tremendous adaptive radiation in the relatively new Lake Victoria, in Eastern Africa. Adaptive radiation is a form of allopatric speciation. At least one pair of closely related species may also show sympatric speciation.

Review

1. Distinguish allopatric from sympatric speciation.
2. Describe two examples of reproductive isolation.
3. Describe the use of hybridization and polyploidy to form new crop species.
4. Analyze the importance of environmental complexity to sympatric speciation for animals.

19.6 Human Causes of Extinction

Learning Objectives

- Describe the effects of global warming on habitats.
- Summarize associations between pollution and species extinction.
- Discuss issues associated with human overpopulation.

Why are these polar bears threatened?

These polar bears are threatened because of global warming. They depend on the sea ice for their hunting grounds, and this ice is melting away. Plus bears have to make a longer and more hazardous journey to get to the remaining ice.

Other Causes of Extinction

In addition to habitat destruction, other human-caused problems are also threatening many species. These include issues associated with climate change, pollution, and over-population.

Global Warming

Another major cause of extinction is **global warming**, which is also known as global climate change. During the past century, the Earth's average temperature has risen by almost 1°C (about 1.3°F). You may not think that is significant, but to organisms that live in the wild and are constantly adapting to their environments, any **climate** change can be hazardous. Recall that burning **fossil fuels** releases gasses into the atmosphere that warm the Earth. Our increased use of fossil fuels, such as coal and oil, is changing the Earth's climate. Any long-term change in the climate can destroy the habitat of a species. Even a brief change in climate may be too stressful for an organism to survive. For example, if the seas increase in temperature, even briefly, it may be too warm for certain types of fish to reproduce.

Pollution

Pollution adds chemicals, noise, heat, or even light to an environment. This can have many different harmful effects on all kinds of organisms. For example, the pesticide DDT nearly eliminated the peregrine falcon in some parts of the world. This pesticide caused falcons to lay eggs with thinner shells. As a result, fewer falcon eggs survived to hatching. Populations of peregrine falcons declined rapidly. DDT was then banned in the U.S. and peregrine falcon populations have recovered.

Water pollution threatens vital freshwater and marine resources throughout the world (**Figure** 19.14). Specifically, industrial and agricultural chemicals, waste, and **acid rain** threaten water. As water is essential for all ecosystems, water pollution can result in the extinction of species.

FIGURE 19.14

A bird that was the victim of an oil spill. About 58,000 gallons of oil spilled from a South Korea-bound container ship when it struck a tower supporting the San Francisco-Oakland Bay Bridge in dense fog in November, 2007.

Finally, soil contamination can also result in extinction. Soil contamination can come from toxic industrial and municipal wastes (**Figure** 19.15), salts from irrigation, and pesticides from agriculture. These all degrade the soil as well. As soil is the foundation of terrestrial ecosystems, this can result in extinction.

Human Overpopulation

Human populations are on the rise. The human population passed the 7 billion mark in October of 2011, and will pass 8 and 9 billion probably before the middle of the century. All these people will need resources such as places to live, food to eat, and water to drink, and they will use energy and create waste. Essentially, human population growth can effect all other causes of extinction. For example, more people on the Earth means more people contributing to global warming and pollution. More people also means more clearing of land for agriculture and development. Recall that development by humans often causes habitats to be destroyed. This destruction can force species to go extinct, or move somewhere else.

FIGURE 19.15
Soil contamination caused by petrochemical products.

Science Friday: Can Underwater Parks Protect Coral?

Coral communities are incredibly important for marine life. In this video by Science Friday, Marine scientists John Bruno and Elizabeth Selig describe the effects of local Marine Protection Areas on preserving coral.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/194517

Summary

- Global climate change is a major cause of extinctions.
- Pollution of chemicals, noise, heat, or even light to an environment can be harmful to organisms.

Explore More

Use the resource below to answer the questions that follow.

- **Causes of Extinction** at http://www.eoearth.org/view/article/150962/

1. What is the primary cause of human-induced extinctions?
2. What is considered the greatest contributor to the extinction of many species?
3. What was the effect effect of the introduction of mammalian predators to New Zealand?

Review

1. Define global warming. Why is global warming an issue to organisms?

2. How could the high human population growth rate drive further extinctions of plants and animals?
3. Give an example of how pollution can threaten organisms.

19.7 References

1. John and Karen Hollingsworth; National Park Service;Alan Eng. http://commons.wikimedia.org/wiki/Image:Sturnella_neglecta2.jpg http://en.wikipedia.org/wiki/Image:EasternMeadowlark23.jpg;https://sk.wikipedia.org/wiki/S%C3%BAbor:Okapi_and_son.jpg . Public Domain
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3. John and Karen Hollingsworth; National Park Service. http://commons.wikimedia.org/wiki/Image:Sturnella_neglecta2.jpg http://en.wikipedia.org/wiki/Image:EasternMeadowlark23.jpg . Public Domain
4. Hawthorn berries: Brian Clift; Apples: Jennifer C.; Hawthorn fly: Joseph Berger; Composite created by CK-12 Foundation. Hawthorn berries: http://www.flickr.com/photos/brianac37/6052521522/; Apples: http://www.flickr.com/photos/29638108@N06/7714246618/; Hawthorn fly: http://www.invasive.org/browse/detail.cfm?imgnum=5402798 . Hawthorn berries and apples: CC BY 2.0; Hawthorn fly: CC BY 3.0;Public Domain
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12. User:Fastfission/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Drosophila_speciation_experiment.svg . Public Domain
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14. =Ilmari Karonen; Flickr: jfh686. http://commons.wikimedia.org/wiki/File:Polyploidization.svg; http://www.flickr.com/photos/jfh686/3613641379/ . Public Domain; CC BY 2.0
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16. United States Government; Hawthorn: David Wright; Apples: liz west. http://commons.wikimedia.org/wiki/File:Rhagoletis_pomonella.png; Hawthorn: http://www.flickr.com/photos/dhwright/6359595339; Apples: http://www.flickr.com/photos/calliope/752015/ . Public Domain; Hawthorn and Apples: CC BY 2.0
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