CK-12 FlexBook

Animal Behavior

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Printed: June 6, 2013

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Contents

CHAPTER 1 Innate Behavior of Animals

- Explain and give examples of innate behavior.

How do kittens know how to "hunt"?

This kitten was probably adopted and separated from its mother at a young age. It never got a lesson in how to stalk and pounce on prey. So how does this kitten know how to attack the ball of yarn? Some behavior does not need to be learned.

Innate Behavior

Many animal behaviors are ways that animals act, naturally. They don't have to learn how to behave in these ways. Cats are natural-born hunters. They don't need to learn how to hunt. Spiders spin their complex webs without learning how to do it from other spiders. Birds and wasps know how to build nests without being taught. These behaviors are called innate.

An **innate behavior** is any behavior that occurs naturally in all animals of a given species. An innate behavior is also called an **instinct**. The first time an animal performs an innate behavior, the animal does it well. The animal does not have to practice the behavior in order to get it right or become better at it. Innate behaviors are also predictable. All members of a species perform an innate behavior in the same way. From the examples described above, you can probably tell that innate behaviors usually involve important actions, like eating and caring for the young.

There are many other examples of innate behaviors. For example, did you know that honeybees dance? The honeybee pictured below has found a source of food (**Figure** 1.1). When the bee returns to its hive, it will do a dance. This dance is called the **waggle dance**. The way the bee moves during its dance tells other bees in the hive where to find the food. Honeybees can do the waggle dance without learning it from other bees, so it is an innate behavior.

Besides building nests, birds have other innate behaviors. One example occurs in gulls, which are pictured below (**Figure** 1.2); one of the chicks is pecking at a red spot on the mother's beak. This innate behavior causes the mother to feed the chick. In many other species of birds, the chicks open their mouths wide whenever the mother returns to the nest (**Figure** 1.2). This innate behavior, called **gaping**, causes the mother to feed them.

FIGURE 1.1
When this honeybee goes back to its hive, it will do a dance to tell the other bees in the hive where it found food.

FIGURE 1.2
Left: This mother gull will feed her chick after it pecks at a red spot on her beak. Both pecking and feeding behaviors are innate. Right: When these baby birds open their mouths wide, the mother instinctively feeds them. This innate behavior is called gaping.

Another example of innate behavior in birds is egg rolling. It happens in some species of water birds, like the graylag goose (**Figure** 1.3). Graylag geese make nests on the ground. If an egg rolls out of the nest, a mother goose uses her bill to push it back into the nest. Returning the egg to the nest helps ensure that the egg will hatch.

Innate Behavior in Human Beings

All animals have innate behaviors, even human beings. Can you think of human behaviors that do not have to be learned? Chances are, you will have a hard time thinking of any. The only truly innate behaviors in humans are called **reflex behaviors**. They occur mainly in babies. Like innate behaviors in other animals, reflex behaviors in human babies may help them survive.

An example of a reflex behavior in babies is the sucking reflex. Newborns instinctively suck on a nipple that is placed in their mouth. It is easy to see how this behavior evolved. It increases the chances of a baby feeding and surviving. Another example of a reflex behavior in babies is the grasp reflex (**Figure** 1.4). Babies instinctively grasp an object placed in the palm of their hand. Their grip may be surprisingly strong. How do you think this behavior might increase a baby's chances of surviving?

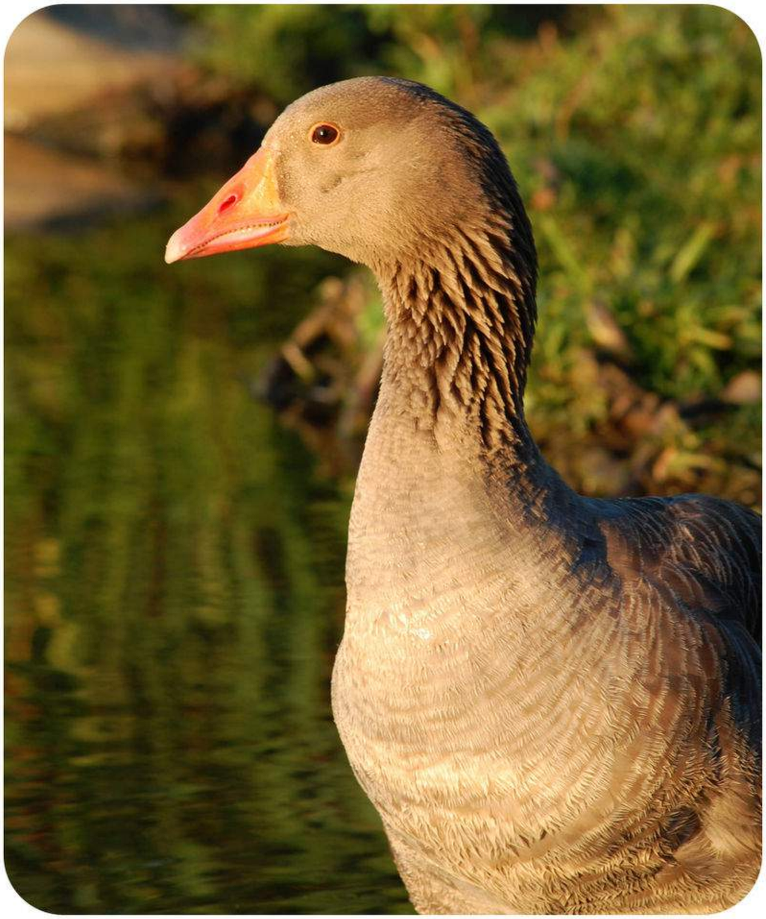

FIGURE 1.3
This female graylag goose is a ground-nesting water bird. Before her chicks hatch, the mother protects the eggs. She will use her bill to push eggs back into the nest if they roll out. This is an example of an innate behavior. How could this behavior increase the mother goose's fitness?

Vocabulary

- **gaping**: Wide opening of a baby bird's mouth in expectation of feeding.
- **innate behavior**: Any behavior that occurs naturally in all animals of a given species.
- **instinct**: Ability of an animal to perform a behavior the first time it is exposed to the proper stimulus.
- **reflex behaviors**: Any behavior that occurs without conscious thought as a response to a stimulus.
- **waggle dance**: Way a honeybee moves to tell other bees in the hive where to find the food.

Summary

- Innate behavior, or instinct, is any behavior that occurs naturally in all animals of a given species.
- Examples of innate behavior include honeybees doing the waggle dance or spiders spinning a web.

Practice

Use the resources below to answer the questions that follow.

- **Molluscs: Moon Snail Preys On Cockles** at http://vimeo.com/37449634 (2:05)

FIGURE 1.4
One of the few innate behaviors in human beings is the grasp reflex. It occurs only in babies.

MEDIA
Click image to the left for more content.

1. What sort of behavior is the moon snail exhibiting?
2. Do you think the moon snail this is learned or innate behavior? Explain and defend your answer.
3. What sort of behavior is the cockle exhibiting?
4. Do you think this is learned or innate behavior? Explain and defend your answer.

- **Spider Crabs vs. Stingray** at http://www.youtube.com/watch?v=evd6NTD1wf4 (4:19)

MEDIA

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1. How many different types of behavior can you see in the crabs in this video? List these different behaviors.
2. Which behaviors of the crabs do you think are innate and which are learned? Explain your answers fully and be specific.
3. How many different types of behavior can you see in the stingray? List these behaviors.
4. Which behaviors of the stingray do you feel are innate and which are learned? Explain your answer fully and be specific.

Review

1. What are some examples of reflex behaviors in humans?
2. What are some examples of innate behavior?

References

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2. Gulls: Brian.gratwicke (Wikimedia); Baby birds: Image copyright Boris Bort, 2010. . Gulls: CC-BY 2.5; Baby birds: Used under license from Shutterstock.com
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CHAPTER 2 Learned Behavior of Animals

- Describe the ways in which behavior can be learned.

Do you play a sport?

If you play a sport like soccer, then you realize it takes a lot of work. Remember how you didn't know at all what you were doing when you first started? You had rules to figure out and skills to practice. Playing a sport is an example of a learned behavior.

Learned Behavior

Just about all human behaviors are learned. **Learned behavior** is behavior that occurs only after experience or practice. Learned behavior has an advantage over **innate behavior**: it is more flexible. Learned behavior can be changed if conditions change. For example, you probably know the route from your house to your school. Assume that you moved to a new house in a different place, so you had to take a different route to school. What if following the old route was an innate behavior? You would not be able to adapt. Fortunately, it is a learned behavior. You can learn the new route just as you learned the old one.

Although most animals can learn, animals with greater intelligence are better at learning and have more learned behaviors. Humans are the most intelligent animals. They depend on learned behaviors more than any other species.

Other highly intelligent species include apes, our closest relatives in the animal kingdom. They include chimpanzees and gorillas. Both are also very good at learning behaviors.

You may have heard of a gorilla named Koko. The psychologist, Dr. Francine Patterson, raised Koko. Dr. Patterson wanted to find out if gorillas could learn human language. Starting when Koko was just one year old, Dr. Patterson taught her to use sign language. Koko learned to use and understand more than 1,000 signs. Koko showed how much gorillas can learn. See *A Conversation with Koko* at http://www.pbs.org/wnet/nature/koko.

Think about some of the behaviors you have learned. They might include riding a bicycle, using a computer, and playing a musical instrument or sport. You probably did not learn all of these behaviors in the same way. Perhaps you learned some behaviors on your own, just by practicing. Other behaviors you may have learned from other people. Humans and other animals can learn behaviors in several different ways.

The following methods of learning will be explored below:

1. Habituation (forming a habit)
2. Observational learning
3. Conditioning
4. Play
5. Insight learning

Habituation

Habituation is learning to get used to something after being exposed to it for a while. Habituation usually involves getting used to something that is annoying or frightening, but not dangerous. Habituation is one of the simplest ways of learning. It occurs in just about every species of animal.

You have probably learned through habituation many times. For example, maybe you were reading a book when someone turned on a television in the same room. At first, the sound of the television may have been annoying. After a while, you may no longer have noticed it. If so, you had become habituated to the sound.

Another example of habituation is shown below (**Figure** 2.1). Crows and most other birds are usually afraid of people. They avoid coming close to people, or they fly away when people come near them. The crows landing on this scarecrow have become used to a "human" in this place. They have learned that the scarecrow poses no danger. They are no longer afraid to come close. They have become habituated to the scarecrow.

Can you see why habituation is useful? It lets animals ignore things that will not harm them. Without habituation, animals might waste time and energy trying to escape from things that are not really dangerous.

Observational Learning

Observational learning is learning by watching and copying the behavior of someone else. Human children learn many behaviors this way. When you were a young child, you may have learned how to tie your shoes by watching your dad tie his shoes. More recently, you may have learned how to dance by watching a pop star dancing on TV. Most likely, you have learned how to do math problems by watching your teachers do problems on the board at school. Can you think of other behaviors you have learned by watching and copying other people?

Other animals also learn through observational learning. For example, young wolves learn to be better hunters by watching and copying the skills of older wolves in their pack. Another example of observational learning is how some monkeys have learned to wash their food. They learned by watching and copying the behavior of other monkeys.

FIGURE 2.1
This scarecrow is no longer scary to these crows. They have become used to its being in this spot and learned that it is not dangerous. This is an example of habituation.

Conditioning

Conditioning is a way of learning that involves a reward or punishment. Did you ever train a dog to fetch a ball or stick by rewarding it with treats? If you did, you were using conditioning. Another example of conditioning is shown below (**Figure** 2.2); the lab rat has been taught to "play basketball" by being rewarded with food pellets. Conditioning also occurs in wild animals. For example, bees learn to find nectar in certain types of flowers because they have found nectar in those flowers before.

Humans learn behaviors through conditioning, as well. A young child might learn to put away his toys by being rewarded with a bedtime story. An older child might learn to study for tests in school by being rewarded with better grades. Can you think of behaviors you have learned by being rewarded for them?

Conditioning does not always involve a reward. It can involve a punishment, instead. A toddler might be punished with a time-out each time he grabs a toy from his baby brother. After several time-outs, he may learn to stop taking his brother's toys.

A dog might be scolded each time she jumps up on the sofa. After repeated scolding, she may learn to stay off the sofa. A bird might become ill after eating a poisonous insect. The bird may learn from this "punishment" to avoid eating the same kind of insect in the future.

FIGURE 2.2

This rat has been taught to put the ball through the hoop by being rewarded with food for the behavior. This is an example of conditioning. What do you think would happen if the rat were no longer rewarded for this behavior?

Learning by Playing

Most young mammals, including humans, like to play. Play is one ways they learn the skills that they will need as adults. Think about how kittens play. They pounce on toys and chase each other. This helps them learn how to be better predators when they are older. Big cats also play. The lion cubs pictured below are playing and practicing their hunting skills at the same time (**Figure** 2.3). The dogs are playing tug-of-war with a toy (**Figure** 2.3). What do you think they are learning by playing together this way?

Other young animals play in different ways. For example, young deer play by running and kicking up their hooves. This helps them learn how to escape from predators.

FIGURE 2.3

Left: These two lion cubs are playing. They are not only having fun, but they are also learning how to be better hunters. Right: These dogs are really playing. This play fighting can help them learn how to be better predators.

Human children learn by playing as well. For example, playing games and sports can help them learn to follow rules and work with others. The toddler pictured below is playing in the sand (**Figure** 2.4). She is learning about the world through play. What do you think she might be learning?

FIGURE 2.4
Playing in a sandbox is fun for young children. It can also help them learn about the world.

Insight Learning

Insight learning is learning from past experiences and reasoning. It usually involves coming up with new ways to solve problems. Insight learning generally happens quickly. An animal has a sudden flash of insight. Insight learning requires relatively great intelligence. Human beings use insight learning more than any other species. They have used their intelligence to solve problems ranging from inventing the wheel to flying rockets into space.

Think about problems you have solved. Maybe you figured out how to solve a new type of math problem or how to get to the next level of a video game. If you relied on your past experiences and reasoning to do it, then you were using insight learning.

One type of insight learning is making tools to solve problems. Scientists used to think that humans were the only animals intelligent enough to make tools. In fact, tool-making was believed to set humans apart from all other animals.

In 1960, primate expert Jane Goodall discovered that chimpanzees also make tools. She saw a chimpanzee strip leaves from a twig. Then he poked the twig into a hole in a termite mound. After termites climbed onto the twig, he pulled the twig out of the hole and ate the insects clinging to it. The chimpanzee had made a tool to "fish" for termites. He had used insight to solve a problem. Since then, chimpanzees have been seen making several different types of tools. For example, they sharpen sticks and use them as spears for hunting. They use stones as hammers to crack open nuts.

Scientists have also observed other species of animals making tools to solve problems. A crow was seen bending a piece of wire into a hook. Then the crow used the hook to pull food out of a tube.

An example of a gorilla using a walking stick is shown below (**Figure** 2.5). Behaviors such as these show that other species of animals can use their experience and reasoning to solve problems. They can learn through insight.

Vocabulary

- **conditioning**: Process of learning through reward or punishment.
- **habituation**: Learning to get used to something after being exposed to it for a while.
- **insight learning**: Learning from past experiences and reasoning.

FIGURE 2.5

This gorilla is using a branch as a tool. She is leaning on it to keep her balance while she reaches down into swampy water to catch a fish.

- **learned behavior**: Behavior that occurs only after experience or practice.
- **observational learning**: Learning by watching and copying the behavior of someone else.

Summary

- Learned behavior is behavior that occurs only after experience or practice.
- Methods of learning include habituation, observational learning, conditioning, play, and insight learning.

Practice

Use the resources below to answer the questions that follow.

- **Octopus Tool Use: The World's Smartest Invertebrate** at http://www.youtube.com/watch?v=AP_dpbTbess (1:21)

MEDIA

Click image to the left for more content.

1. What sort of behavior do you feel this octopus is exhibiting? Explain your reasoning fully.
2. Do you think this behavior counts as "tool use"? Explain your thinking fully.

- **Octopus Open a Jar** at http://www.youtube.com/watch?v=5LYxJHi-RO0 (2:59)

MEDIA

Click image to the left for more content.

- **Octopus Opening Jar** at http://www.youtube.com/watch?v=bU_J8TuBkwE (1:05)

MEDIA

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1. The octopi in the above two videos are both opening jars. Observe their behavior closely.

a. Do you think they are both displaying the same type of learning? Explain your reasoning fully, and be as specific as you can be.
b. Do you think the amount of time it takes an octopus to open the jar is reflective of intelligence? Explain your thinking fully and be specific.

Review

1. Give an example of observational learning.
2. What is conditioning?

References

1. Image copyright Svetolk, 2012. . Used under license from Shutterstock.com
2. David Allen (Flickr: whiteoakart). . CC-BY-NC-SA 2.0
3. Lion cubs: Image copyright Jake Sorensen, 2010; Dogs: Image copyright Joy Brown, 2010. . Used under licenses from Shutterstock.com
4. Image copyright Danila, 2010. . Used under license from Shutterstock.com
5. Breuer T, Ndoundou-Hockemba M, Fishlock V (2005) First Observation of Tool Use in Wild Gorillas. PLoS Biol 3(11): e380. doi:10.1371/journal.pbio.0030380. . CC-BY 2.5

CHAPTER 3 Animal Behaviors

- Give examples of animal behavior, and explain why animal behavior is important.

Why do spiders spin webs?

You have probably seen a spiderweb before. You may even know that spiders create webs to catch their prey. This is an example of animal behavior. Animals have many different behaviors.

Introduction to Animal Behavior

Barking, purring, and playing are just some of the ways in which dogs and cats behave. These are examples of animal behaviors. **Animal behavior** is any way that animals act, either alone or with other animals.

Examples of Animal Behavior

Can you think of examples of animal behaviors? What about insects and birds? How do they behave? Pictured below are just some of the ways in which these, and other animals act (**Figure** 3.1). Look at the pictures and read about the behaviors. Think about why the animal is behaving that way.

FIGURE 3.1
These pictures show examples of animal behaviors. Why do the animals behave these ways?

Importance of Animal Behavior

Why do animals behave the way they do? The answer to this question depends on what the behavior is. A cat chases a mouse to catch it. A mother dog nurses her puppies to feed them. All of these behaviors have the same purpose: getting or providing food. All animals need food for energy. They need energy to move around. In fact, they need energy just to stay alive. Energy allows all the processes inside cells to occur. Baby animals also need energy to grow and develop.

Birds and wasps build nests to have a safe place to store their eggs and raise their young. Many other animals build nests for the same reason. Animals protect their young in other ways, as well. For example, a mother dog not only nurses her puppies. She also washes them with her tongue and protects them from strange people or other animals. All of these behaviors help the young survive and grow up to be adults.

Rabbits run away from foxes and other predators to stay alive. Their speed is their best defense. Lizards sun themselves on rocks to get warm because they cannot produce their own body heat. When they are warmer, they can move faster and be more alert. This helps them escape from predators and also find food.

All of these animal behaviors are important. They help the animals get food for energy, make sure their young survive, or ensure that they, themselves, survive. Behaviors that help animals or their young survive, increase the animals' **fitness.** Animals with higher fitness have a better chance of passing their **genes** on to the next generation. If genes control behaviors that increase fitness, the behaviors become more common in the species. This occurs through the process of evolution by natural selection.

Vocabulary

- **animal behavior**: Way in which animals act, either alone or with other animals.
- **fitness**: Relative ability of an organism to survive and produce fertile offspring.
- **gene**: Unit of DNA that contains code for the creation of one protein.

Summary

- Animal behavior is any way that animals act, either alone or with other animals.
- Animal behavior may be aimed at getting food for energy, making sure their young survive, or ensuring that

they, themselves, survive.

Practice

Use the resources below to answer the questions that follow.

- **Animal Behavior** at http://www.youtube.com/watch?v=6hREwakXmAo (9:52)

MEDIA
Click image to the left for more content.

1. When do animals learn innate behavior?
2. Can you think of why "grasping" behavior would help human babies survival?
3. Explain "fixed action" behavior. Be as complete as you can be in your answer and include an example.
4. How does a crow vending machine work?
5. Compare and contrast "trial and error" learning and "observational" learning. Be as specific as you can in your answer.
6. How do "mirror neurons" work? How do they aid learning?

- **Cnidarians: Anemone Swims Away From Sea Star** at http://vimeo.com/37443347 (2:01)

MEDIA
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1. What type of behavior do you think the sea anemone (*Stomphia coccinea*) is exhibiting? Explain your thinking fully and be specific; the correctness of your answer depends on your reasoning.

Review

1. What are some animal behaviors that are aimed at getting food?
2. What are some animal behaviors that are aimed at protecting the young?

References

1. Cat and mouse: Image copyright Eric Isselee, 2010; Dog: Magalie L'Abbé; Bird: Image copyright Alta Oosthuizen, 2010; Wasp: Image copyright FILATOV ALEXEY, 2010; Lizard: Image copyright Dennis Donohue, 2012; Rabbit: Image copyright AnetaPics, 2010. . Dog: CC-BY-NC 2.0; Remaining images: Used under licenses from Shutterstock.com

Chapter 4 Social Behavior of Animals

- Describe social behavior in animals.

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, 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** 4.1). A colony may have millions of ants. All of the ants in the colony work together as a single unit. Each ant has a specific job. 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 4.1
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** 4.2). 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.

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** 4.3). They show very clearly why cooperation is important. A single ant would not be able to carry this large insect back to the nest to feed the other ants. With cooperation, the job is easy.

Animals in many other species cooperate. For example, lions live in groups called prides (**Figure** 4.4). All the lions in the pride cooperate. 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 is 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.

Vocabulary

- **cooperation**: Working together with others.
- **social animals**: Animals that live in groups with other members of their species.

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.

Practice

Use the resource below to answer the questions that follow.

FIGURE 4.2
All the honeybees in this colony work together. Each bee has a certain job to perform. The bees are gathered together to fly to a new home. How do you think they knew it was time to gather together?

- **Wolf Hunting Tactics** at http://www.youtube.com/watch?v=2jXxtQRy47A (2:54)

MEDIA
Click image to the left for more content.

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.

FIGURE 4.3
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 insect with other ants that do not leave the nest.

FIGURE 4.4
Members of this lion pride work together. Males cooperate by defending the pride. Females cooperate by hunting and sharing the food.

c. Does your answer apply to all situations? Can you think of a scenario that might cause you to change your original answer?

2. Notice the vocalizations of the coyote (*Canis latrans*) when it encounters the wolves. What does this sound like? What do you think the coyote is trying to convey, and why does it do it in this manner?

Review

1. What makes social animals unique?
2. What are some examples of how social animals cooperate?

References

1. Jacob Enos. . CC-BY 2.0
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4. Rick marin. . Public Domain

CHAPTER 5 Cyclic Behavior of Animals

- Identify animal behaviors that occur in cycles.

What are these butterflies doing?

Monarch butterflies gather in large groups as they migrate south each fall. They return to the north in the spring. This migration is a cycle that repeats every year.

Cycles of Behavior

Many animal behaviors change in a regular way. They go through cycles. Some cycles of behavior repeat each year. Other cycles of behavior repeat every day.

Yearly Cycles

An example of a behavior with a yearly cycle is **hibernation**. Hibernation is a state in which an animal's body processes are slower than usual, and its body temperature falls. An animal uses less energy than usual during hibernation. This helps the animal survive during a time of year when food is scarce. Hibernation may last for weeks or months. Animals that hibernate include species of bats, squirrels, and snakes.

Most people think that bears hibernate. In fact, bears do not go into true hibernation. In the winter, they go into a deep sleep. However, their body processes do not slow down very much. Their body temperature also remains about the same as usual. Bears can be awakened easily from their winter sleep.

Another example of a behavior with a yearly cycle is **migration**. Migration is the movement of animals from one place to another. Migration is an innate behavior that is triggered by changes in the environment. For example, animals may migrate when the days get shorter in the fall. Migration is most common in birds, fish, and insects. In the Northern Hemisphere, many species of birds, including robins and geese, travel south for the winter. They migrate to areas where it is warmer and where there is more food. They return north in the spring. A flock of migrating geese is pictured below (**Figure** 5.1).

FIGURE 5.1

These geese are flying south for the winter. Flocks of geese migrate in V-shaped formations.

Some animals migrate very long distances. The map shown below shows the migration route of a species of hawk called Swainson's hawk (**Figure** 5.2). About how many miles do the hawks travel from start to finish? Are you surprised that birds migrate that far? Some species of birds migrate even farther.

Birds and other migrating animals follow the same routes each year. How do they know where to go? It depends on the species. Some animals follow landmarks, such as rivers or coastlines. Other animals are guided by the position of the sun, the usual direction of the wind, or other clues in the environment.

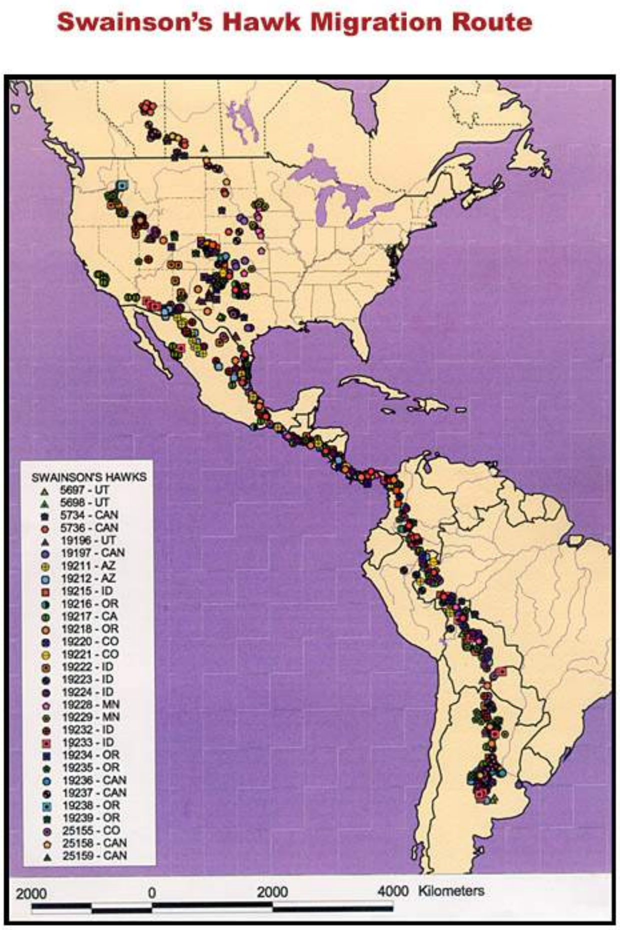

FIGURE 5.2

The migration route of Swainson's hawk starts in North America and ends in South America. Scientists learned their migration route by attaching tiny tracking devices to the birds. The birds were then tracked by satellite. On the migration south, the hawks travel almost 5,000 miles from start to finish.

Daily Cycles

Many animal behaviors change at certain times of day, day after day. For example, most animals go to sleep when the sun sets and wake up when the sun rises. Animals that are active during the daytime are called **diurnal**. Some animals do the opposite. They sleep all day and are active during the night. These animals are called **nocturnal**.

Animals may eat and drink at certain times of day as well. Humans have daily cycles of behavior, too. Most people start to get sleepy after dark and have a hard time sleeping when it is light outside. Daily cycles of behavior are called **circadian rhythms**.

In many species, including humans, circadian rhythms are controlled by a tiny structure called the **biological clock**. This structure is located in a gland at the base of the brain. The biological clock sends signals to the body. The signals cause regular changes in behavior and body processes. The amount of light entering the eyes helps control the biological clock. The clock causes changes that repeat every 24 hours.

Vocabulary

- **biological clock**: Structure that controls the activities of an organism whose activities change on a regular 24-hour cycle.
- **circadian rhythms**: Regular change in biology or behavior that occurs in a 24-hour cycle.

- **diurnal**: Animals that are active during the daytime and rest during the night.
- **hibernation**: State in which an animal's body processes are slower than usual, and its body temperature falls in order to conserve energy when food is scarce.
- **migration**: Regular movement of animals each year, usually to find food, mates, or other resources.
- **nocturnal**: Animals that are active during the night and sleep all day.

Summary

- Yearly cycles of behavior include hibernation and migration.
- Daily cycles of behavior, including sleeping a waking, are called circadian rhythms.

Practice

Use the resources below to answer the questions that follow.

- **Red Knot Migration - Port Royal Sound** at http://www.youtube.com/watch?v=P21xTCFrJbU (2:07)

MEDIA
Click image to the left for more content.

- **Thousands of Red Knots migrate through New Jersey** at http://www.youtube.com/watch?v=TE5EHoBWdAA (2:55)

MEDIA
Click image to the left for more content.

1. How far do Red Knots (*Calidris canutus*) migrate each year?
2. Are Red Knots the only species of bird to use horseshoe crab (*Limulus polyphemus*) eggs as a resource?
3. What information do scientists collect from the red Knots? How do they use this information?
4. Why do scientists think Red Knot populations are declining? How is this connected to their extremely long migration?

- **Ocean Life - Vertical Migration Aggregation** at http://www.youtube.com/watch?v=zVQd9pn8j6E (7:16)

MEDIA

Click image to the left for more content.

1. What is the largest migration of animals on the planet? When does this occur?
2. Why do animals undergo this migration? What types of organisms undergo this migration?
3. How does the timing of this migration vary throughout the year?

Review

1. What are examples of yearly cycles of behavior?
2. What is the difference between a nocturnal and a diurnal animal?

References

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2. Courtesy of the U.S. Geological Survey. . Public Domain

CHAPTER 6 Reproductive Behavior of Animals

- Explain the purpose of mating behavior.
- Describe how animals defend their territory.

Why do these birds pair up?

These birds are pairing up so that they can produce offspring. Many birds keep 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.

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 pictured below (**Figure** 6.1); this bird is called a blue-footed booby. He is doing a dance to attract a female

FIGURE 6.1
This blue-footed booby is a species of sea bird. The male pictured here is doing a courtship "dance." He is trying to attract a female for mating.

for mating. During the dance, he spreads out his wings and stamps his feet on the ground. You can watch a video of a blue-footed booby doing his courtship dance at: http://www.youtube.com/watch?v=oYmzdvMoUUA.

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** 6.2). The predator thinks she is injured and will be easy prey. The mother leads the predator away from the nest and then flies away.

FIGURE 6.2
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?

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.

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.

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** 6.3).

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.

Vocabulary

- **courtship behaviors**: Pairing of an adult male and female to produce young.
- **display behavior**: Fixed set of actions that carries a specific message.
- **mating**: Special behaviors that help attract a mate.
- **territorial**: Defending a particular area.

FIGURE 6.3
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.

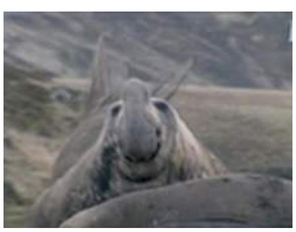
Summary

- 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.

Practice

Use the resources below to answer the questions that follow.

- **Dominant Male Elephant Seal** at http://www.youtube.com/watch?v=9UYFGSyUxRc (2:26)



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The Northern elephant seal (*Mirounga angustirostris*) has a harem based mating system, where a dominant male defends the females in his harem from other males attempting to mate with them.

1. Does the dominant male father all the pups from his harem?
2. How do you think the size of a harem affects a male's ability to defend his harem? Explain your reasoning.
3. Do you think dominant males enjoy the same reproductive benefits under all circumstances? Explain your answer fully.

- **Behavior on a Sage Grouse Lek** at http://www.youtube.com/watch?v=QYMHbFUTgAY (1:15)

MEDIA

Click image to the left for more content.

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? Explain your answer fully.

- **Elk Fighting in River** at http://www.youtube.com/watch?v=GUQcMZLZpx8 (2:45)

MEDIA

Click image to the left for more content.

1. Notice the male elk (*Cervus canadensis*) which enters the video at the 2:07 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. Give an example of courtship behavior.
2. Give an example of display behavior exhibited by a territorial animal.

References

1. Image copyright Mariko Yuki, 2012. . Used under license from Shutterstock.com
2. Audrey. . CC-BY 2.0
3. mtsofan (Flickr). . CC-BY-NC-SA 2.0

CHAPTER 7 Animal Communication

- List ways in which animals communicate.

How do monkeys communicate?

You won't find a monkey texting a friend. They make noises. They make faces. They even use scents to pass along a message. Just because monkeys don't talk like you and me doesn't mean that they don't communicate!

Communication

What does the word "communication" make you think of? Talking on a cell phone? Texting? Writing? Those are just a few of the ways in which human beings communicate. Most other animals also communicate. **Communication** is any way in which animals share information, and they do this in many different ways.

Do all animals talk to each other? Probably not, but many do communicate. Like human beings, many other animals live together in groups. Some insects, including ants and bees, are well known for living in groups. In order for animals to live together in groups, they must be able to communicate with each other.

Animal communication, like most other animal behaviors, increases the ability to survive and have offspring. This is known as fitness. Communication increases fitness by helping animals find food, defend themselves from predators, mate, and care for offspring.

Communication with Sound

Some animals communicate with sound. Most birds communicate this way. Birds use different calls to warn other birds of danger, or to tell them to flock together. Many other animals also use sound to communicate. For example, monkeys use warning cries to tell other monkeys in their troop that a predator is near. Frogs croak to attract female frogs as mates. Gibbons use calls to tell other gibbons to stay away from their area.

Communication with Sight

Another way some animals communicate is with sight. By moving in certain ways or by "making faces," they show other animals what they mean. Most primates communicate in this way. For example, a male chimpanzee may raise his arms and stare at another male chimpanzee. This warns the other chimpanzee to keep his distance. The chimpanzee pictured below may look like he is smiling, but he is really showing fear (**Figure** 7.1). He is communicating to other chimpanzees that he will not challenge them.

FIGURE 7.1
This chimpanzee is communicating with his face. His expression is called a "fear grin." It tells other chimpanzees that he is not a threat.

Look at the peacock pictured below (**Figure** 7.2). Why is he raising his beautiful tail feathers? He is also communicating. He is showing females of his species that he would be a good mate.

FIGURE 7.2
This peacock is using his tail feathers to communicate. What is he "saying"?

Communication with Scent

Some animals communicate with scent. They release chemicals that other animals of their species can smell or detect in some other way. Ants release many different chemicals. Other ants detect the chemicals with their antennae. This explains how ants are able to work together. The different chemicals that ants produce have different meanings. Some of the chemicals signal to all of the ants in a group to come together. Other chemicals warn of danger. Still other chemicals mark trails to food sources. When an ant finds food, it marks the trail back to the nest by leaving behind a chemical on the ground. Other ants follow the chemical trail to the food.

Many other animals also use chemicals to communicate. You have probably seen male dogs raise their leg to urinate on a fire hydrant or other object. Did you know that the dogs were communicating? They mark their area with a chemical in their urine. Other dogs can smell the chemical. The scent of the chemical tells other dogs to stay away.

Human Communication

Like other animals, humans communicate with one another. They mainly use sound and sight to share information. The most important way in which humans communicate is with language. **Language** is the use of symbols to communicate. In human languages, the symbols are words. They stand for many different things. Words stand for things, people, actions, feelings, or ideas. Think of several common words. What does each word stand for?

Another important way in which humans communicate is with facial expressions. Look at the face of the young child pictured below (**Figure** 7.3). Can you tell from her face how she is feeling?

Humans also use gestures to communicate. What are people communicating when they shrug their shoulders? When they shake their head? These are just a few examples of the ways in which humans share information without using words.

Vocabulary

- **communication**: Any way in which animals share information.
- **language**: Method of communication using signs or symbols.

Summary

- Animals communicate, or share information, through sound, sight, and scent.
- Humans primarily communicate through use of language, facial expressions, and gestures.

Practice

Use the resources below to answer the questions that follow.

- **Can Monkeys Talk?** at http://wrl.it/show/197403/12898528 (3:36)

1. How do the vervet monkeys (*Chlorocebus pygerythrus*) respond when they hear a "leopard" call?
2. How do the vervet monkeys respond when they hear an "eagle" call?
3. How do the vervet monkeys respond when the hear a "snake" call?
4. Given the vervet monkeys responses to specific calls, do you think they are using language? Explain your reasoning fully.

- **How Do Tigers Communicate?** at http://www.youtube.com/watch?v=LL99pufzHjo (1:33)

FIGURE 7.3
What does this girl's face say about how she is feeling?

MEDIA
Click image to the left for more content.

1. What are some of the different ways tigers (*Panthera tigris*) communicate?
2. In what sort of ways do tigers communicate through smell?
3. Do you think using different smells to communicate is analogous to using different words? Explain your reasoning fully, and be as specific as possible.

Review

1. Give some examples of how animals communicate with scent.
2. Give some examples of how animals communicate through sight.

References

1. Frans de Waal. . CC-BY 2.5
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3. Christine Szeto (Flickr: christine [cbszeto]). . CC-BY 2.0

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Printed: March 20, 2014

Contents

CHAPTER 1 Water and Life

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

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

Another name for this compound is. . . water. Water can create some absolutely beautiful sights. Iguassu Falls is the largest series of waterfalls on the planet, located in Brazil, Argentina, and Paraguay. And water is necessary for life. The importance of water to life cannot be emphasized enough. All life needs water. Life started in water. Essentially, without this simple three atom molecule, life would not exist.

Water

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

Water, Water Everywhere

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

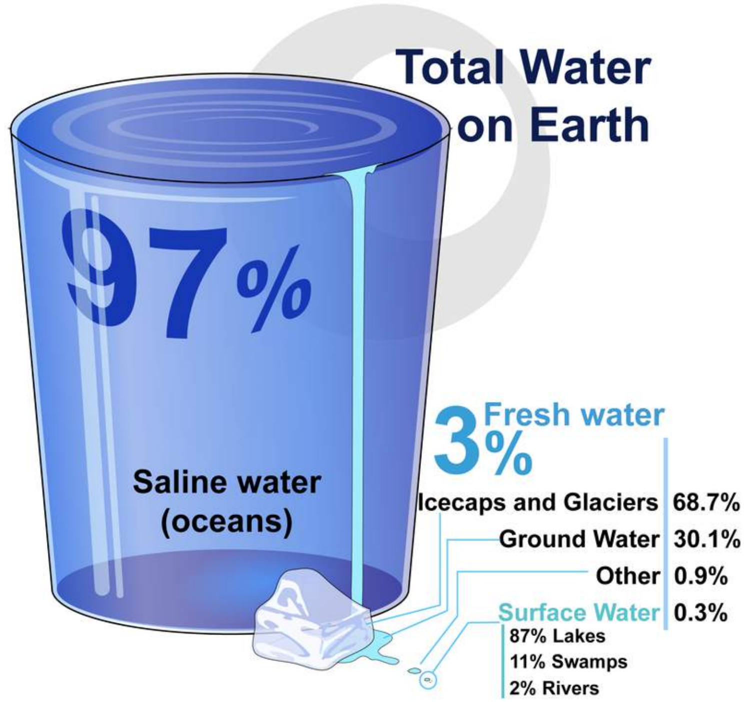

FIGURE 1.1

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

Structure and Properties of Water

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

Chemical Structure of Water

To understand some of water's properties, you need to know more about its chemical structure. As you have seen, each molecule of water consists of one atom of oxygen and two atoms of hydrogen. The oxygen atom in a water molecule attracts negatively-charged electrons more strongly than the hydrogen atoms do. As a result, the oxygen atom has a slightly negative charge, and the hydrogen atoms have a slightly positive charge. A difference in electrical charge between different parts of the same molecule is called **polarity**, making water a **polar molecule**. The diagram in **Figure** 1.2 shows water's polarity.

Opposites attract when it comes to charged molecules. In the case of water, the positive (hydrogen) end of one water molecule is attracted to the negative (oxygen) end of a nearby water molecule. Because of this attraction, weak bonds form between adjacent water molecules, as shown in **Figure** 1.3. The type of bond that forms between molecules is called a **hydrogen bond**. Bonds between molecules are not as strong as bonds within molecules, but in water they are strong enough to hold together nearby molecules.

Properties of Water

Hydrogen bonds between water molecules explain some of water's properties. For example, hydrogen bonds explain why water molecules tend to stick together. Have you ever watched water drip from a leaky faucet or from a melting icicle? If you have, then you know that water always falls in drops rather than as separate molecules. The dew drops in **Figure** 1.4 are another example of water molecules sticking together.

Hydrogen bonds cause water to have a relatively high boiling point of 100°C (212°F). Because of its high boiling point, most water on Earth is in a liquid state rather than in a gaseous state. Water in its liquid state is needed by all

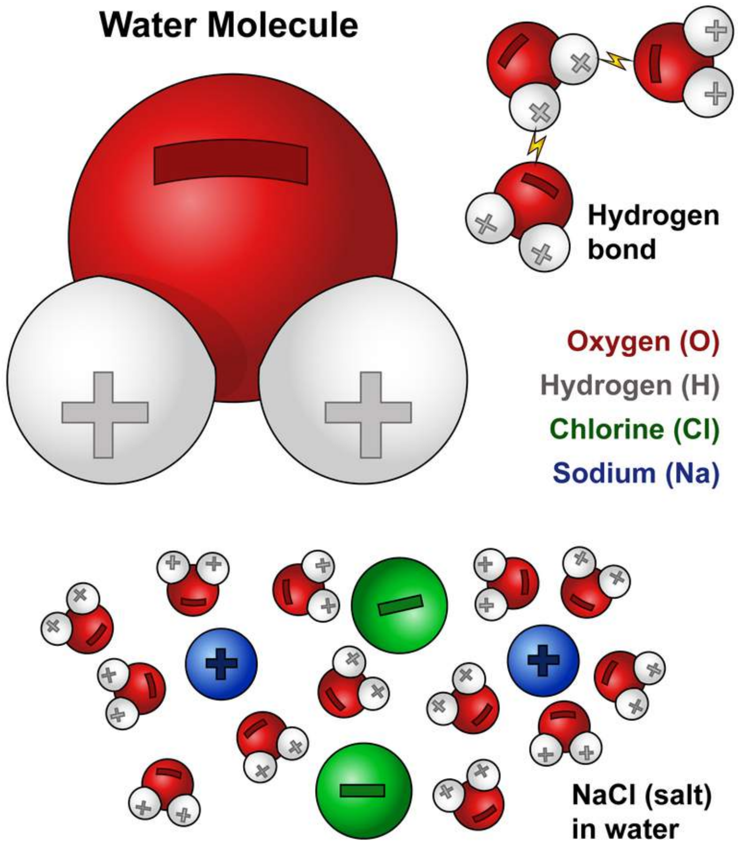

FIGURE 1.2
Water Molecule. This diagram shows the positive and negative parts of a water molecule.

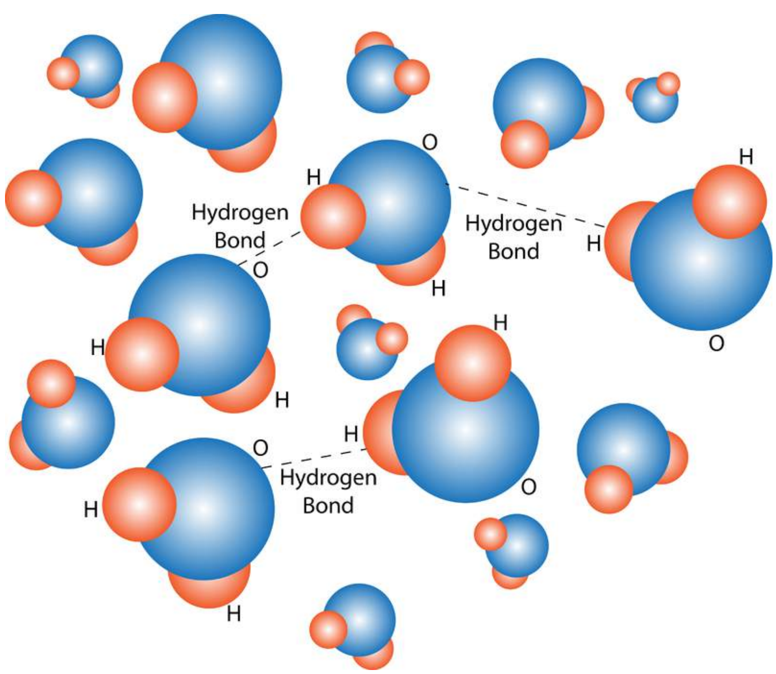

FIGURE 1.3
Hydrogen Bonding in Water Molecules. Hydrogen bonds form between nearby water molecules. How do you think this might affect water's properties?

FIGURE 1.4
Droplets of Dew. Drops of dew cling to a spider web in this picture. Can you think of other examples of water forming drops? (Hint: What happens when rain falls on a newly waxed car?)

living things. Hydrogen bonds also cause water to expand when it freezes. This, in turn, causes ice to have a lower density (mass/volume) than liquid water. The lower density of ice means that it floats on water. For example, in cold climates, ice floats on top of the water in lakes. This allows lake animals such as fish to survive the winter by staying in the water under the ice.

Water and Life

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

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

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

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

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

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

Summary

- Water is needed by all known forms of life.
- Due to the difference in the distribution of charge, water is a polar molecule.
- Hydrogen bonds hold adjacent water molecules together.
- Water is involved in many biochemical reactions. As a result, just about all life processes depend on water.

Practice

Use these resources to answer the questions that follow.

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

1. How do hydrogen and oxygen bind to form water?
2. Why is water a polar molecule?
3. Describe the bond between water molecules.

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

1. Describe two properties of water that make it important to life.
2. Why is the specific heat of water important?
3. Why does ice float?

Review

1. Where is most of Earth's water found?

2. What is polarity? Describe the polarity of water.

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

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

5. Explain why metabolism in organisms depends on water.

References

1. LadyofHats for the CK-12Foundation. . CC-BY-NC-SA 3.0
2. CK-12 Foundation. Water Molecule. CC-BY-NC-SA 3.0
3. CK-12 Foundation. Hydrogen Bonding in Water Molecule. CC-BY-NC-SA 3.0
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CHAPTER 2 Chemistry of Life

- Define matter, element, atom, molecule, and compound.

What's happening in this cup?

The formation of the vapor 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. 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, helium (He) always has two protons (**Figure** 2.1), 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.

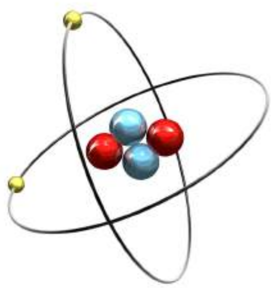

FIGURE 2.1

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** 2.2). 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.

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 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.

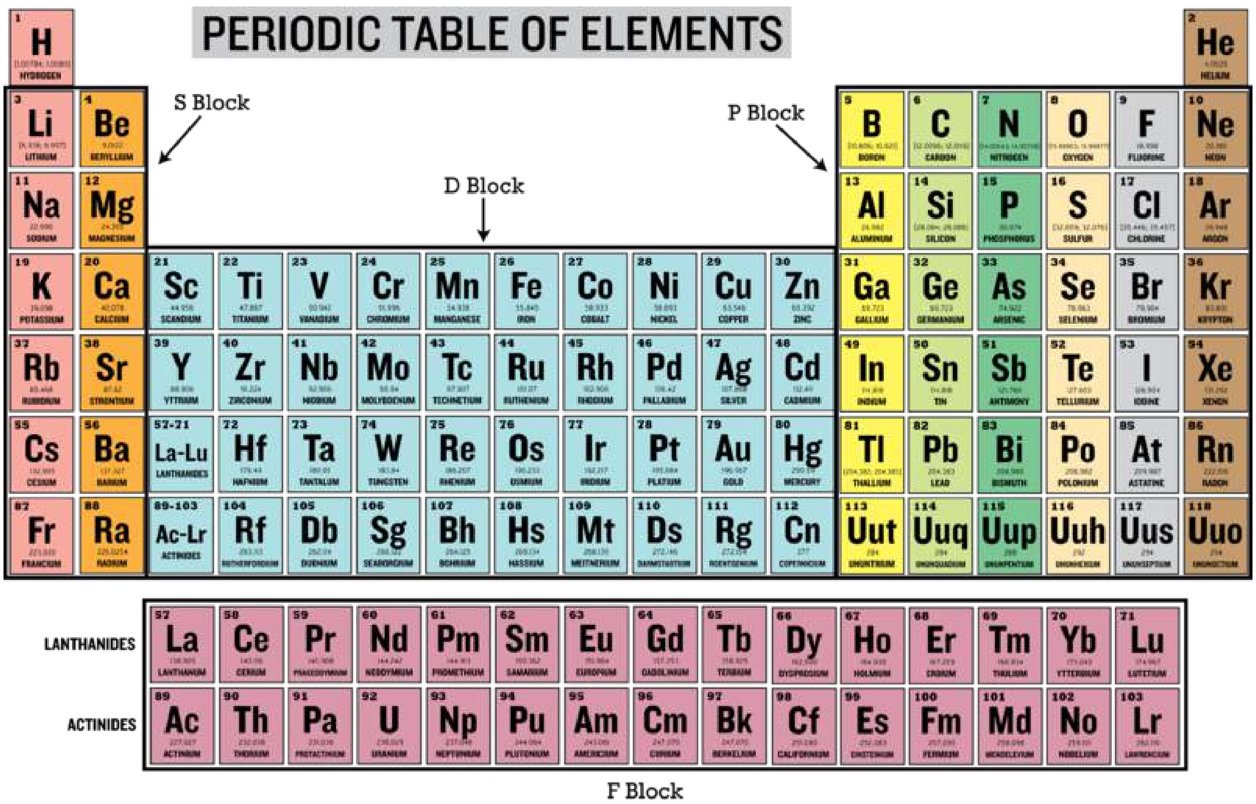

FIGURE 2.2

The periodic table groups the elements based on their properties.

Vocabulary

- **atom**: Simplest and smallest particle of matter that still has chemical properties of the element.
- **atomic number**: Number of protons in an atom.
- **cell**: Basic unit of structure and function of a living organism; the basic unit of life.
- **chemical reaction**: Process that breaks or forms the bonds between atoms of molecules and compounds.
- **compound**: Combination of two or more elements.
- **electron**: Negatively charged particle that helps make up an atom.
- **element**: Substance that cannot be broken down into simpler substances.
- **ion**: Charged atom; an atom that has gained or lost one or more electrons.
- **matter**: Anything that has mass and takes up space.
- **molecule**: Combination of two or more atoms.
- **neutron**: Uncharged particle that helps make up an atom.
- **periodic table**: Chart that organizes elements according to their unique characteristics.
- **products**: End results of a chemical reaction.
- **proton**: Positively charged particle that helps make up an atom.
- **reactants**: Molecules that come together to start a chemical reaction.

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.

Practice

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?

Play the quiz game below.

- **Atoms and Matter** at http://www.neok12.com/quiz/ATOM0001 .

Review

1. What is an element?
2. What is the difference between the terms molecule and compound?
3. Describe the composition of an atom.

References

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CHAPTER 3 Significance of Carbon

- Explain why carbon is essential to life on Earth.

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

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

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** 3.1. Water is not an organic compound.

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

FIGURE 3.1
A water molecule always has this composition, one atom of oxygen and two atoms of hydrogen.

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** 3.1. Each type is also described below.

TABLE 3.1: **Types of Organic Compounds**

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

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

Energy From Carbon?

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

Summary

- Carbon is the main element in organic compounds. Carbon can form stable bonds with many elements, including itself.

1. What is an organic compound? Roughly how many organic compounds exist?
2. Describe the element carbon.
3. What is the chemical composition of aspirin? Is it a natural or synthetic compound?
4. Describe organic reactions.

Review

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

2. Which type(s) of organic compounds provide energy?

3. Which organic compound stores genetic information?

4. Examples of proteins include ____________.

References

1. LadyofHats for the CK-12 Foundation. . CC-BY-NC-SA 3.0

CHAPTER 4 Organic Compounds

- Describe the four main classes of organic molecules that are the building blocks of life.

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** 4.1, are:

1. Proteins.
2. Carbohydrates.
3. Lipids.
4. Nucleic Acids.

TABLE 4.1:

	Proteins	Carbohydrates	Lipids	Nucleic Acids
Elements	C, H, O, N, S	C, H, O	C, H, O, P	C, H, O, P, N

TABLE 4.1: (continued)

	Proteins	Carbohydrates	Lipids	Nucleic Acids
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** 4.1) 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.

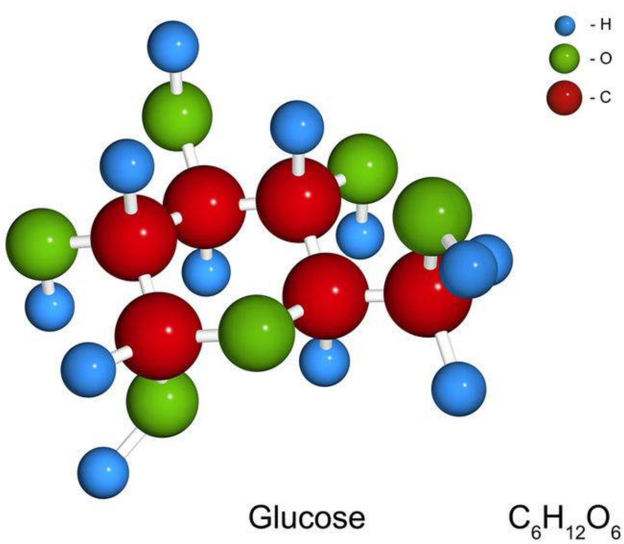


FIGURE 4.1
A molecule of glucose, a type of carbohydrate.

Proteins

Proteins are molecules that have many different functions in living things. All proteins are made of monomers called **amino acids** (**Figure** 4.2) that connect together like beads on a necklace (**Figure** 4.3). 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.

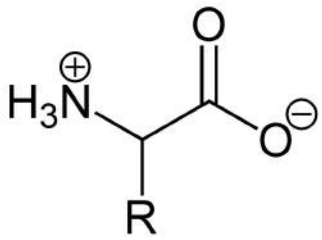


FIGURE 4.2
This model shows the general structure of all amino acids. Only the side chain, R, varies from one amino acid to another. KEY: H = hydrogen, N = nitrogen, C = carbon, O = oxygen, R = variable side chain.

FIGURE 4.3
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** 4.4).

FIGURE 4.4
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** 4.5).

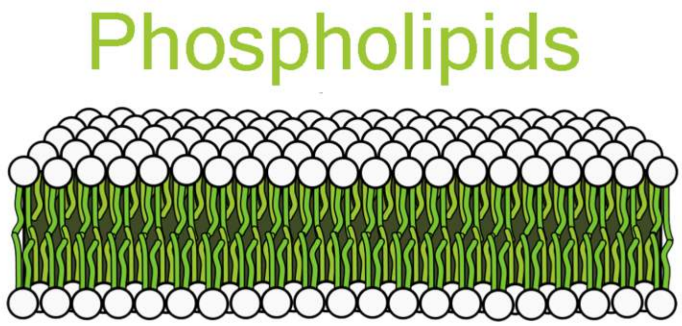


FIGURE 4.5
Phospholipids in a membrane, shown as two layers (a bilayer) of phospholipids facing each other.

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** 4.6). 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.

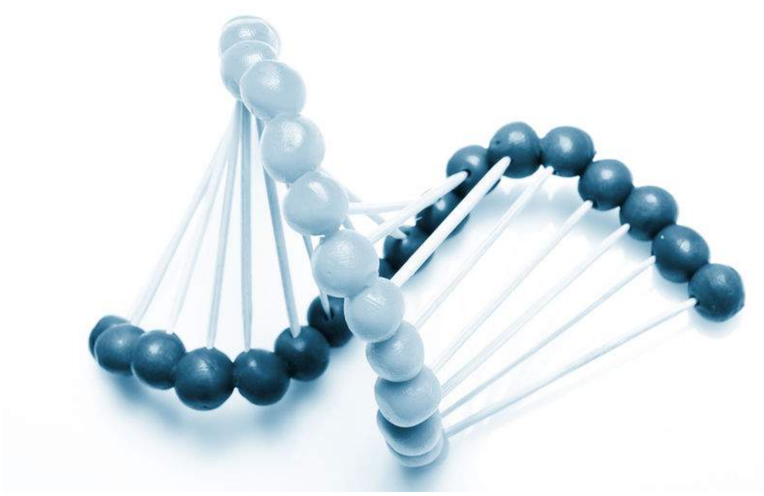


FIGURE 4.6
A model representing DNA, a nucleic acid.

Vocabulary

- **amino acid**: Small molecule used to build proteins.
- **antibody**: Protein that identifies pathogens or other substances as being harmful; can destroy pathogens by attaching to the cell membrane of the pathogen.

- **ATP (adenosine triphosphate)**: Usable form of energy inside the cell.
- **carbohydrate**: Organic compound such as sugar and starch that provides an energy source for animals.
- **deoxyribonucleic acid (DNA)**: Nucleic acid that is the genetic material of all organisms.
- **enzyme**: Protein that speeds up chemical reactions.
- **glucose**: Simple sugar molecule with the chemical formula $C_6H_{12}O_6$.
- **glycogen**: Storage carbohydrate in animals.
- **lipid**: Organic compound that is insoluble in water and includes fats, oils, and waxes.
- **macromolecule**: Molecule containing a large number of atoms.
- **monomer**: Small building block molecule.
- **monosaccharide**: Simple sugar, such as glucose, that is a building block of carbohydrates.
- **nucleic acid**: Organic compound that can carry genetic information.
- **organic compound**: Compound built around the element carbon.
- **phospholipid**: Lipid molecule with a hydrophilic ("water-loving") head and two hydrophobic ("water-hating") tails; makes up the cell membrane.
- **polysaccharide**: Large carbohydrate usually containing hundreds or thousands of monosaccharides.
- **protein**: Organic compound composed of amino acids and includes enzymes, antibodies, and muscle fibers.
- **ribonucleic acid (RNA)**: Single-stranded nucleic acid involved in protein synthesis.
- **starch**: Storage carbohydrate in plants.

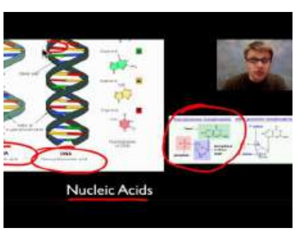
Summary

- 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.

Practice

Use the resources below to answer the questions that follow.

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



MEDIA

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1. What four categories of molecules 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 are proteins? What smaller units can proteins be broken down into?
5. What five nucleic acids are used by organisms? Where are they used?
6. What are three different types of carbohydrates?

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

MEDIA

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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 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?

References

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3. CK-12 Foundation - Sam McCabe. . CC-BY-NC-SA 3.0
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CHAPTER 5 Carbohydrates

- Describe the structure and function of the four major types of organic compounds, focusing on carbohydrates.

Sugar. Does this look like biological energy?

As a child, you may have been told that sugar is bad for you. Well, that's not exactly true. Essentially, carbohydrates are made of sugar, from a single sugar molecule to thousands of sugar molecules 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** 5.1. 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.

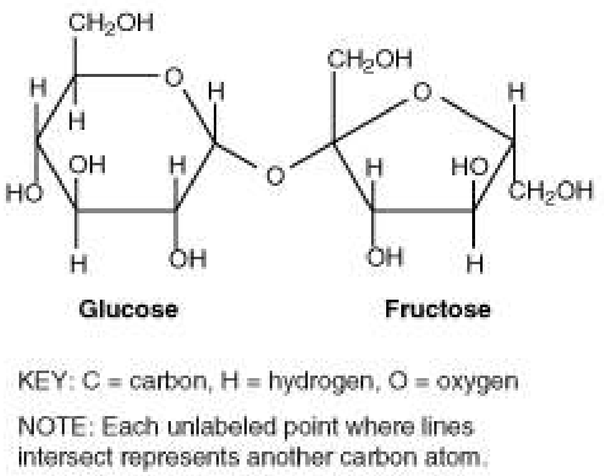


FIGURE 5.1

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** 5.1). Monosaccharides and disaccharides are also called **simple sugars**. They provide the major source of energy to living cells

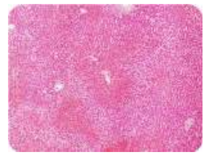
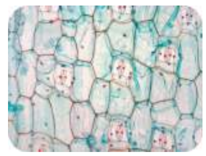
Polysaccharides

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** 5.1. Which type of complex carbohydrate does your own body use to store energy?

TABLE 5.1: Complex Carbohydrates

Name	Function	Example	
Starch	Used by plants to store energy.		A potato stores starch in underground tubers.

TABLE 5.1: (continued)

Name	Function	Example	
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.

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 biofeuls from the sugars in cellulose. See *Biofuels: Beyond Ethanol* at http://www.kqed.org/quest/television/biofuels-beyond-ethanol for further information.

MEDIA
Click image to the left for more content.

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.

Practice

Use these resources to answer the questions that follow.

- **Biomolecules - the Carbohydrates** at http://www.wisc-online.com/Objects/ViewObject.aspx?ID=AP13104 .

1. What do carbohydrates provide to the cell?
2. Describe glucose.
3. What is an isomer? Give an example.
4. What is a disaccharide? Give an example.
5. What is the role of starch?

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

1. How many monomers may make a polysaccharide?
2. What determines the function of a polysaccharide?
3. Describe 3 properties of cellulose.
4. What is the main function of starch?
5. What is the main structural difference between starch and glycogen?

Review

1. List three facts about glucose.

2. 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?

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

References

1. Booyabazooka. . Public Domains

CHAPTER 6 Lipids

- Describe the structure and function of the four major types of organic compounds, focusing on 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** 6.1. The straight chains can be packed together very tightly, allowing them to store energy in a compact form. This explains why saturated fatty acids are solids at room temperature. Animals use saturated fatty acids to store energy.

Unsaturated Fatty Acids

In **unsaturated fatty acids**, some carbon atoms are not bonded to as many hydrogen atoms as possible. Instead, they are bonded to other groups of atoms. Wherever carbon binds with these other groups of atoms, it causes chains to bend (see **Figure** above). 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** 6.2.

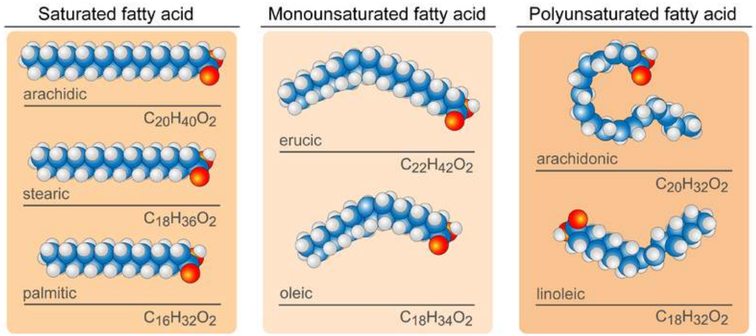


FIGURE 6.1
Fatty Acids. Saturated fatty acids have straight chains, like the three fatty acids shown in the upper left. Unsaturated fatty acids have bent chains, like all the other fatty acids in the figure.

FIGURE 6.2
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.

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.

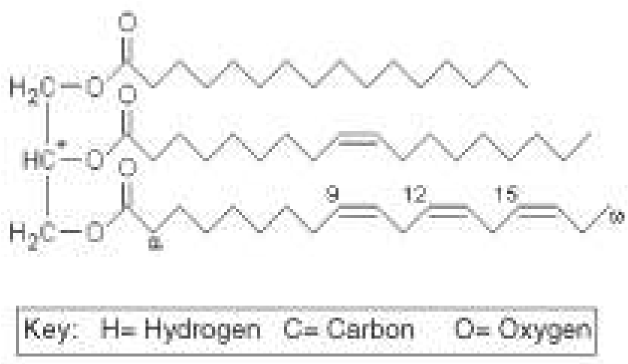


FIGURE 6.3

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

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.

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.

Practice

Use these resources to answer the questions that follow.

- **Biomolecules - The Lipids** at http://www.wisc-online.com/Objects/ViewObject.aspx?ID=AP13204 .

1. What is the defining property of a lipid?
2. Give 3 examples of lipids.
3. What are the roles of natural fats?
4. Describe the structure of phospholipid molecules.
5. What are the functions of cholesterol?

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

1. Describe the structure of triglyceride molecules.
2. What are the roles of triglycerides and phospholipids?
3. Which are non-polar molecules, triglycerides or phospholipids?
4. What determines a fat's function?

Review

1. What is a lipid?
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.

References

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CHAPTER 7 Proteins

- Describe the structure and function of the four major types of organic compounds, focusing on proteins.

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

Proteins as food. To you, these may not look appetizing (or they might), but they do provide a nice supply of amino acids, the building blocks of proteins. Proteins have many important roles, from transporting, signaling, receiving, and catalyzing to storing, defending, and allowing for movement. Where do you get the amino acids needed so your cells can make their own proteins? If you cannot make 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 the titins, found in muscle, which are composed from almost 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, is its sequence of amino acids. Higher levels of protein structure are described in **Figure** 7.2. The complex structures of different proteins give them unique properties, which they need to carry out their various jobs in living organisms. You can learn more about protein structure by watching the animation at the following link: http://www.stolaf.edu/people/giannini/flashanimat/proteins/protein%20structure.swf .

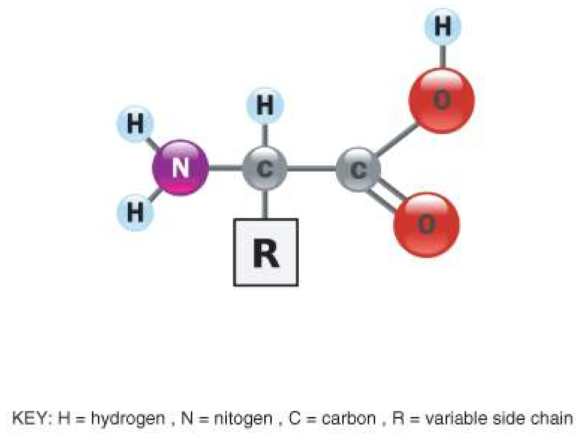

FIGURE 7.1
General Structure of Amino Acids. This model shows the general structure of all amino acids. Only the side chain, R, varies from one amino acid to another. For example, in the amino acid glycine, the side chain is simply hydrogen (H). In glutamic acid, in contrast, the side chain is CH_2CH_2COOH. Variable side chains give amino acids acids different chemical properties. The order of amino acids, together with the properties of the amino acids, determines the shape of the protein, and the shape of the protein determines the function of the protein. KEY: H = hydrogen, N = nitrogen, C = carbon, O = oxygen, R = variable side chain

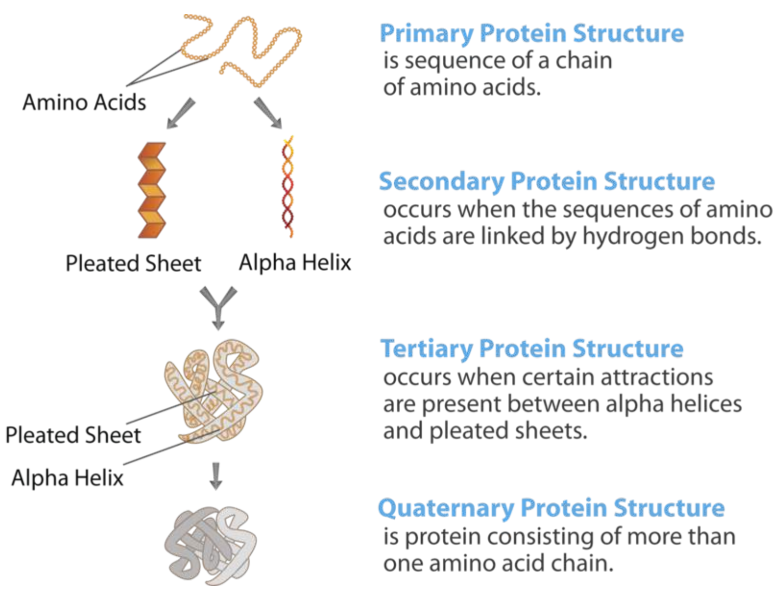

FIGURE 7.2
Protein Structure. The structure of a protein starts with its sequence of amino acids. What determines the secondary structure of a protein? What are two types of secondary protein structure?

Functions of Proteins

Proteins play many important roles in living things. Some proteins help cells keep their shape, and some make up muscle tissues. **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 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** 7.3.

A short video describing protein function can be viewed at http://www.youtube.com/watch?v=T500B5yTy58&featu

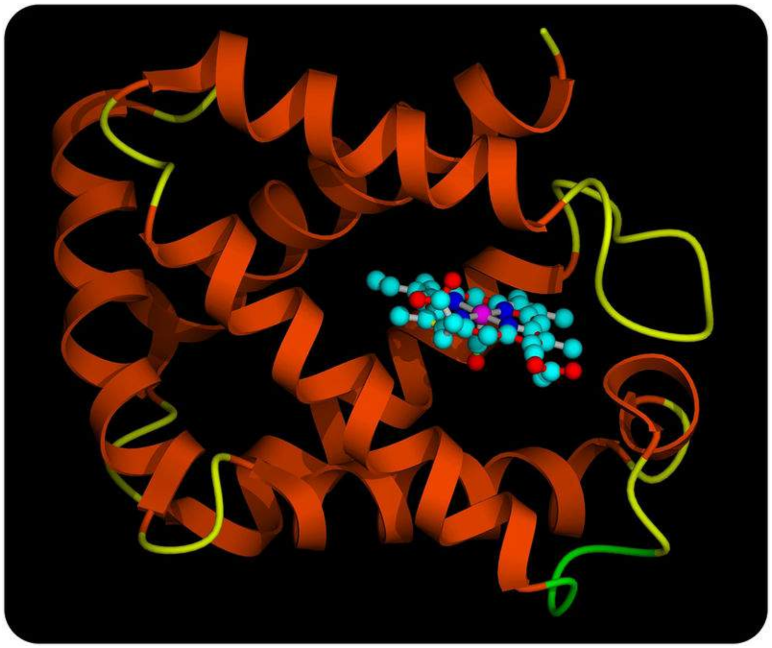

FIGURE 7.3

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

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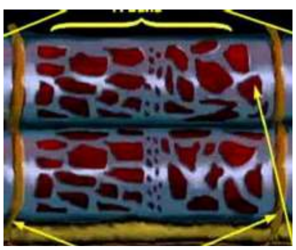

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As you view *Protein Functions in the Body,* focus on these concepts:

1. the amount of protein in each cell,
2. the roles of different types of proteins.

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.

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.

Practice

Use these resources to answer the questions that follow.

- **Biomolecules - The Proteins** at http://www.wisc-online.com/Objects/ViewObject.aspx?ID=AP13304 .

1. Give 3 examples of proteins.
2. What determines the primary structure of a protein?
3. What determines the protein's function?
4. How can a protein's conformation be disrupted?

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

1. How many different proteins are in a cell?
2. What function do receptor proteins and structural proteins have in nerve cells?
3. What is the information used to make an individual protein?
4. What is the part of the cell where proteins are made?

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

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

Review

1. What determines the primary structure of a protein?

2. State two functions of proteins.

3. Proteins are made out of ____________.

4. Describe the role of hemoglobin.

References

1. YassineMrabet. . Public Domain
2. CK-12 Foundation. . CC-BY-NC-SA 3.0
3. Image copyright ynse, 2010. . Used under license from Shutterstock.com

CHAPTER 8 Enzymes

- Explain the importance of enzymes to living organisms.

What is a biological catalyst?

This super fast train can obviously reach great speeds. And there's a lot of technology that helps this train go fast. Speaking of helping things go fast brings us to enzymes. Life could not exist without enzymes. Essentially, enzymes are biological catalysts that speed up biochemical reactions.

Enzymes

Enzymes and Biochemical Reactions

Most chemical reactions within organisms would be impossible under the conditions in cells. For example, the body temperature of most organisms is too low for reactions to occur quickly enough to carry out life processes. Reactants may also be present in such low concentrations that it is unlikely they will meet and collide. Therefore, the rate of most biochemical reactions must be increased by a catalyst. A **catalyst** is a chemical that speeds up chemical reactions. In organisms, catalysts are called **enzymes**. Essentially, enzymes are biological catalysts.

Like other catalysts, enzymes are not reactants in the reactions they control. They help the reactants interact but are not used up in the reactions. Instead, they may be used over and over again. Unlike other catalysts, enzymes are usually highly specific for particular chemical reactions. They generally catalyze only one or a few types of reactions.

Enzymes are extremely efficient in speeding up reactions. They can catalyze up to several million reactions per second. As a result, the difference in rates of biochemical reactions with and without enzymes may be enormous. A typical biochemical reaction might take hours or even days to occur under normal cellular conditions without an enzyme, but less than a second with an enzyme.

Enzymes, an overview of these proteins, can be viewed at http://www.youtube.com/watch?v=E90D4BmaVJM&feature=related (9:43).

MEDIA

Click image to the left for more content.

As you view *Enzymes,* focus on these concepts:

1. the role of enzymes in nature,
2. other uses of enzymes.

Importance of Enzymes

Enzymes are involved in most of the chemical reactions that take place in organisms. About 4,000 such reactions are known to be catalyzed by enzymes, but the number may be even higher.

In animals, an important function of enzymes is to help digest food. Digestive enzymes speed up reactions that break down large molecules of carbohydrates, proteins, and fats into smaller molecules the body can use. Without digestive enzymes, animals would not be able to break down food molecules quickly enough to provide the energy and nutrients they need to survive.

Summary

- Enzymes are biological catalysts. They speed up biochemical reactions.
- Enzymes are involved in most of the chemical reactions that take place in organisms.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Enzymes as Catalysts**

1. What are enzymes?
2. What are substrates? What is the enzyme-substrate complex?
3. How do enzymes work?
4. What happens to the enzyme during a reaction?

Review

1. What are enzymes?

2. Explain why organisms need enzymes to survive.

CHAPTER 9 Enzyme Function

- Explain the importance of enzymes to living organisms.
- Describe how enzymes function.

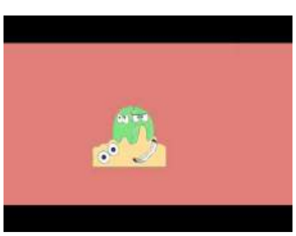
Do cells have one enzyme with lots of functions, or many enzymes, each with just one function?

Enzymes. Magical proteins necessary for life. So how do enzymes work? How do they catalyze just one specific biochemical reaction? In a puzzle, only two pieces will fit together properly. Understanding that is one of the main steps in understanding how enzymes work.

Enzyme Function

How do **enzymes** speed up biochemical reactions so dramatically? Like all **catalysts**, enzymes work by lowering the **activation energy** of chemical reactions. Activation energy is the energy needed to start a chemical reaction. This is illustrated in **Figure** 9.1. The biochemical reaction shown in the figure requires about three times as much activation energy without the enzyme as it does with the enzyme.

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



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As you view *Enzyme Animation,* focus on this concept:

1. how enzymes function.

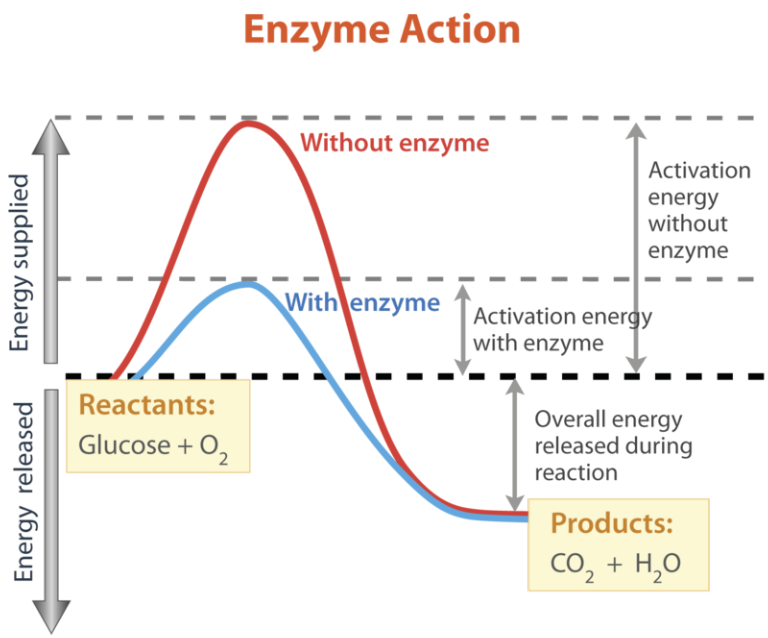


FIGURE 9.1

The reaction represented by this graph is a combustion reaction involving the reactants glucose ($C_6H_{12}O_6$) and oxygen (O_2). The products of the reaction are carbon dioxide (CO_2) and water (H_2O). Energy is also released during the reaction. The enzyme speeds up the reaction by lowering the activation energy needed for the reaction to start. Compare the activation energy with and without the enzyme.

Enzymes generally lower activation energy by reducing the energy needed for reactants to come together and react. For example:

- Enzymes bring reactants together so they don't have to expend energy moving about until they collide at random. Enzymes bind both reactant molecules (called the **substrate**), tightly and specifically, at a site on the enzyme molecule called the **active site** (**Figure** 9.2).
- By binding reactants at the active site, enzymes also position reactants correctly, so they do not have to overcome intermolecular forces that would otherwise push them apart. This allows the molecules to interact with less energy.
- Enzymes may also allow reactions to occur by different pathways that have lower activation energy.

The active site is specific for the reactants of the biochemical reaction the enzyme catalyzes. Similar to puzzle pieces fitting together, the active site can only bind certain substrates.

The activities of enzymes also depend on the temperature, ionic conditions, and the pH of the surroundings. Some enzymes work best at acidic pHs, while others work best in neutral environments.

- Digestive enzymes secreted in the acidic environment (low pH) of the stomach help break down proteins into smaller molecules. The main digestive enzyme in the stomach is **pepsin**, which works best at a pH of about 1.5. These enzymes would not work optimally at other pHs. Trypsin is another enzyme in the digestive system, which breaks protein chains in food into smaller parts. Trypsin works in the small intestine, which is not an acidic environment. Trypsin's optimum pH is about 8.
- Biochemical reactions are optimal at physiological temperatures. For example, most biochemical reactions work best at the normal body temperature of 98.6˚F. Many enzymes lose function at lower and higher temperatures. At higher temperatures, an enzyme's shape deteriorates. Only when the temperature comes back to normal does the enzyme regain its shape and normal activity.

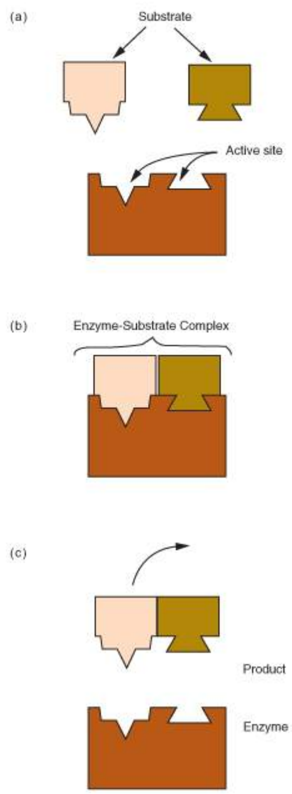


FIGURE 9.2
This enzyme molecule binds reactant molecules—called substrate—at its active site, forming an enzyme-substrate complex. This brings the reactants together and positions them correctly so the reaction can occur. After the reaction, the products are released from the enzyme's active site. This frees up the enzyme so it can catalyze additional reactions.

Summary

- Enzymes work by lowering the activation energy needed to start biochemical reactions.
- The activities of enzymes depend on the temperature, ionic conditions, and the pH of the surroundings.

Practice I

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Enzymes as Catalysts**

1. What determines an enzyme's function?
2. What molecules react in a biochemical reaction?
3. How do enzymes lower activation energy?
4. What is a transition state?
5. How many substrates can an enzyme convert into products?

Practice II

- **Enzyme Kinetics** at http://www.kscience.co.uk/animations/model.swf .

Review

1. How do enzymes speed up biochemical reactions?
2. Distinguish between the conditions needed for the proper functioning of pepsin and trypsin.

References

1. CK-12 Foundation. . CC-BY-NC-SA 3.0
2. CK-12 Foundation. . CC-BY-NC-SA 3.0

CHAPTER 10 Nucleic Acids

- Describe the structure and function of the four major types of organic compounds, focusing on nucleic acids.

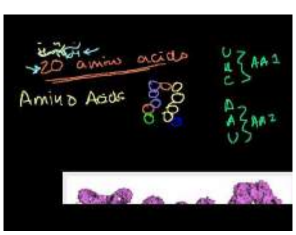
You may have heard that something is "encoded in your DNA." What does that mean?

Nucleic acids. Essentially the "instructions" or "blueprints" of life. Deoxyribonucleic acid, or DNA, is the unique blueprints to make the proteins that give you your traits. Half of these blueprints come from your mother, and half from your father. Therefore, every person that has ever lived - except for identical twins - has his or her own unique set of blueprints - or instructions - or DNA.

Nucleic Acids

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

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



MEDIA

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As you view *DNA,* focus on the following concept:

1. the structure and role of DNA.

Structure of Nucleic Acids

Each nucleotide consists of three smaller molecules:

1. sugar
2. phosphate group
3. nitrogen base

If you look at **Figure** 10.1, you will see that the sugar of one nucleotide binds to the phosphate group of the next nucleotide. These two molecules alternate to form the backbone of the nucleotide chain. This backbone is known as the *sugar-phosphate backbone.* The nitrogen bases in a nucleic acid stick out from the backbone. There are four different types of bases: cytosine (C), adenine (A), guanine (G), and either thymine (T) in DNA, or uracil (U) in RNA. In DNA, bonds form between bases on the two nucleotide chains and hold the chains together. Each type of base binds with just one other type of base: cytosine always binds with guanine, and adenine always binds with thymine. These pairs of bases are called **complementary base pairs**.

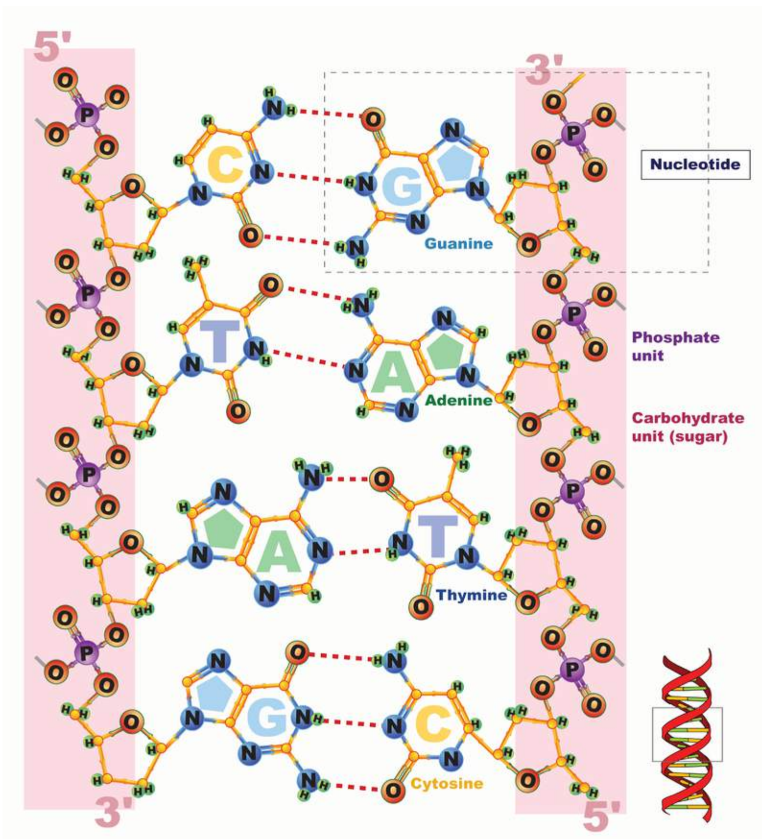

FIGURE 10.1
Nucleic Acid. Sugars and phosphate groups form the backbone of a polynucleotide chain. Hydrogen bonds between complementary bases hold two polynucleotide chains together.

The binding of complementary bases allows DNA molecules to take their well-known shape, called a **double helix**, which is shown in **Figure** 10.2. A double helix is like a spiral staircase. The double helix shape forms naturally and is very strong, making the two polynucleotide chains difficult to break apart.

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

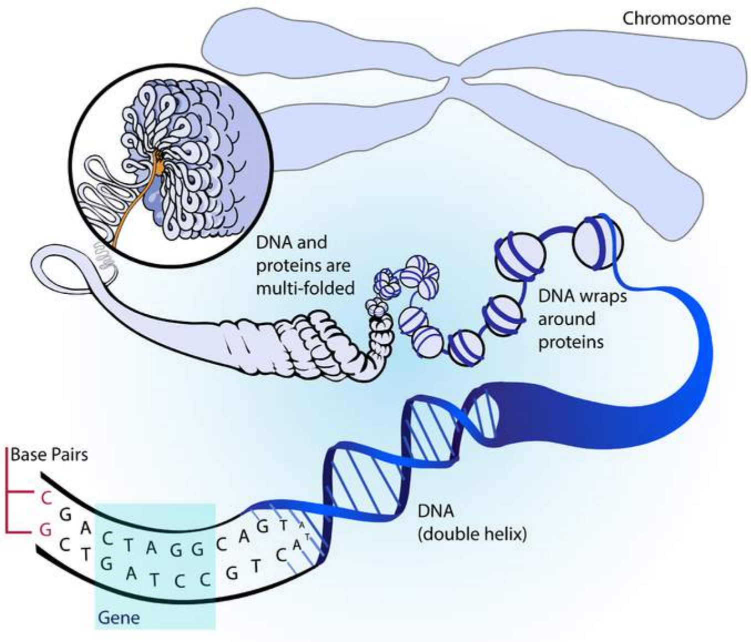

FIGURE 10.2

DNA Molecule. Bonds between complementary bases help form the double helix of a DNA molecule. The letters A, T, G, and C stand for the bases adenine, thymine, guanine, and cytosine. The sequence of these four bases in DNA is a code that carries instructions for making proteins. Shown is how the DNA winds into a chromosome.

Roles of Nucleic Acids

DNA is also known as the hereditary material or genetic information. It is found in genes, and its sequence of bases makes up a code. Between "starts" and "stops," the code carries instructions for the correct sequence of amino acids in a protein (see **Figure** 10.3). DNA and RNA have different functions relating to the genetic code and proteins. Like a set of blueprints, DNA contains the genetic instructions for the correct sequence of amino acids in proteins. RNA uses the information in DNA to assemble the correct amino acids and help make the protein. The information in DNA is passed from parent cells to daughter cells whenever cells divide. The information in DNA is also passed from parents to offspring when organisms reproduce. This is how inherited characteristics are passed from one generation to the next.

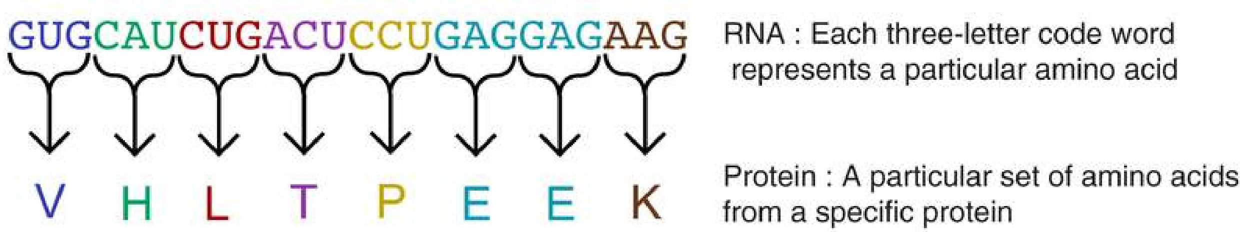

FIGURE 10.3

The letters G, U, C, and A stand for the bases in RNA. Each group of three bases makes up a code word, and each code word represents one amino acid (represented here by a single letter, such as V, H, or L). A string of code words specifies the sequence of amino acids in a protein.

Summary

- DNA and RNA are nucleic acids. Nucleic acids are built of small units called nucleotides.
- The bases of DNA are adenine, guanine, cytosine and thymine. In RNA, thymine is replaced by uracil.
- In DNA, A always binds to T, and G always binds to C.
- The shape of the DNA molecule is known as a double helix.
- DNA contains the genetic instructions for the correct sequence of amino acids in proteins. RNA uses the information in DNA to assemble the correct amino acids and help make the protein.

Practice

Use this resource to answer the questions that follow.

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

1. Why is DNA referred to as the "instructions"?
2. Where is DNA located in the cell?
3. What do A, C, G and T refer to? How can only four letters tell the cell what to do?
4. What is a gene?

Review

1. Identify the three parts of a nucleotide.

2. What is DNA?

3. What are complementary base pairs? Give an example.

4. Describe the shape of DNA.

5. How are DNA and RNA related to proteins?

References

1. Mariana Ruiz Villarreal [Wikimedia: LadyofHats]. Nucleic Acid. Public Domain
2. . DNA Molecule. CC-BY-NC-SA 3.0
3. Madprime, modified by CK-12 Foundation. . CC-BY-SA 2.5

CK-12 FlexBook

Biotechnology

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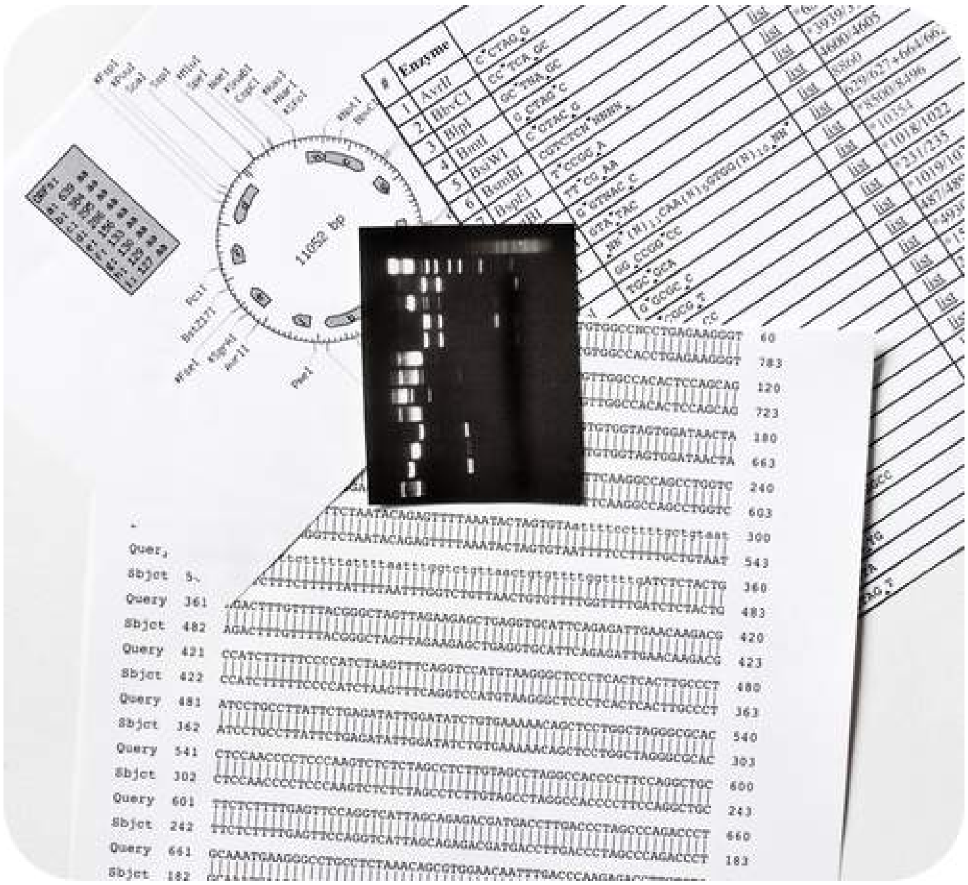
Printed: March 31, 2014

Contents

CONCEPT 1 Biotechnology

- Describe gene cloning and the polymerase chain reaction.



So how does a scientist work with DNA?

It always starts with the sequence. Once the sequence is known, so much more can be done. Specific regions can be isolated, cloned, amplified, and then used to help us.

Biotechnology Methods

Biotechnology is the use of technology to change the genetic makeup of living things for human purposes. Generally, the purpose of biotechnology is to create organisms that are useful to humans or to cure genetic disorders. For example, biotechnology may be used to create crops that resist insect pests or yield more food, or to create new treatments for human diseases.

Biotechnology: The Invisible Revolution can be seen at http://www.youtube.com/watch?v=OcG9q9cPqm4 .

What does biotechnology have to do with me? is discussed in the following video: http://www.youtube.com/watch?v=rrT5BT_7HdI&feature=related (10:01).

Biotechnology uses a variety of techniques to achieve its aims. Two commonly used techniques are gene cloning and the polymerase chain reaction.

Gene Cloning

Gene cloning is the process of isolating and making copies of a gene. This is useful for many purposes. For example, gene cloning might be used to isolate and make copies of a normal gene for gene therapy. Gene cloning involves four steps: isolation, ligation, transformation, and selection. You can watch an interactive animation about gene cloning at this link: http://www.teachersdomain.org/asset/biot09_int_geneclone/ .

1. In isolation, an enzyme (called a restriction enzyme) is used to break DNA at a specific base sequence. This is done to isolate a gene.
2. During **ligation** , the enzyme **DNA ligase** combines the isolated gene with plasmid DNA from bacteria. (A **plasmid** is circular DNA that is not part of a chromosome and can replicate independently.) Ligation is illustrated in **Figure** 1.1 . The DNA that results is called **recombinant DNA** .
3. In **transformation** , the recombinant DNA is inserted into a living cell, usually a bacterial cell. Changing an organism in this way is also called **genetic engineering** .
4. Selection involves growing transformed bacteria to make sure they have the recombinant DNA. This is a necessary step because transformation is not always successful. Only bacteria that contain the recombinant DNA are selected for further use.

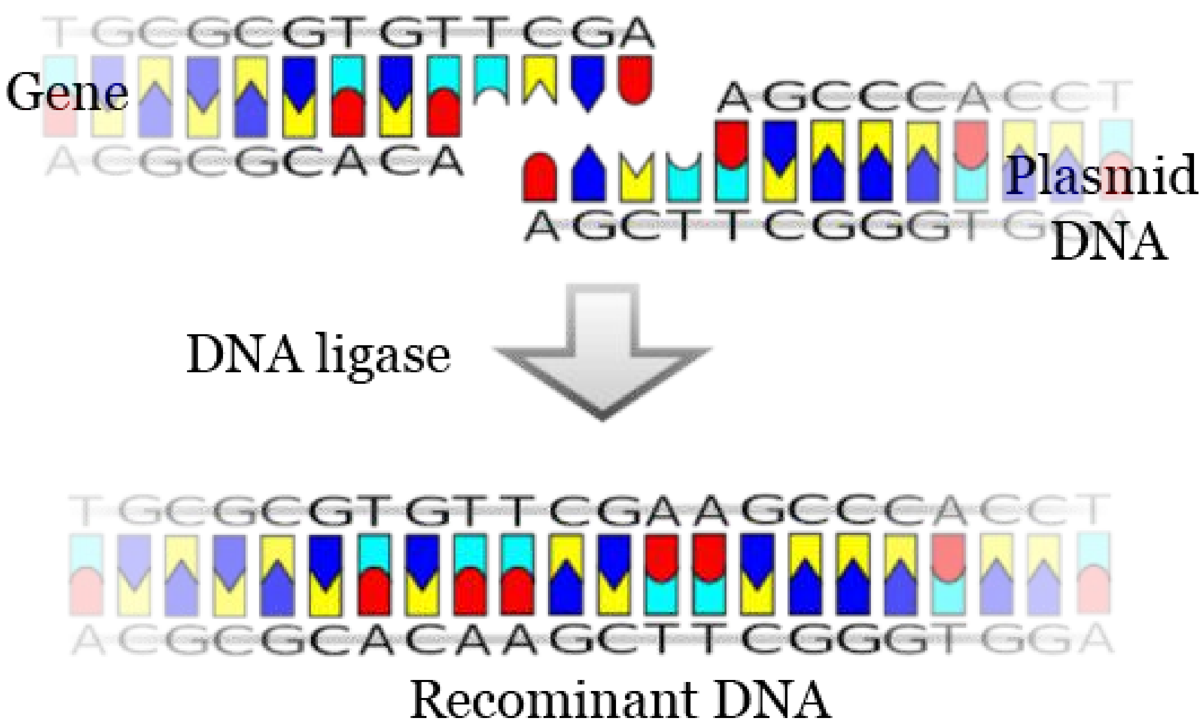


FIGURE 1.1

Ligation. DNA ligase joins together an isolated gene and plasmid DNA. This produces recombinant DNA.

Recombinant DNA technology is discussed in the following videos and animations: http://www.youtube.com/watch?v=x2jUMG2E-ic (4.36), http://www.youtube.com/watch?v=Jy15BWVxTC0 (0.50), http://www.youtube.com/watch?v=sjwNtQYLKeU&feature=related (7.20), http://www.youtube.com/watch?v=Fi63VjfhsfI (3:59).

Polymerase Chain Reaction

The **polymerase chain reaction (PCR)** makes many copies of a gene or other DNA segment. This might be done in order to make large quantities of a gene for genetic testing. PCR involves three steps: **denaturing** , **annealing** , and **extension** . The three steps are illustrated in **Figure** 1.2 . They are repeated many times in a cycle to make large quantities of the gene. You can watch animations of PCR at these links:

- http://www.dnalc.org/resources/3d/19-polymerase-chain-reaction.html
- http://www.teachersdomain.org/asset/biot09_int_pcr/ .

1. Denaturing involves heating DNA to break the bonds holding together the two DNA strands. This yields two single strands of DNA.
2. Annealing involves cooling the single strands of DNA and mixing them with short DNA segments called **primers** . Primers have base sequences that are complementary to segments of the single DNA strands. As a result, bonds form between the DNA strands and primers.
3. Extension occurs when an enzyme (**Taq polymerase** or Taq DNA polymerase) adds nucleotides to the primers. This produces new DNA molecules, each incorporating one of the original DNA strands.

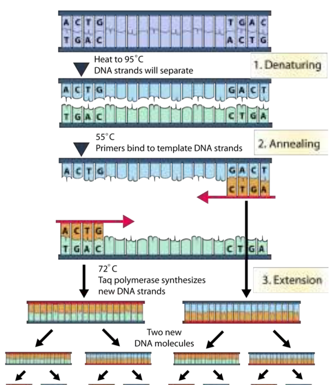


FIGURE 1.2

The Polymerase Chain Reaction. The polymerase chain reaction involves three steps. High temperatures are needed for the process to work. The enzyme Taq polymerase is used in step 3 because it can withstand high temperatures.

Summary

- Biotechnology is the use of technology to change the genetic makeup of living things for human purposes.
- Gene cloning is the process of isolating and making copies of a DNA segment such as a gene.
- The polymerase chain reaction makes many copies of a gene or other DNA segment.

Practice

Use this resource and the videos associated with this resource to answer the questions that follow.

- **Polymerase Chain Reaction** at http://www.dnalc.org/resources/spotlight/index.html .

1. Who developed PCR?
2. What does PCR allow?
3. Describe the 3 steps involved in PCR.
4. Approximately how many copies of a specific segment of DNA can be made by PCR?

Review

1. Define biotechnology.
2. What is recombinant DNA?
3. Identify the steps of gene cloning.
4. What is the purpose of the polymerase chain reaction?

References

1. Madeleine Price Ball, modified by CK-12 Foundation. . CC-BY-SA 2.5
2. CK-12 Foundation. . CC-BY-NC-SA 3.0

CONCEPT 2 Biotechnology Applications

- Explain how DNA technology is applied in medicine and agriculture.

Why would anyone grow plants like this?

Developing better crops is a significant aspect of biotechnology. Crops that are resistant to damage from insects or droughts must have a significant role in the world's future. And it all starts in the lab.

Applications of Biotechnology

Methods of biotechnology can be used for many practical purposes. They are used widely in both medicine and agriculture. To see how biotechnology can be used to solve crimes, watch the video "Justice DNA—Freeing the Innocent" at the following link: http://www.pubinfo.vcu.edu/secretsofthesequence/playlist_frame.asp .

Applications in Medicine

In addition to gene therapy for genetic disorders, biotechnology can be used to transform bacteria so they are able to make human proteins. **Figure** 2.1 shows how this is done to produce a **cytokine** , which is a small protein that helps fight infections. Proteins made by the bacteria are injected into people who cannot produce them because of mutations.

Insulin was the first human protein to be produced in this way. Insulin helps cells take up glucose from the blood. People with type 1 diabetes have a mutation in the gene that normally codes for insulin. Without insulin, their blood

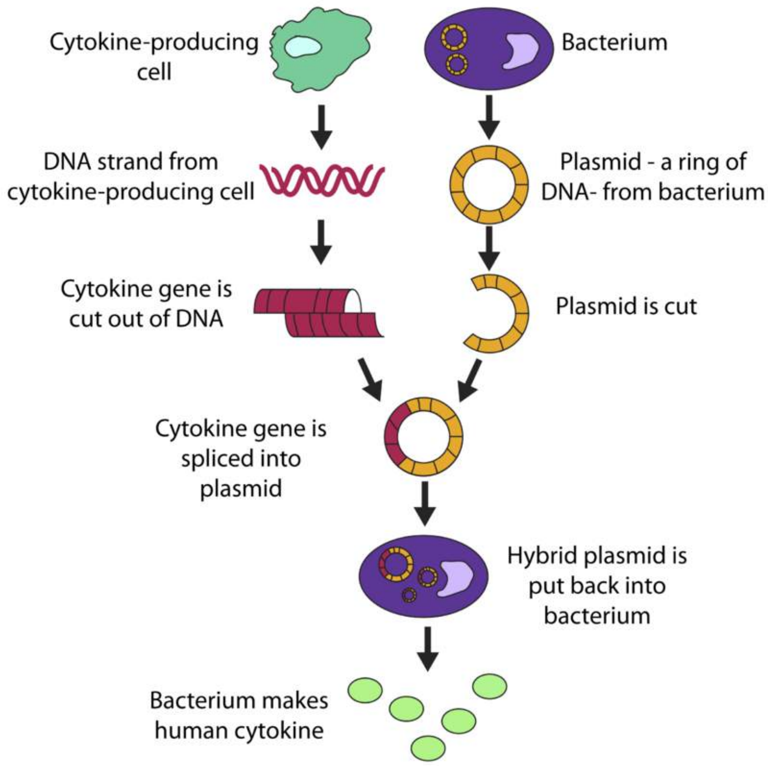


FIGURE 2.1

Genetically Engineering Bacteria to Produce a Human Protein. Bacteria can be genetically engineered to produce a human protein, such as a cytokine. A cytokine is a small protein that helps fight infections.

glucose rises to harmfully high levels. At present, the only treatment for type 1 diabetes is the injection of insulin from outside sources. Until recently, there was no known way to make insulin outside the human body. The problem was solved by gene cloning. The human insulin gene was cloned and used to transform bacterial cells, which could then produce large quantities of human insulin.

Pharmacogenomics

We know that, thanks to our DNA, each of us is a little bit different. Some of those differences are obvious, like eye and hair color. Others are not so obvious, like how our bodies react to medication. Researchers are beginning to look at how to tailor medical treatments to our genetic profiles, in a relatively new field called **pharmacogenomics** . Some of the biggest breakthroughs have been in cancer treatment. For additional information on this "personalized medicine," listen to http://www.kqed.org/quest/radio/personalized-medicine and see http://www.kqed.org/quest/blog/2009/09/11/reporters-notes-personalized-medicine/ .

Synthetic Biology

Imagine living cells acting as memory devices, biofuels brewing from yeast, or a light receptor taken from algae that makes photographs on a plate of bacteria. The new field of **synthetic biology** is making biology easier to engineer so that new functions can be derived from living systems. Find out the tools that synthetic biologists are using and the exciting things they are building at http://www.kqed.org/quest/television/decoding-synthetic-biology and http://www.kqed.org/quest/television/web-extra-synthetic-biology-extended-interview .

MEDIA

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Applications in Agriculture

Biotechnology has been used to create transgenic crops. **Transgenic crops** are genetically modified with new genes that code for traits useful to humans. The diagram in **Figure** 2.2 shows how a transgenic crop is created. You can learn more about how scientists create transgenic crops with the interactive animation "Engineer a Crop: Transgenic Manipulation" at this link: http://www.pbs.org/wgbh/harvest/engineer/transgen.html .

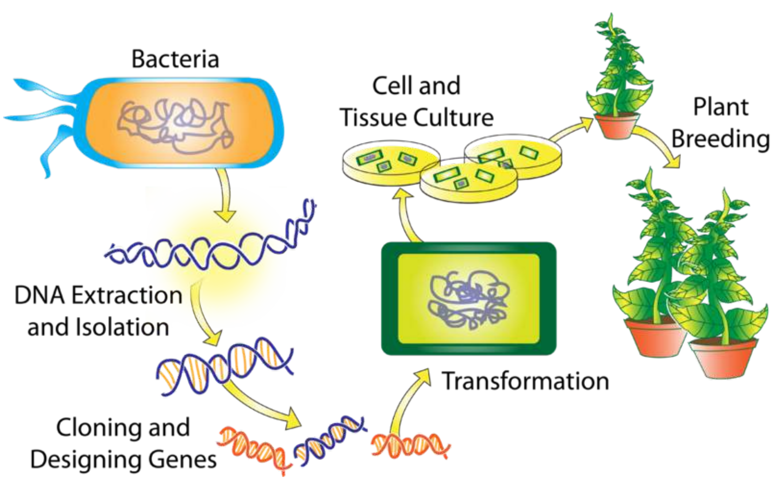

FIGURE 2.2

Creating a Transgenic Crop. A transgenic crop is genetically modified to be more useful to humans.

Transgenic crops have been created with a variety of different traits, such as yielding more food, tasting better, surviving drought, and resisting insect pests. Scientists have even created a transgenic purple tomato that contains a cancer-fighting compound (see **Figure** 2.3). To learn how scientists have used biotechnology to create plants that can grow in salty soil, watch the video "Salt of the Earth - Engineering Salt-tolerant Plants" at this link: http://www.sosq.vcu.edu/videos.aspx .

Biotechnology in agriculture is discussed at http://www.youtube.com/watch?v=IY3mfgbe-0c (6:40).

FIGURE 2.3
Transgenic Purple Tomato. A purple tomato is genetically modified to contain a cancer-fighting compound. A gene for the compound was transferred into normal red tomatoes.

Summary

- Biotechnology can be used to transform bacteria so they are able to make human proteins, such as insulin.
- It can also be used to create transgenic crops, such as crops that yield more food or resist insect pests.

Practice I

Use these resources to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Agricultural Applications**

1. How can biotechnology help with agricultural issues?
2. What is test-tube cloning?
3. Describe Golden rice.
4. Describe the applications of a Ti plasmid.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Medical Applications**

1. Describe how advances in biotechnology have helped medical applications.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Legal Applications**

1. What is a DNA fingerprint? Does every person have an unique DNA fingerprint?
2. How is a DNA fingerprint used?

Practice II

- **Craig Venter** at http://www.tedmed.com/videos-info?name=Craig_Venter_at_TEDMED_2010&q=updated&year=all

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Review

1. Make a flow chart outlining the steps involved in creating a transgenic crop.
2. Explain how bacteria can be genetically engineered to produce a human protein.

References

1. CK-12 Foundation. . CC-BY-NC-SA 3.0
2. CK-12 Foundation. . CC-BY-NC-SA 3.0
3. Purple tomato: Dave; Red tomato: spisharam. . Purple tomato: GNU-FDL 1.2; Red tomato: CC-BY-SA 2.0

Concept 3 Recombinant DNA

- Explain how recombinant DNA technology works.

Can we alter DNA?

You might think that DNA is stable and unchangeable. For the most part you are right. However, there are new technologies that allow us to alter the DNA of humans and other organisms.

Recombinant DNA

Recombinant DNA is the combination of DNA from two different sources. For example, it is possible to place a human gene into bacterial DNA. Recombinant DNA technology is useful in gene cloning and in identifying the function of a gene.

Recombinant DNA technology can also be used to produce useful proteins, such as insulin. To treat diabetes, many people need insulin. Previously, insulin had been taken from animals. Through recombinant DNA technology, bacteria were created that carry the human gene which codes for the production of insulin. These bacteria become tiny factories that produce this protein. Recombinant DNA technology helps create insulin so it can be used by humans.

Recombinant DNA technology is used in gene cloning. A **clone** is an exact copy. Genes are cloned for many reasons, including use in medicine and in agriculture.

Below are the steps used to copy, or clone, a gene:

1. A gene or piece of DNA is put in a **vector** , or carrier molecule, producing a recombinant DNA molecule.
2. The vector is placed into a host cell, such as a bacterium.
3. The gene is copied (or cloned) inside of the bacterium. As the bacterial DNA is copied, so is the vector DNA. As the bacteria divide, the recombinant DNA molecules are divided between the new cells. Over a 12 to 24 hour period, millions of copies of the cloned DNA are made.
4. The cloned DNA can produce a protein (like insulin) that can be used in medicine or in research.

Plasmids

Bacteria have small rings of DNA in the cytoplasm, called **plasmids** (**Figure** 3.1). When putting foreign DNA into a bacterium, the plasmids are often used as a vector. Viruses can also be used as vectors.

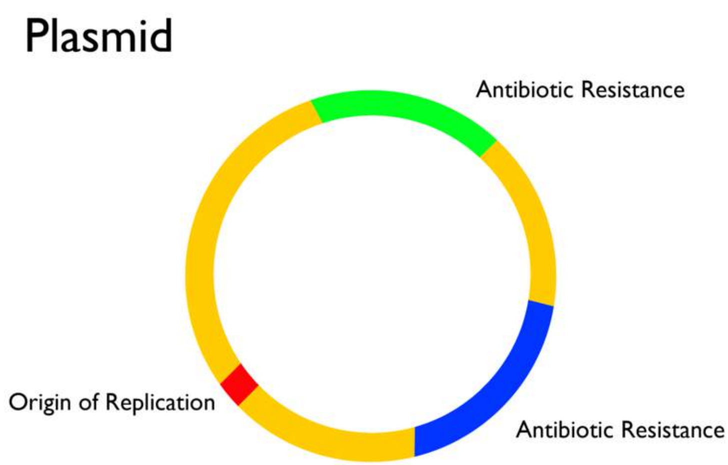


FIGURE 3.1
This image shows a drawing of a plasmid. The plasmid has two large segments and one small segment depicted. The two large segments (green and blue) indicate antibiotic resistances usually used in a screening procedure. The antibiotic resistance segments ensure only bacteria with the plasmid will grow. The small segment (red) indicates an origin of replication. The **origin of replication** is where DNA replication starts, copying the plasmid.

Vocabulary

- **clone** : To make a copy.
- **origin of replication** : Where DNA replication starts, copying the plasmid.
- **plasmid** : Small ring of DNA in the cytoplasm of a bacterium.
- **recombinant DNA** : Combination of DNA from two different sources.
- **vector** : Carrier molecule for a segment of DNA.

Summary

- Recombinant DNA is the combination of DNA from two different sources.
- Gene cloning is making an exact copy of a gene.

Practice

Use the resource below to answer the questions that follow.

- **Stanley Cohen and Herbert Boyer** at http://www.dnalc.org/view/16033-Stanley-Cohen-and-Herbert-Boyer-1972.html

1. What bacteria were used to create the first recombinant DNA?
2. In the plasmid pSC101, what does the SC stand for? What gene did this plasmid carry?
3. What does DNA ligase do? How is it used in recombinant DNA technology?
4. What did Cohen and Boyer do to get a bacteria to take up the recombinant plasmid they had made? What does this suggest about how bacteria respond to changing environmental conditions?
5. Since not all of the plasmids that Cohen and Boyer created carried both genes they were seeking to transfer, how did they isolate the bacteria that had plasmids with both genes?

6. Did the technique from question 5 result in bacterial colonies containing only plasmids with both genes? Explain your answer fully.

Review

1. What is recombinant DNA technology?
2. Explain the process of gene cloning.

References

1. CK-12 Foundation - Sam McCabe. . CC-BY-NC-SA 3.0

Concept 4 Biotechnology in Agriculture

- Explain how biotechnology can be used in agriculture.

Have you ever eaten genetically engineered foods?

Most likely, yes. The majority of the corn in the United States is genetically engineered. Corn syrup is used to sweeten many things, like this Coke. Corn is also fed to the cows that provided this hamburger.

Biotechnology in Agriculture

Biotechnology is changing the genetic makeup of living things to make a useful product. Biotechnology has led scientists to develop useful applications in agriculture and food science. These include the development of

transgenic crops. In transgenic crops, genes are placed into plants to give the crop a beneficial trait. Benefits include:

- Improved yield from crops.
- Increased resistance of crops to environmental stresses.
- Increased nutritional qualities of food crops.
- Improved taste, texture or appearance of food.
- Reduced dependence on fertilizers, insecticides, and other chemicals.

Crops are obviously dependent on environmental conditions. Drought can destroy crop yields, as can too much rain and floods. But what if crops could be developed to withstand these harsh conditions?

Biotechnology will allow the development of crops containing genes that will help them to withstand harsh conditions. For example, drought and salty soil are two significant factors affecting how well crops grow. But there are crops that can withstand these harsh conditions. Why? Probably because of that plant's genetics. So scientists are studying plants that can cope with these extreme conditions. They hope to identify and isolate the genes that control these beneficial traits. The genes could then be transferred into more desirable crops, with the hope of producing the same traits in those crops.

Thale cress (**Figure** 4.1), a species of ***Arabidopsis*** (*Arabidopsis thaliana*), is a tiny weed that is often used for plant research, because it is very easy to grow, and its DNA has been mapped. Scientists have identified a gene from this plant, At-DBF2, that gives the plant resistance to some environmental stresses. When this gene is inserted into tomato and tobacco cells, the cells were able to withstand environmental stresses like salt, drought, cold, and heat far better than ordinary cells. If these results prove successful in larger trials, then At-DBF2 genes could help in engineering crops that can better withstand harsh environments.

FIGURE 4.1
Thale cress (*Arabidopsis thaliana*).

Vocabulary

- ***Arabidopsis*** (*Arabidopsis thaliana*): Tiny weed that is often used for plant research, because it is very easy to grow, and its DNA has been mapped.
- **biotechnology** : Changing the genetic makeup of living things to make a useful product.
- **transgenic** : Containing a gene transferred from another organism.

Summary

- Transgenic crops have extra genes that were placed into them to give the crop a beneficial trait.
- In the future, crops may be genetically altered to withstand harsh conditions.

Practice

Use the resources below to answer the questions that follow.

- **How Do You Disable A Gene** at http://www.youtube.com/watch?v=QEbVpj7EbwU (6:19)

MEDIA
Click image to the left for more content.

1. What approach do scientists use to disable genes in *Arabidopsis* ? How does this work? Be as specific and complete in your answer as you can.
2. What do scientists use to insert DNA into *Arabidopsis* ? How does this work?
3. Can scientists insert whole genes into *Arabidopsis* ? How is this situation useful for agriculture? Explain your answer as fully as you can.
4. How are the *Araidopsis* mutants valuable to botanists in general?

- Go to this site to learn some of the pros and cons about using biotechnology in agriculture: http://www.ornl.gov/sci/techresources/Human_Genome/elsi/gmfood.shtml

1. What are the purported environmental benefits to using biotechnology in agriculture?
2. What are the purported environmental dangers to using biotechnology in agriculture?
3. What is the purported societal benefit to using biotechnology in agriculture? Can you think of any others?
4. What is the purported societal danger to using biotechnology in agriculture? Can you think of any others?

Review

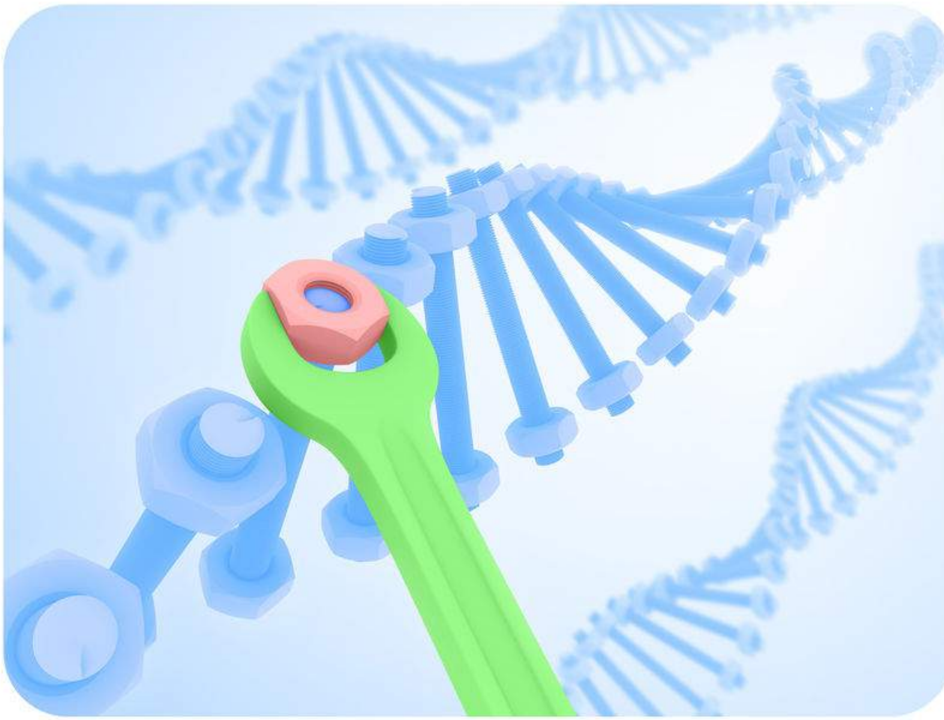
1. What is a transgenic plant?
2. What are some examples of how biotechnology might be used in agriculture?

References

1. Quentin Groom (Wikimedia: Qgroom). Thale cress ("Arabidopsis thaliana"). public domain

Concept 5 Gene Therapy

- Describe how gene therapy works.



Can doctors fix your DNA?

There are many genetic disorders that are due to a single gene. What if we could fix this faulty gene? With the development of gene therapy, that may eventually be possible for many types of genetic disorders.

Gene Therapy

Gene therapy is the insertion of genes into a person's cells to cure a genetic disorder. Could gene therapy be the cure for AIDS? No, AIDS is caused by a virus. Gene therapy only works to fix disorders caused by a faulty gene. The patient would have had this disorder from birth. Though gene therapy is still in experimental stages, the common use of this therapy may occur during your lifetime.

There are two main types of gene therapy:

1. One done inside the body (***in vivo***).
2. One done outside the body (***ex vivo***).

Both types of gene therapy use a **vector** , or carrier molecule for the gene. The vector helps incorporate the desired gene into the patient's DNA. Usually this vector is modified viral DNA in which the viral genes have been removed.

In Vivo Gene Therapy

During *in vivo* gene therapy, done inside the body, the vector with the gene of interest is introduced directly into the patient and taken up by the patient's cells (**Figure** 5.1). For example, cystic fibrosis gene therapy is targeted at the respiratory system, so a solution with the vector can be sprayed into the patient's nose. Recently, *in vivo* gene therapy was also used to partially restore the vision of three young adults with a rare type of eye disease.

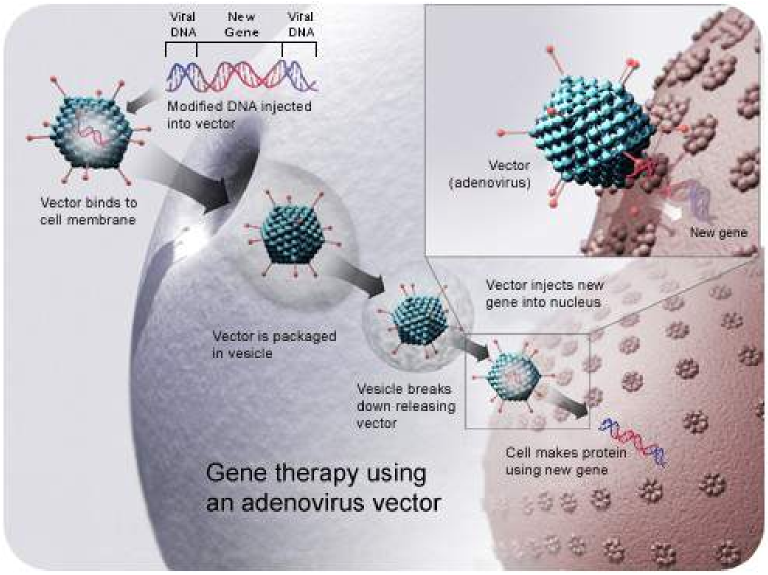


FIGURE 5.1
During gene therapy, adenovirus is a possible vector to carry the desired gene and insert it into the patient's DNA.

In *ex vivo* gene therapy, done outside the body, cells are removed from the patient and the proper gene is inserted using a virus as a vector. The modified cells are placed back into the patient.

One of the first uses of this type of gene therapy was in the treatment of a young girl with a rare genetic disease, adenosine deaminase deficiency, or ADA deficiency. People with this disorder are missing the ADA enzyme, which breaks down a toxin called deoxyadenosine. If the toxin is not broken down, it accumulates and destroys immune cells. As a result, individuals with ADA deficiency do not have a healthy immune system to fight off infections. In the gene therapy treatment for this disorder, bone marrow stem cells were taken from the girl's body, and the missing gene was inserted into these cells outside the body. Then the modified cells were put back into her bloodstream. This treatment successfully restored the function of her immune system, but only with repeated treatments.

Vocabulary

- ***ex vivo*** : Performed in an artificial environment outside the living organism.
- **gene therapy** : Insertion of genes into a person's cells to cure a genetic disorder.
- ***in vivo*** : Performed inside the living organism.
- **vector** : Carrier molecule for a segment of DNA.

Summary

- Gene therapy, the insertion of genes into a person's cells to cure a genetic disorder, can be *ex vivo* (outside the body) or *in vivo* (inside the body).
- Gene therapy is still in the experimental stages, but some trials have been successful.

Practice

Use the resource below to answer the questions that follow.

- **Gene Therapy: Cystic Fibrosis** at http://learn.genetics.utah.edu/content/tech/genetherapy/cysticfibrosis/

1. What is an "ionic gradient"? How does cystic fibrosis affect the ionic gradient in cells? What effect does this have?
2. What five questions need to be answered to determine if a disease is a good candidate for gene therapy?
3. Why would an adenovirus vector be a bad choice for treating cystic fibrosis?
4. What gene is responsible for virus replication?
5. Once you have created a vector to deliver your gene, how do you produce a large number of the vector?
6. How many types of vectors did researchers try to use to develop an effective gene therapy for cystic fibrosis?
7. Is there an effective gene therapy treatment for cystic fibrosis?

Review

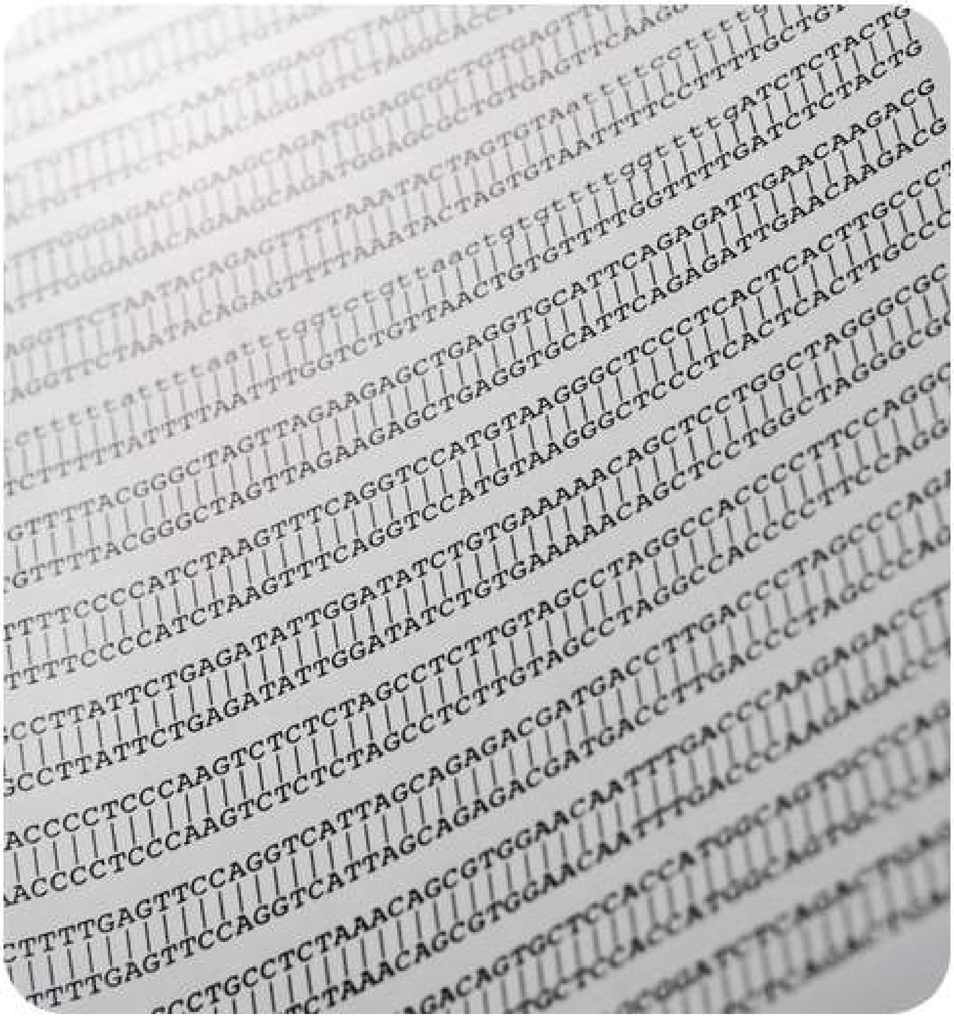
1. Could gene therapy someday cure the common cold? Why or why not?
2. What's the difference between *ex vivo* and *in vivo* gene therapy?

References

1. Courtesy of the National Institutes of Health (NIH). . Public Domain

CONCEPT 6 Human Genome

- Define the human genome.



All these ACGTs. What are they?

Over three billion of them from a human form the human genome - the human genetic material - all the information needed to encode a human being. It would take about 9.5 years to read out loud - without stopping - the more than three billion pairs of bases in one person's genome.

The Human Genome

What makes each one of us unique? You could argue that the environment plays a role, and it does to some extent. But most would agree that your parents have something to do with your uniqueness. In fact, it is our **genes** that make each one of us unique – or at least genetically unique. We all have the genes that make us human: the genes for skin and bones, eyes and ears, fingers and toes, and so on. However, we all have different skin colors, different bone sizes, different eye colors and different ear shapes. In fact, even though we have the same genes, the products of these genes work a little differently in most of us. And that is what makes us unique.

The **human genome** is the **genome** - all the DNA - of *Homo sapiens*. Humans have about 3 billion bases of information, divided into roughly 20,000 to 22,000 genes, which are spread among non-coding sequences and distributed among 24 distinct chromosomes (22 **autosomes** plus the X and Y **sex chromosomes**) (6.1). The genome is all of the hereditary information encoded in the DNA, including the genes and non-coding sequences.

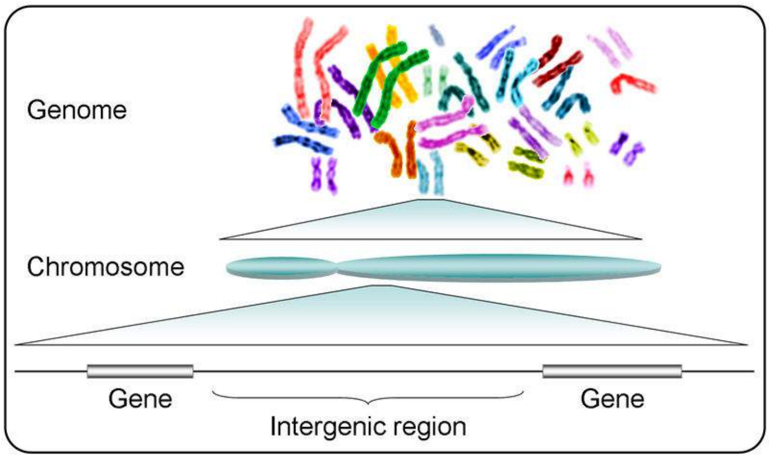


FIGURE 6.1
Human Genome, Chromosomes, and Genes. Each chromosome of the human genome contains many genes as well as noncoding intergenic (between genes) regions. Each pair of chromosomes is shown here in a different color.

Thanks to the **Human Genome Project** , scientists now know the DNA sequence of the entire human genome. The Human Genome Project is an international project that includes scientists from around the world. It began in 1990, and by 2003, scientists had sequenced all 3 billion base pairs of human DNA. Now they are trying to identify all the genes in the sequence. The Human Genome Project has produced a reference sequence of the human genome. The human genome consists of protein-coding **exons** , associated **introns** and regulatory sequences, genes that encode other RNA molecules, and "junk" DNA - regions in which no function as yet been identified.

FIGURE 6.2
You can watch a video about the Human Genome Project and how it cracked the "code of life" at this link: http://www.pbs.org/wgbh/nova/genome/program.html .

Our Molecular Selves video discusses the human genome, and is available at http://www.genome.gov/25520211 or http://www.youtube.com/watch?v=XuUpnAz5y1g&feature=related .

MEDIA
Click image to the left for more content.

ENCODE: The Encyclopedia of DNA Elements

In September 2012, ENCODE, The **Enc**yclopedia **o**f **D**NA **E**lements, was announced. ENCODE was a colossal project, involving over 440 scientists in 32 labs the world-over, whose goal was to understand the human genome. It had been thought that about 80% of the human genome was "junk" DNA. ENCODE has established that this is not true. Now it is thought that about 80% of the genome is active. In fact, much of the human genome is regulatory sequences, on/off switches that tell our genes what to do and when to do it. Dr. Eric Green, director of the National Human Genome Research Institute of the National Institutes of Health which organized this project, states, "It's this incredible choreography going on, of a modest number of genes and an immense number of ... switches that are choreographing how those genes are used."

It is now thought that at least three-quarters of the genome is involved in making RNA, and most of this RNA appears to help regulate gene activity. Scientists have also identified about 4 million sites where proteins bind to DNA and act in a regulatory capacity. These new findings demonstrate that the human genome has remarkable and precise, and complex, controls over the expression of genetic information within a cell.

See *ENCODE data describes function of human genome* at http://www.genome.gov/27549810 for additional information.

Summary

- The human genome consists of about 3 billion base pairs of DNA.
- In 2003, the Human Genome Project finished sequencing all 3 billion base pairs.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Non-Majors Biology → Search: **Human Genome Project**

1. What were 3 goals of the Human Genome Project?
2. How many genes are on chromosome #1?
3. How big is the human genome?
4. How much genetic variation is there among people?
5. How much of the genome is not part of any gene?

Review

1. Describe the human genome.

2. What has the Human Genome Project achieved?

References

1. Plociam. . CC-BY 2.0

CONCEPT 7 Human Genome Project

- Explain what sequencing a genome tells us.

What is your genetic code?

The letters here represent the bases in someone's DNA. It is now possible to find out a person's entire genetic code by determining all the bases in his or her DNA. What might be the benefits?

Human Genome Project

A person's **genome** is all of his or her genetic information. In other words, the human genome is all the information that makes us human.

The **Human Genome Project** (**Figure** 7.1) was an international effort to sequence all 3 billion bases that make up our DNA and to identify within this code more than 20,000 human genes. Scientists also completed a chromosome map, identifying where the genes are located on each of the chromosomes. The Human Genome Project was completed in 2003. Though the Human Genome Project is finished, analysis of the data will continue for many years.

Exciting applications of the Human Genome Project include the following:

- The genetic basis for many diseases can be more easily determined. Now there are tests for over 1,000 genetic disorders.
- The technologies developed during this effort, and since the completion of this project, will reduce the cost of sequencing a person's genome. This may eventually allow many people to sequence their individual genome.
- Analysis of your own genome could determine if you are at risk for specific diseases.
- Knowing you might be genetically prone to a certain disease would allow you to make preventive lifestyle changes or have medical screenings.

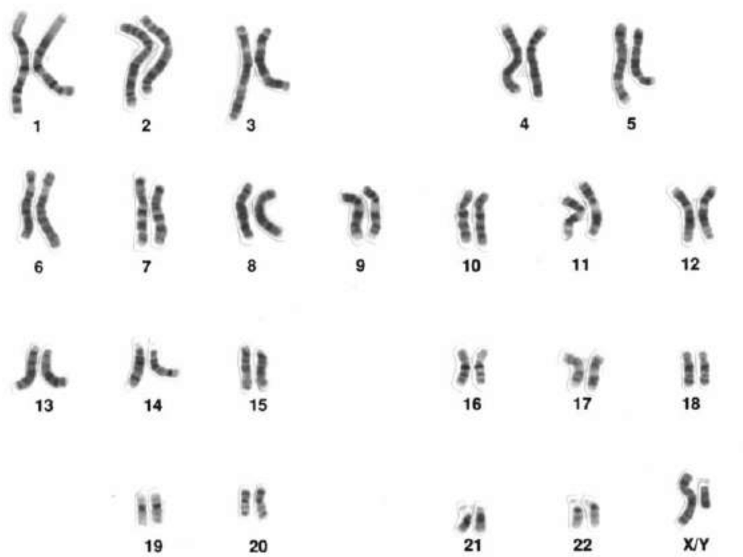


FIGURE 7.1
To complete the Human Genome Project, all 23 pairs of chromosomes in the human body were sequenced. Each chromosome contains thousands of genes. This is a karyotype, a visual representation of an individual's chromosomes lined up by size.

Vocabulary

- **genome** : Complete genetic code of an organism.
- **Human Genome Project** : International effort to sequence all 3 billion bases that make up our DNA and to identify within this code more than 20,000 human genes.

Summary

- The Human Genome Project involved an international effort to sequence all 3 billion bases that make up our DNA and to identify within this code more than 20,000 human genes.
- Analysis of your own genome could determine if you are at risk for specific diseases.

Practice

Use the resource below to answer the questions that follow.

- **PCR Virtual Lab** at http://learn.genetics.utah.edu/content/labs/pcr/

1. How many copies of DNA sequences can be made in a matter of hours using PCR?
2. How much DNA do you need to start the PCR process?
3. Can you use the same primers for every DNA sequence you want to investigate? Why or why not?
4. How many "ingredients" go into your PCR tube? What are they?
5. Why was PCR technology crucial to the sequencing of the human genome? Explain your answer as fully as you can.

Review

1. Describe the Human Genome Project.
2. Would you want to know your own genome? Why or why not?

References

1. Courtesy of the National Human Genome Research Institute. . Public Domain

Concept 8 Ethical, Legal, and Social Issues of Biotechnology

- Identify some of the ethical, legal, and social issues raised by biotechnology.

Right or wrong? Good or bad? Legal or illegal?

The completion of The Human Genome Project is one of the most important scientific events of the past 50 years. However, is knowing all of our DNA a good thing? The advancement of biotechnology has raised many interesting ethical, legal and social questions.

Ethical, Legal, and Social Issues

Imagine someone analyzes part of your DNA. Who controls that information? What if your health insurance company found out you were predisposed to develop a devastating genetic disease. Might they decide to cancel your insurance? Privacy issues concerning genetic information is an important issue in this day and age.

ELSI stands for Ethical, Legal and Social Issues. It's a term associated with the Human Genome project. This project didn't only have the goal to identify all the genes in the human genome, but also to address the ELSI that might arise from the project. Rapid advances in DNA-based research, human genetics, and their applications have resulted in new and complex ethical and legal issues for society.

Concerns from Biotechnology

The use of biotechnology has raised a number of ethical, legal, and social issues. Here are just a few:

- Who owns genetically modified organisms such as bacteria? Can such organisms be patented like inventions?
- Are genetically modified foods safe to eat? Might they have unknown harmful effects on the people who consume them?

- Are genetically engineered crops safe for the environment? Might they harm other organisms or even entire ecosystems?
- Who controls a person's genetic information? What safeguards ensure that the information is kept private?
- How far should we go to ensure that children are free of mutations? Should a pregnancy be ended if the fetus has a mutation for a serious genetic disorder?

Addressing such issues is beyond the scope of this concept. The following example shows how complex the issues may be:

A strain of corn has been created with a gene that encodes a natural pesticide. On the positive side, the **transgenic** corn is not eaten by insects, so there is more corn for people to eat. The corn also doesn't need to be sprayed with chemical pesticides, which can harm people and other living things. On the negative side, the transgenic corn has been shown to cross-pollinate nearby milkweed plants. Offspring of the cross-pollinated milkweed plants are now known to be toxic to monarch butterfly caterpillars that depend on them for food. Scientists are concerned that this may threaten the monarch species as well as other species that normally eat monarchs.

As this example shows, the pros of biotechnology may be obvious, but the cons may not be known until it is too late. Unforeseen harm may be done to people, other species, and entire ecosystems. No doubt the ethical, legal, and social issues raised by biotechnology will be debated for decades to come. For a recent debate about the ethics of applying biotechnology to humans, watch the video at the link below. In the video, a Harvard University professor of government and a Princeton University professor of bioethics debate the science of "perfecting humans." http://www.youtube.com/watch?v=-BPna-fSNOE

Summary

- Biotechnology has raised a number of ethical, legal, and social issues. For example, are genetically modified foods safe to eat, and who controls a person's genetic information?

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Practical and Ethical Concerns**

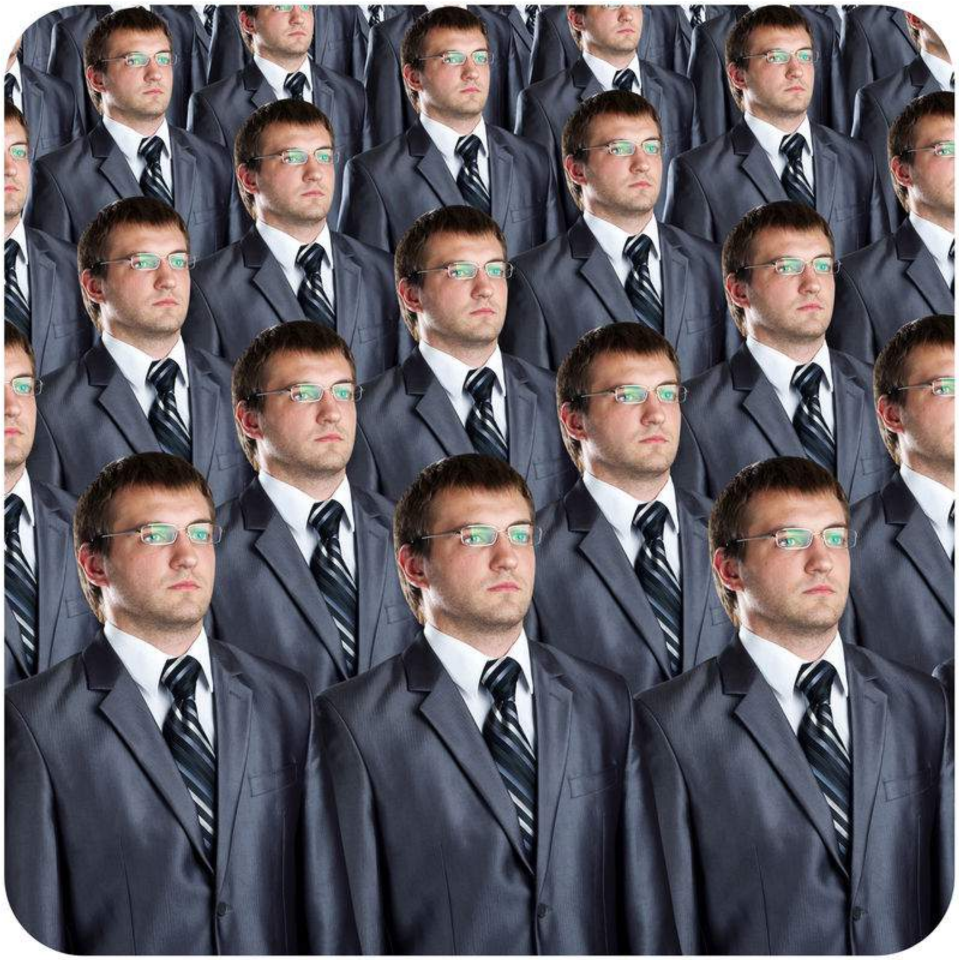
1. What are two concerns associated with biotechnology?
2. Why could genetically engineered plants replace naturally grown plants?
3. What is cloning? What was the first cloned large mammal?
4. What are two ethical considerations associated with the human genome sequence?

Review

1. Identify an ethical, legal, or social issue raised by biotechnology. State your view on the issue, and develop a logical argument to support your view.

CONCEPT 9 Cloning

- Describe the process of cloning.



Would you like to clone yourself?

Although it's illegal to clone humans in the United States, it is possible to clone many types of animals. What might be the consequences if we allowed human cloning?

Cloning

Cloning is the process of creating an exact replica of an organism. The clone's DNA is exactly the same as the parent's DNA. Bacteria and plants have long been able to clone themselves through asexual reproduction. In animals, however, cloning does not happen naturally. In 1997, that all changed when a sheep named Dolly was the first mammal ever to be successfully cloned. Other animals can now also be cloned in a laboratory.

The process of producing an animal like Dolly starts with a single cell from the animal that is going to be cloned. Below are the steps involved in the process of cloning:

1. In the case of Dolly, cells from the mammary glands were taken from the adult that was to be cloned. But other somatic cells can be used. **Somatic cells** come from the body and are not gametes like sperm or egg.

2. The nucleus is removed from this cell.
3. The nucleus is placed in a donor egg that has had its nucleus removed.
4. The new cell is stimulated with an electric shock and embryo development begins, as if it were a normal **zygote** .
5. The resulting embryo is implanted into a mother sheep, where it continue its development (**Figure** 9.1).

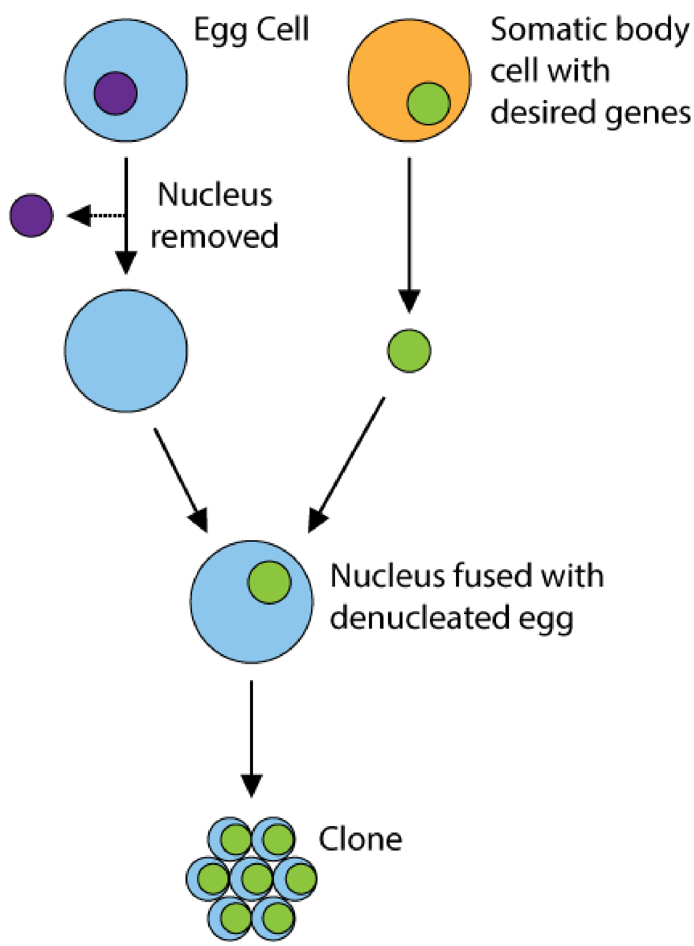


FIGURE 9.1
To clone an animal, a nucleus from the animal's cells are fused with an egg cell (from which the nucleus has been removed) from a donor.

Is Cloning Easy?

Cloning is not always successful. Most of the time, this cloning process does not result in a healthy adult animal. The process has to be repeated many times until it works. In fact, 277 tries were needed to produce Dolly. This high failure rate is one reason that human cloning is banned in the United States. In order to produce a cloned human, many attempts would result in the surrogate mothers experiencing miscarriages, stillbirths, or deformities in the infant. There are also many additional ethical considerations related to human cloning. Can you think of reasons why people are for or against cloning?

Vocabulary

- **cloning** : Process of creating an exact replica of an organism.
- **somatic cell** : Cell that comes from the body and is not a gamete cell like a sperm or egg.
- **zygote** : Cell that forms when a sperm and egg unite; the first cell of a new organism.

Summary

- Cloning, or creating an exact replica of an organism, is now possible for many animals.
- There are many ethical considerations related to human cloning, and it is now illegal to clone humans in the United States.

Practice

Use the resource below to answer the questions that follow.

- **Click and Clone** at http://learn.genetics.utah.edu/content/tech/cloning/clickandclone/

1. What is the first step in cloning?
2. How are the blunt and sharp pipettes used in the cloning process?
3. How many cell divisions does the modified embryo go through before it is implanted in the surrogate mother?
4. What step did scientists determine was crucial to the success of this process?

Review

1. Describe the process of creating a clone.
2. What are some reasons to ban human cloning?

References

1. CK-12 Foundation - Zachary Wilson. . CC-BY-NC-SA 3.0

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Contents

CHAPTER 1 Cell Division

- Explain what cell division is and why cells need to divide.

Do cells get worn out?

Yes, just like this truck, cells cannot last forever. Cells do eventually wear out. At that point, they need to be replaced. This is one reason that your cells divide. New cells that result after cells divide are also used for growth and to repair cuts.

Why Cells Divide

Imagine the first stages of life. In humans and other animals, a sperm fertilizes an egg, forming the first cell. But humans are made up of trillions of cells, so where do the new cells come from? Remember that according to the **cell theory**, all cells come from existing cells. From that first cell, called a **zygote**, an entire baby will develop. And each cell in that baby will be genetically identical, meaning that each cell will have exactly the same DNA.

How does a new life go from one cell to so many? The cell divides in half, creating two cells. Then those two cells divide, for a total of four cells. The new cells continue to divide and divide. One cell becomes two, then four, then eight, and so on (**Figure** 1.1). This continual process of a cell dividing and creating two new cells is known as **cell division.** Cell division is part of a cycle of cellular growth and division known as the cell cycle—cells must grow before they divide. The **cell cycle** describes the "life" of a eukayrotic cell.

Most cell division produces genetically identical cells, meaning they have the same DNA. The process of **mitosis** ensures that each cell has the same DNA. A special form of cell division, called **meiosis**, produces cells with half as much DNA as the parent cell. These cells are used for reproduction. In prokaryotic organisms, cell division is how those organisms reproduce.

Besides the development of a baby, there are many other reasons that cell division is necessary for life:

1. To grow and develop, you must form new cells. Imagine how often your cells must divide during a growth spurt. Growing just an inch requires countless cell divisions. Your body must produce new bone cells, new skin cells, new cells in your blood vessels and so on.

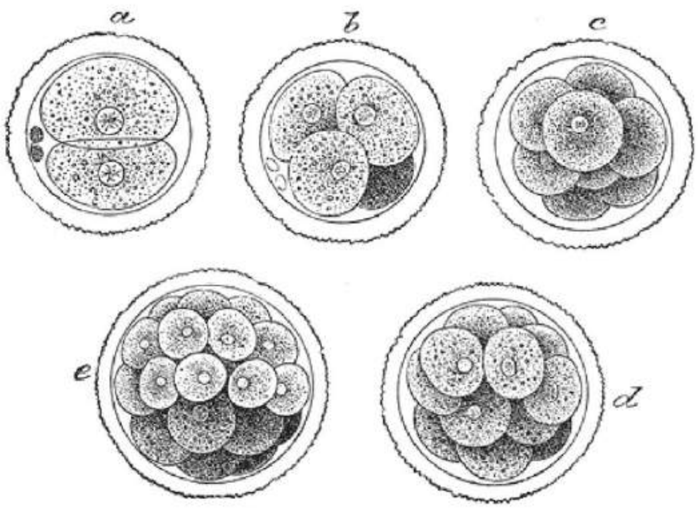


FIGURE 1.1
Cells divide repeatedly to produce an embryo. Previously the one-celled zygote (the first cell of a new organism) divided to make two cells (a). Each of the two cells divides to yield four cells (b), then the four cells divide to make eight cells (c), and so on. Through cell division, an entire embryo forms from one initial cell.

2. Cell division is also necessary to repair damaged cells. Imagine you cut your finger. After the scab forms, it will eventually disappear and new skin cells will grow to repair the wound. Where do these cells come from? Some of your existing skin cells divide and produce new cells.
3. Your cells can also simply wear out. Over time you must replace old and worn-out cells. Cell division is essential to this process.

Vocabulary

- **cell cycle**: Phases that a cell goes through from one cell division to the next; describes the "life" of a eukaryotic cell.
- **cell division**: Process in which a parent cell divides to form daughter cells.
- **cell theory**: Scientific theory that all living things are made up of cells, all life functions occur within cells, and all cells come from already existing cells.
- **meiosis**: Cell division process that results in haploid gametes; contains two rounds of cell division.
- **mitosis**: Division of the nucleus.
- **zygote**: First cell of a new organism created by the union of sperm and egg.

Summary

- Cells must divide repeatedly for an embryo to develop or for you to grow.
- Cells also divide in order to replace damaged or worn-out cells.

Practice

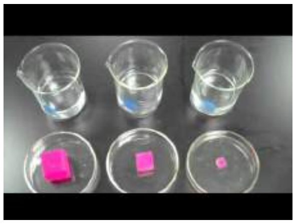
Use the resources below to answer the questions that follow.

- **Why Must A Cell Divide** at http://plaza.ufl.edu/alallen/pgl/modules/rio/stingarees/module/why.html

1. What limits the size a cell can become? Be as specific as you can.

2. If you double the size of a cube, how does this affect the surface to volume ratio?

- **Importance of Surface to Volume Ratios** at http://www.youtube.com/watch?v=xuG4ZZ1GbzI (2:45)



MEDIA

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1. Does the rate at which materials diffuse into a cell vary with the size of the cell? What controls the rate of diffusion?
2. What does this mean for large cells?

Review

1. How does an embryo develop from a fertilized egg?
2. List some reasons that cells must divide.

References

1. From 1918 version of Gray's Anatomy. . Public Domain

CHAPTER 2 Cell Cycle

- Describe the cell cycle.

Do cells have a life cycle?

Yes, just like a butterfly passes through different phases, such as caterpillar, chrysalis, and adult butterfly, there are a series of phases in a cell's life as it gets ready to divide. The sequence of phases leading up to cell division and then ending with cell division itself is called the cell cycle.

Cell Cycle

The process of cell division in eukaryotic cells is carefully controlled. The **cell cycle** (**Figure** 2.1) is the life cycle of a cell, with cell division at the end of the cycle. Like a human life cycle, which is made up of different phases, like childhood, adolescence, and adulthood, the cell cycle also occurs in a series of phases.

These steps can be divided into two main components: interphase and the mitotic phase. **Interphase** is the stage when the cell mostly performs its "everyday" functions. For example, it is when a kidney cell does what a kidney cell is supposed to do. The cell also gets ready to divide during this time. The cell divides during the mitotic phase, which consists of mitosis and cytokinesis.

Most of the cell cycle consists of interphase, the time between cell divisions. Interphase can be divided into three stages:

1. The first growth phase (G1): During the G1 stage, the cell doubles in size and doubles the number of organelles.
2. The synthesis phase (S): The DNA is replicated during this phase. In other words, an identical copy of all the cell's DNA is made. This ensures that each new cell has a set of genetic material identical to that of the parental cell. This process is called **DNA replication**.
3. The second growth phase (G2): Proteins are synthesized that will help the cell divide. At the end of interphase, the cell is ready to enter mitosis.

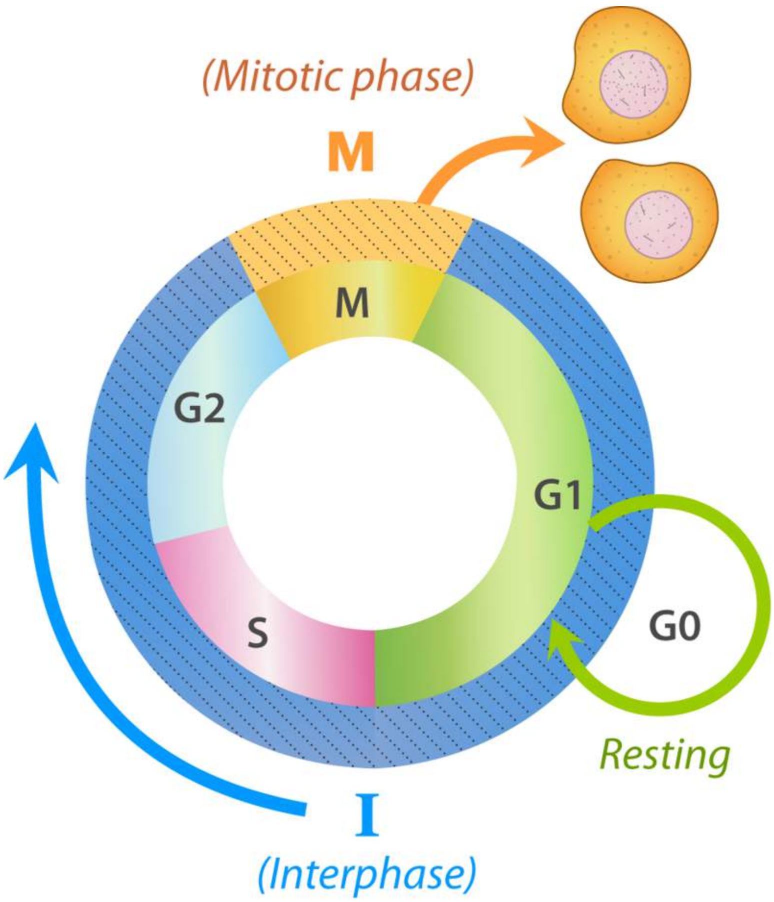


FIGURE 2.1
Notice that most of the cell cycle is spent in interphase (G1, S, and G2).

During **mitosis**, the nucleus divides. One nucleus becomes two nuclei, each with an identical set of **chromosomes**. Mitosis is followed by **cytokinesis**, when the cytoplasm divides, resulting in two cells. After cytokinesis, cell division is complete. The one parent cell (the dividing cell) forms two genetically identical daughter cells (the cells that divide from the parent cell). The term "genetically identical" means that each cell has an identical set of DNA, and this DNA is also identical to that of the parent cell. If the cell cycle is not carefully controlled, it can cause a disease called **cancer** in which the cells divide out of control. A tumor can result from this kind of growth.

Vocabulary

- **cancer**: Disease that occurs when the cell cycle is not regulated and cells divide out of control.
- **cell cycle**: Phases that a cell goes through from one cell division to the next; describes the "life" of a eukaryotic cell.
- **chromosome**: Structure made of DNA and proteins that contains the genetic material of a cell.
- **cytokinesis**: Division of the cytoplasm.

- **DNA replication**: Synthesis of new DNA; occurs during the S phase of the cell cycle.
- **interphase**: Stage of the cell cycle when the cell grows, synthesizes DNA, and prepares to divide.
- **mitosis**: Division of the nucleus.

Summary

- The cell cycle describes the "life" of a cell.
- Interphase, the stage of the cell cycle when the cell, preparing to divide, is divided into the G1, S, and G2 stages.
- The nucleus divides during mitosis, and the cytoplasm divides during cytokinesis.

Practice

Use the resource below to answer the questions that follow.

- **Cell Division and Cell Cycle** at http://vimeo.com/9536315 (5:34)

MEDIA
Click image to the left for more content.

1. What are the three major phases of the cell cycle?
2. Why do you think it is important for a cell to grow before it replicates its DNA? Be as specific as you can in your answer.
3. What happens during the S phase of interphase?
4. What happens during mitosis?
5. What is the function of spindle fibers? Where do they attach?
6. What is the function of meiosis?

Review

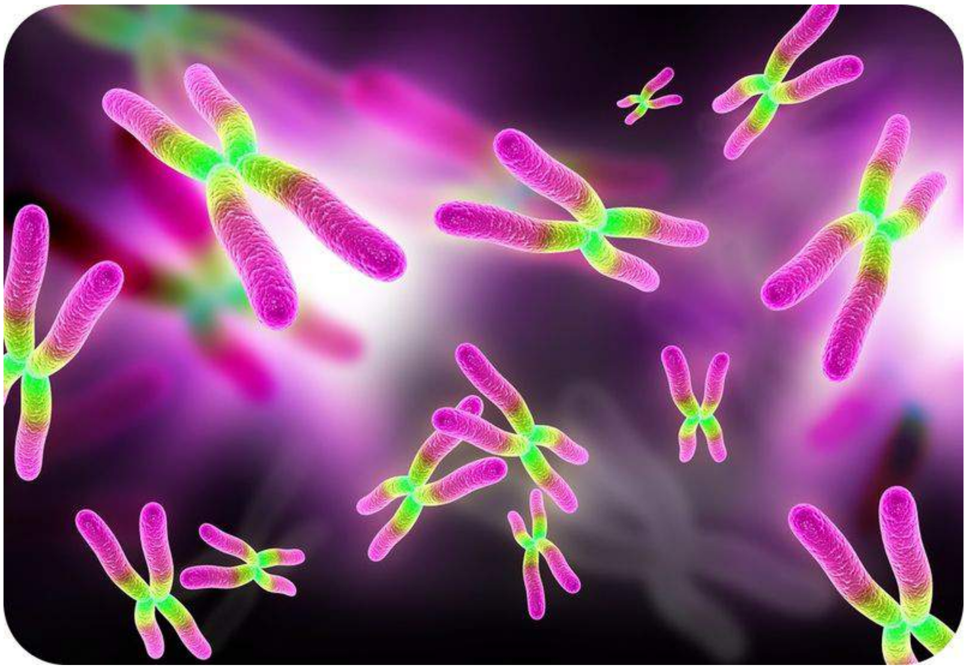
1. What are the two main components of the cell cycle?
2. What occurs during interphase?
3. Describe the main events of the mitotic phase.
4. Define cancer.

References

1. CK-12 Foundation - Hana Zavadska. . CC-BY-NC-SA 3.0

CHAPTER 3 Mitosis and Cytokinesis

- Explain chromosome structure and the four stages 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** 3.1). 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.

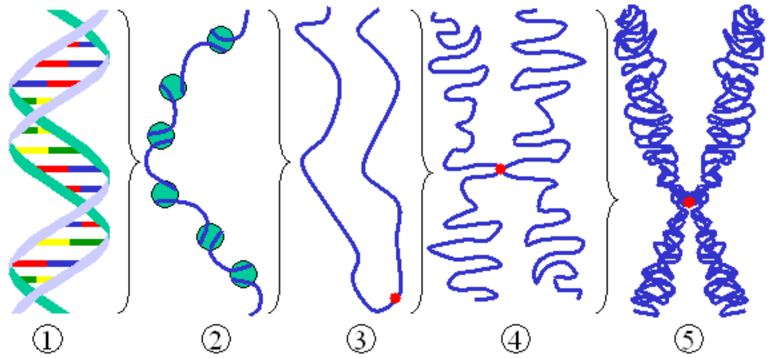


FIGURE 3.1

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.

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** 3.2).

1. **Prophase**: The chromosomes "condense," or become 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.

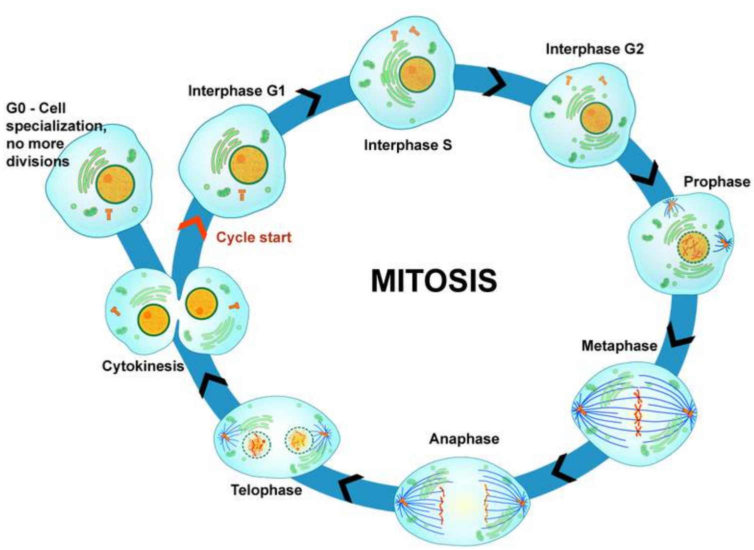


FIGURE 3.2

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.

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** 3.3).

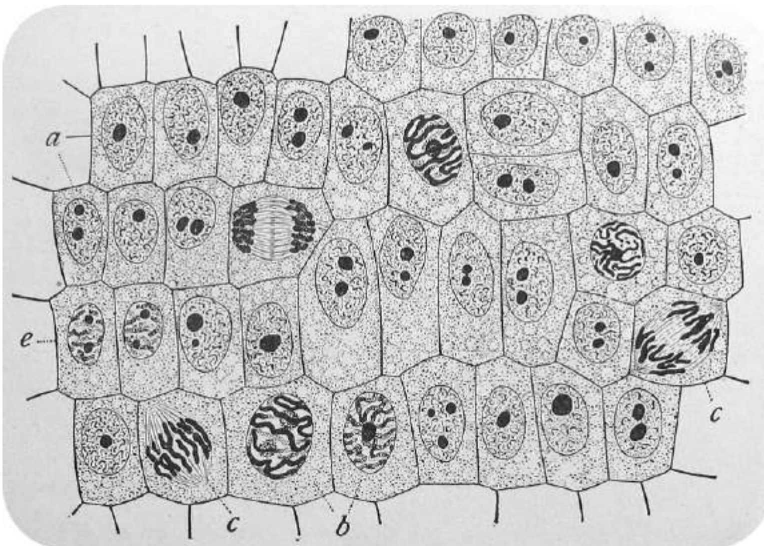


FIGURE 3.3

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?

Vocabulary

- **anaphase**: Third phase of mitosis in which sister chromatids separate and move to opposite sides of the cell.
- **centromere**: Region of a chromosome where sister chromatids are joined together.
- **chromosome**: Structure made of DNA and proteins that contains the genetic material of a cell.
- **cytokinesis**: Division of the cytoplasm.
- **metaphase**: Second phase of mitosis in which the chromosomes are aligned in the center of the cell.
- **mitosis**: Division of the nucleus.
- **nucleus**: Eukaryotic cell structure that contains the genetic material, DNA.
- **prophase**: Initial phase of mitosis in which chromosomes condense, the nuclear envelope dissolves and the spindle begins to form.
- **sister chromatids**: Two identical copies of a chromosome.
- **spindle**: Structure that helps separate the sister chromatids during mitosis; also separates homologous chromosomes during meiosis.
- **telophase**: Final phase of mitosis in which a nuclear envelop forms around each of the two sets of chromosomes.

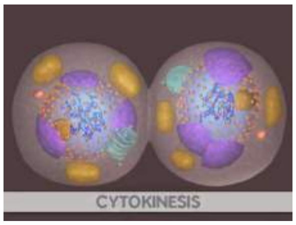
Summary

- The DNA in the nucleus wraps around proteins to form chromosomes.
- During mitosis, the newly duplicated chromosomes are divided into two daughter nuclei.
- Mitosis occurs in four phases, called prophase, metaphase, anaphase, and telophase.

Practice

Use the resource below to answer the questions that follow.

- **Mitosis** by NDSU VCell Productions at http://www.youtube.com/watch?v=C6hn3sA0ip0 (6:11)



MEDIA

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1. When does the "classic" chromosome structure of DNA appear during mitosis? What form is the DNA in prior to this change?
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?

- **Identify mitosis phases** at http://www.neok12.com/quiz/CELDIV06

Review

1. What are chromosomes?
2. In what phase of mitosis are chromosomes moving toward opposite sides of the cell?

References

1. Magnus Manske. . Public Domain
2. CK-12 Foundation - Zachary Wilson and Mariana Ruiz Villarreal (LadyofHats) (cell images are available under the public domain and can be found at http://commons.wikimedia.org/wiki/User:LadyofHats/gallery2). . CC-BY-NC-SA 3.0
3. Edmund Beecher Wilson. . Public Domain

CHAPTER 4 Asexual vs. Sexual Reproduction

- Name the types of asexual reproduction.
- Explain how plants and animals reproduce sexually.

Do animals always have two parents?

No, not all animals have two parents. When necessary, some animals can be produced from just one parent. Some reptiles, such as this Komodo dragon, have only one parent. The process of creating offspring from just one individual is called asexual reproduction.

Reproduction

Animals and other organisms cannot live forever. They must reproduce if their species is to survive. But what does it mean to reproduce? **Reproduction** is the ability to make the next generation, and it is one of the basic characteristics of life. Two methods of reproduction are:

1. **Asexual reproduction**, the process of forming a new individual from a single parent.
2. **Sexual reproduction**, the process of forming a new individual from two parents.

There are advantages and disadvantages to each method, but the result is always the same: a new life begins.

Asexual Reproduction

When humans reproduce, there are two parents involved. DNA must be passed from both the mother and father to the child. Humans cannot reproduce with just one parent; humans can only reproduce sexually. But having just one parent is possible in other eukaryotic organisms, including some insects, fish, and reptiles. These organisms can reproduce asexually, meaning the offspring ("children") have a single parent and share the exact same genetic material as the parent. This is very different from reproduction in humans. Bacteria, being a prokaryotic, single-celled organism, must reproduce asexually.

The advantage of asexual reproduction is that it can be very quick and does not require the meeting of a male and female organism. The disadvantage of asexual reproduction is that organisms do not receive a mix of traits from both parents. An organism that is born through asexual reproduction only has the DNA from the one parent. In fact, the offspring is genetically an exact copy of the parent. This can cause problems for the individual. For example, if the parent has a gene that causes a particular disease, the offspring will also have the gene that causes that disease. Organisms produced sexually may or may not inherit the disease gene because they receive a mix of their parents' genes.

Types of organisms that reproduce asexually include:

1. Prokaryotic organisms, like bacteria. Bacteria reproduce through **binary fission**, where they grow and divide in half (**Figure** 4.1). First, their chromosome replicates and the cell enlarges. The cell then divides into two cells as new membranes form to separate the two cells. After cell division, the two new cells each have one identical chromosome. This simple process allows bacteria to reproduce very rapidly.
2. Flatworms, an invertebrate animal species. Flatworms divide in two, then each half regenerates into a new flatworm identical to the original, a process called **fragmentation**.
3. Different types of insects, fish, and lizards. These organisms can reproduce asexually through a process called parthenogenesis. **Parthenogenesis** happens when an unfertilized egg cell grows into a new organism. The resulting organism has half the amount of genetic material of the parent. Parthenogenesis is common in honeybees. In a hive, the sexually produced eggs become workers, while the asexually produced eggs become drones.

Sexual Reproduction

During sexual reproduction, two parents are involved. Most animals are **dioecious**, meaning there is a separate male and female sex, with the male producing sperm and the female producing eggs. When a sperm and egg meet during **fertilization**, a **zygote**, the first cell of a new organism, is formed (**Figure** 4.2). This process combines the genetic material from both parents. The resulting organism will be genetically unique. The zygote will divide by mitosis and grow into the embryo.

Let's explore how animals, plants, and fungi reproduce sexually:

- Animals often have **gonads**, organs that produce eggs or sperm. The male gonads are the **testes**, and the female gonads are the **ovaries**. Testes produce sperm; ovaries produce eggs. Sperm and egg, the two sex cells, are known as **gametes**, and can combine two different ways, both of which combine the genetic material from the two parents. Gametes have half the amount of the genetic material of a regular body cell. In humans, gametes have one set of 23 chromosomes. Gametes are produced through a special type of cell division known as **meiosis**.

1. Fish and other aquatic animals release their gametes in the water, which is called **external fertilization** (**Figure** 4.3). These gametes will combine by chance.
2. Animals that live on land reproduce by **internal fertilization**. Typically males have a penis that deposits sperm into the vagina of the female. Birds do not have penises, but they do have a chamber called the cloaca that they place close to another bird's cloaca to deposit sperm.

- Plants can also reproduce sexually, but their reproductive organs are different from animals' gonads. Plants that have flowers have their reproductive parts in the flower. The sperm is contained in the pollen, while the egg is contained in the ovary, deep within the flower. The sperm can reach the egg two different ways:

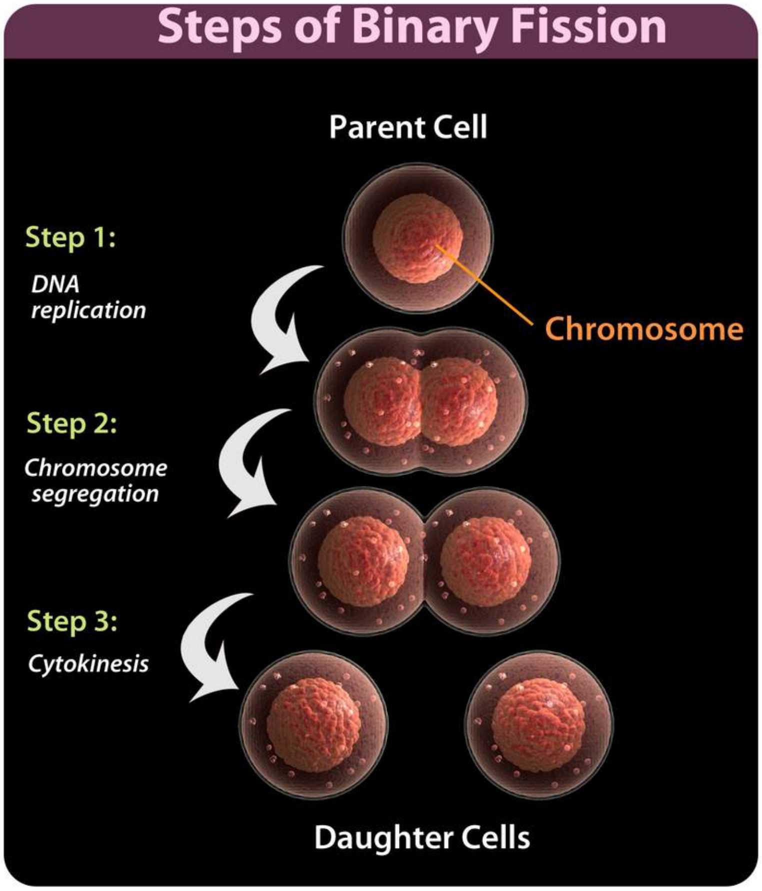

FIGURE 4.1
Bacteria reproduce by binary fission. Shown is one bacterium reproducing and becoming two bacteria.

FIGURE 4.2
During sexual reproduction, a sperm fertilizes an egg.

FIGURE 4.3
This fish guards her eggs, which will be fertilized externally.

1. In **self-pollination**, the egg is fertilized by the pollen of the same flower.
2. In **cross-pollination**, sperm from the pollen of one flower fertilizes the egg of another flower. Like other types of sexual reproduction, cross-pollination allows new combinations of traits. Cross-pollination occurs when pollen is carried by the wind to another flower. It can also occur when animal pollinators, like honeybees or butterflies (**Figure** 4.4), carry the pollen from flower to flower.

FIGURE 4.4
Butterflies receive nectar when they deposit pollen into flowers, resulting in cross-pollination.

- Fungi can also reproduce sexually, but instead of female and male sexes, they have (+) and (-) strains. When the filaments of a (+) and (-) fungi meet, the zygote is formed. Just like in plants and animals, each zygote receives DNA from two parent strains.

Vocabulary

- **asexual reproduction**: Process of forming a new individual from a single parent.
- **binary fission**: Reproduction through growth and division of the cell, as in bacteria.
- **cross-pollination**: Process during which sperm from the pollen of one flower fertilizes the egg of another flower.
- **dioecious**: Species having distinct male and female organisms.
- **external fertilization**: Process during which egg and sperm meet after being released into water.
- **fertilization**: Union of a sperm and egg.
- **fragmentation**: Reproductive process in which a new organism forms from a fragment of a parent organism.
- **gamete**: Sex cell, such as sperm or egg.
- **gonad**: Organ that produces eggs or sperm.
- **internal fertilization**: Process during which egg and sperm meet inside the female, usually after the male's penis deposits sperm into the vagina of the female.
- **meiosis**: Process of cell division during which the chromosome number is halved in order to produce gametes.
- **ovaries**: Female gonads that produce egg.
- **parthenogenesis**: Growth of an unfertilized egg cell into a new organism.
- **reproduction**: Process of forming a new individual.
- **sexual reproduction**: Process of forming a new individual from two parents.
- **self-pollination**: Process during which sperm from the pollen of one flower fertilizes the egg of the same flower.
- **testes**: Male gonads that produce sperm.
- **zygote**: Cell that forms when a sperm and egg unite; the first cell of a new organism.

Summary

- Types of asexual reproduction, when a new individual is formed from a single parent, include binary fission in bacteria and parthenogenesis in some animals.
- During sexual reproduction in animals, fertilization can be internal or external.
- Cross-pollination allows sexual reproduction in plants.

Practice

Use the resource below to answer the questions that follow.

- **Plant reproduction: Asexual Reproduction** at http://www.youtube.com/watch?v=drcnTg7ZCoc (2:57)

MEDIA
Click image to the left for more content.

1. How does the production of "bulbs" benefit plants?
2. How can an organism benefit from asexual reproduction? Be specific and thorough in your answer.
3. What kinds of environmental conditions favor asexual reproduction?
4. What can be a negative effect of asexual reproduction? Is this more applicable to the individual or the population?

Review

1. What is the advantage of sexual reproduction?
2. How does internal fertilization differ from external fertilization?

References

1. Image copyright MichaelTaylor, 2010, modified by CK-12 Foundation. . Used under license from Shutterstock.com
2. Image copyright James Steidl, 2010. . Used under license from Shutterstock.com
3. Chika Watanabe. . CC-BY 2.0
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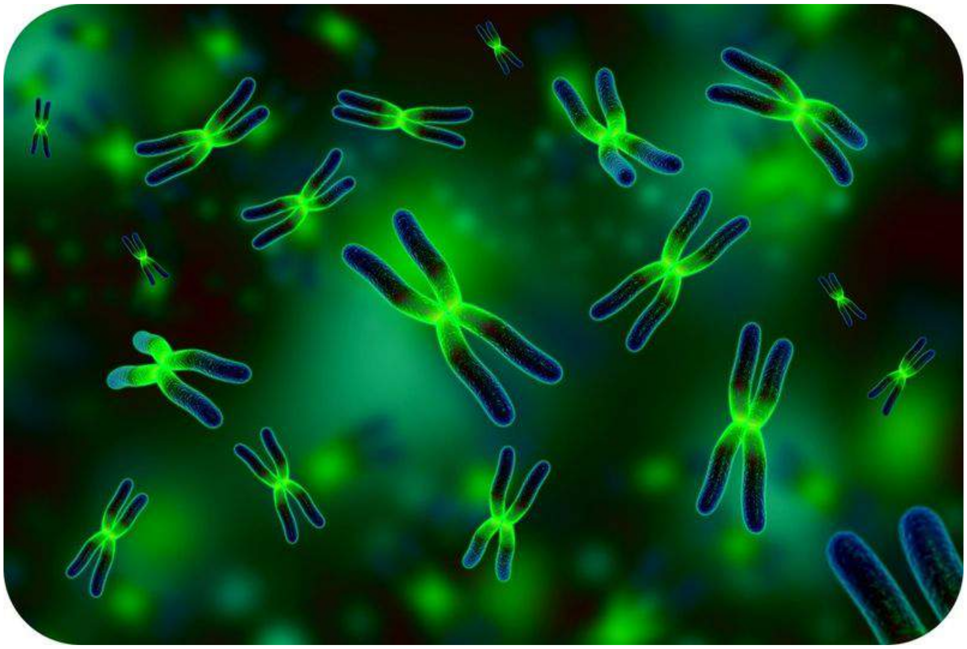
CHAPTER 5 Meiosis

- List the stages of meiosis and explain what happens in each stage.



Do you have ALL your parents' chromosomes?

No, you only received half of your mother's chromosomes and half of your father's chromosomes. If you inherited them all, you would have twice the number of chromosomes that you're supposed to have. Humans typically have 23 pairs of chromosomes. If you received all your parents' chromosomes, you would have 46 pairs!

Introduction to Meiosis

Sexual reproduction combines gametes from two parents. **Gametes** are reproductive cells, such as sperm and egg. As gametes are produced, the number of chromosomes must be reduced by half. Why? The **zygote** must contain genetic information from the mother and from the father, so the gametes must contain half of the chromosomes found in normal body cells. When two gametes come together at fertilization, the normal amount of chromosomes results. Gametes are produced by a special type of cell division known as **meiosis**. Meiosis contains two rounds of cell division without DNA replication in between. This process reduces the number of chromosomes by half.

Human cells have 23 pairs of chromosomes, and each chromosome within a pair is called a **homologous chromosome**. For each of the 23 chromosome pairs, you received one chromosome from your father and one chromosome from your mother. **Alleles** are alternate forms of genes found on chromosomes. Homologous chromosomes have the same genes, though they may have different alleles. So, though homologous chromosomes are very similar, they are not identical. The homologous chromosomes are separated when gametes are formed. Therefore, gametes have only 23 chromosomes, not 23 pairs.

Haploid vs. Diploid

A cell with two sets of chromosomes is **diploid**, referred to as *2n*, where *n* is the number of sets of chromosomes. Most of the cells in a human body are diploid. A cell with one set of chromosomes, such as a gamete, is **haploid**, referred to as n. Sex cells are haploid. When a haploid sperm (n) and a haploid egg (n) combine, a diploid zygote will be formed ($2n$). In short, when a diploid zygote is formed, half of the DNA comes from each parent.

Overview of Meiosis

Before meiosis begins, DNA replication occurs, so each chromosome contains two sister chromatids that are identical to the original chromosome. Meiosis (**Figure** 5.1) is divided into two divisions: Meiosis I and Meiosis II. Each division can be divided into the same phases: prophase, metaphase, anaphase, and telophase. Cytokinesis follows telophase each time. Between the two cell divisions, DNA replication does not occur. Through this process, one diploid cell will divide into four haploid cells.

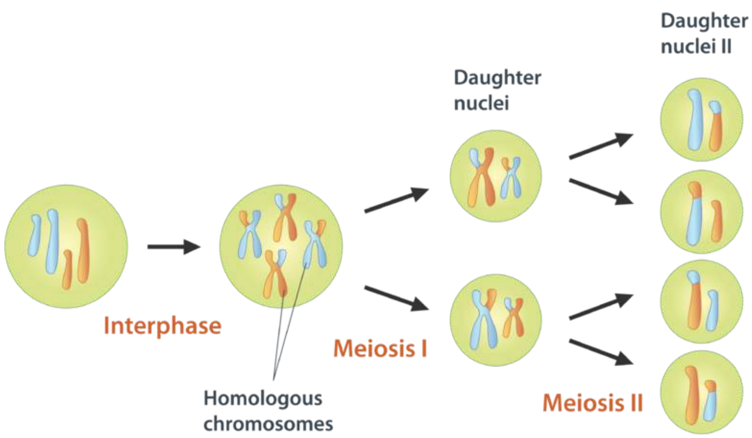


FIGURE 5.1

Overview of Meiosis. During meiosis, four haploid cells are created from one diploid parent cell.

Meiosis I

During meiosis I, the pairs of homologous chromosomes are separated from each other. This requires that they line up in their homologous paris during metaphase I. The steps are outlined below:

1. Prophase I: The homologous chromosomes line up together. During this time, a process that only happens in meiosis can occur. This process is called **crossing-over** (**Figure** 5.2), which is the exchange of DNA between homologous chromosomes. Crossing-over forms new combinations of alleles on the resulting chromosome. Without crossing-over, the offspring would always inherit all of the alleles on one of the homologous chromosomes. Also during prophase I, the **spindle** forms, the chromosomes condense as they coil up tightly, and the nuclear envelope disappears.
2. Metaphase I: The homologous chromosomes line up in their pairs in the middle of the cell. Chromosomes from the mother or from the father can each attach to either side of the spindle. Their attachment is random, so all of the chromosomes from the mother or father do not end up in the same gamete. The gamete will contain some chromosomes from the mother and some chromosomes from the father.
3. Anaphase I: The homologous chromosomes are separated as the spindle shortens, and begin to move to opposite sides of the cell.
4. Telophase I: The spindle fibers dissolves, but a new nuclear envelope does not need to form. This is because, after cytokinesis, the nucleus will immediately begin to divide again. No DNA replication occurs between meiosis I and meiosis II because the chromosomes are already duplicated. After cytokinesis, two haploid cells result, each with chromosomes made of sister chromatids.

Since the separation of chromosomes into gametes is random during meiosis I, this process results in different combinations of chromosomes (and alleles) in each gamete. With 23 pairs of chromosomes, there is a possibility of over 8 million different combinations of chromosomes (2^{23}) in a human gamete.

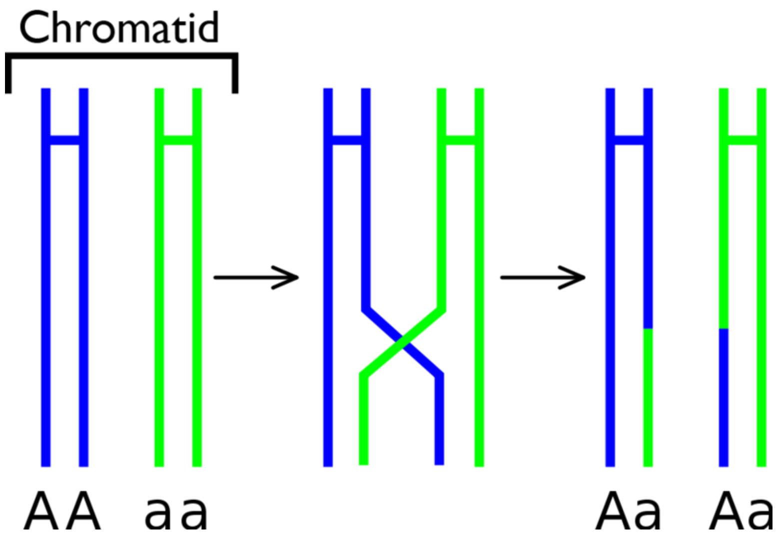


FIGURE 5.2
During crossing-over, segments of DNA are exchanged between non-sister chromatids of homologous chromosomes. Notice how this can result in an allele (A) on one chromosome being moved onto the other chromosome.

Meiosis II

During meiosis II, the sister chromatids are separated and the gametes are generated. This cell division is similar to that of **mitosis**, but results in four genetically unique haploid cells. The steps are outlined below:

1. Prophase II: The chromosomes condense.
2. Metaphase II: The chromosomes line up one on top of each other along the middle of the cell, similar to how they line up in mitosis. The spindle is attached to the centromere of each chromosome.
3. Anaphase II: The sister chromatids separate as the spindle shortens and move to opposite ends of the cell.
4. Telophase II: A nuclear envelope forms around the chromosomes in all four cells. This is followed by cytokinesis.

After cytokinesis, each cell has divided again. Therefore, meiosis results in four haploid genetically unique daughter cells, each with half the DNA of the parent cell (**Figure** 5.3). In human cells, the parent cell has 46 chromosomes, so the cells produced by meiosis have 23 chromosomes. These cells will become gametes.

Vocabulary

- **allele**: Alternate form of a gene.
- **crossing-over**: Exchange of DNA between homologous chromosomes that occurs during prophase I of meiosis.
- **diploid**: Having two sets of chromosomes; *2n*.
- **gamete**: Reproductive cell, such as sperm or egg.
- **haploid**: Having one set of chromosomes, as in sperm and egg; *n*.
- **homologous chromosomes**: Pair of chromosomes that have the same size and shape and contain the same genes, but different alleles.
- **meiosis**: Process of cell division during which the chromosome number is halved in order to produce gametes.
- **mitosis**: Division of the nucleus.
- **sexual reproduction**: Process of forming a new individual from two parents.

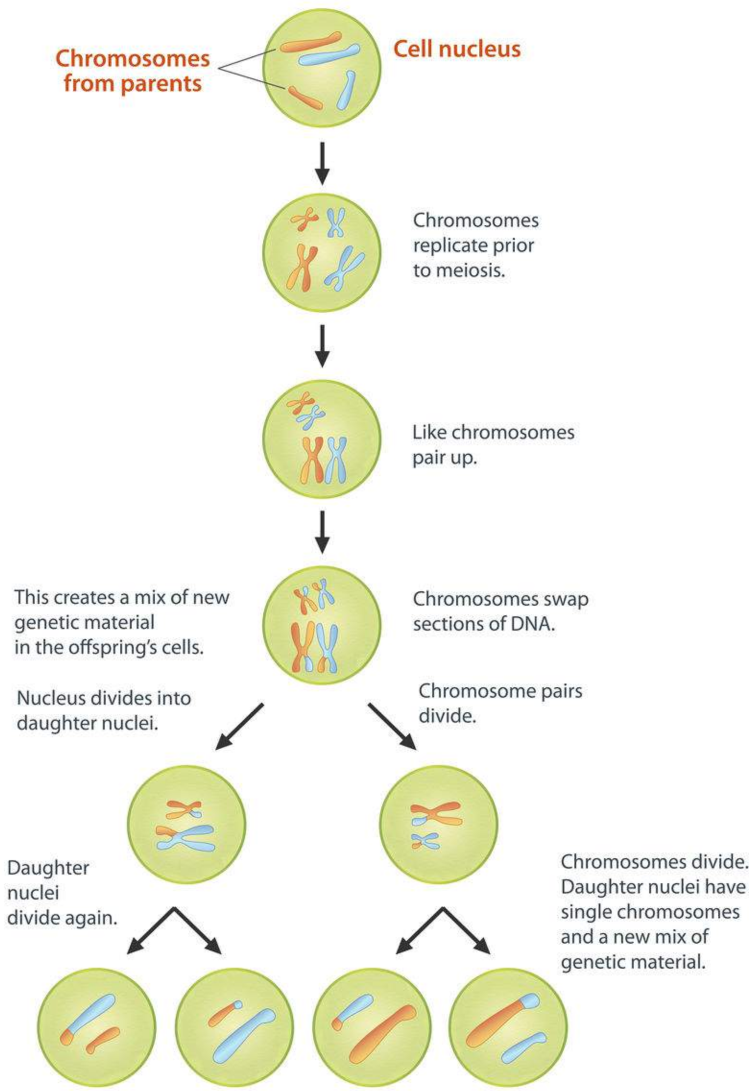


FIGURE 5.3

An overview of meiosis.

- **spindle**: Structure that helps separate the sister chromatids during mitosis; also separates homologous chromosomes during meiosis.
- **zygote**: Cell that forms when a sperm and egg unite; the first cell of a new organism.

Summary

- Meiosis is a process of cell division that reduces the chromosome number by half and produces sex cells, or gametes.
- Meiosis is divided into two parts: Meiosis I and Meiosis II. Each part is similar to mitosis and can be divided into the same phases: prophase, metaphase, anaphase, and telophase.
- Crossing-over occurs only during prophase I.
- Four genetically unique haploid cells result from meiosis.

Practice

Use the resource below to answer the questions that follow.

- **Meiosis** on YouTube at http://www.youtube.com/watch?v=kVMb4Js99tA (2:58)

MEDIA
Click image to the left for more content.

1. How does a diploid organism differ from a haploid organism?
2. When does recombination of chromatids occur? What effect does recombination of chromatids have on the diversity of offspring?
3. What happens during metaphase I of meiosis? How does this compare to the metaphase of mitosis?
4. What is the product of meiosis?

- **Identify meiosic phases** at http://www.neok12.com/quiz/CELDIV08

Review

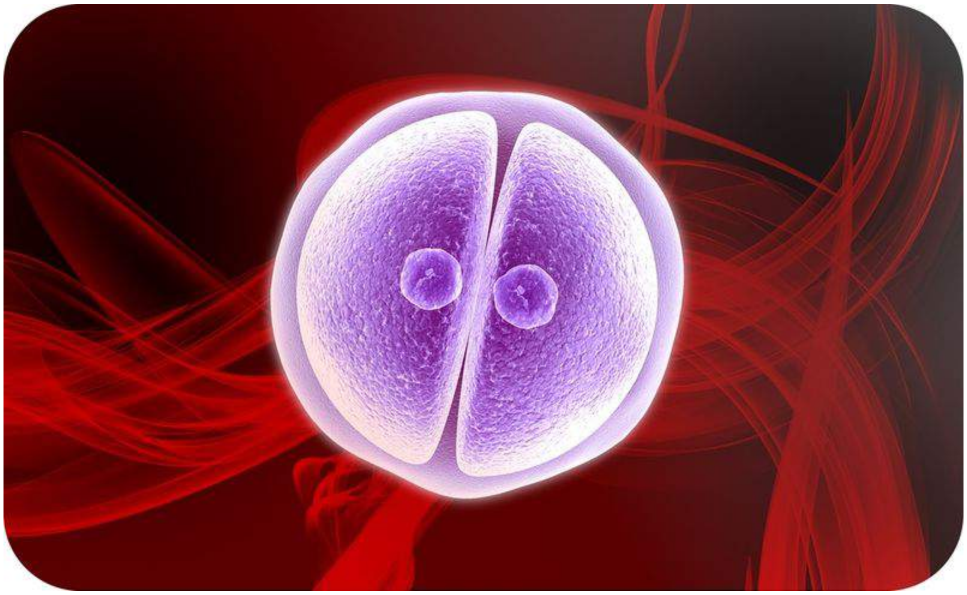
1. What is the difference between a haploid cell and a diploid cell?
2. Describe the steps of Meiosis I and Meiosis II.
3. Describe crossing-over.
4. What is the outcome of meiosis?

References

1. CK-12 Foundation - Hana Zavadska. . CC-BY-NC-SA 3.0
2. Masur (Wikimedia). . Public Domain
3. CK-12 Foundation - Hana Zavadska. . CC-BY-NC-SA 3.0

CHAPTER 6 Mitosis vs. Meiosis

- Distinguish between mitosis and meiosis.



Mitosis or Meiosis?

This represents a tiny embryo just beginning to form. Once an egg is fertilized, the resulting single cell must divide many, many times to develop a fetus. Both mitosis and meiosis involve cell division; is this type of cell division an example of mitosis or meiosis? The answer is mitosis. With each division you are making a genetically exact copy of the parent cell, which only happens through mitosis.

Mitosis vs. Meiosis

Mitosis, meiosis, and sexual reproduction are discussed at http://www.youtube.com/watch?v=kaSIjIzAtYA (18:23).

MEDIA

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Both **mitosis** and **meiosis** result in eukaryotic cells dividing. So what is the difference between mitosis and meiosis? The primary difference is the differing goals of each process. The goal of mitosis is to produce two **daughter cells** that are genetically identical to the parent cell, meaning the new cells have exactly the same DNA as the parent cell. Mitosis happens when you want to grow, for example. You want all your new cells to have the same DNA as the previous cells. The goal of meiosis, however, is to produce sperm or eggs, also known as **gametes**. The resulting gametes are not genetically identical to the parent cell. Gametes are **haploid** cells, with only half the DNA present in the **diploid** parent cell. This is necessary so that when a sperm and an egg combine at **fertilization**, the resulting

zygote has the correct amount of DNA—not twice as much as the parents. The zygote then begins to divide through mitosis.

Pictured below is a comparison between **binary fission** (**Figure** 6.1), which is cell division of prokaryotic organisms, mitosis, and meiosis. Mitosis and meiosis are also compared in the table that follows (**Table** 6.1).

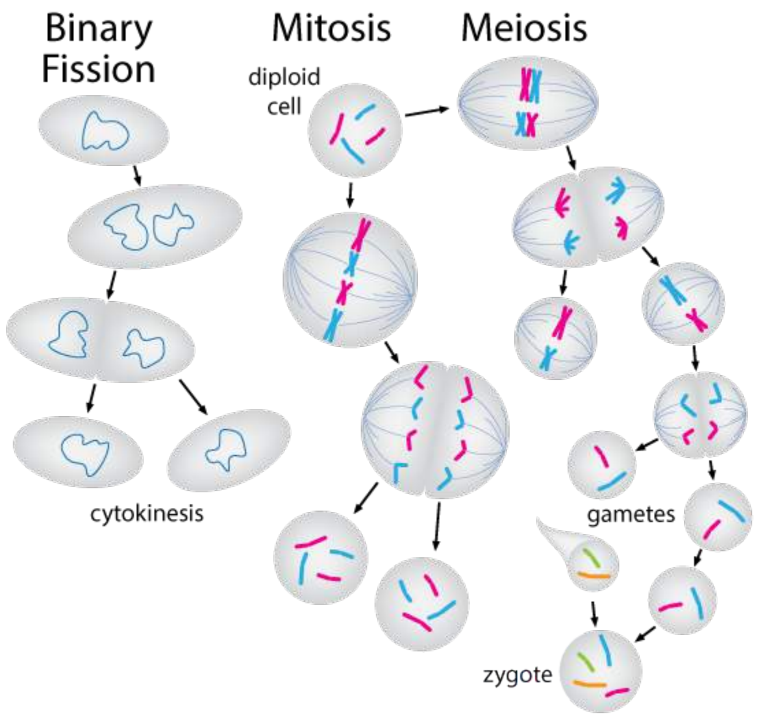

FIGURE 6.1

A comparison between binary fission, mitosis, and meiosis.

TABLE 6.1:

	Mitosis	**Meiosis**
Purpose:	To produce new cells	To produce gametes
Number of cells produced:	2	4
Rounds of Cell Division:	1	2
Haploid or Diploid:	Diploid	Haploid
Daughter cells identical to parent cells?	Yes	No
Daughter cells identical to each other?	Yes	No

Vocabulary

- **binary fission**: Reproduction through growth and division of the cell, as in bacteria.
- **daughter cells**: Cells that result from division of the parent cell during mitosis or meiosis.
- **diploid**: Having two sets of chromosomes; $2n$.
- **fertilization**: Union of a sperm and egg.
- **gamete**: Sex cell, such as sperm or egg.
- **haploid**: Having one set of chromosomes, as in sperm and egg; n.
- **meiosis**: Process in cell division that reduces the chromosome number in order to make gametes.

- **mitosis**: Process in cell division during which the nucleus divides so that a new cell is produced that is identical to the parent cell.
- **zygote**: Cell that forms when a sperm and egg unite; the first cell of a new organism.

Summary

- The goal of mitosis is to produce a new cell that is identical to the parent cell.
- The goal of meiosis is to produce gametes that have half the DNA of the parent cell.

Practice

Use the resources below to answer the questions that follow.

- **Mitosis and Meiosis Simulation** at http://www.youtube.com/watch?v=zGVBAHAsjJM (11:53)

MEDIA

Click image to the left for more content.

1. What are homologous chromosomes?
2. How do the location of specific genes compare between homologous chromosomes?
3. What is a tetrad? Why are they an important feature of meiosis?
4. How does meiosis differ between females and males? Why do you think this is? Explain your reasoning as much as possible.

- **How Cells Divide** at http://www.pbs.org/wgbh/nova/body/how-cells-divide.html

1. How many daughter cells arise from mitosis? How many daughter cells are produced in meiosis?
2. How is the location of the chromosomes during prophase of mitosis different from their location during prophase I of meiosis? Why is this difference significant?
3. How does the attachment of spindle fibers differ between mitosis and meiosis?
4. Is anaphase I or anaphase II in meiosis more analogous to anaphase in mitosis? Explain your reasoning.
5. How many steps are there in mitosis? How many steps are there in meiosis?
6. How does interphase I of meiosis differ from interphase II of meiosis?

Review

1. What is the goal of mitosis? Of meiosis?
2. How many cells are created during mitosis? During meiosis?

References

1. CK-12 Foundation - Zachary Wilson. . CC-BY-NC-SA 3.0

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Cell Energetics

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Jean Brainard, Ph.D.

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Printed: May 31, 2013

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Contents

CHAPTER 1 Energy and Biochemical Reactions

- State the role of energy in chemical reactions.

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 $\rightarrow$ Products + Heat

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

Endothermic 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** 1.1.

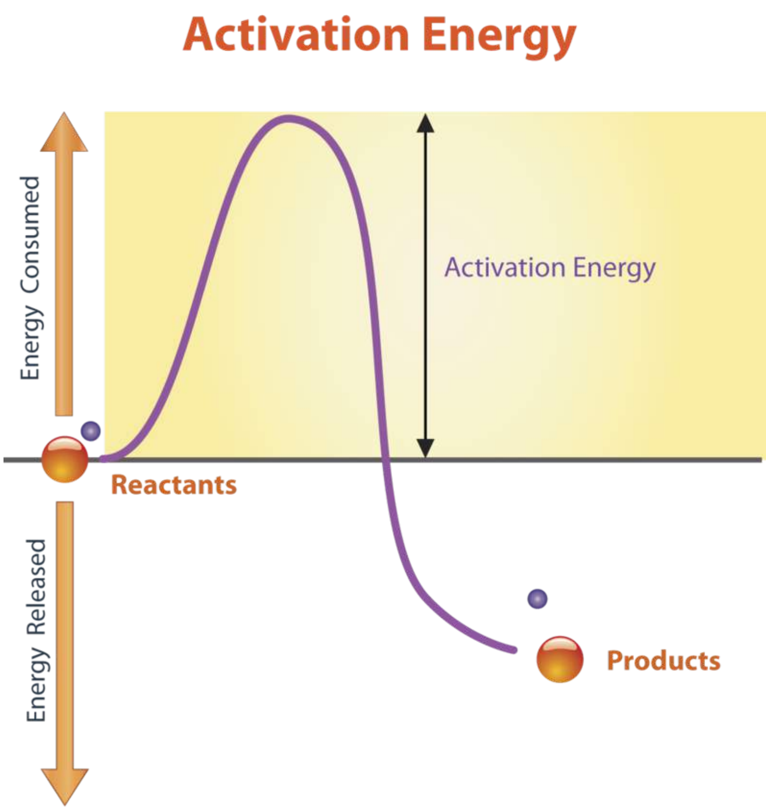
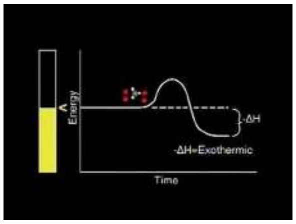


FIGURE 1.1
Activation Energy. Activation energy provides the "push" needed to start a chemical reaction. Is the chemical reaction in this figure an exothermic or endothermic reaction?

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.

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



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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.

Practice

Use this resource to answer the questions that follow.

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

1. What is energy?
2. Why do living organisms need energy?
3. What is the main difference between potential and kinetic energy?
4. What is the original source of most energy used by living organisms on Earth?

Review

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

2. Why do all chemical reactions require activation energy?

References

1. CK-12 Foundation. . CC-BY-NC-SA 3.0

CHAPTER 2 Glucose and ATP

- Compare and contrast glucose and ATP.

Needs lots of energy?

To run a marathon, probably. Where does this extra energy come from? Carbohydrate loading is a strategy used by endurance athletes to maximize the storage of energy, in the form of glycogen, in the muscles. Glycogen forms an energy reserve that can be quickly mobilized to meet a sudden need for glucose, which is then turned into ATP through the process of cellular respiration.

Glucose and ATP

Energy-Carrying Molecules

You know that the fish you had for lunch contained protein molecules. But do you know that the atoms in that protein could easily have formed the color in a dragonfly's eye, the heart of a water flea, and the whiplike tail of a *Euglena* before they hit your plate as sleek fish muscle? Food consists of organic (carbon-containing) molecules which store energy in the chemical bonds between their atoms. Organisms use the atoms of food molecules to build larger organic molecules including proteins, DNA, and fats (lipids) and use the energy in food to power life processes. By breaking the bonds in food molecules, cells release energy to build new compounds. Although some energy dissipates as heat at each energy transfer, much of it is stored in the newly made molecules. Chemical bonds in organic molecules are a reservoir of the energy used to make them. Fueled by the energy from food molecules, cells can combine and recombine the elements of life to form thousands of different molecules. Both the energy (despite some loss) and the materials (despite being reorganized) pass from producer to consumer – perhaps from algal tails, to water flea hearts, to dragonfly eye colors, to fish muscle, to you!

The process of photosynthesis, which usually begins the flow of energy through life, uses many different kinds of energy-carrying molecules to transform sunlight energy into chemical energy and build food. Some carrier molecules hold energy briefly, quickly shifting it like a hot potato to other molecules. This strategy allows energy to be released in small, controlled amounts. An example starts in **chlorophyll,** the green pigment present in most plants, which helps convert solar energy to chemical energy. When a chlorophyll molecule absorbs light energy, electrons are excited and "jump" to a higher energy level. The excited electrons then bounce to a series of carrier molecules, losing a little energy at each step. Most of the "lost" energy powers some small cellular task, such as moving ions across a membrane or building up another molecule. Another short-term energy carrier important to photosynthesis, **NADPH**, holds chemical energy a bit longer but soon "spends" it to help to build sugar.

Two of the most important energy-carrying molecules are **glucose** and **ATP**, adenosine triphosphate. These are nearly universal fuels throughout the living world and are both key players in photosynthesis, as shown below.

Glucose

A molecule of glucose, which has the chemical formula $C_6H_{12}O_6$, carries a packet of chemical energy just the right size for transport and uptake by cells. In your body, glucose is the "deliverable" form of energy, carried in your blood through capillaries to each of your 100 trillion cells. Glucose is also the carbohydrate produced by photosynthesis, and as such is the near-universal food for life.

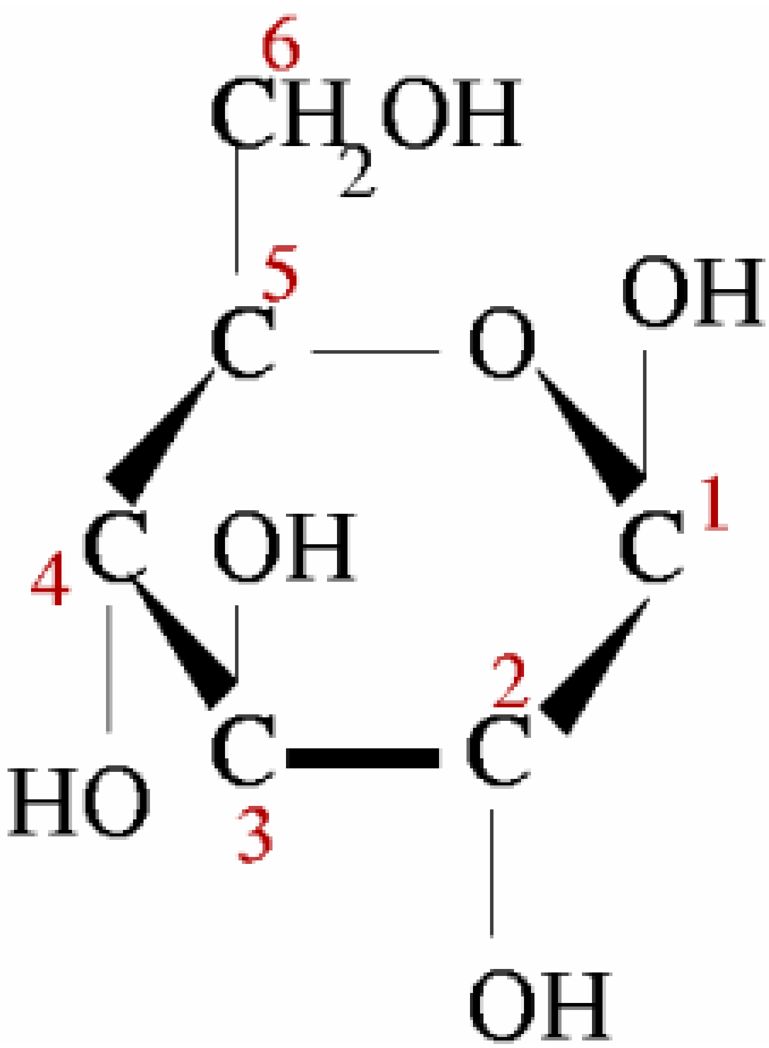


FIGURE 2.1

Glucose is the energy-rich product of photosynthesis, a universal food for life. It is also the primary form in which your bloodstream delivers energy to every cell in your body. The six carbons are numbered.

ATP

ATP molecules store smaller quantities of energy, but each releases just the right amount to actually do work within a cell. Muscle cell proteins, for example, pull each other with the energy released when bonds in ATP break open (discussed below). The process of photosynthesis also makes and uses ATP - for energy to build glucose! ATP, then, is the useable form of energy for your cells.

Why do we need both glucose and ATP?

Why don't plants just make ATP and be done with it? If energy were money, ATP would be a quarter. Enough money to operate a parking meter or washing machine. Glucose would be a ten dollar bill – much easier to carry around in your wallet, but too large to do the actual work of paying for parking or washing. Just as we find several denominations of money useful, organisms need several "denominations" of energy – a smaller quantity for work within cells, and a larger quantity for stable storage, transport, and delivery to cells.

Let's take a closer look at a molecule of ATP. Although it carries less energy than glucose, its structure is more complex. The "A" in ATP refers to the majority of the molecule, adenosine, a combination of a nitrogenous base and a five-carbon sugar. The "P" indicates the three phosphates, linked by bonds which hold the energy actually used by cells. Usually, only the outermost bond breaks to release or spend energy for cellular work.

An ATP molecule, shown below, is like a rechargeable battery: its energy can be used by the cell when it breaks apart into ADP (adenosine diphosphate) and phosphate, and then the "worn-out battery" ADP can be recharged using new energy to attach a new phosphate and rebuild ATP. The materials are recyclable, but recall that energy is not!

How much energy does it cost to do your body's work? A single cell uses about 10 million ATP molecules per second, and recycles all of its ATP molecules about every 20-30 seconds.

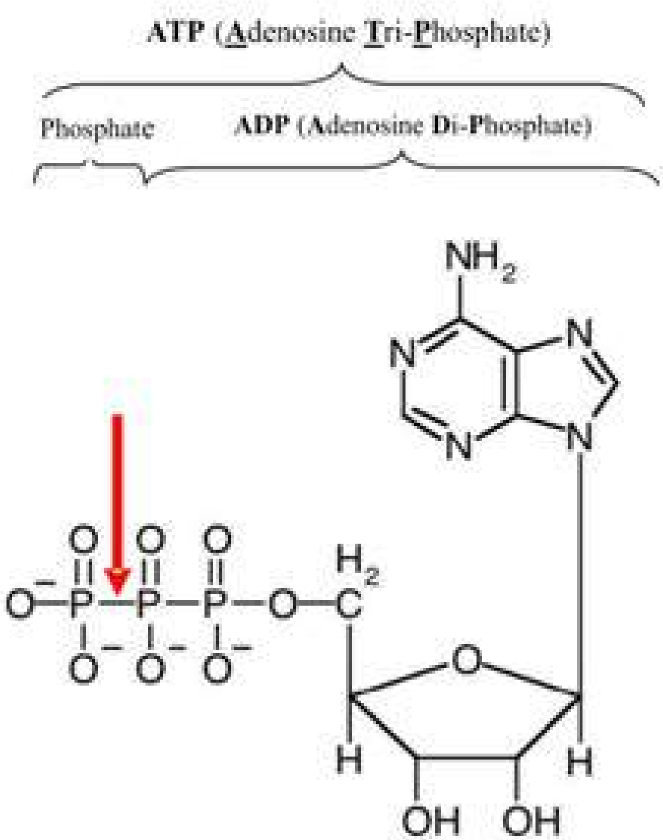
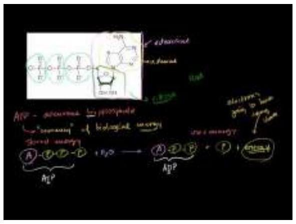


FIGURE 2.2

A red arrow shows the bond between two phosphate groups in an ATP molecule. When this bond breaks, its chemical energy can do cellular work. The resulting ADP molecule is recycled when new energy attaches another phosphate, rebuilding ATP.

A explanation of ATP as "biological energy" is found at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/18/YQfWiDlFEcA.



MEDIA

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Summary

- Glucose is the carbohydrate produced by photosynthesis. Energy-rich glucose is delivered through your blood to each of your cells.
- ATP is the usable form of energy for your cells.

Practice

Use these resources to answer the questions that follow.

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

1. Where does a cell's chemical energy come from?
2. How does a cell start breaking down glucose? Does this process need oxygen?
3. What is the purpose of glycolysis?

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **The Glycolytic Pathway**

1. What is the chemical formula of glucose? Describe the structure of glucose molecules.
2. Where does our glucose come from? What happens to this glucose?
3. Glycolysis produces a net total of how many ATP molecules?

Review

1. The fact that all organisms use similar energy-carrying molecules shows one aspect of the grand "Unity of Life." Name two universal energy-carrying molecules, and explain why most organisms need both carriers rather than just one.

2. A single cell uses about 10 million ATP molecules per second. Explain how cells use the energy and recycle the materials in ATP.

3. ATP and glucose are both molecules that organisms use for energy. They are like the tank of a tanker truck that delivers gas to a gas station and the gas tank that holds the fuel for a car. Which molecule is like the tank of the delivery truck, and which is like the gas tank of the car? Explain your answer.

References

1. Rob Hooft. . GNU-FDL 1.2

2. cacycle. . GNU-FDL 1.2

CHAPTER 3 Photosynthesis

- 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. So once again, how does a plant get the food it needs to survive?

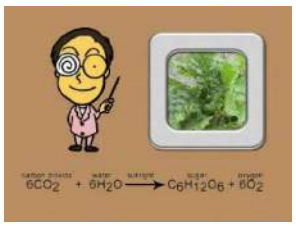
Through photosynthesis. **Photosynthesis** is the process plants use to make their own "food" from the sun's energy, carbon dioxide, and water. During photosynthesis, carbon dioxide and water combine with solar energy to create **glucose**, a carbohydrate ($C_6H_{12}O_6$), and oxygen.

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

Glucose 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.**

The Photosynthesis Song can be heard at http://www.youtube.com/watch?v=C1_uez5WX1o (1:52).



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Vocabulary

- **ATP (adenosine triphosphate)**: Usable form of energy inside the cell.
- **autotroph**: Organism that produces complex organic compounds from simple inorganic molecules using a source of energy such as sunlight.
- **cellular respiration**: Process of breaking down glucose to obtain energy in the form of ATP.
- **chloroplast**: Organelle that carries out photosynthesis in plants.
- **glucose**: Simple sugar with the chemical formula $C_6H_{12}O_6$; a product of photosynthesis.
- **heterotroph**: Organism which obtains carbon from outside sources.
- **photosynthesis**: Process by which specific organisms (including all plants) use the sun's energy to make their own food from carbon dioxide and water; process that converts the energy of the sun, or solar energy, into carbohydrates, a type of chemical energy.
- **producer**: Organism that produces food (glucose) for itself and other organisms.

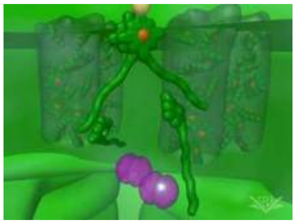
Summary

- 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.

Practice

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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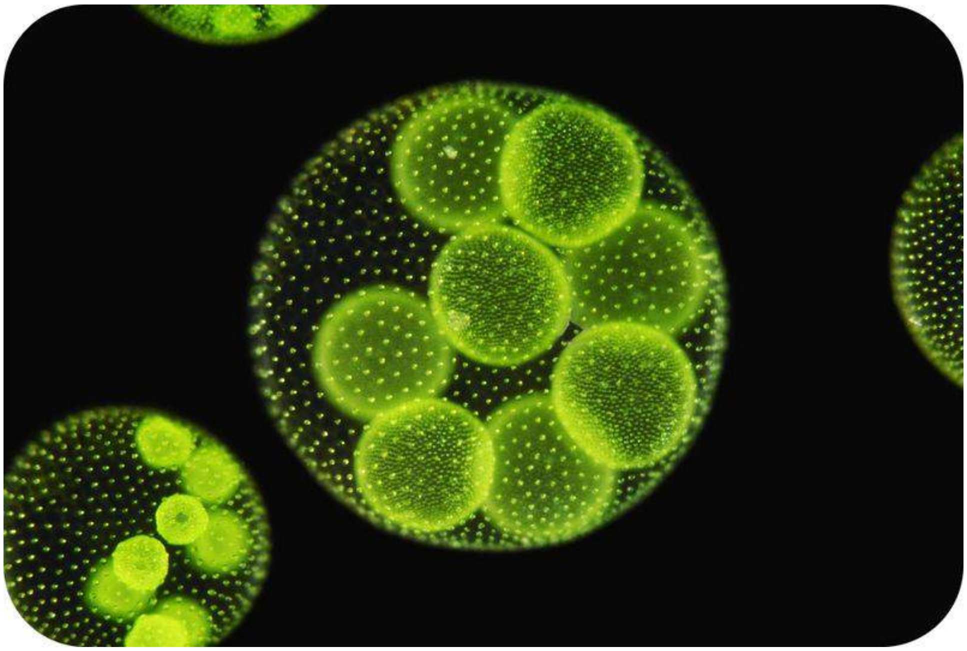
1. Where does the energy for photosynthesis come from?
2. In photosynthesis, how does the movement of electrons along the electron transport chain affect hydrogen ions (H^+)? How does this compare to what happens in the mitochondria during cellular respiration?
3. Do all organisms which carry out photosynthesis 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? Which ones are involved in photosynthesis?

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?

CHAPTER 4 Light Reactions of Photosynthesis

- Describe what happens during 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.

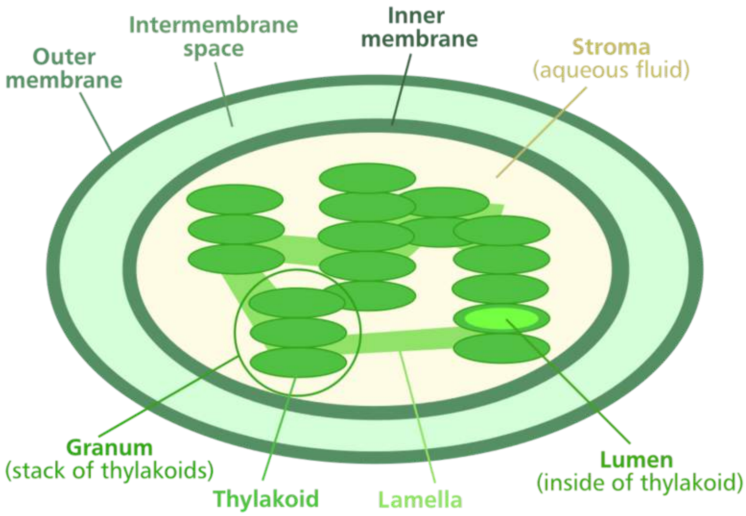


FIGURE 4.1
The chloroplast is the photosynthesis factory of the plant.

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.
- 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.

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).

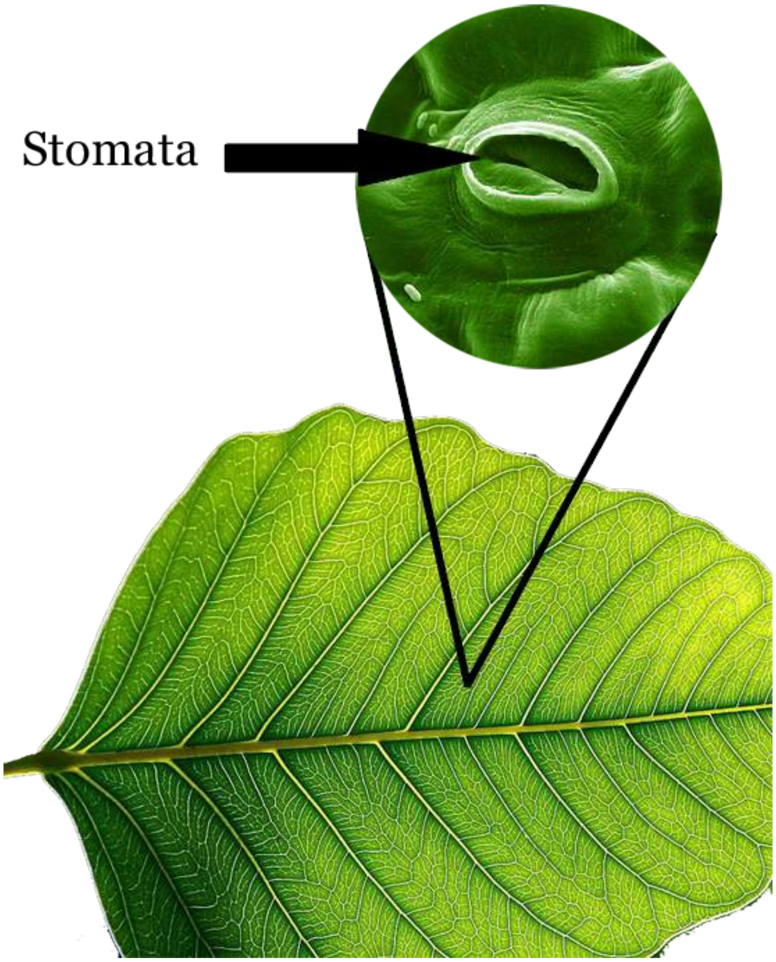


FIGURE 4.2
Stomata are special pores that allow gasses to enter and exit the leaf.

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.

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.

Vocabulary

- **Calvin cycle**: Second stage of photosynthesis in which carbon atoms from carbon dioxide are combined, using the energy in ATP and NADPH to make glucose.
- **chlorophyll**: Pigment that absorbs sunlight and gives plants their green color.

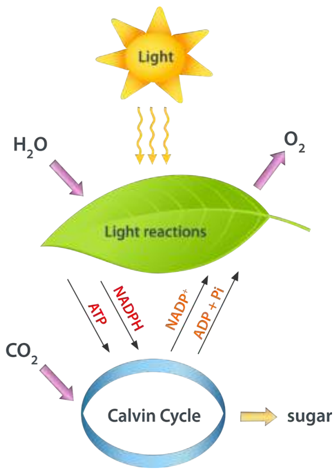


FIGURE 4.3

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.

- **chloroplast**: Organelle that carries out photosynthesis in plants.
- **electron transport chain**: Series of electron-transport molecules that pass high-energy electrons from molecule to molecule and capture their energy.
- **glucose**: Simple sugar with the chemical formula $C_6H_{12}O_6$; a product of photosynthesis.
- **light reactions**: First stage of photosynthesis in which light energy from the sun is captured and changed into chemical energy that is stored in ATP and NADPH.
- **products**: End results of a chemical reaction.
- **reactants**: Molecules that come together to start a chemical reaction.
- **stomata**: Special pores in leaves; carbon dioxide enters the leaf and oxygen exits the leaf through these pores.
- **stroma**: Fluid that fills the interior space that surrounds the thylakoids in the chloroplast.
- **thylakoid**: Stack of flattened sacs of membrane in the chloroplast.

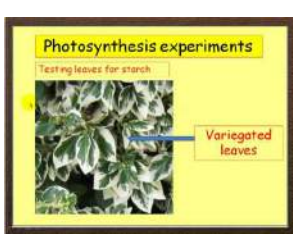
Summary

- 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.

Practice

Use the resources below to answer the following questions.

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



MEDIA

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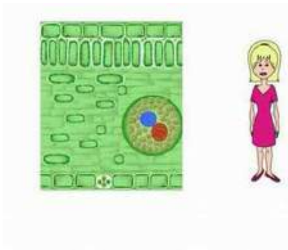
1. How do autotrophs differ from heterotrophs? How are they the same?

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?

- **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?

References

1. Ollin (Wikimedia). . Public Domain
2. Stomata: Dartmouth Electron Microscope Facility and Photohound; Leaf: Jon Sullivan/PD Photo.org. . Public Domain
3. CK-12 Foundation - Hana Zavadska. . CC-BY-NC-SA 3.0

CHAPTER 5 Calvin Cycle

- Describe the Calvin cycle.

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?

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

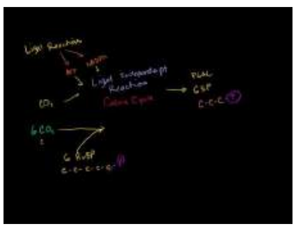
Carbon dioxide water light energy glucose (stored chemical energy) oxygen gas

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.

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



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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** 5.1). 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.

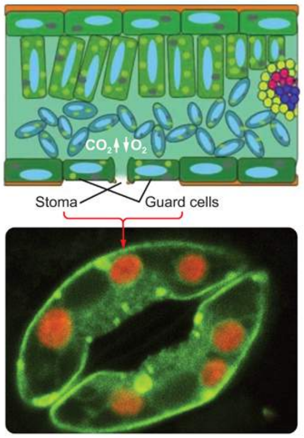
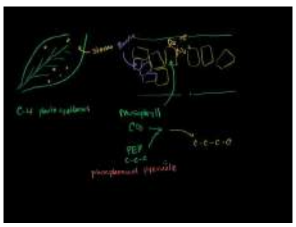


FIGURE 5.1

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).

See http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/31/7ynX_F-SwNY (16:58) for further information.



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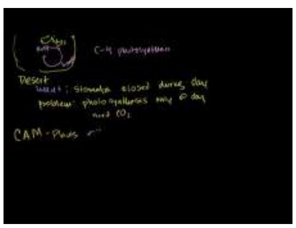
Cacti and succulents such as the jade plant avoid water loss by fixing CO_2 only at night. These plants close their stomata during the day and open them only in the cooler and more humid nighttime hours. Leaf structure differs slightly from that of C_4 plants, but the fixation pathways are similar. The family of plants in which this pathway was discovered gives the pathway its name, Crassulacean Acid Metabolism, or CAM (**Figure** 5.2). All three carbon fixation pathways lead to the Calvin cycle to build sugar.

See http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/32/xp6Zj24h8uA (8:37) for further information.



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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** 5.3, 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 the diagram below to identify the major aspects of the process:

FIGURE 5.2
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.

- 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. 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, $C_6H_{12}O_6$.

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.

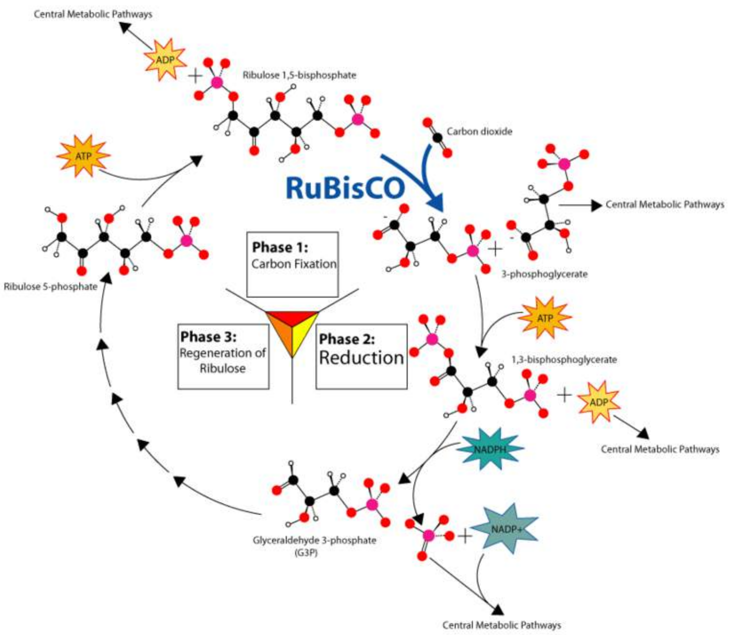

FIGURE 5.3

Overview of the Calvin Cycle Pathway.

- The final product of the Calvin cycle is glucose.

Practice I

Use these resources to answer the questions that follow.

- http://www.hippocampus.org/Biology→ Biology for AP* → Search: **The Calvin-Benson Cycle: Overview**

1. What are carbon assimilation and carbon fixation?
2. Why are most plants called C_3 plants?
3. Describe RuBisCo.
4. What is a C_4 plant?

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **The Conversion of Carbon Dioxide to Sugar**

1. How does CO_2 enter the leaf?
2. What is Ribulose-1,5-bisphosphate?
3. What happens to some of the Glyceraldehyde-3-phosphate?
4. What happens to RuBisCo at night?

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **The Calvin-Benson Cycle: Summary**

1. What eventually happens to the carbon that enters plants as part of CO_2?
2. What happens to the ATP and NADPH made during the light reactions?
3. What happens to energy during photorespiration?
4. What is a main advantage of C_4 plants?

Practice II

- **Photosynthesis** at http://johnkyrk.com/photosynthesisdark.html.

Review

1. What happens during the carbon fixation step of the Calvin cycle?
2. Explain what might happen if the third step of the Calvin cycle did not occur.

References

1. Maksim; Alex Costa, Gross L, PLoS Biology Vol. 4/10/2006, ed. 358. . Public Domain; CC-BY
2. John Talbot, lobo235, Jill Robidoux. . CC-BY 2.0
3. Mike Jones. . CC-BY-SA 2.5

CHAPTER 6 Cellular Respiration

- Describe the process of cellular respiration.

Why do you need food?

The main reason you need to eat is to get energy. Food is your body's only supply of energy. However, this energy must be converted from pizza (or any other food you eat) into an energy source that your body can use. The process of getting energy from your food is called cellular respiration.

What is Cellular Respiration?

How does the food you eat provide energy? When you need a quick boost of energy, you might reach for an apple or a candy bar. But cells do not "eat" apples or candy bars; these foods need to be broken down so that cells can use them. Through the process of **cellular respiration**, the energy in food is changed into energy that can be used by the body's cells. Initially, the sugars in the food you eat are digested into the simple sugar **glucose**, a **monosaccharide**. Recall that glucose is the sugar produced by the plant during photosynthesis. The glucose, or the **polysaccharide** made from many glucose molecules, such as **starch**, is then passed to the organism that eats the plant. This organism could be you, or it could be the organism that you eat. Either way, it is the glucose molecules that holds the energy.

ATP

Specifically, during cellular respiration, glucose is converted into ATP (**Figure** 6.1). **ATP**, or adenosine triphosphate, is chemical energy the cell can use. It is the molecule that provides energy for your cells to perform work, such as moving your muscles as you walk down the street. But cellular respiration is slightly more complicated than just converting glucose into ATP. Cellular respiration can be described as the reverse or opposite of photosynthesis. During cellular respiration, glucose, in the presence of oxygen, is converted into carbon dioxide and water. The process can be summarized as: glucose + oxygen $\rightarrow$ carbon dioxide + water. During this process, the energy stored in glucose is converted into ATP.

Energy is stored in the bonds between the phosphate groups (PO_4^-) of the ATP molecule. When ATP is broken down into ADP (adenosine diphosphate) and inorganic phosphate, energy is released. When ADP and inorganic phosphate are joined to form ATP, energy is stored. During cellular respiration, about 36-38 ATP molecules are produced for every glucose molecule.

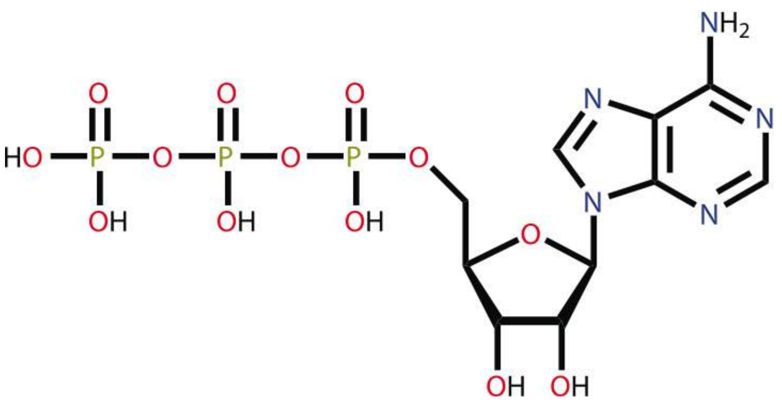

FIGURE 6.1

The structural formula for adenosine triphosphate (ATP). During cellular respiration, energy from the chemical bonds of the food you eat must be converted into ATP.

Vocabulary

- **ATP (adenosine triphosphate)**: Usable form of energy inside the cell.
- **cellular respiration**: Process of breaking down glucose to obtain energy in the form of ATP.
- **glucose**: Simple sugar with the chemical formula $C_6H_{12}O_6$; a product of photosynthesis.
- **monosaccharide**: Simple sugar, such as glucose, that is a building block of carbohydrates.
- **polysaccharide**: Large carbohydrate usually containing hundreds or thousands of monosaccharides.
- **starch**: Large, complex carbohydrate; found in foods such as vegetables and grains; broken down by the body into sugars that provide energy.

Summary

- Through the process of cellular respiration, the energy in food is converted into energy that can be used by the body's cells.
- During cellular respiration, glucose and oxygen are converted into ATP, carbon dioxide, and water.

Practice

Use the resource below to answer the questions that follow.

- **Define Cellular Respiration** at http://www.youtube.com/watch?v=Sr9rYgYS1Fc (1:02)

MEDIA

Click image to the left for more content.

1. What is cellular respiration?
2. Do plant cells respire?
3. What kinds of molecules are used for cellular respiration? Give specific examples.
4. What is the use of ATP? How does this make them vital to the functioning of cells?

Review

1. What is the purpose of cellular respiration?
2. What is ATP?

References

1. Image copyright Leonid Andronov, 2012. . Used under license from Shutterstock.com

CHAPTER 7 Process of Cellular Respiration

- Explain the steps 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** 7.1). 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.

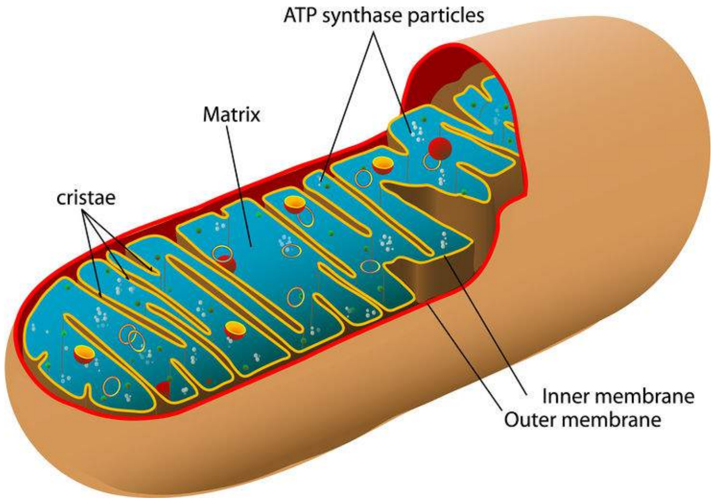

FIGURE 7.1
Most of the reactions of cellular respiration are carried out in the mitochondria.

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 two ATP. 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^+) out of the thylakoid. This establishes a proton gradient across the thylakoid membrane. These protons then flow back into the thylakoid by facilitated diffusion. During this process, ATP is made by adding inorganic phosphate to ADP. 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.

Vocabulary

- **aerobic**: In the presence of oxygen.
- **anaerobic**: In the absence of oxygen.
- **ATP**: Usable form of energy inside the cell; adenosine triphosphate.
- **cellular respiration**: Process of breaking down glucose to obtain energy in the form of ATP.
- **cristae**: Inner membrane folds of the mitochondrion.
- **electron transport chain**: Series of electron-transport molecules that pass high-energy electrons from molecule to molecule and capture their energy.
- **glucose**: Simple sugar with the chemical formula $C_6H_{12}O_6$; a product of photosynthesis.
- **glycolysis**: First stage of cellular respiration in which glucose is split to form two molecules of pyruvate.
- **Krebs cycle**:Second stage of cellular respiration in which two pyruvate molecules react to form NADH, and $FADH_2$ and a small amount of ATP.
- **mitochondrion** (*plural* **mitochondria**): Organelle of the cell in which energy is generated.
- **pyruvate**: Three-carbon product of glycolysis.
- **reactants**: Raw ingredients (starting materials) in a chemical reaction.

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.

Practice

Use the resources below to answer the following questions

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

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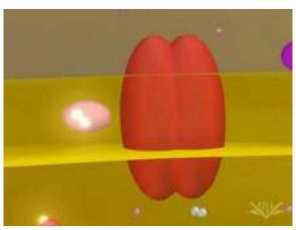
1. Where does glycolysis occur?
2. When glucose is broken down what is produced?
3. Does glycolysis require oxygen?

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

1. Which types 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 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?

- **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. Where does the electron transport chain in mitochondria start? Where does it end?
3. What is a "mobile transfer molecule"? What ones occur in mitochondria? What is their function?

Review

1. Where is glucose broken down to form ATP?
2. Write the chemical reaction for the overall process of cellular respiration.

References

1. Mariana Ruiz Villarreal (LadyofHats), modified by CK-12 Foundation. . Public Domain

Chapter 8 Glycolysis

- Give an overview of glycolysis.

How do you slice a molecule of glucose in half?

With sharp knives? Not really. But you lyse it 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** 8.1. You can watch an animation of the steps of glycolysis at this link: http://www.youtube.com/watch?v=6JGXayUyNVw.

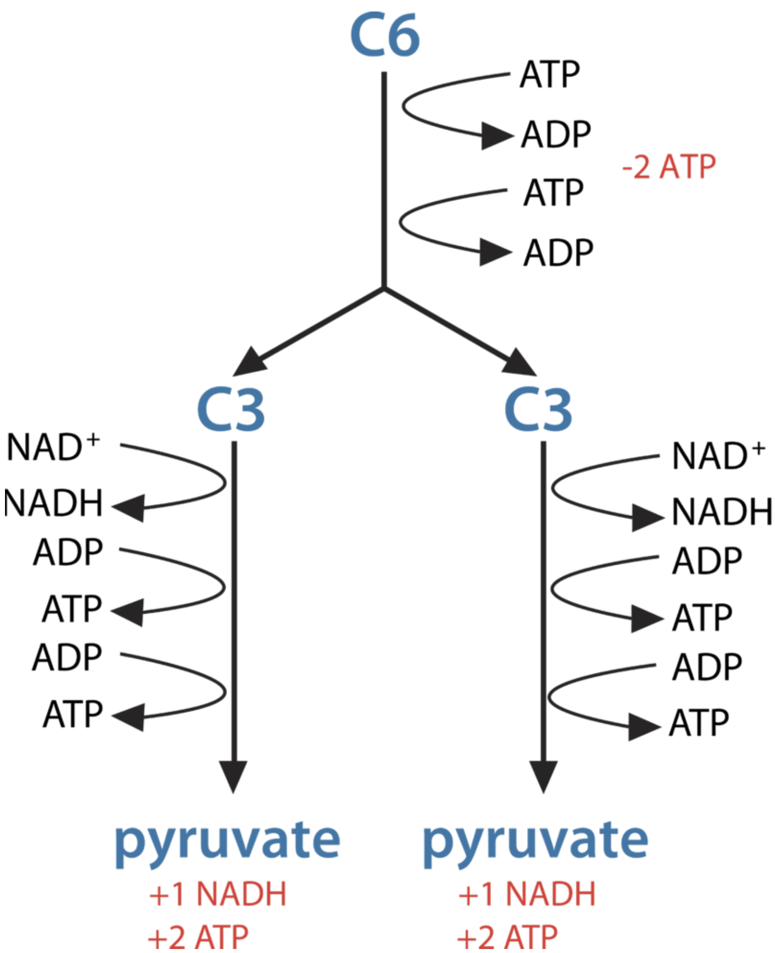
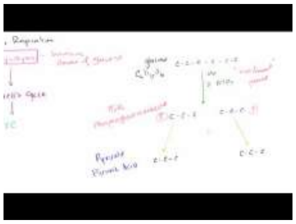


FIGURE 8.1
In glycolysis, glucose (C6) is split into two 3-carbon (C3) pyruvate molecules. This releases energy, which is transferred to ATP. How many ATP molecules are made during this stage of cellular respiration?

Results of Glycolysis

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

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



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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.

Practice I

Use these resources to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Glycolsis: Summary**

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

1. How do cells get chemical energy?
2. Define glycolysis. Where does glycolysis take place?
3. When is the maximum amount of energy released?
4. How can glycolysis be regulated?
5. What is hexokinase?

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **The Glycolytic Pathway**

1. What does glucose supply? Where does glucose come from?
2. Describe the overall process of glycolysis.
3. What happens during the energy gaining phase of glycolysis?
4. What is the total gain in ATP from glycolysis?
5. What is an isomerase?
6. Why are reactions 1, 3, and 10 considered spontaneous?
7. What are the final products of glycolysis?

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **The Regulation of Glycolysis**

1. What are the major control points of glycolysis?
2. Define feedback inhibition.
3. How is PFK regulated during glycolysis?
4. Is citrate an inhibitor or activator of PFK?

Practice II

- **Glycolysis** at http://johnkyrk.com/glycolysis.html.

Review

1. What is glycolysis?
2. Describe what happens during glycolysis. How many ATP molecules are gained during this stage?
3. Defend this statement: "Glycolysis is a universal and ancient pathway for making ATP."

References

1. CK-12 Foundation. . CC-BY-NC-SA 3.0

CHAPTER 9 Krebs Cycle

- List the steps of the Krebs cycle, and identify its products.

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** 9.1. You can watch an animated version at this link: http://www.youtube.com/watch?v=p-k0biO1DT8&feature=related.

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

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** 9.1). 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

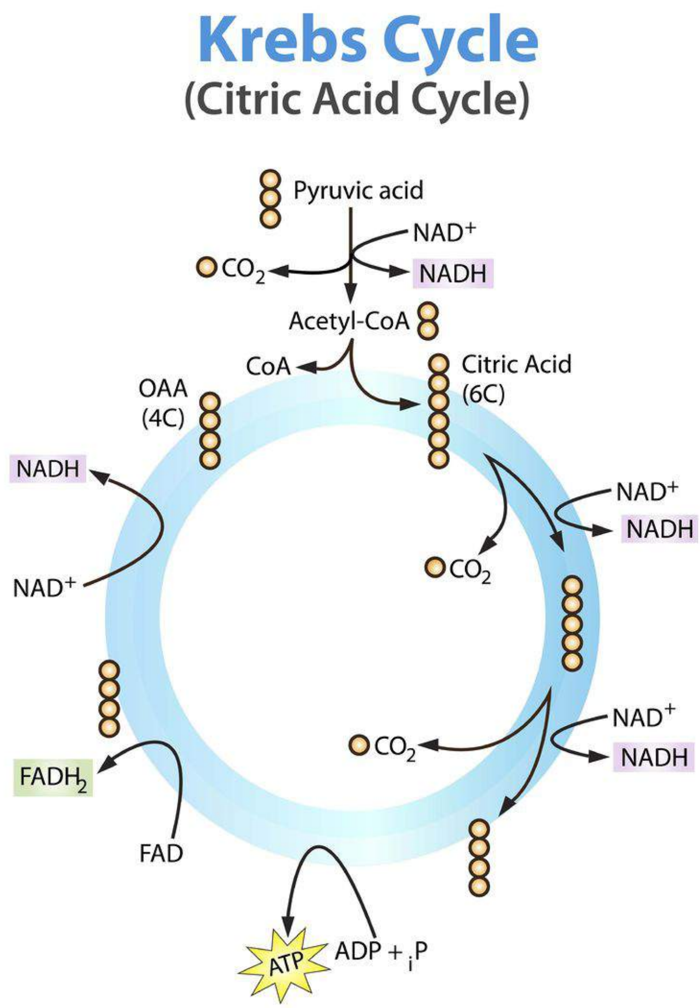


FIGURE 9.1

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 $FADH_2$ are produced?

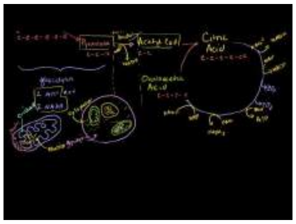
because glycolysis produces two pyruvic acid molecules when it splits glucose. Watch the OSU band present the Krebs cycle: http://www.youtube.com/watch?v=FgXnH087JIk&feature=related.

Results of the Krebs Cycle

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

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

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



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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.

Practice I

Use these resources to answer the questions that follow.

- **The Citric Acid Cycle** at http://virtuallabs.stanford.edu/other/biochem/TCA.swf.

1. Where does the Krebs cycle occur in the cell?
2. What is the first product of this cycle?
3. How many reactions does it take to complete the cycle?

- http://www.hippocampus.org/Biology→ Biology for AP* → Search: **The TCA Cycle: Summary**

- http://www.hippocampus.org/Biology→ Biology for AP* → Search: **The TCA Cycle: Overview**

1. Provide a definition for the Krebs or TCA cycle.
2. What are the roles of NADH and $FADH_2$?
3. Will the TCA cycle occur in the absence of oxygen?

- http://www.hippocampus.org/Biology→ Biology for AP* → Search: **The TCA Cycle**

1. What must happen to pyruvate for it to enter the mitochondria?
2. What is the function of Coenzyme A?
3. Is reaction 1 reversible? Why or why not?
4. How many NADH molecules are produced during the Krebs cycle?
5. How do carbon atoms leave the Krebs cycle?

Practice II

- **Krebs Cycle** at http://johnkyrk.com/krebs.html.

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.

References

1. CK-12 Foundation. . CC-BY-NC-SA 3.0

CHAPTER 10 Electron Transport

- Explain how electron transport results in many molecules 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?)

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

Transporting Electrons

High-energy electrons are released from NADH and $FADH_2$, and they move along **electron transport chains**, like those used in photosynthesis. The electron transport chains are on the inner membrane of the mitochondrion. As the high-energy electrons are transported along the chains, some of their energy is captured. This energy is used to pump hydrogen ions (from NADH and $FADH_2$) across the inner membrane, from the matrix into the intermembrane space. Electron transport in a mitochondrion is shown in **Figure** 10.1.

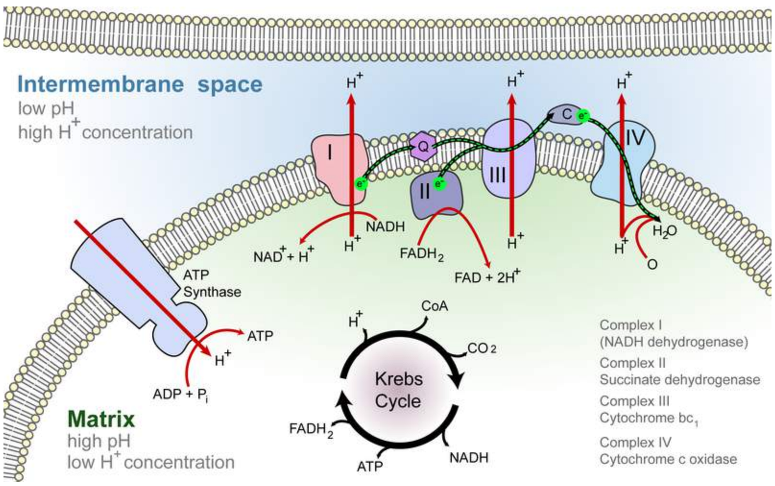

FIGURE 10.1
Electron-transport chains on the inner membrane of the mitochondrion carry out the last stage of cellular respiration.

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.

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

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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.

Practice I

Use these resources to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Electron Transport, ATP Synthesis, and Chemiosmosis: Overview**

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **The Electron Transport Chain**

1. Where, specifically, is the electron transport chain located?
2. How many electrons does NADH donate to the first electron acceptor?
3. What is the role of Coenzyme Q in electron transport?
4. What is the role of molecular oxygen in this process?
5. How is the proton gradient formed?
6. What are the results of the removal of protons from the matrix?
7. Define the proton-motive force.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **The Synthesis of ATP**

1. What is ATP synthase?
2. Describe how ATP synthase works.

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

1. Describe the chemiosmotic model.

Practice II

- **Mitochondria** at http://johnkyrk.com/mitochondrion.html.

Review

1. Summarize the overall task of Stage III of aerobic respiration.

2. Explain the principle of chemiosmosis.

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

References

1. LadyofHats for the CK-12 Foundation. . CC-BY-NC-SA 3.0

CHAPTER 11 Connecting Cellular Respiration and Photosynthesis

- 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.

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** 11.1) and cellular respiration worldwide helps to keep atmospheric oxygen and carbon dioxide at stable levels.

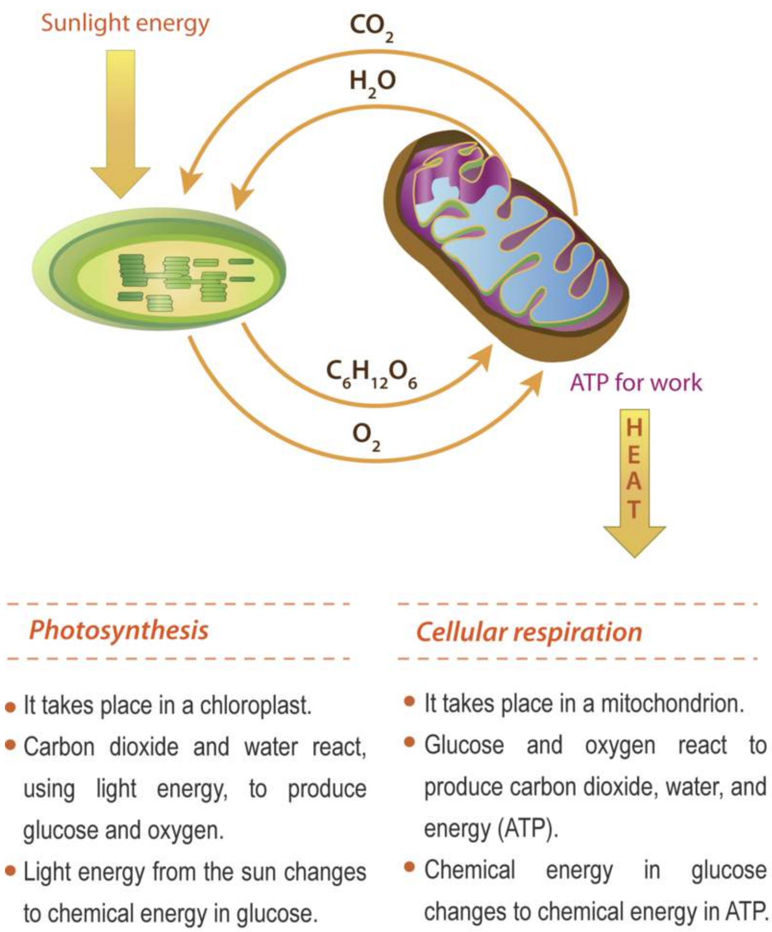


FIGURE 11.1
Cellular respiration and photosynthesis are direct opposite reactions. Some of the ATP made in the mitochondria is used as energy for work, and some is lost to the environment as heat.

Vocabulary

- **carbon cycle**: Pathways through which carbon is recycled through the biosphere.
- **cellular respiration**: Process of breaking down glucose to obtain energy in the form of ATP.
- **photosynthesis**: Process by which specific organisms (including all plants) use the sun's energy to make their own food from carbon dioxide and water; process that converts the energy of the sun, or solar energy, into carbohydrates, a type of chemical energy.

- **products**: End results of a chemical reaction.
- **reactants**: Molecules that come together to start a chemical reaction.

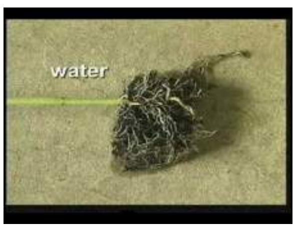
Summary

- 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.

Practice

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 as specific and complete as you can in your answer.
2. What is needed for cellular respiration to occur? Be as specific and complete as you can in your answer.
3. 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?

References

1. CK-12 Foundation - Hana Zavadska; Mitochondrion: Image copyright MiAdS, 2010. . Used under license from Shutterstock.com

CHAPTER 12 Fermentation

- Explain the purpose of fermentation and discuss the two types of fermentation.

How is wine made?

You probably realize that grapes are needed to make wine. You might not realize, however, that yeast are also central in the process of making wine. Yeast take the sugars from the grapes and convert them into alcohol through the process of fermentation.

Fermentation

Sometimes cells need to obtain energy from sugar, but there is no oxygen present to complete cellular respiration. In this situation, cellular respiration can be **anaerobic**, occurring in the absence of oxygen. In this process, called

fermentation, only the first step of respiration, **glycolysis**, occurs, producing two ATP; no additional ATP is produced. Therefore, the organism only obtains the two ATP molecules per glucose molecule from glycolysis. Compared to the 36-38 ATP produced under **aerobic** conditions, **anaerobic respiration** is not a very efficient process. Fermentation allows the first step of cellular respiration to continue and produce some ATP, even without oxygen.

Yeast (single-celled eukaryotic organisms) perform **alcoholic fermentation** in the absence of oxygen. The products of alcoholic fermentation are ethyl alcohol (drinking alcohol) and carbon dioxide. This process is used to make common food and drinks. For example, alcoholic fermentation is used to bake bread. The carbon dioxide bubbles allow the bread to rise and become fluffy. Meanwhile, the alcohol evaporates. In wine making, the sugars of grapes are fermented to produce wine.

Animals and some bacteria and fungi carry out **lactic acid fermentation.** Lactic acid is a waste product of this process. Our muscles perform lactic acid fermentation during strenuous exercise, since oxygen cannot be delivered to the muscles quickly enough. The buildup of lactic acid is believed to make your muscles sore after exercise. Bacteria that produce lactic acid are used to make cheese and yogurt. The lactic acid causes the proteins in milk to thicken. Lactic acid also causes tooth decay, because bacteria use the sugars in your mouth for energy.

Pictured below are some products of fermentation (**Figure** 12.1).

FIGURE 12.1

Products of fermentation include cheese (lactic acid fermentation) and wine (alcoholic fermentation).

Vocabulary

- **aerobic**: In the presence of oxygen.
- **alcoholic fermentation**: Making ethyl alcohol and carbon dioxide from sugars in the absence of oxygen.
- **anaerobic**: In the absence of oxygen.
- **anaerobic respiration**: Respiration in the absence of oxygen; fermentation.
- **fermentation**: Process of making ATP from sugars in the absence of oxygen.
- **glycolysis**: First stage of cellular respiration in which glucose is split to form two molecules of pyruvate.
- **lactic acid fermentation**: Making lactic acid from sugars in the absence of oxygen.

Summary

- Fermentation happens in the absence of oxygen.
- Only the two ATP from glycolysis are produced under anaerobic conditions.
- Alcoholic fermentation and lactic acid fermentation are the two types of fermentation.

Practice

Use the resource below to answer the questions that follow.

- **Anaerobic Respiration** at http://www.youtube.com/watch?v=s3MhJ7buOeA (2:01)

MEDIA

Click image to the left for more content.

1. Where in the cell does anaerobic respiration take place?
2. What happens to pyruvate during anaerobic respiration? How does yeast differ from other organisms regarding the fate of pyruvate?
3. How can glycolysis participate in anaerobic repiration?
4. How much ATP is produced by the breakdown of pyruvate? How much ATP is produced overall by fermentation? Where does this ATP come from?
5. How does the amount of ATP gained from anaerobic respiration compare to the amount of ATP gained from aerobic respiration?
6. How to you think the growth and activity levels compare between organisms carrying out anaerobic respiration and organisms carrying out aerobic respiration?

Review

1. What is the difference between alcoholic fermentation and lactic acid fermentation?
2. If an organism could make ATP from sugars with or without the presence of oxygen, which would be preferred and why?

References

1. Garrett and Kitty Wilkin (Flickr: Gare and Kitty). . CC-BY-NC-SA 2.0

CHAPTER 13 Anaerobic vs Aerobic Respiration

- 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 I: Introduction" 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 "Cellular Respiration II: 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. 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.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology→ Biology for AP* → Search: **Metabolic Strategies**

1. What is the role of oxygen in aerobic metabolism?
2. What is the role of oxygen in anaerobic metabolism?
3. Aerobic metabolism involves what processes?
4. Anaerobic metabolism is also known by what name?
5. How is water formed in the presence of oxygen?
6. Which form of metabolism produces more energy?

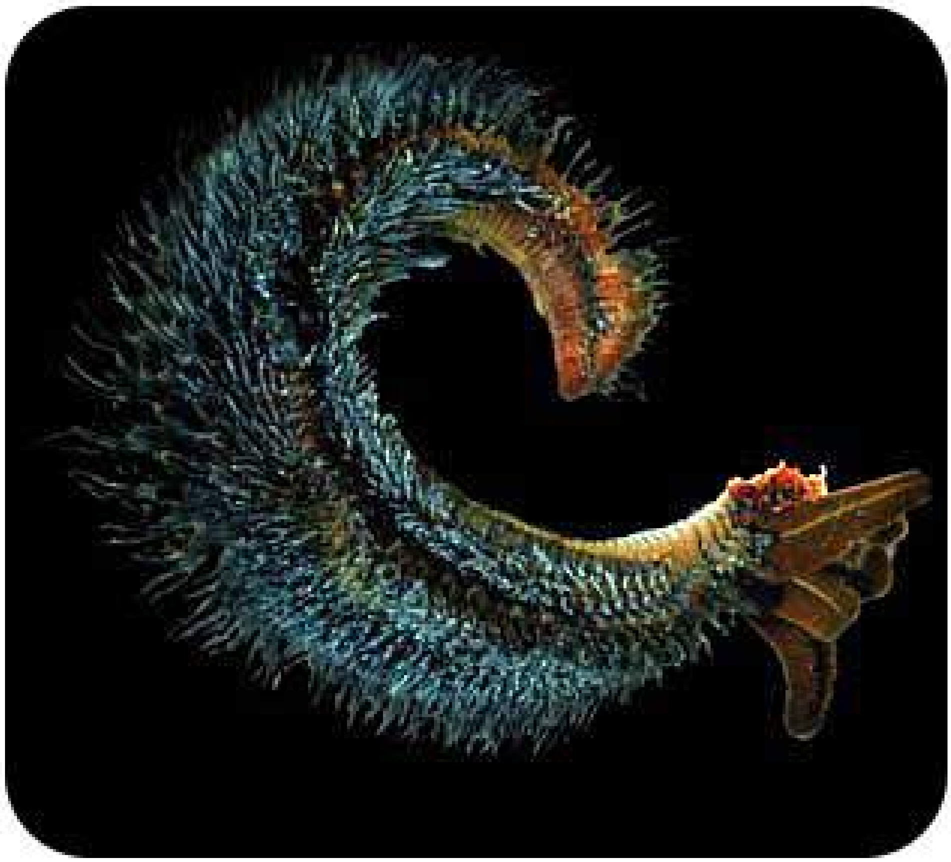
Review

1. Define aerobic and anaerobic respiration.

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

CHAPTER 14 Chemosynthesis

- Define chemosynthesis.



Is it possible to live in temperatures over 175°F?

It is if you're a Pompeii worm. The Pompeii worm, the most heat-tolerant animal on Earth, lives in the deep ocean at super-heated hydrothermal vents. Covering this deep-sea worm's back is a fleece of bacteria. These microbes contain all the genes necessary for life in extreme environments.

Chemosynthesis

Why do bacteria that live deep below the ocean's surface rely on chemical compounds instead of sunlight for energy to make food?

Most autotrophs make food by photosynthesis, but this isn't the only way that autotrophs produce food. Some bacteria make food by another process, which uses chemical energy instead of light energy. This process is called **chemosynthesis**. In chemosynthesis, one or more carbon molecules (usually carbon dioxide or methane, CH_4) and nutrients is converted into organic matter, using the oxidation of inorganic molecules (such as hydrogen gas, hydrogen sulfide (H_2S) or ammonia (NH_3)) or methane as a source of energy, rather than sunlight. In hydrogen sulfide chemosynthesis, in the presence of carbon dioxide and oxygen, carbohydrates (CH_2O) can be produced:

$CO_2 + O_2 + 4H_2S \rightarrow CH_2O + 4S + 3H_2O$

Many organisms that use chemosynthesis are **extremophiles,** living in harsh conditions such as the absence of sunlight and a wide range of water temperatures, some approaching the boiling point. Some chemosynthetic bacteria live around deep-ocean vents known as "black smokers." Compounds such as hydrogen sulfide, which flow out of the vents from Earth's interior, are used by the bacteria for energy to make food. Consumers that depend on these bacteria to produce food for them include giant tubeworms, like those pictured in **Figure** 14.1. These organisms are known as **chemoautotrophs.** Many chemosynthetic microorganisms are consumed by other organisms in the ocean, and symbiotic associations between these organisms and respiring heterotrophs are quite common.

FIGURE 14.1

Tubeworms deep in the Gulf of Mexico get their energy from chemosynthetic bacteria. Tubeworms have no mouth, eyes or stomach. Their survival depends on a symbiotic relationship with the billions of bacteria that live inside them. These bacteria convert the chemicals that shoot out of the hydrothermal vents into food for the worm.

Summary

- Chemosynthesis is a process in which some organisms use chemical energy instead of light energy to produce "food."

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Chemiosmosis in Plants**

1. How is the proton gradient established across the thylakoid membrane?
2. What is the proton motive force?
3. Why is the pH of the thylakoid lumen lower than that of the surrounding stroma?
4. What is ATP synthase?
5. What drives the synthesis of ATP?

Review

1. What is chemosynthesis?

2. Why do bacteria that live deep below the ocean's surface rely on chemical compounds instead of sunlight for energy to make food?

References

1. Image copyright John A. Anderson, 2010. . Used under license from Shutterstock.com

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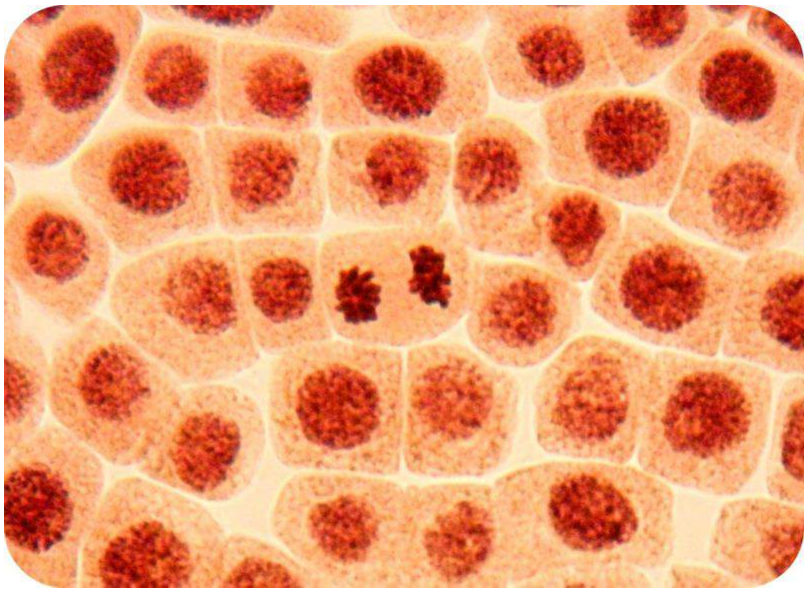
Contents

CHAPTER 1 Cell Biology

- Explain how cells are observed.
- Define the three main parts of the cell theory.
- 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. You may use light microscopes in the classroom. You can use a light microscope to see cells (**Figure** 1.1). 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?

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** 1.2). Without electron microscopes, we would not know what the inside of a cell looked like.

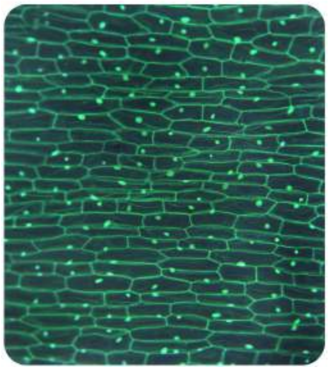


FIGURE 1.1
The outline of onion cells are visible under a light microscope.

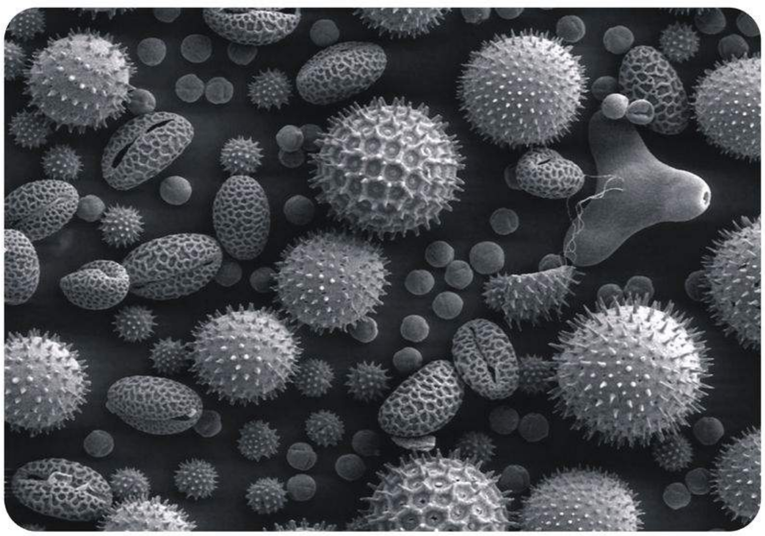


FIGURE 1.2
An electron microscope allows scientists to see much more detail than a light microscope, as with this sample of pollen.

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** 1.3). 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.

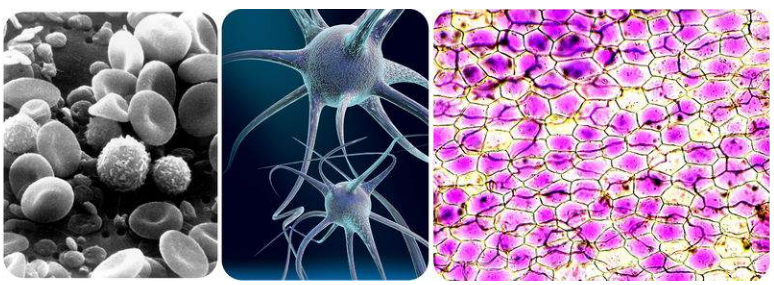


FIGURE 1.3
Red blood cells (*left*) are specialized to carry oxygen in the blood. Neurons (*center*) are shaped to conduct electrical impulses to many other nerve cells. These epidermal cells (*right*) make up the "skin" of plants. Note how the cells fit tightly together.

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** 1.4).

Vocabulary

- **cell**: Basic unit of structure and function of a living organism; the basic unit of life.
- **cell theory**: Scientific theory that all living things are made up of cells, all life functions occur within cells, and all cells come from already existing cells.
- **electron microscope**: Microscope that uses a beam of electrons to magnify an object.
- **microscope**: An instrument that uses lenses to produce magnified images of small objects.
- **organ**: Tissues that work together to perform a specialized function.
- **organ system**: Organs that work together to perform a certain function.
- **tissue**: Groups of cells that work together to perform a specific function.

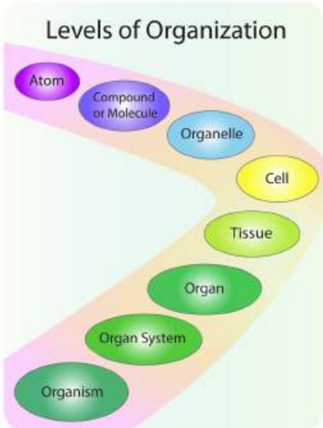


FIGURE 1.4
Levels of organization, from the atom to the organism.

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.

Practice

Use the sliding bar to zoom in on this animation to get an idea of the relative sizes of your cells.

- **Cell Size and Scale - The University of Utah** at http://learn.genetics.utah.edu/content/begin/cells/scale/

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?

References

1. Image copyright Jubal Harshaw, 2010. . Used under license from Shutterstock.com
2. Dartmouth Electron Microscope Facility. . Public Domain
3. Red blood cells: Courtesy of the National Cancer Institute; Neurons: Image copyright Promotive, 2012; Epidermal cells: Image copyright A.R. Monko, 2012. . Red blood cells: Public Domain; Neurons and epidermal cells: Used under licenses from Shutterstock.com
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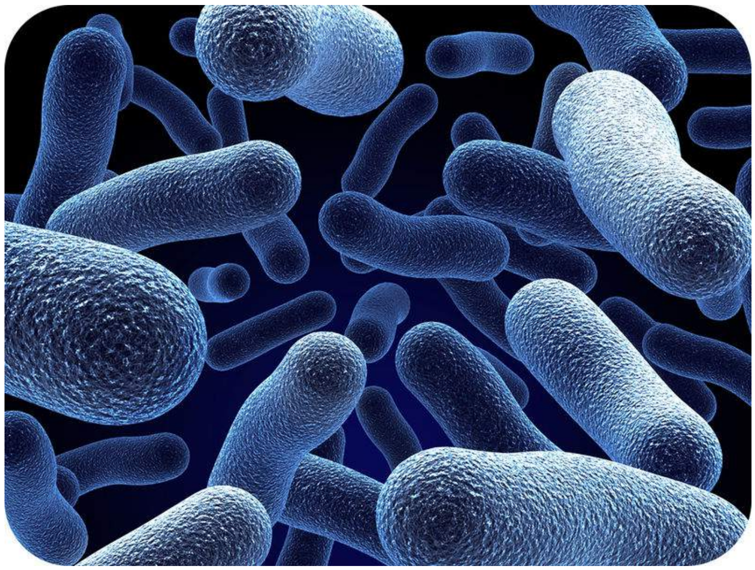
Chapter 2 Prokaryotic and Eukaryotic Cells

- Distinguish between eukaryotic and prokaryotic cells.



Are bacteria cells like our cells?

Yes and no. Bacteria cells are similar to our cells in some ways. Like our cells, bacteria cells have DNA and a plasma membrane. But bacteria are unique in other ways. They are called prokaryotic cells because of these differences.

Prokaryotic and Eukaryotic

There are two basic types of cells, **prokaryotic cells** and **eukaryotic cells**. The main difference between eukaryotic and prokaryotic cells is that eukaryotic cells have a **nucleus**. The nucleus is where cells store their **DNA**, which is the genetic material. The nucleus is surrounded by a membrane. Prokaryotic cells do not have a nucleus. Instead, their DNA floats around inside the cell. Organisms with prokaryotic cells are called **prokaryotes**. All prokaryotes are single-celled organisms. Bacteria and Archaea are the only prokaryotes. Organisms with eukaryotic cells are called **eukaryotes**. Animals, plants, fungi, and protists are eukaryotes. All multi-cellular organisms are eukaryotes. Eukaryotes may also be single-celled.

Both prokaryotic and eukaryotic cells have structures in common. All cells have a plasma membrane, ribosomes, cytoplasm, and DNA. The **plasma membrane**, or cell membrane, is the phospholipid layer that surrounds the cell and protects it from the outside environment. **Ribosomes** are the non-membrane bound organelles where proteins are made, a process called **protein synthesis.** The **cytoplasm** is all the contents of the cell inside the cell membrane, not including the nucleus.

Eukaryotic Cells

Eukaryotic cells usually have multiple **chromosomes**, composed of DNA and protein. Some eukaryotic species have just a few chromosomes, others have close to 100 or more. These chromosomes are protected within the nucleus. In addition to a nucleus, eukaryotic cells include other membrane-bound structures called **organelles**. Organelles allow eukaryotic cells to be more specialized than prokaryotic cells. Pictured below are the organelles of eukaryotic cells (**Figure** 2.1), including the **mitochondria**, **endoplasmic reticulum**, and **Golgi apparatus**. These will be discussed in additional concepts.

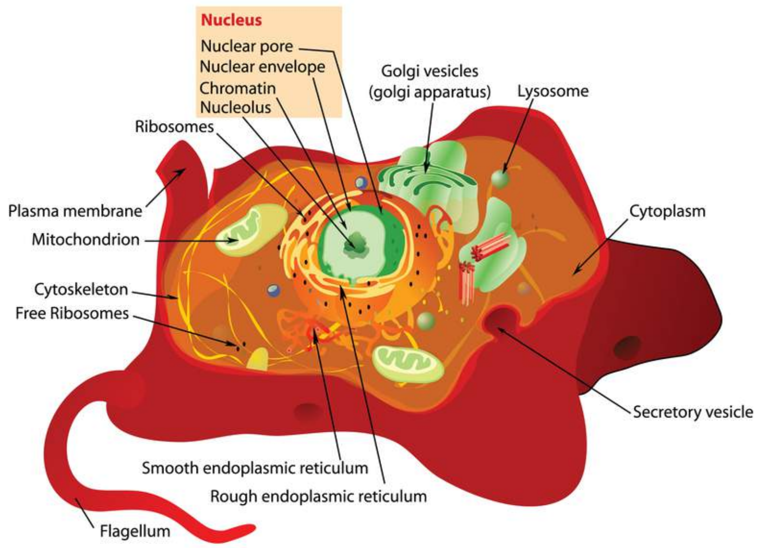


FIGURE 2.1
Eukaryotic cells contain a nucleus and various other special compartments surrounded by membranes, called organelles. The nucleus is where the DNA (chromatin) is stored.

Prokaryotic Cells

Prokaryotic cells (**Figure** 2.2) are usually smaller and simpler than eukaryotic cells. They do not have a nucleus or other membrane-bound organelles. In prokaryotic cells, the DNA, or genetic material, forms a single large circle that coils up on itself. The DNA is located in the main part of the cell.

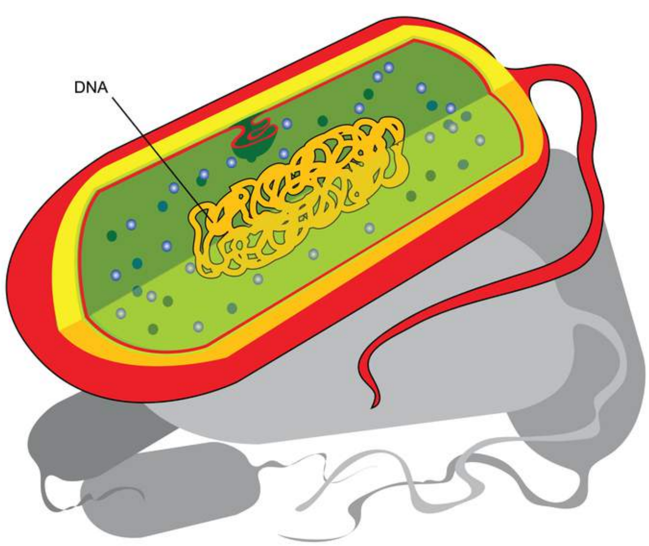


FIGURE 2.2
Prokaryotes do not have a nucleus. Instead, their genetic material is located in the main part of the cell.

TABLE 2.1: Comparison of Prokaryotic and Eukaryotic Cells

Feature	Prokaryotic cells	Eukaryotic cells
Nucleus	No	Yes
DNA	Single circular piece of DNA	Multiple chromosomes
Membrane-enclosed organelles	No	Yes
Examples	Bacteria	Plants, animals, fungi

Vocabulary

- **cytoplasm**: Entire contents of the cell inside the plasma membrane, excluding the nucleus.
- **deoxyribonucleic acid (DNA)**: Nucleic acid that is the genetic material of all organisms.
- **endoplasmic reticulum**: Organelle that is the site of lipid synthesis and protein modification.
- **eukaryote**: Organism with cells containing a nucleus and membrane-bound organelles.
- **eukaryotic cell**: Cell that contains a nucleus and membrane-bound organelles.
- **Golgi apparatus**: Organelle that processes and packages proteins.
- **mitochondrion** (*plural* **mitochondria**): Organelle of the cell in which energy is generated.
- **nucleus**: Cell structure that contains the genetic material, DNA.
- **organelle**: Structure within the cell that has a specific role.
- **plasma membrane**: The lipid barrier that surrounds the cell; known as the cell membrane.
- **prokaryote**: Organism that lacks a nucleus; i.e. bacteria.
- **prokaryotic cell**: Cell without a nucleus or membrane-bound organelles.
- **ribosome**: Organelle in which proteins are made (protein synthesis).

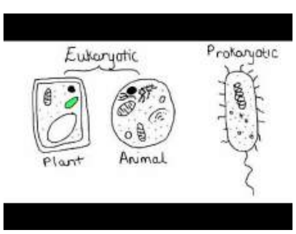
Summary

- All cells have a plasma membrane, ribosomes, cytoplasm, and DNA.
- Prokaryotic cells lack a nucleus and membrane-bound structures.
- Eukaryotic cells have a nucleus and membrane-bound structures called organelles.

Practice

Use the resource below to answer the questions that follow.

- **Compare Prokaryotic and Eukaryotic Cells** at http://www.youtube.com/watch?v=QON4z9vo7Ag (1:55)



MEDIA

Click image to the left for more content.

1. What does "naked" DNA mean? What kinds of organisms have "naked" DNA?
2. Where do you find membrane bound organelles? Are plasmids membrane bound organelles?
3. What is the size of mitochondria in prokaryotes?

- **Quizzes on Prokaryotic or Eukaryotic by neoK12** at http://www.neok12.com/quiz/CELSTR03 and http://www.neok12.com/quiz/CELSTR04

Review

1. What do all cells have in common?
2. What are organelles?
3. Compare the location of the genetic material of eukaryotic cells and prokaryotic cells.
4. What are some examples of eukaryotes?

References

1. Mariana Ruiz Villarreal (LadyofHats), modified by CK-12 Foundation. . Public Domain
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Chapter 3 Cell Transport

- Describe the properties of a phospholipid and of the cell membrane.

How is a cell membrane like a castle wall?

The walls of a castle, like the cell membrane, are designed to keep out dangerous things. Whether you're concerned about an enemy army or a disease-causing bacteria, you don't want to allow everything to enter! However, in order to survive, there are some things that the cell (or the castle) does need to let in.

Introduction to Cell Transport

Cells are found in all different types of environments, and these environments are constantly changing. For example, one-celled organisms, like bacteria, can be found on your skin, in the ground, or in all different types of water.

Therefore, cells need a way to protect themselves. This job is done by the **cell membrane**, which is also known as the plasma membrane.

Controlling the Cell Contents

The cell membrane is **semipermeable**, or selectively permeable, which means that only some molecules can pass through the membrane. If the cell membrane were completely permeable, the inside of the cell would be the same as the outside of the cell. It would be impossible for the cell to maintain **homeostasis**. Homeostasis means maintaining a stable internal environment. For example, if your body cells have a temperature of 98.6°F, and it is freezing outside, your cells will maintain homeostasis if the temperature of the cells stays the same and does not drop with the outside temperature.

How does the cell ensure it is semipermeable? How does the cell control what molecules enter and leave the cell? The composition of the cell membrane helps to control what can pass through it.

Composition of the Cell Membrane

Molecules in the cell membrane allow it to be semipermeable. The membrane is made of a double layer of phospholipids (a "bilayer") and proteins (**Figure** 3.1). Recall that phospholipids, being lipids, do not mix with water. It is this quality that allows them to form the outside barrier of the cell.

A single phospholipid molecule has two parts:

1. A head that is **hydrophilic**, or water-loving.
2. A tail that is **hydrophobic**, or water-fearing.

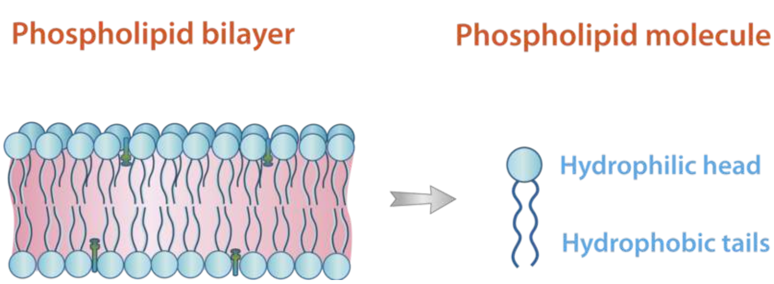


FIGURE 3.1
The cell membrane is made up of a phospholipid bilayer, two layers of phospholipid molecules.

There is water found on both the inside and the outside of cells. Since hydrophilic means water-loving, and they want to be near water, the heads face the inside and outside of the cell where water is found. The water-fearing, hydrophobic tails face each other in the middle of the cell membrane, because water is not found in this space. The phospholipid bilayer allows the cell to stay intact in a water-based environment.

An interesting quality of the plasma membrane is that it is very "fluid" and constantly moving, like a soap bubble. Due to the composition of the cell membrane, small molecules such as oxygen and carbon dioxide can pass freely through the membrane, but other molecules cannot easily pass through the plasma membrane. These molecules need assistance to get across the membrane. That assistance will come in the form of **transport proteins.**

Vocabulary

- **cell membrane**: Lipid barrier that surrounds the cell; also known as the plasma membrane.
- **homeostasis**: Ability of an organism to maintain stable internal conditions, such body temperature, regardless of outside conditions.

- **hydrophilic**: Can combine with water (water-loving).
- **hydrophobic**: Does not combine with water (water-fearing).
- **phospholipid**: Lipid molecule with a hydrophilic ("water-loving") head and two hydrophobic ("water-hating") tails; makes up the cell membrane.
- **semipermeable**: Allowing only certain materials to pass through; characteristic of the cell membrane.
- **transport protein**: Protein that assists molecules entering or leaving the cell.

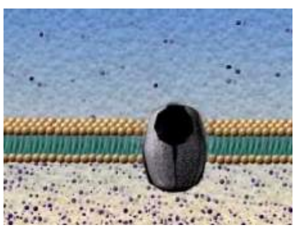
Summary

- The cell membrane is selectively permeable, meaning only some molecules can get through.
- The cell membrane is made of a double layer of phospholipids, each with a hydrophilic (water-loving) head and a hydrophobic (water-fearing) tail.

Practice

Use the resources below to answer the following questions.

- **Active and Passive Transport** at http://www.youtube.com/watch?v=kfy92hdaAH0 (6:13)



MEDIA

Click image to the left for more content.

1. How is passive transport different from active transport?
2. What are three types of passive transport? What do these all have in common? Be as specific and thorough as you can.
3. What does the body use iodine for? What kind of transport is necessary to transport this molecule into a cell?
4. What happens to the receptor complex in "receptor mediated endocytosis"?

Read through the tutorial below and answer the questions that follow.

- **Membrane tutorial** at http://www.bio.davidson.edu/people/macampbell/111/memb-swf/membranes.swf

1. Can proteins in the plasma membrane move around the membrane? Why is this characteristic beneficial to the cell? Think carefully and be as thorough in your answer as possible.
2. What are five functions of the membrane in cells?
3. What types of lipids are found in plasma membranes? What characteristics do these types of lipids share?

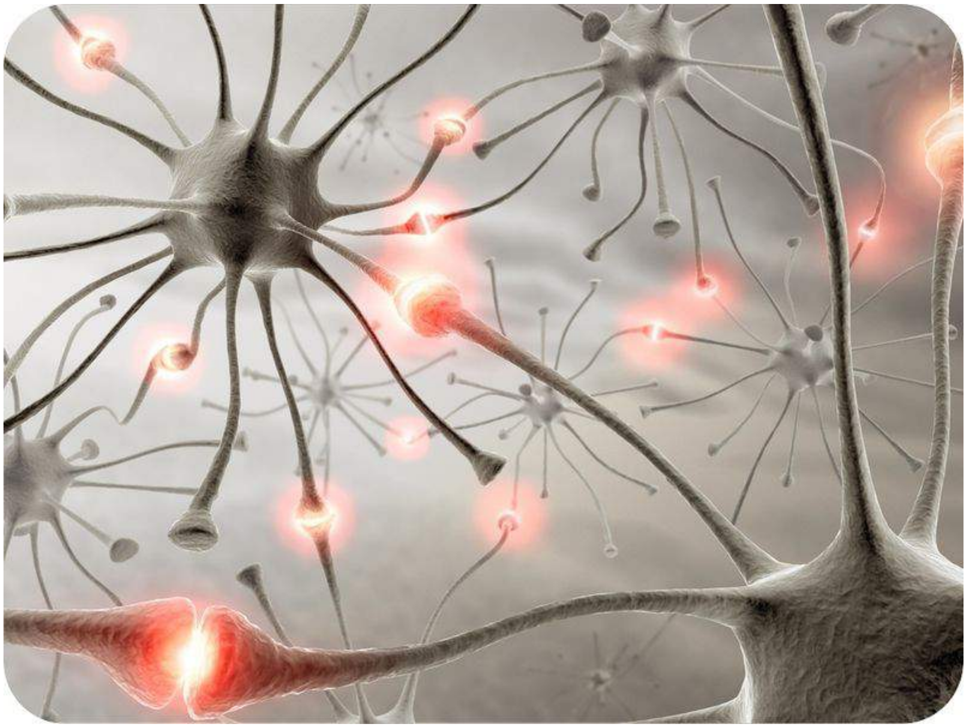
Review

1. Why is the plasma membrane considered selectively permeable?
2. Explain the composition of the cell membrane.

References

1. CK-12 Foundation - Hana Zavadska. . CC-BY-NC-SA 3.0

Chapter 4 Animal and Plant Cells



Lesson Objectives

- List the organelles of the cell and their functions.
- Distinguish between plant and animal cells.

Check Your Understanding

- What is a cell?
- How do we visualize cells?

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. Thus, most organelles are NOT found in prokaryotic cells.

Below are the main organelles found in eukaryotic cells (**Figure** 2.1):

1. The **nucleus** of a cell is like a safe containing the factory's trade secrets. The nucleus contains the genetic material-the information about how to build thousands of proteins.
2. The **mitochondria** are the powerhouses of the cell; they provide the energy needed to power chemical reactions. This 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.
9. The **cytoskeleton** gives the cell its shape, and the **flagella** helps the cell to move. Prokaryotic cells may also have flagella.

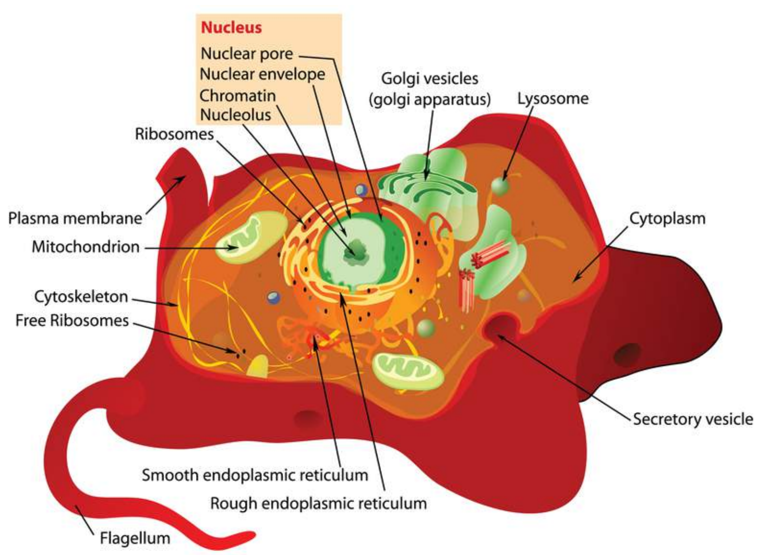


FIGURE 4.1

Figure 2.1 Eukaryotic cells contain special compartments surrounded by membranes, called organelles. For example, notice in this image the mitochondria, lysosomes, and Golgi apparatus.

Plant Cells

FIGURE 4.2

Do plants have cells like yours?

Yes, your cells are actually very similar to a plant's cells. For example, they are both eukaryotic cells, both contain DNA in a nucleus, and both make proteins in ribosomes. However, plant cells also differ in some crucial ways from your own cells.

Even though plants and animals are both eukaryotes, plant cells differ in some ways from animal cells (**Figure**2.2) Plant cells have a large central vacuole, are surrounded by a cell wall, and have chloroplasts, which are the organelles of **photosynthesis**.

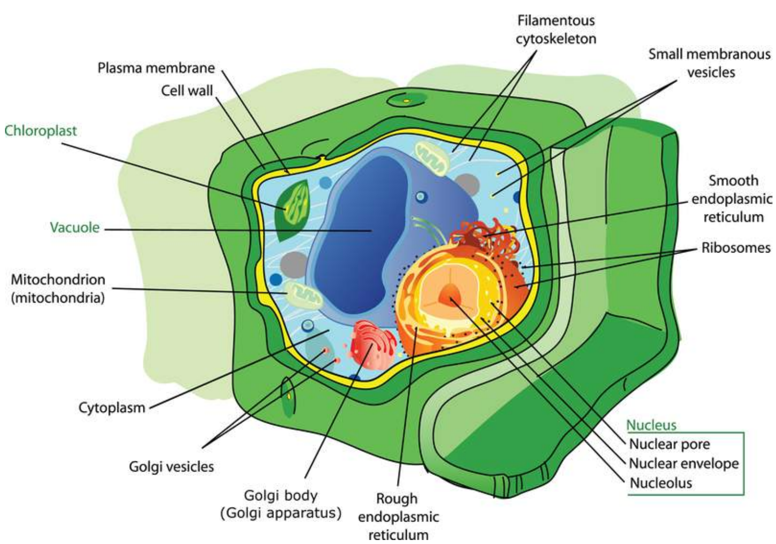


FIGURE 4.3

Figure 2.2 The Plant Cell

First, plant cells have a large central **vacuole** that holds a mixture of water, nutrients, and wastes. A plant cell's vacuole can make up 90% of the cell's volume. The large central vacuole essentially stores water. What happens when a plant does not get enough water? In animal cells, vacuoles are much smaller. **Cell Wall**

Second, plant cells have a **cell wall**, while animal cells do not (**Figure** 2.3). The cell wall surrounds the plasma membrane but does not keep substances from entering or leaving the cell.

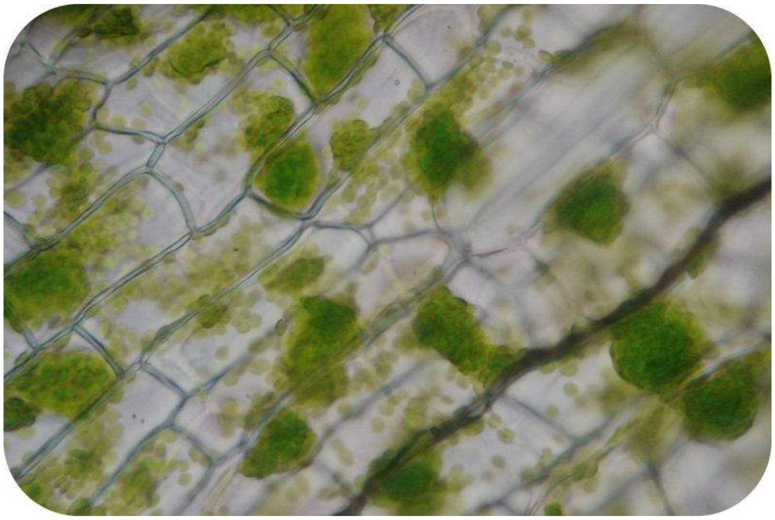


FIGURE 4.4

Figure 2.3 A cell wall gives the plant cell strength and protection.

Plastids

A third difference between plant and animal cells is that plants have several kinds of organelles called **plastids**. And there are several different kinds of plastids in plant cells. For example, **Chloroplasts** are needed for photosynthesis, leucoplasts can store starch or oil, and brightly colored chromoplasts give some flowers and fruits their yellow, orange, or red color. It is the presence of chloroplasts and the ability to photosynthesize, that is one of the defining features of a plant. No animal or fungi can photosynthesize, and only some protists are able to. The photosynthetic protists are the plantlike protists, represented mainly by the unicellular algae. **View the Plant and Animal Cell Animation - Cells alive**

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

Assignment

1. Select "Animal Cell". Click on the following organelles: nucleus, cell membrane, mitochondrion, ribosomes, and nucleolus and record a fact about each organelle in your SLJ.

2. Select "Plant Cell". Click on the following organelles: cell wall, chloroplast, and vacuole. Record a fact about each organelle in your SLJ.

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.
- Plant and animal cells differ in that plants have a large central vacuole, while animals have smaller vacuoles.
- Plant cells also have cell walls and plastids, while animal cells do not.

Points to Consider

- What do you think could happen if your cells divide uncontrollably?
- When new life is formed, do you think it receives all the DNA of the mother and the father?
- Why do you think you might need new cells throughout your life?

References

1. Mariana Ruiz Villarreal (LadyofHats), modified by CK-12 Foundation. . Public Domain
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CHAPTER 5 Diffusion

- Describe different types of passive transport.

What will eventually happen to these dyes?

They will all blend together. The dyes will move through the water until an even distribution is achieved. The process of moving from areas of high amounts to areas of low amounts is called diffusion.

Passive Transport

Probably the most important feature of a cell's phospholipid membranes is that they are **selectively permeable** or **semipermeable**. A membrane that is selectively permeable has control over what molecules or ions can enter or leave the cell, as shown in **Figure** 5.1. 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.

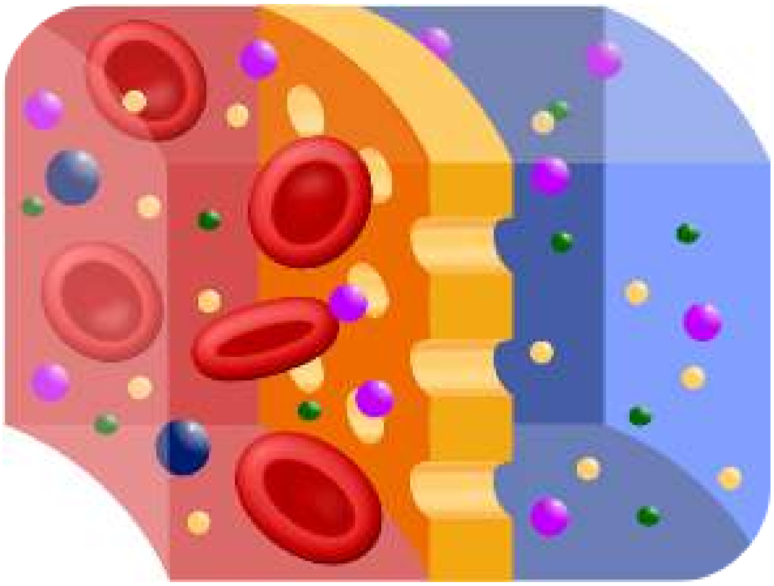


FIGURE 5.1
A selectively permeable membrane allows certain molecules through, but not others.

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 bilayer. Transport proteins within the membrane allow these molecules to pass through the membrane, and 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 three main ways that molecules can pass through a phospholipid membrane. The first way requires no energy input by the cell and is called passive transport. The second way requires that the cell uses energy to pull in or pump out certain molecules and ions and is called active transport. The third 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.

Passive transport is a way that small molecules or ions move across the cell membrane without input of energy by the cell. The three main kinds of passive transport are diffusion, osmosis, and facilitated diffusion.

Diffusion

Diffusion is the movement of molecules from an area of high concentration of the molecules to an area with a lower concentration. The difference in the concentrations of the molecules in the two areas is called the **concentration gradient**. Diffusion will continue until this gradient has been eliminated. Since diffusion moves materials from an area of higher concentration to the lower, it is described as moving solutes "down the concentration gradient." The end result of diffusion is an equal concentration, or **equilibrium**, of molecules on both sides of the membrane.

If a molecule can pass freely through a cell membrane, it will cross the membrane by diffusion (**Figure** 5.2).

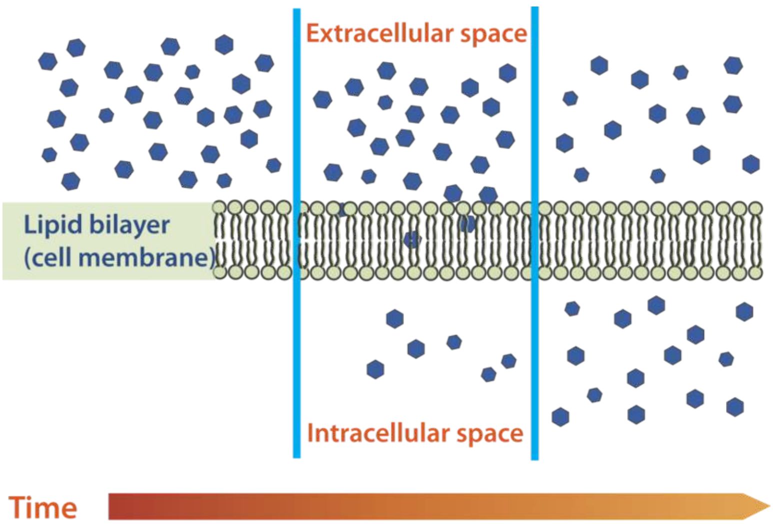


FIGURE 5.2
Molecules move from an area of high concentration to an area of lower concentration until an equilibrium is met. The molecules continue to cross the membrane at equilibrium, but at equal rates in both directions.

Summary

- The cell membrane is selectively permeable, allowing only certain substances to pass through.
- Passive transport is a way that small molecules or ions move across the cell membrane without input of energy by the cell. The three main kinds of passive transport are diffusion, osmosis, and facilitated diffusion.
- Diffusion is the movement of molecules from an area of high concentration of the molecules to an area with a lower concentration.

Practice I

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Transport Mechanisms**

1. Is simple diffusion a form of passive transport? Explain your answer.
2. What is a concentration gradient?
3. Give an example of a molecule that can enter a cell by simple diffusion.

Practice II

- **Diffusion, Osmosis and Active Transport** at http://www.concord.org/activities/diffusion-osmosis-and-active-transport.

Review

1. What is diffusion?

2. What is a concentration gradient?

3. What is meant by passive transport?

References

1. [Wikimedia: Pidalka44]. . Public Domain
2. Mariana Ruiz Villarreal [Wikimedia: LadyofHats]. . CC-BY-NC-SA 3.0

Chapter 6 Osmosis

- Describe different types of passive transport.

Saltwater Fish vs. Freshwater Fish?

Fish cells, like all cells, have semi-permeable membranes. Eventually, the concentration of "stuff" on either side of them will even out. A fish that lives in salt water will have somewhat salty water inside itself. Put it in the freshwater, and the freshwater will, through osmosis, enter the fish, causing its cells to swell, and the fish will die. What will happen to a freshwater fish in the ocean?

Osmosis

Imagine you have a cup that has 100ml water, and you add 15g of table sugar to the water. The sugar dissolves and the mixture that is now in the cup is made up of a **solute** (the sugar) that is dissolved in the **solvent** (the water). The mixture of a solute in a solvent is called a **solution**.

Imagine now that you have a second cup with 100ml of water, and you add 45 grams of table sugar to the water. Just like the first cup, the sugar is the solute, and the water is the solvent. But now you have two mixtures of different solute concentrations. In comparing two solutions of unequal solute concentration, the solution with the higher solute concentration is **hypertonic**, and the solution with the lower solute concentration is **hypotonic**. Solutions of equal solute concentration are **isotonic**. The first sugar solution is hypotonic to the second solution. The second sugar solution is hypertonic to the first.

You now add the two solutions to a beaker that has been divided by a selectively permeable membrane, with pores that are too small for the sugar molecules to pass through, but are big enough for the water molecules to pass through. The hypertonic solution is on one side of the membrane and the hypotonic solution on the other. The hypertonic solution has a lower water concentration than the hypotonic solution, so a concentration gradient of water now exists across the membrane. Water molecules will move from the side of higher water concentration to the side of lower concentration until both solutions are isotonic. At this point, **equilibrium** is reached.

Osmosis is the diffusion of water molecules across a selectively permeable membrane from an area of higher concentration to an area of lower concentration. Water moves into and out of cells by osmosis. If a cell is in a hypertonic solution, the solution has a lower water concentration than the cell cytosol, and water moves out of the cell until both solutions are isotonic. Cells placed in a hypotonic solution will take in water across their membrane until both the external solution and the cytosol are isotonic.

A cell that does not have a rigid cell wall, such as a red blood cell, will swell and lyse (burst) when placed in a hypotonic solution. Cells with a cell wall will swell when placed in a hypotonic solution, but once the cell is turgid (firm), the tough cell wall prevents any more water from entering the cell. When placed in a hypertonic solution, a cell without a cell wall will lose water to the environment, shrivel, and probably die. In a hypertonic solution, a cell with a cell wall will lose water too. The plasma membrane pulls away from the cell wall as it shrivels, a process called **plasmolysis**. Animal cells tend to do best in an isotonic environment, plant cells tend to do best in a hypotonic environment. This is demonstrated in **Figure** 6.1.

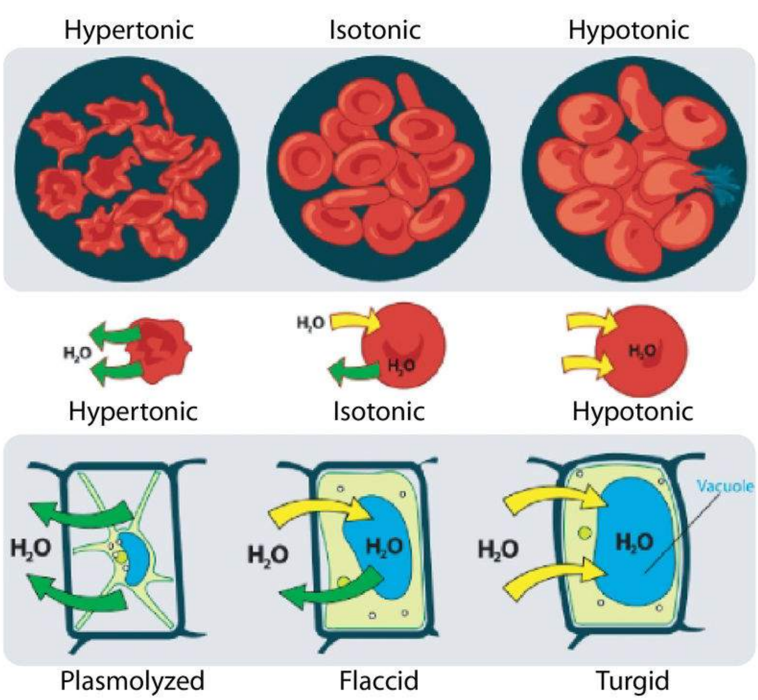


FIGURE 6.1

Unless an animal cell (such as the red blood cell in the top panel) has an adaptation that allows it to alter the osmotic uptake of water, it will lose too much water and shrivel up in a hypertonic environment. If placed in a hypotonic solution, water molecules will enter the cell, causing it to swell and burst. Plant cells (bottom panel) become plasmolyzed in a hypertonic solution, but tend to do best in a hypotonic environment. Water is stored in the central vacuole of the plant cell.

Osmotic Pressure

When water moves into a cell by osmosis, osmotic pressure may build up inside the cell. If a cell has a cell wall, the wall helps maintain the cell's water balance. **Osmotic pressure** is the main cause of support in many plants. When a plant cell is in a hypotonic environment, the osmotic entry of water raises the turgor pressure exerted against the cell wall until the pressure prevents more water from coming into the cell. At this point the plant cell is turgid. The effects of osmotic pressures on plant cells are shown in **Figure** 6.2.

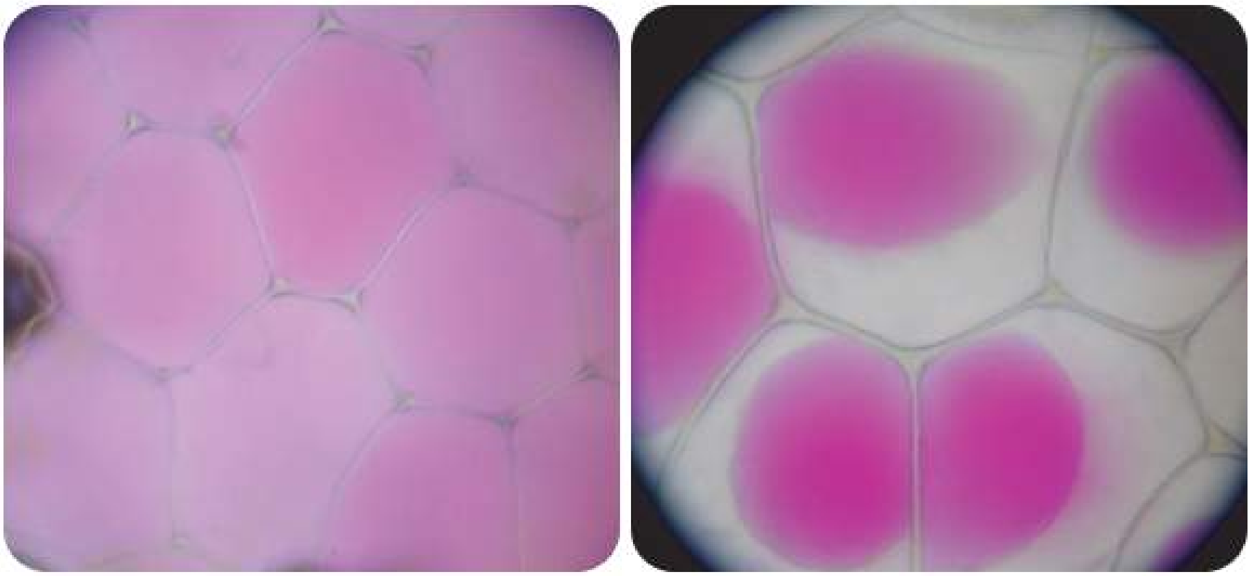
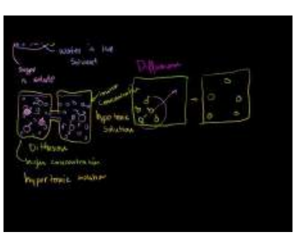


FIGURE 6.2
The central vacuoles of the plant cells in the left image are full of water, so the cells are turgid. The plant cells in the right image have been exposed to a hypertonic solution; water has left the central vacuole and the cells have become plasmolysed.

The action of osmosis can be very harmful to organisms, especially ones without cell walls. For example, if a saltwater fish (whose cells are isotonic with seawater), is placed in fresh water, its cells will take on excess water, lyse, and the fish will die. Another example of a harmful osmotic effect is the use of table salt to kill slugs and snails.

Diffusion and osmosis are discussed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/34/aubZU0iWtgI (18:59).



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Controlling Osmosis

Organisms that live in a hypotonic environment such as freshwater, need a way to prevent their cells from taking in too much water by osmosis. A **contractile vacuole** is a type of vacuole that removes excess water from a cell. Freshwater protists, such as the paramecium shown in **Figure** 6.3, have a contractile vacuole. The vacuole is surrounded by several canals, which absorb water by osmosis from the cytoplasm. After the canals fill with water, the water is pumped into the vacuole. When the vacuole is full, it pushes the water out of the cell through a pore.

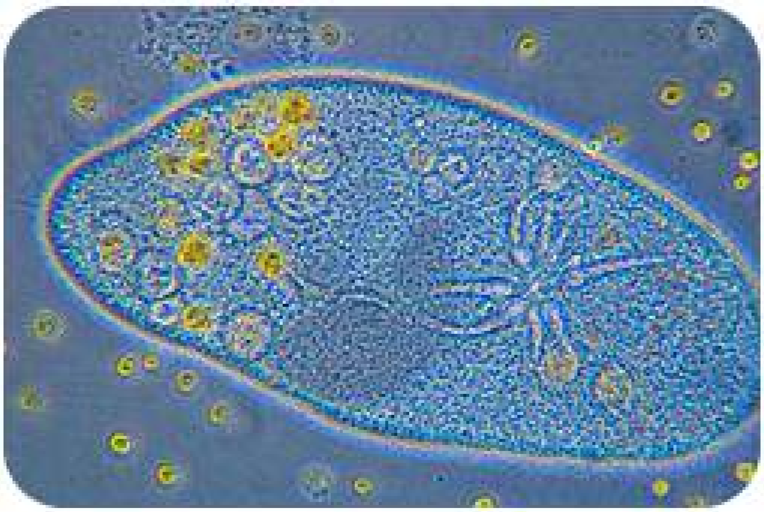

FIGURE 6.3

The contractile vacuole is the star-like structure within the paramecium (at center-right)

Summary

- Osmosis is the diffusion of water.
- In comparing two solutions of unequal solute concentration, the solution with the higher solute concentration is hypertonic, and the solution with the lower concentration is hypotonic. Solutions of equal solute concentration are isotonic.
- A contractile vacuole is a type of vacuole that removes excess water from a cell.

Practice I

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Transport Mechanisms**

1. Define osmosis.
2. Is osmosis a form of diffusion? Explain your answer.
3. Why is osmosis important in biology?

Practice II

- **Diffusion, Osmosis and Active Transport** at http://www.concord.org/activities/diffusion-osmosis-and-active-transport

- **Osmosis**

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Review

1. What is osmosis? What type of transport is it?
2. How does osmosis differ from diffusion?

References

1. Mariana Ruiz Villarreal [Wikimedia: LadyofHats]. . Public Domain
2. Mnolf. . CC-BY-SA 2.0
3. . Jasper Nance. CC-BY-NC-ND 2.0

CHAPTER 7 Facilitated Diffusion

- Describe different types of passive transport.

Can you help me move?

What is one of the questions no one likes to be asked? Sometimes the cell needs help moving things as well, or facilitating the diffusion process. And this would be the job of a special type of protein.

Facilitated Diffusion

Facilitated diffusion is the diffusion of solutes through transport proteins in the plasma membrane. Facilitated diffusion is a type of passive transport. Even though facilitated diffusion involves transport proteins, it is still passive transport because the solute is moving down the concentration gradient.

Small nonpolar molecules can easily diffuse across the cell membrane. However, due to the hydrophobic nature of the lipids that make up cell membranes, polar molecules (such as water) and ions cannot do so. Instead, they diffuse across the membrane through transport proteins. A **transport protein** completely spans the membrane, and allows certain molecules or ions to diffuse across the membrane. Channel proteins, gated channel proteins, and carrier proteins are three types of transport proteins that are involved in facilitated diffusion.

A **channel protein**, a type of transport protein, acts like a pore in the membrane that lets water molecules or small ions through quickly. Water channel proteins allow water to diffuse across the membrane at a very fast rate. Ion channel proteins allow ions to diffuse across the membrane.

A **gated channel protein** is a transport protein that opens a "gate," allowing a molecule to pass through the membrane. Gated channels have a binding site that is specific for a given molecule or ion. A stimulus causes the "gate" to open or shut. The stimulus may be chemical or electrical signals, temperature, or mechanical force, depending on the type of gated channel. For example, the sodium gated channels of a nerve cell are stimulated by a chemical signal which causes them to open and allow sodium ions into the cell. Glucose molecules are too big to diffuse through the plasma membrane easily, so they are moved across the membrane through gated channels. In this way glucose diffuses very quickly across a cell membrane, which is important because many cells depend on glucose for energy.

A **carrier protein** is a transport protein that is specific for an ion, molecule, or group of substances. Carrier proteins "carry" the ion or molecule across the membrane by changing shape after the binding of the ion or molecule. Carrier proteins are involved in passive and active transport. A model of a channel protein and carrier proteins is shown in **Figure** 7.1.

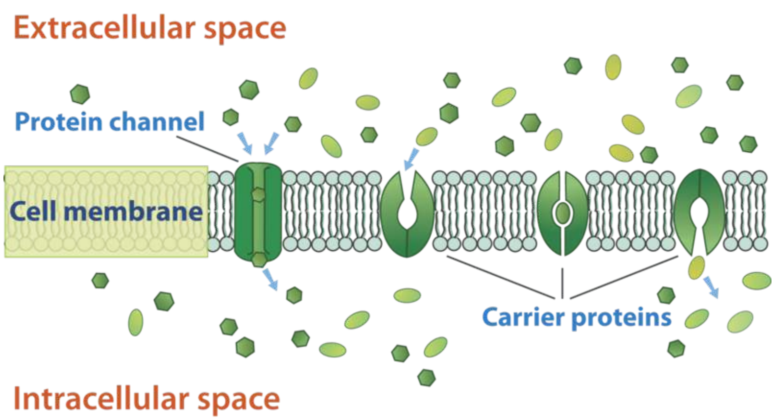
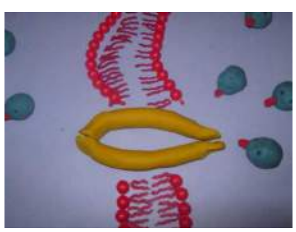


FIGURE 7.1
Facilitated diffusion through the cell membrane. Channel proteins and carrier proteins are shown (but not a gated-channel protein). Water molecules and ions move through channel proteins. Other ions or molecules are also carried across the cell membrane by carrier proteins. The ion or molecule binds to the active site of a carrier protein. The carrier protein changes shape, and releases the ion or molecule on the other side of the membrane. The carrier protein then returns to its original shape.

An animation depicting facilitated diffusion can be viewed at http://www.youtube.com/watch?v=OV4PgZDRTQw&feature=related (1:36).



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Ion Channels

Ions such as sodium (Na^{+}), potassium (K^{+}), calcium (Ca^{2+}), and chloride (Cl^{-}), are important for many cell functions. Because they are polar, these ions do not diffuse through the membrane. Instead they move through ion channel proteins where they are protected from the hydrophobic interior of the membrane. **Ion channels** allow the formation of a concentration gradient between the extracellular fluid and the cytosol. Ion channels are very specific, as they allow only certain ions through the cell membrane. Some ion channels are always open, others are "gated" and can be opened or closed. Gated ion channels can open or close in response to different types of stimuli, such as electrical or chemical signals.

Summary

- Facilitated diffusion is the diffusion of solutes through transport proteins in the plasma membrane. Channel proteins, gated channel proteins, and carrier proteins are three types of transport proteins that are involved in facilitated diffusion.

Practice I

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Transport Mechanisms**

1. Describe the structure of a transport protein.
2. Give an example of a molecule transported by a transport protein.
3. What is carrier-mediated diffusion? How does this process function?

Practice II

- **Membrane Channels** at http://phet.colorado.edu/en/simulation/membrane-channels.

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Review

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

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

References

1. CK-12 Foundation - Hana Zavadska, based on image by Mariana Ruiz Villarreal (LadyofHats). . CC-BY-NC-SA 3.0

CHAPTER 8 Active Transport

- Explain how different types of active transport occur.

Need to move something really heavy?

If you did, it would take a lot of energy. Sometimes, moving things into or out of the cell also takes energy. How would the cell move something against a concentration gradient? It starts by using energy.

Active Transport

In contrast to facilitated diffusion, which does not require energy and carries molecules or ions down a **concentration gradient**, active transport pumps molecules and ions against a concentration gradient. Sometimes an organism needs to transport something against a concentration gradient. The only way this can be done is through active transport, which uses energy that is produced by respiration (ATP). In active transport, the particles move across a cell membrane from a lower concentration to a higher concentration. **Active transport** is the energy-requiring process of pumping molecules and ions across membranes "uphill" - against a concentration gradient.

- The active transport of small molecules or ions across a cell membrane is generally carried out by transport proteins that are found in the membrane.
- Larger molecules such as starch can also be actively transported across the cell membrane by processes called endocytosis and exocytosis.

Homeostasis and Cell Function

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 called 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 set point (the normal level or range). Homeostasis is a dynamic equilibrium rather than an unchanging state. The cellular processes discussed in both the "Passive Transport" and "Active Transport" concepts all play an important role in homeostatic regulation. You will learn more about homeostasis in other concepts.

Summary

- Active transport is the energy-requiring process of pumping molecules and ions across membranes against a concentration gradient.
- Active transport processes help maintain homeostasis.

Practice I

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology→ Biology for AP* → Search: **Transport Mechanisms**

1. What is the main difference between active transport and diffusion?
2. What is cotransport?
3. What molecule is required in active transport?

Practice II

- **Diffusion, Osmosis and Active Transport** at http://www.concord.org/activities/diffusion-osmosis-and-active-transport.

- **Active Transport**

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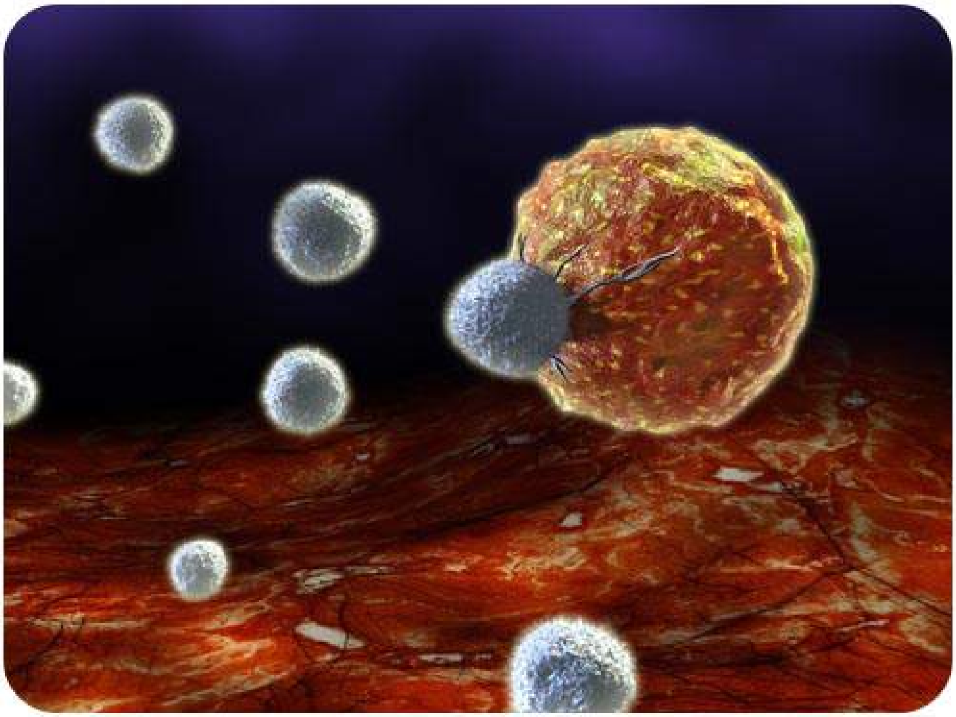
Review

1. What is active transport?

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

CHAPTER 9 Exocytosis and Endocytosis

- Explain how different types of active transport occur.



What does a cell "eat"?

Is it possible for objects larger than a small molecule to be engulfed by a cell? Of course it is. This image depicts a cancer cell being attacked by a cell of the immune system. Cells of the immune system consistently destroy pathogens by essentially "eating" them.

Vesicle Transport

Some molecules or particles are just too large to pass through the plasma membrane or to move through a transport protein. So cells use two other active transport processes to move these macromolecules (large molecules) into or out of the cell. Vesicles or other bodies in the cytoplasm move macromolecules or large particles across the plasma membrane. There are two types of vesicle transport, endocytosis and exocytosis. Both processes are **active transport** processes, requiring energy.

Endocytosis and Exocytosis

Endocytosis is the process of capturing a substance or particle from outside the cell by engulfing it with the cell membrane. The membrane folds over the substance and it becomes completely enclosed by the membrane. At this point a membrane-bound sac, or vesicle, pinches off and moves the substance into the cytosol. There are two main kinds of endocytosis:

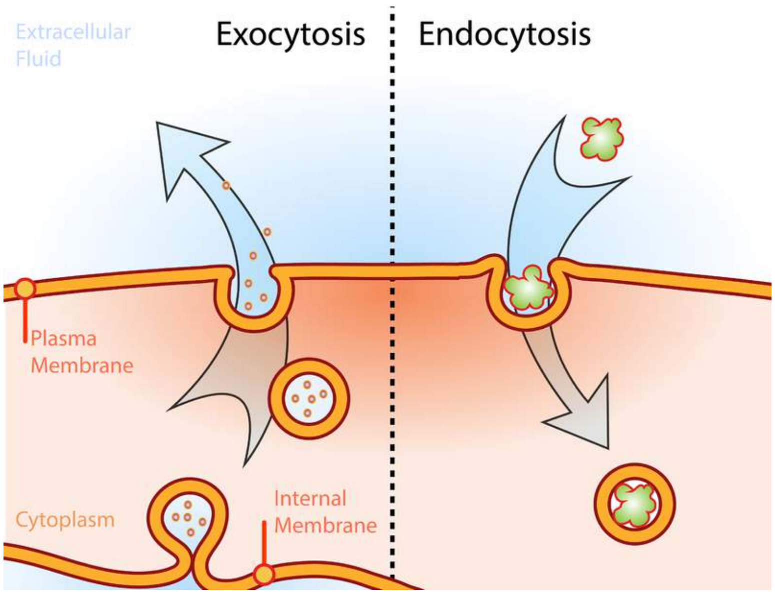


FIGURE 9.1
Illustration of the two types of vesicle transport, exocytosis and endocytosis.

- **Phagocytosis**, or *cellular eating,* occurs when the dissolved materials enter the cell. The plasma membrane engulfs the solid material, forming a phagocytic vesicle.
- **Pinocytosis**, or *cellular drinking,* occurs when the plasma membrane folds inward to form a channel allowing dissolved substances to enter the cell, as shown in **Figure** 9.2. When the channel is closed, the liquid is encircled within a pinocytic vesicle.

FIGURE 9.2
Transmission electron microscope image of brain tissue that shows pinocytotic vesicles. Pinocytosis is a type of endocytosis.

Exocytosis describes the process of vesicles fusing with the plasma membrane and releasing their contents to the outside of the cell, as shown in **Figure** 9.3. Exocytosis occurs when a cell produces substances for export, such as a protein, or when the cell is getting rid of a waste product or a toxin. Newly made membrane proteins and membrane lipids are moved on top the plasma membrane by exocytosis. For a detailed animation of cellular secretion, see http

://vcell.ndsu.edu/animations/constitutivesecretion/first.htm.

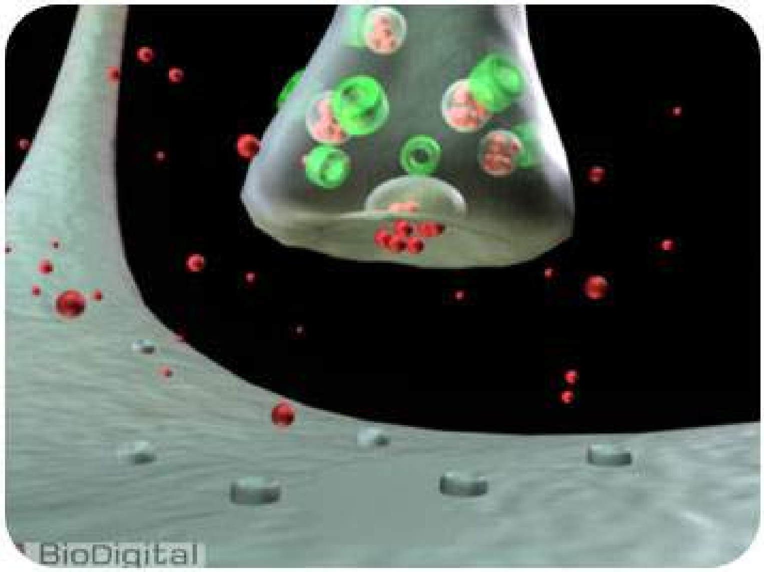


FIGURE 9.3
Illustration of an axon releasing dopamine by exocytosis.

Summary

- Active transport is the energy-requiring process of pumping molecules and ions across membranes against a concentration gradient.
- Endocytosis is the process of capturing a substance or particle from outside the cell by engulfing it with the cell membrane, and bringing it into the cell.
- Exocytosis describes the process of vesicles fusing with the plasma membrane and releasing their contents to the outside of the cell.
- Both endocytosis and exocytosis are active transport processes.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Transport Mechanisms**

1. Compare endocytosis to exocytosis.
2. Describe the process of endocytosis.
3. What are the differences between phagocytosis, pinocytosis, and receptor-mediated endocytosis?
4. How are hormones released from a cell?

Review

1. What is the difference between endocytosis and exocytosis?

2. Why is pinocytosis a form of endocytosis?

3. Are vesicles involved in passive transport? Explain.

References

1. LadyofHats for the CK-12 Foundation. . CC-BY-NC-SA 3.0
2. Louisa Howard, Miguel Marin-Padilla. . Public Domain
3. BioDigital Systems LLC. . GNU-FDL 1.2

CHAPTER 10 Sodium-Potassium Pump

- Explain how different types of active transport occur.
- Explain how the sodium-potassium pump functions.

What is this incredible object?

Would it surprise you to learn that it is a human cell? The image represents an active human nerve cell. How nerve cells function will be the focus of another concept. However, active transport processes play a significant role in the function of these cells. Specifically, it is the sodium-potassium pump that is active in the axons of these nerve cells.

The Sodium-Potassium Pump

Active transport is the energy-requiring process of pumping molecules and ions across membranes "uphill" - against a concentration gradient. To move these molecules against their concentration gradient, a carrier protein is needed. Carrier proteins can work with a concentration gradient (during passive transport), but some carrier proteins can move solutes against the concentration gradient (from low concentration to high concentration), with an input of energy. As in other types of cellular activities, ATP supplies the energy for most active transport. One way ATP powers active transport is by transferring a phosphate group directly to a carrier protein. This may cause the carrier protein to change its shape, which moves the molecule or ion to the other side of the membrane. An example of this type of active transport system, as shown in **Figure** 10.1, is the **sodium-potassium pump,** which exchanges sodium ions for potassium ions across the plasma membrane of animal cells.

As is shown in **Figure** 10.1, three sodium ions bind with the protein pump inside the cell. The carrier protein then gets energy from ATP and changes shape. In doing so, it pumps the three sodium ions out of the cell. At that point, two potassium ions move in from outside the cell and bind to the protein pump. The sodium-potassium pump is found in the plasma membrane of almost every human cell and is common to all cellular life. It helps maintain cell potential and regulates cellular volume.

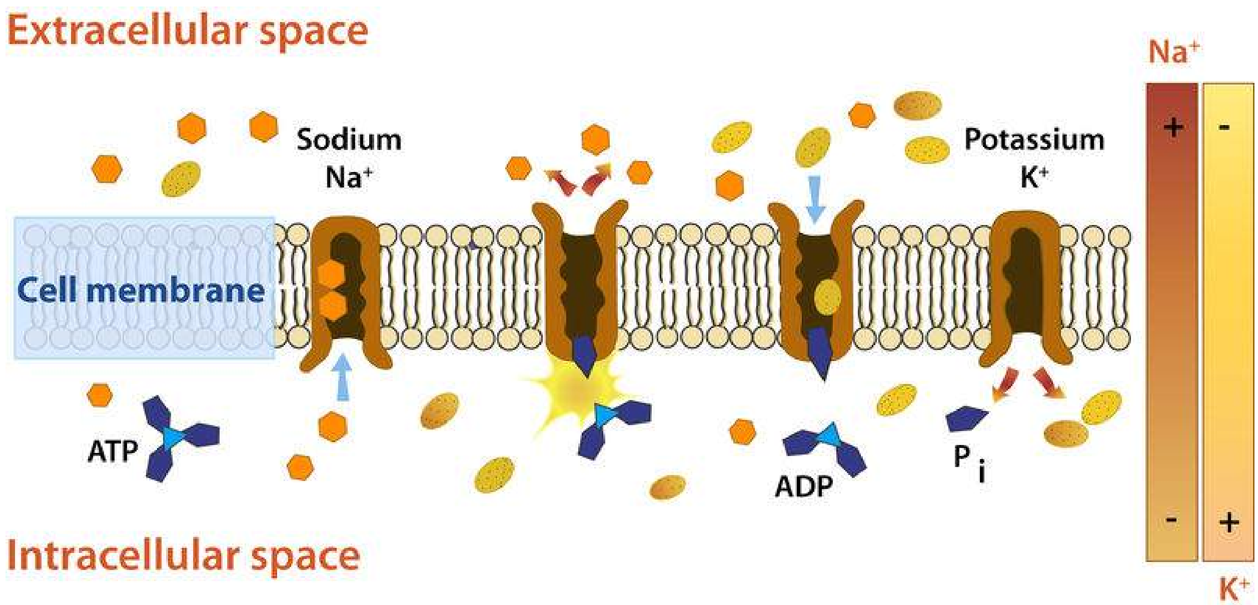
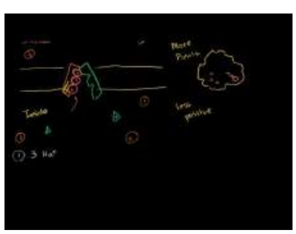


FIGURE 10.1

The sodium-potassium pump system moves sodium and potassium ions against large concentration gradients. It moves two potassium ions into the cell where potassium levels are high, and pumps three sodium ions out of the cell and into the extracellular fluid.

A more detailed look at the sodium-potassium pump is available at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/40/C_H-ONQFjpQ (13:53) and http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/41/ye3rTjLCvAU (6:48).



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The Electrochemical Gradient

The active transport of ions across the membrane causes an electrical gradient to build up across the plasma membrane. The number of positively charged ions outside the cell is greater than the number of positively charged ions in the cytosol. This results in a relatively negative charge on the inside of the membrane, and a positive charge on the outside. This difference in charges causes a voltage across the membrane. Voltage is electrical potential energy that is caused by a separation of opposite charges, in this case across the membrane. The voltage across a membrane is called **membrane potential**. Membrane potential is very important for the conduction of electrical impulses along nerve cells.

Because the inside of the cell is negative compared to outside the cell, the membrane potential favors the movement of positively charged ions (cations) into the cell, and the movement of negative ions (anions) out of the cell. So, there are two forces that drive the diffusion of ions across the plasma membrane—a chemical force (the ions' concentration gradient), and an electrical force (the effect of the membrane potential on the ions' movement). These two forces working together are called an **electrochemical gradient**, and will be discussed in detail in "Nerve Cell" and "Nerve Impulses" concepts.

Summary

- Active transport is the energy-requiring process of pumping molecules and ions across membranes against a concentration gradient.
- The sodium-potassium pump is an active transport pump that exchanges sodium ions for potassium ions.

Practice

Use this resource to answer the questions that follow.

- **Sodium Potassium Pump (ATPase)** at http://www.youtube.com/watch?v=Z9tPTDRjCYU&feature=fvwrel

1. Why is the size difference between a sodium and potassium ion important?
2. Are there more sodium ions on the outside of cells or the inside?
3. Are there more potassium ions on the outside of cells or the inside?
4. Describe the role of ATP in active transport.

Review

1. What is active transport?

2. Describe how the sodium-potassium pump functions.

References

1. Mariana Ruiz Villarreal [Wikimedia: LadyofHats]. . Public Domain

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Contents

CHAPTER 1 Organization of Living Things

- Describe the organization of organisms.

***Organization of Living Things*. What does this mean?**

We know it all starts with the cell. And for some species it ends with the cell. But for others, the cells come together to form tissues, tissues form organs, organs form organ systems, and organ systems combine to form an organism.

Levels of Organization

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

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

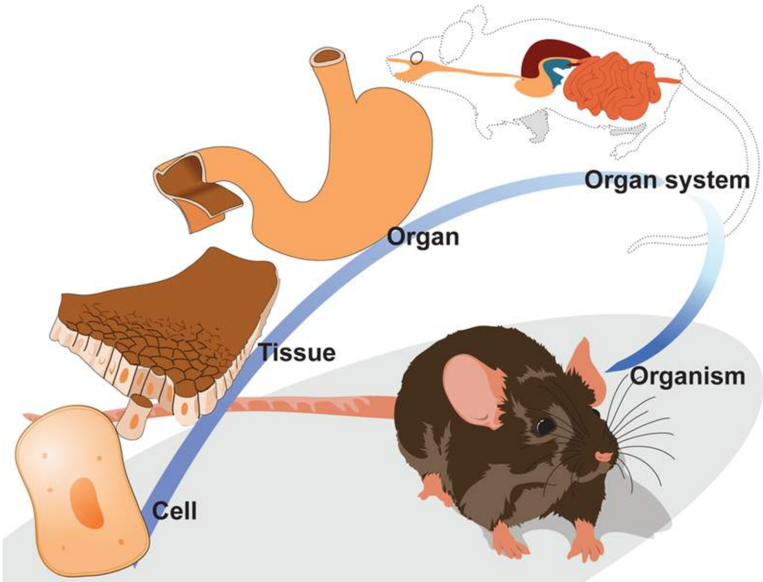

FIGURE 1.1
An individual mouse is made up of several organ systems. The system shown here is the digestive system, which breaks down food into a form that cells can use. One of the organs of the digestive system is the stomach. The stomach, in turn, consists of different types of tissues. Each type of tissue is made up of cells of the same type.

Examples of these levels of organization are shown in **Figure** 1.1.

There are also levels of organization above the individual organism. These levels are illustrated in **Figure** 1.2.

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

Diversity of Life

Life on Earth is very diverse. The diversity of living things is called **biodiversity**. A measure of Earth's biodiversity is the number of different species of organisms that live on Earth. At least 10 million different species live on Earth today. They are commonly grouped into six different kingdoms. Examples of organisms within each kingdom are shown in **Figure** 1.3.

Summary

- Many individual organisms can be organized into the following levels: cells, tissues, organs, and organs systems.
- An ecosystem consists of all the populations in a given area, together with the nonliving environment.
- The biosphere is the part of Earth where all life exists.
- The diversity of living things is called biodiversity.

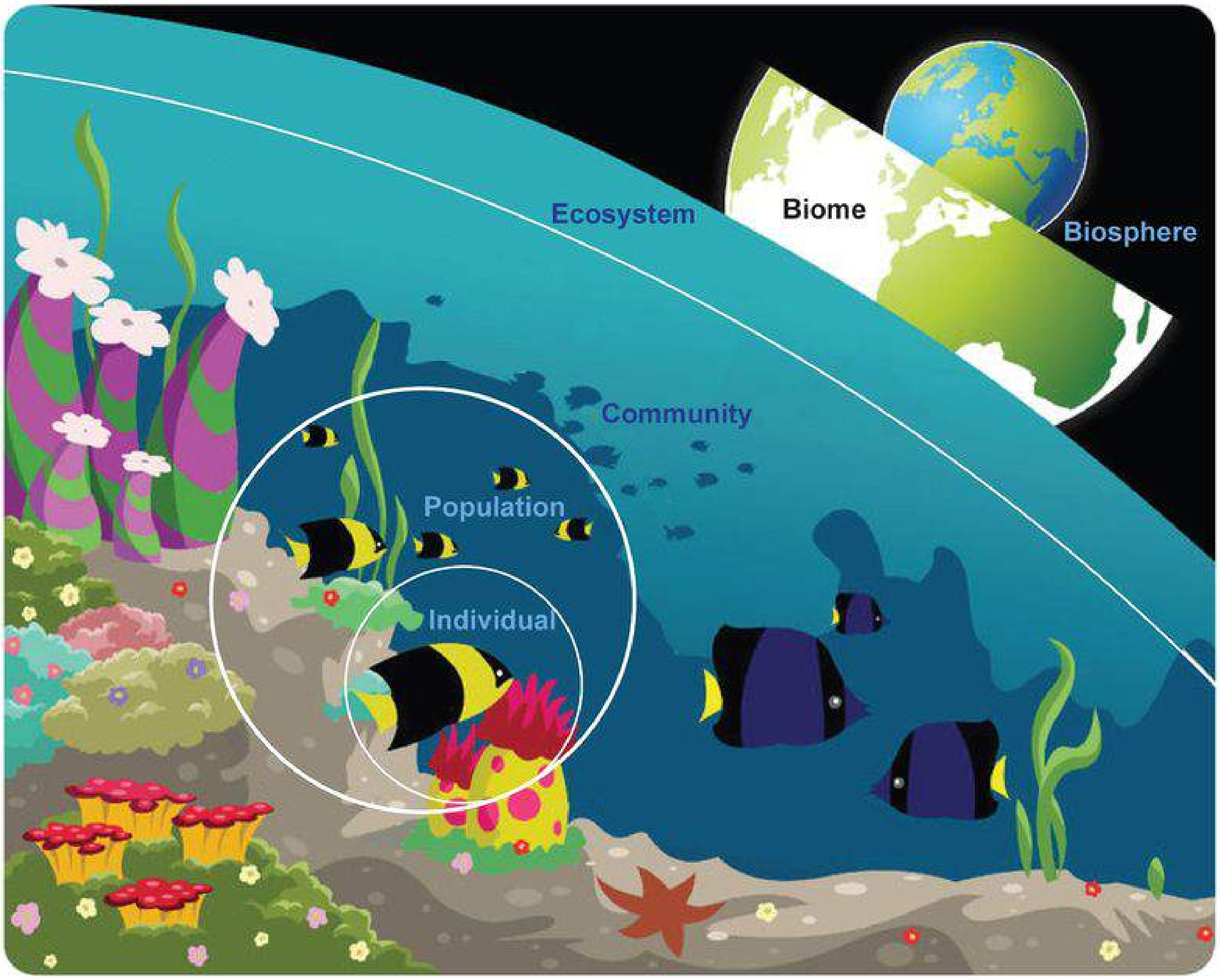

FIGURE 1.2
This picture shows the levels of organization in nature, from the individual organism to the biosphere.

Making Connections

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Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Community Ecology: Overview**

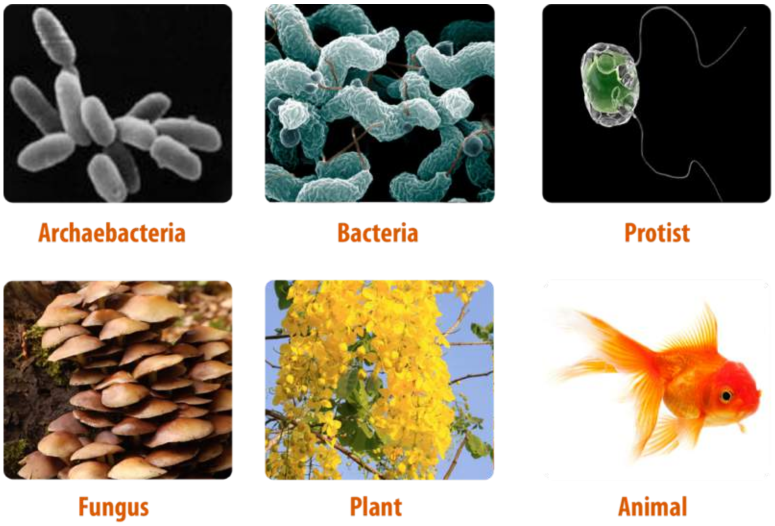


FIGURE 1.3
Diversity of life from Archaebacteria to Plants and Animals.

1. What is the biological definition of a community?
2. What is species diversity?
3. What type of area may have high species diversity? What type of area may have low species diversity?
4. What are the major benefits of adaptive radiation?

Review

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

2. Explain how a population differs from a community.

3. What is biodiversity?

References

1. Mariana Ruiz Villarreal [Wikimedia: LadyofHats]. . Public Domain
2. CK-12 Foundation. . CC-BY-NC-SA 3.0
3. (Archaebacteria) NASA; (Bacteria) De Wood, Chris Pooley, USDA, ARS; (Protist) Image copyright MichaelTaylor, 2010; (Fungus) Image copyright turtleman, 2010; (Plant) Image copyright momopixs, 2012; (Animal) Image copyright Alex Staroseltsev, 2010. . Archaebacteria and bacteria images under the public domain; remaining images used under license from Shutterstock.com

CHAPTER 2 Linnaean Classification

- Outline the Linnaean classification, and define binomial nomenclature.

In biology, what would classification refer to?

There are millions and millions of species, so classifying organisms into proper categories can be a difficult task. To make it easier for all scientists to do, a classification system had to be developed.

Linnaean Classification

The evolution of life on Earth over the past 4 billion years has resulted in a huge variety of species. For more than 2,000 years, humans have been trying to classify the great diversity of life. The science of classifying organisms is called **taxonomy.** Classification is an important step in understanding the present diversity and past evolutionary history of life on Earth.

All modern classification systems have their roots in the **Linnaean classification** system. It was developed by Swedish botanist Carolus Linnaeus in the 1700s. He tried to classify all living things that were known at his time. He grouped together organisms that shared obvious physical traits, such as number of legs or shape of leaves. For his contribution, Linnaeus is known as the "father of taxonomy." You can learn more about Linnaeus and his system of classification by watching the video at this link: http://teachertube.com/viewVideo.php?video_id=169889. The Linnaean system of classification consists of a hierarchy of groupings, called **taxa** (singular, taxon). Taxa range from the kingdom to the species (see **Figure** 2.1). The **kingdom** is the largest and most inclusive grouping. It consists of organisms that share just a few basic similarities. Examples are the plant and animal kingdoms. The **species** is the smallest and most exclusive grouping. It consists of organisms that are similar enough to produce fertile offspring together. Closely related species are grouped together in a **genus.**

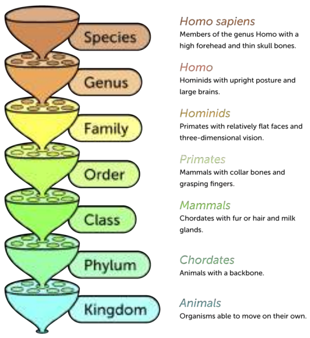


FIGURE 2.1
Linnaean Classification System: Classification of the Human Species. This chart shows the taxa of the Linnaean classification system. Each taxon is a subdivision of the taxon below it in the chart. For example, a species is a subdivision of a genus. The classification of humans is given in the chart as an example.

Binomial Nomenclature

Perhaps the single greatest contribution Linnaeus made to science was his method of naming species. This method, called **binomial nomenclature**, gives each species a unique, two-word Latin name consisting of the genus name and the species name. An example is *Homo sapiens*, the two-word Latin name for humans. It literally means "wise human." This is a reference to our big brains. Why is having two names so important? It is similar to people having a first and a last name. You may know several people with the first name Michael, but adding Michael's last name usually pins down exactly whom you mean. In the same way, having two names uniquely identifies a species.

Revisions in Linnaean Classification

Linnaeus published his classification system in the 1700s. Since then, many new species have been discovered. The biochemistry of many organisms has also become known. Eventually, scientists realized that Linnaeus's system of classification needed revision. A major change to the Linnaean system was the addition of a new taxon called the domain. A **domain** is a taxon that is larger and more inclusive than the kingdom. Most biologists agree there are three domains of life on Earth: Bacteria, Archaea, and Eukaryota (see **Figure** 2.2). Both Bacteria and Archaea consist of single-celled prokaryotes. Eukaryota consists of all eukaryotes, from single-celled protists to humans. This domain includes the Animalia (animals), Plantae (plants), Fungi (fungi), and Protista (protists) kingdoms.

Summary

- Classification is an important step in understanding life on Earth.
- All modern classification systems have their roots in the Linnaean classification system.
- The Linnaean system is based on similarities in obvious physical traits. It consists of a hierarchy of taxa, from the kingdom to the species.
- Each species is given a unique two-word Latin name.
- The recently added domain is a larger and more inclusive taxon than the kingdom.

Practice

Use these resources to answer the questions that follow.

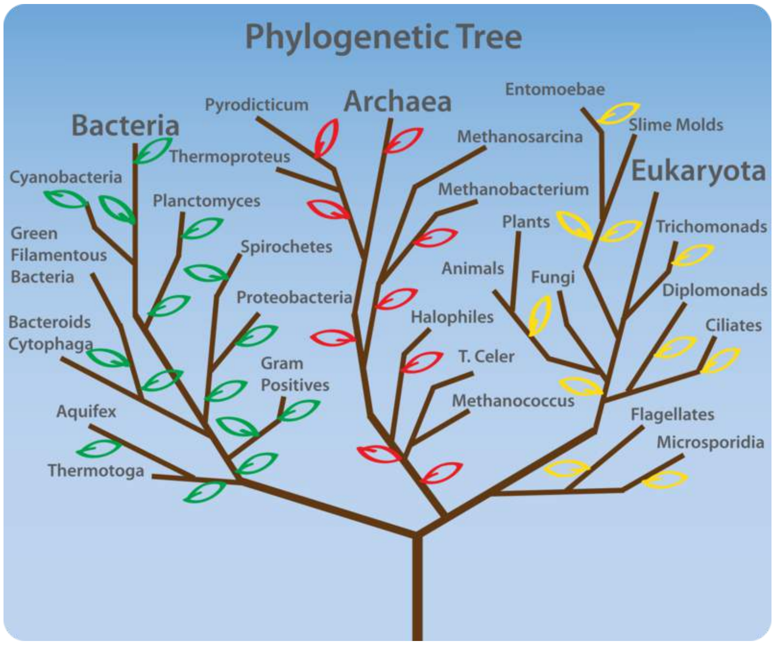


FIGURE 2.2

Three-Domain Classification. This diagram shows the three domains of organisms that currently live on Earth.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Naming Organisms**

1. Describe the binomial system of nomenclature.
2. Distinguish between genus and species.
3. Why are species placed into different genera?
4. Define taxonomy and describe the role of taxonomists.
5. How are bats and humans related?

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Modern Taxonomy**

1. Compare early taxonomy to modern taxonomy.
2. What is a domain? What are the various domains?

Review

1. What is taxonomy?

2. Define taxon and give an example.

3. What is binomial nomenclature? Why is it important?

4. What is a domain? What are the three domains of life on Earth?

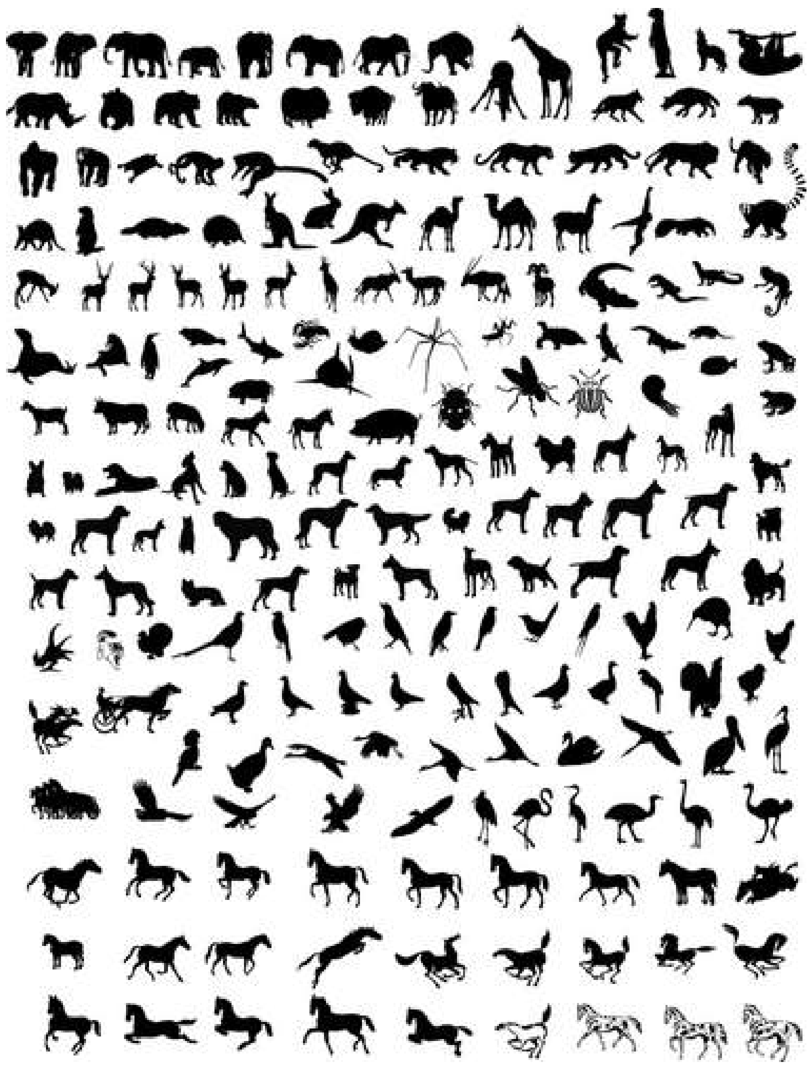
5. Create a taxonomy, modeled on the Linnaean classification system, for a set of common objects, such as motor vehicles, tools, or office supplies. Identify the groupings that correspond to the different taxa in the Linnaean system.

References

1. Peter Halasz, modified by CK-12 Foundation. . CC-BY-SA 3.0

CHAPTER 3 Phylogenetic Classification

- Describe phylogenetic classification, and explain how it differs from Linnaean classification.



Can two different species be related?

Of course they can. For example, there are many different species of mammals, or of one type of mammal, such as mice. And they are all related. In other words, how close or how far apart did they separate from a common ancestor during evolution? Determining how different species are evolutionarily related can be a tremendous task.

Phylogenetic Classification

Linnaeus classified organisms based on obvious physical traits. Basically, organisms were grouped together if they looked alike. After Darwin published his theory of evolution in the 1800s, scientists looked for a way to classify organisms that showed phylogeny. **Phylogeny** is the evolutionary history of a group of related organisms. It is represented by a **phylogenetic tree**, like the one in **Figure** 3.1.

One way of classifying organisms that shows phylogeny is by using the clade. A **clade** is a group of organisms that includes an ancestor and all of its descendants. Clades are based on **cladistics**. This is a method of comparing traits

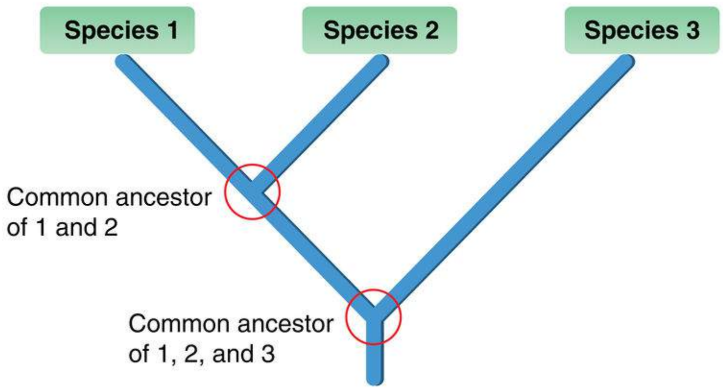


FIGURE 3.1
This phylogenetic tree shows how three hypothetical species are related to each other through common ancestors. Do you see why Species 1 and 2 are more closely related to each other than either is to Species 3?

in related species to determine ancestor-descendant relationships. Clades are represented by **cladograms**, like the one in **Figure** 3.2. This cladogram represents the mammal and reptile clades. The reptile clade includes birds. It shows that birds evolved from reptiles. Linnaeus classified mammals, reptiles, and birds in separate classes. This masks their evolutionary relationships.

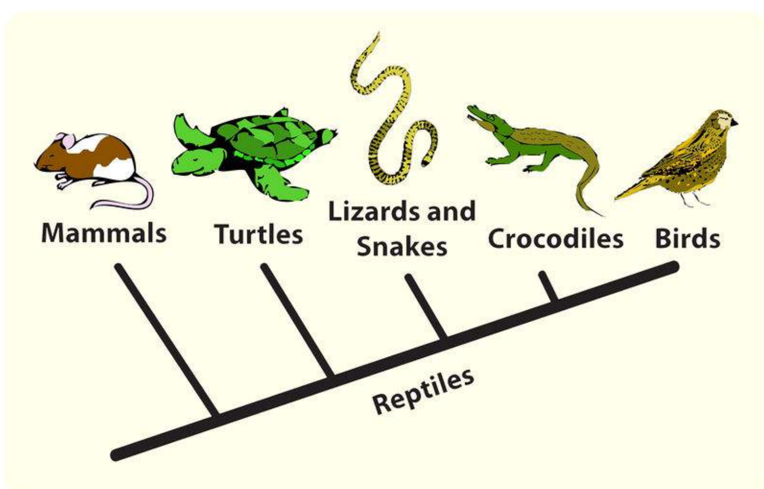


FIGURE 3.2
This cladogram classifies mammals, reptiles, and birds in clades based on their evolutionary relationships.

Summary

- Phylogeny is the evolutionary history of group of related organisms. It is represented by a phylogenetic tree that shows how species are related to each other through common ancestors.
- A clade is a group of organisms that includes an ancestor and all of its descendants. It is a phylogenetic classification, based on evolutionary relationships.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Constructing Phylogenetic Trees**

1. Describe how convergence can confuse taxonomists.
2. What are the purposes of a phylogenetic tree and a cladogram? What is the difference between them?
3. What is the relationship between a clade and a taxon?
4. What is an ancestral trait? How is such a trait used to build a cladogram?
5. Distinguish between homologous and analogous structures.
6. Humans are most closely related to which of the following: goldfish, lizard, or dog?

Review

1. What is cladistics, and what is it used for?

2. Dogs and wolves are more closely related to each other than either is to cats. Draw a phylogenetic tree to show these relationships.

3. Explain why reptiles and birds are placed in the same clade.

References

1. CK-12 Foundation. . CC-BY-NC-SA 3.0
2. CK-12 Foundation. . CC-BY-NC-SA 3.0

CHAPTER 4 Domains of Life

- Distinguish between the three domains of life.

What do you have in common with pond scum?

Humans are in the same domain as trees and algae, which makes up the "pond scum" you see here. What could they possibly have in common? It is the location of their DNA inside their cells. Their cells all have a nucleus that is home to their genetic material.

The Domains of Life

Let's explore the **domain**, the least specific category of classification.

All of life can be divided into three domains, based on the type of cell of the organism:

1. **Bacteria**: cells do not contain a nucleus.
2. **Archaea**: cells do not contain a nucleus; they have a different cell wall from bacteria.
3. **Eukarya**: cells do contain a nucleus.

Archaea and Bacteria

The Archaea and Bacteria domains (**Figure** 4.1) are both entirely composed of small, single-celled organisms and seem very similar, but they also have significant differences. Both are composed of **prokaryotic cells**, which are cells without a nucleus. In addition, both domains are composed of species that reproduce asexually (**asexual reproduction**) by dividing in two. Both domains also have species with cells surrounded by a **cell wall**, however, the cell walls are made of different materials. Bacterial cell walls contain the polysaccharide **peptidoglycan**. Lastly, Archaea often live in extreme environments including hot springs, geysers, and salt flats. Bacteria do not live in these environments.

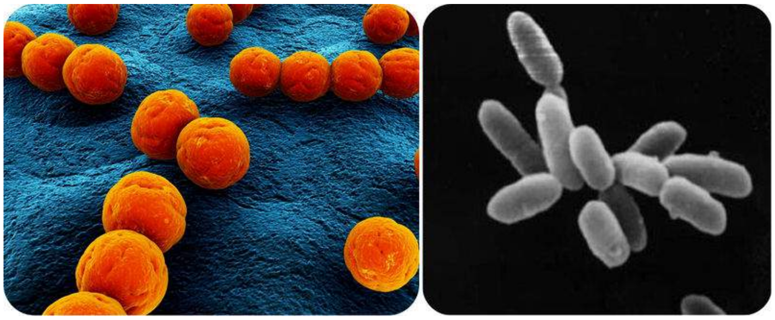


FIGURE 4.1

The Group D *Streptococcus* organism (*left*) is in the domain Bacteria, one of the three domains of life. The *Halobacterium* (*right*) is in the domain Archaea, another one of the three domains.

Eukarya

All of the cells in the domain Eukarya keep their genetic material, or **DNA**, inside the **nucleus**. The domain Eukarya is made up of four kingdoms:

1. Plantae: Plants, such as trees and grasses, survive by capturing energy from the sun, a process called **photosynthesis**.
2. Fungi: Fungi, such as mushrooms and molds, survive by "eating" other organisms or the remains of other organisms. These organisms absorb their nutrients from other organisms.
3. Animalia: Animals also survive by eating other organisms or the remains of other organisms. Animals range from tiny ants to the largest whales, and include arthropods, fish, amphibians, reptiles, and mammals (**Figure** 4.2).
4. Protista: Protists are not all descended from a single common ancestor in the way that plants, animals, and fungi are. Protists are all the eukaryotic organisms that do not fit into one of the other three kingdoms. They include many kinds of microscopic one-celled organisms, such as algae and plankton, but also giant seaweeds that can grow to be 200 feet long.

FIGURE 4.2

Diversity of Animals. These photos give just an inkling of the diversity of organisms that belong to the animal kingdom. (A) Sponge (B) Flatworm (C) Flying Insect (D) Frog (E) Tiger (F) Gorilla.

Plants, animals, fungi, and protists might seem very different, but remember that if you look through a microscope, you will find similar cells with a membrane-bound nucleus in all of them. These are **eukaryotic cells**. These cells also have membrane-bound **organelles**, which prokaryotic cells lack. The main characteristics of the three domains of life are summarized in **Table** 4.1.

Table 4.1:

	Archaea	Bacteria	Eukarya
Multicelluar	No	No	Yes
Cell Wall	Yes, without peptidoglycan	Yes, with peptidoglycan	Varies. Plants and fungi have a cell wall; animals do not.
Nucleus (DNA inside a membrane)	No	No	Yes
Organelles inside a membrane	No	No	Yes

Vocabulary

- **Archaea**: Single-celled organism with no nucleus and a different cell wall than bacteria, often thriving in extreme environments.
- **asexual reproduction**: Process of forming a new individual from a single.
- **Bacteria**: Single-celled organisms that do not contain a nucleus.
- **cell wall**: Tough outer layer of prokaryotic cells and plant cells; helps support and protect the cell.
- **DNA**: Deoxyribonucleic acid; a nucleic acid that is the genetic material of all organisms.
- **domain**: Three primary, broadest categories of living things.
- **Eukarya**: Organisms that keep their genetic material, or DNA, inside the nucleus.
- **eukaryotic cell**: Cell that contains a nucleus and membrane-bound organelles.
- **nucleus**: Membrane enclosed organelle in eukaryotic cells that contains the DNA; primary distinguishing feature between a eukaryotic and prokaryotic cell; the information center, containing instructions for making all the proteins in a cell, as well as how much of each one.
- **organelle**: Structure within the cell that has a specific role.
- **peptidoglycan**: Complex molecule consisting of sugars and amino acids that makes up the bacterial cell wall.
- **photosynthesis**: The process by which specific organisms (including all plants) use the sun's energy to make their own food from carbon dioxide and water; process that converts the energy of the sun, or solar energy, into carbohydrates, a type of chemical energy.
- **prokaryotic cell**: Cell without a nucleus or membrane-bound organelles.

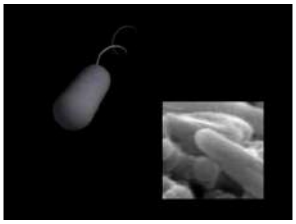
Summary

- All life can be classified into three domains: Bacteria, Archaea, and Eukarya.
- Organisms in the domain Eukarya keep their genetic material in a nucleus and include the plants, animals, fungi, and protists.

Practice

Use the resource below to answer the questions that follow.

- **Exploring Deep-Subsurface: Life Domains** at http://www.youtube.com/watch?v=UI7Yvu4McDU (8:02)



MEDIA

Click image to the left for more content.

1. What are the three domains of life?
2. What category do the individual organisms that we can see with our naked eye fall into?
3. What is an extremophile? What domain is known for these organisms? Note: recent work has shown that extremophiles are not the only members of this domain.
4. How do Archaea and Bacteria differ? How are they the same?
5. Which domain of life seems to be absent for deep-subsurface communities?

Review

1. Compare and contrast the domains Archaea and Bacteria.
2. Name three different examples of organisms in the domain Eukarya.

References

1. "Streptococcus": Image copyright Sebastian Kaulitzki, 2010; "Halobacterium": Courtesy of NASA. . "Streptococcus": Used under license from Shutterstock.com; "Halobacterium": Public Domain
2. (A) tsnoni; (B) Richard Ling; (C) Reinhold Stansich (Reini68); (D) Rusty Clark; (E) Jeff Kubina; (F) Image copyright Mike Price, 2011. . (A) CC-BY 2.0; (B) CC-BY-NC-SA 2.0; (C) CC-BY-NC-SA 2.0; (D) CC-BY 2.0; (E) CC-BY 2.0; (F) Used under license from Shutterstock.com

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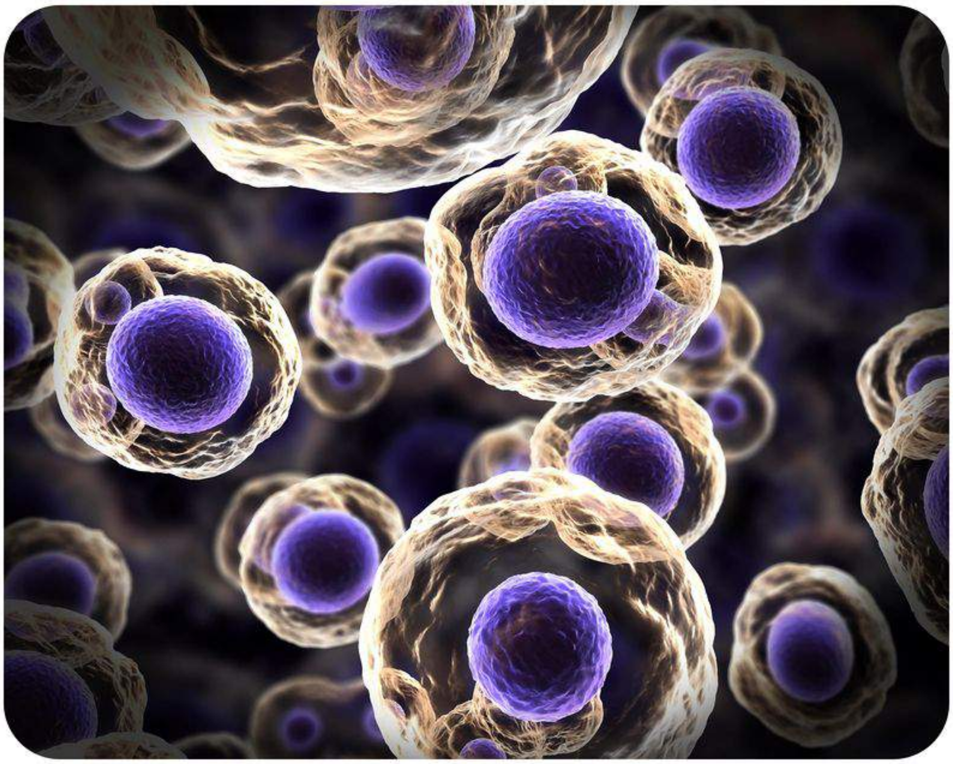
Contents

CHAPTER 1 Cell Nucleus

- Outline the form and function of the nucleus.



Where does the DNA live?

The answer depends on if the cell is prokaryotic or eukaryotic. The main difference between the two types of cells is the presence of a nucleus. And in eukaryotic cells, DNA lives in the nucleus.

The Nucleus

The **nucleus** is a membrane-enclosed organelle found in most eukaryotic cells. The nucleus is the largest organelle in the cell and contains most of the cell's genetic information (mitochondria also contain DNA, called mitochondrial DNA, but it makes up just a small percentage of the cell's overall DNA content). The genetic information, which contains the information for the structure and function of the organism, is found encoded in DNA in the form of genes. A **gene** is a short segment of DNA that contains information to encode an RNA molecule or a protein strand. DNA in the nucleus is organized in long linear strands that are attached to different proteins. These proteins help the DNA coil up for better storage in the nucleus. Think how a string gets tightly coiled up if you twist one end while holding the other end. These long strands of coiled-up DNA and proteins are called **chromosomes.** Each chromosome contains many genes. The function of the nucleus is to maintain the integrity of these genes and to control the activities of the cell by regulating gene expression. **Gene expression** is the process by which the information in a gene is "decoded" by various cell molecules to produce a functional gene product, such as a protein molecule or an RNA molecule.

The degree of DNA coiling determines whether the chromosome strands are short and thick or long and thin. Between cell divisions, the DNA in chromosomes is more loosely coiled and forms long, thin strands called

chromatin. Before the cell divides, the chromatin coil up more tightly and form chromosomes. Only chromosomes stain clearly enough to be seen under a microscope. The word chromosome comes from the Greek word *chroma* (color), and *soma* (body), due to its ability to be stained strongly by dyes.

The Nuclear Envelope

The **nuclear envelope** is a double membrane of the nucleus that encloses the genetic material. It separates the contents of the nucleus from the cytoplasm. The nuclear envelope is made of two lipid bilayers, an inner membrane and an outer membrane. The outer membrane is continuous with the rough endoplasmic reticulum. Many tiny holes called **nuclear pores** are found in the nuclear envelope. These nuclear pores help to regulate the exchange of materials (such as RNA and proteins) between the nucleus and the cytoplasm.

The Nucleolus

The nucleus of many cells also contains a non-membrane bound organelle called a **nucleolus**, shown in **Figure** 1.1. The nucleolus is mainly involved in the assembly of ribosomes. **Ribosomes** are organelles made of protein and ribosomal RNA (rRNA), and they build cellular proteins in the cytoplasm. The function of the rRNA is to provide a way of decoding the genetic messages within another type of RNA (called mRNA), into amino acids. After being made in the nucleolus, ribosomes are exported to the cytoplasm, where they direct protein synthesis.

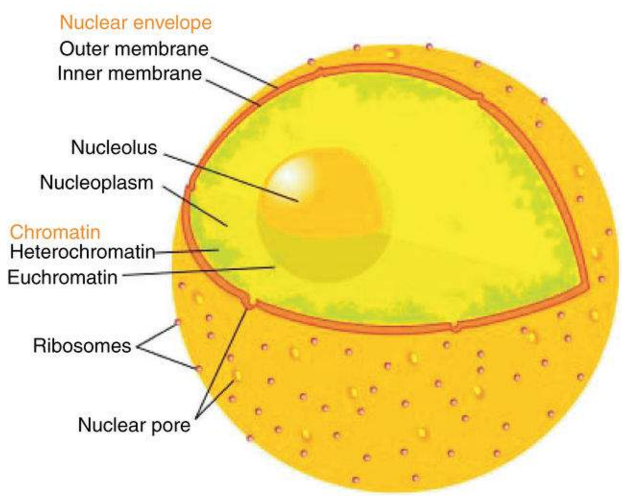


FIGURE 1.1

The eukaryotic cell nucleus. Visible in this diagram are the ribosome-studded double membranes of the nuclear envelope, the DNA (as chromatin), and the nucleolus. Within the cell nucleus is a viscous liquid called nucleoplasm, similar to the cytoplasm found outside the nucleus. The chromatin (which is normally invisible), is visible in this figure only to show that it is spread throughout the nucleus.

Summary

- The nucleus is a membrane-enclosed organelle, found in most eukaryotic cells, which stores the genetic material (DNA).
- The nucleus is surrounded by a double lipid bilayer, the nuclear envelope, which is embedded with nuclear pores.

- The nucleolus is inside the nucleus, and is where ribosomes are made.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Cellular Organelles**

1. How big is a typical nucleus?
2. Describe the structure and role of the nuclear envelope.
3. What is a nuclear pore?
4. What is chromatin?
5. What is the difference between nucleoplasm and cytoplasm?
6. What occurs in the nucleolus?

Review

1. What is the role of the nucleus of a eukaryotic cell?
2. Describe the nuclear membrane.
3. What are nuclear pores?
4. What is the role of the nucleolus?

References

1. Mariana Ruiz Villarreal [Wikimedia: LadyofHats]. . Public Domain

CHAPTER 2 DNA, the Genetic Material

- Outline discoveries that led to knowledge of DNA's structure and function.

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 (nonvirulent) (see **Figure** 2.1). 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.

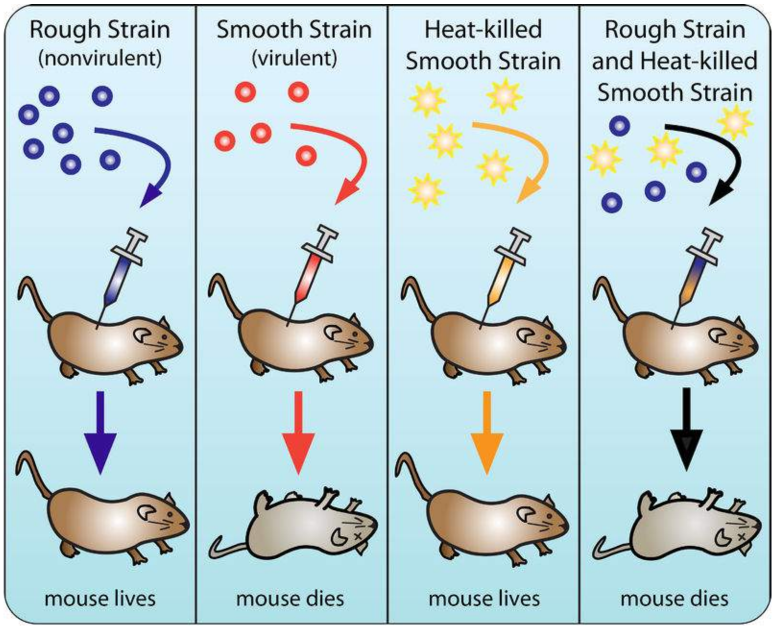


FIGURE 2.1

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.

Practice 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?

Practice 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. Outline research that determined that DNA is the genetic material.

2. What is transformation?

References

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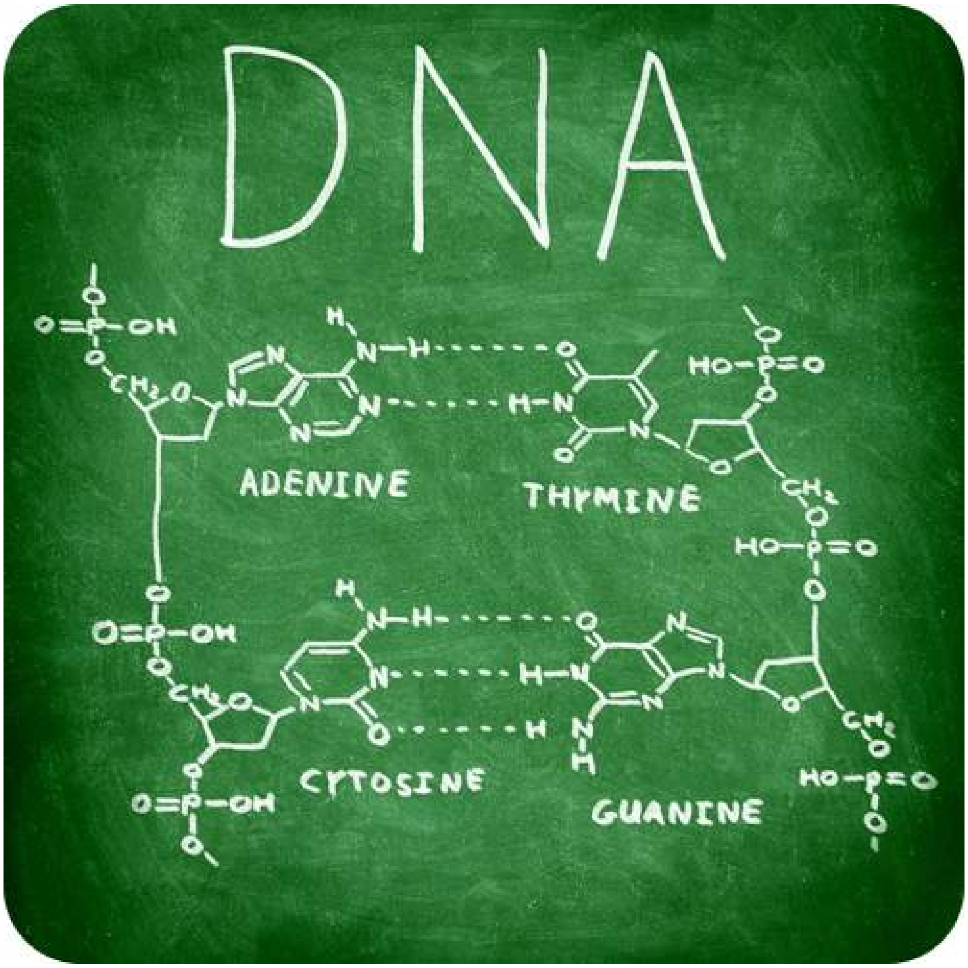
CHAPTER 3 DNA Structure and Replication

- Outline discoveries that led to knowledge of DNA's structure and function.



How do these four structures form DNA?

In an extremely elegant model, that's how. As you will soon see, the model predicts how the DNA sequence can code for proteins, and how the molecule can be replicated.

DNA Structure and Replication

Chargaff's Rules

Other important discoveries about DNA were made in the mid-1900s by Erwin Chargaff. He studied DNA from many different species. He was especially interested in the four different nitrogen bases of DNA: adenine (A), guanine (G), cytosine (C), and thymine (T) (see **Figure** 3.1). Chargaff found that concentrations of the four bases differed from one species to another. However, within each species, the concentration of adenine was always about the same as the concentration of thymine. The same was true of the concentrations of guanine and cytosine. These observations came to be known as **Chargaff's rules**. The significance of the rules would not be revealed until the structure of DNA was discovered.

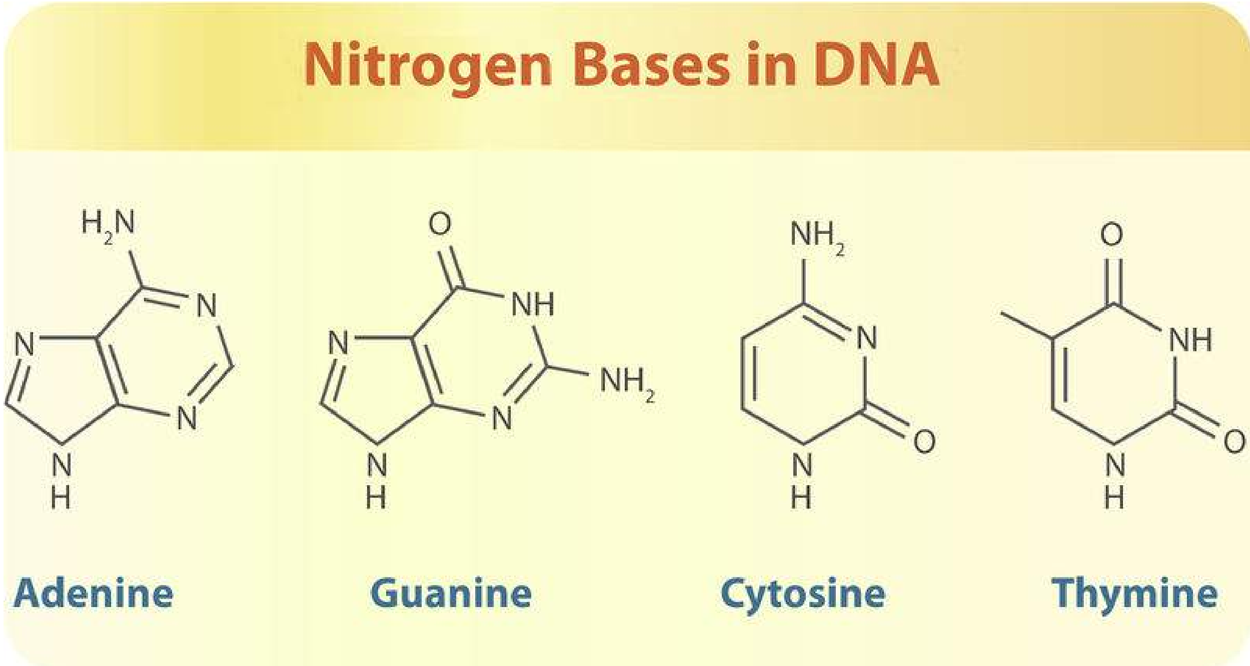


FIGURE 3.1
Nitrogen Bases in DNA. The DNA of all species has the same four nitrogen bases.

The Double Helix

After DNA was found to be the genetic material, scientists wanted to learn more about it. James Watson and Francis Crick are usually given credit for discovering that DNA has a **double helix** shape, like a spiral staircase (see **Figure** 3.2). The discovery was based on the prior work of Rosalind Franklin and other scientists, who had used X rays to learn more about DNA's structure. Franklin and these other scientists have not always been given credit for their contributions. You can learn more about Franklin's work by watching the video at this link: http://www.youtube.com/watch?v=s3whouvZYG8 (7:47).

FIGURE 3.2
The DNA molecule has a double helix shape. This is the same basic shape as a spiral staircase. Do you see the resemblance? Which parts of the DNA molecule are like the steps of the spiral staircase?

The double helix shape of DNA, together with Chargaff's rules, led to a better understanding of DNA. DNA, as a nucleic acid, is made from **nucleotide** monomers, and the DNA double helix consists of two polynucleotide chains. Each nucleotide consists of a sugar (deoxyribose), a phosphate group, and a nitrogen-containing base (A, C, G, or T).

Scientists concluded that bonds (hydrogen bonds) between complementary bases hold together the two polynucleotide chains of DNA. Adenine always bonds with its complementary base, thymine. Cytosine always bonds with its complementary base, guanine. If you look at the nitrogen bases in **Figure** 3.1, you will see why. Adenine and guanine have a two-ring structure. Cytosine and thymine have just one ring. If adenine were to bind with guanine and cytosine with thymine, the distance between the two DNA chains would be variable. However, when a one-ring molecule binds with a two-ring molecule, the distance between the two chains is kept constant. This maintains the uniform shape of the DNA double helix. These **base pairs** (A-T or G-C) stick into the middle of the double helix, forming, in essence, the steps of the spiral staircase.

DNA Replication

Knowledge of DNA's structure helped scientists understand how DNA replicates. **DNA replication** is the process in which DNA is copied. It occurs during the synthesis (S) phase of the eukaryotic cell cycle. DNA replication begins when an enzyme breaks the bonds between complementary bases in DNA (see **Figure** 3.3). This exposes the bases inside the molecule so they can be "read" by another enzyme and used to build two new DNA strands with complementary bases. The two daughter molecules that result each contain one strand from the parent molecule and one new strand that is complementary to it. As a result, the two daughter molecules are both identical to the parent molecule. DNA replication is a **semi-conservative** process because half of the parent DNA molecule is conserved in each of the two daughter DNA molecules. The process of DNA replication is actually much more complex than this simple summary. You can see a detailed animation of the process at this link: http://www.youtube.com/watch?v=-mtLXpgjHL0&NR=1 (2:05).

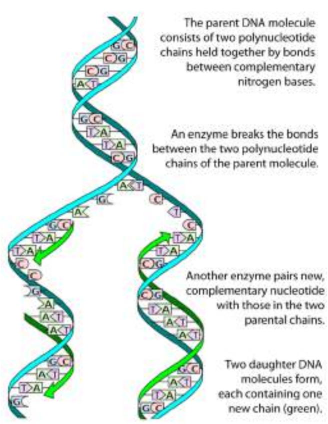


FIGURE 3.3

DNA Replication. DNA replication is a semi-conservative process. Half of the parent DNA molecule is conserved in each of the two daughter DNA molecules.

Summary

- Chargaff's rules state that the amount of A is similar to the amount of T, and the amount of G is similar to the amount of C.
- Watson and Crick discovered that DNA has a double helix shape, consisting of two polynucleotide chains held together by bonds between complementary bases.

- DNA replication is semi-conservative: half of the parent DNA molecule is conserved in each of the two daughter DNA molecules.

Making Connections

MEDIA

Click image to the left for more content.

Practice I

Use these resources to answer the questions that follow.

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

1. Define bacterial transformation.
2. Describe the results of Griffith's experiment.
3. Who first determined that DNA is the transforming agent?
4. Describe the structure of a bacteriophage.
5. Why did Hershey and Chase use radioactive phosphorus to "label" DNA?
6. Explain the results and conclusion of the Hershey and Chase experiment.

- http://www.hippocampus.org/Biology → Non-Majors Biology → Search: **DNA Structure and Function**

1. Describe the structure of a single strand of DNA.
2. The phrase "sides of the ladder" refers to what structure(s)?
3. Why is there a specific pairing pattern among the bases?
4. Why are the two strands of the double helix "perfect and specific compliments"?
5. List three functions of DNA that are based on its structure.

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

1. Why must DNA be replicated?
2. When does replication occur?
3. Describe the first step of replication.
4. Why is each strand of DNA able to serve as a template for replication?
5. Explain the meaning of semi-conservative replication.

Practice II

- **Label the Diagram of a Cell and DNA** at http://www.neok12.com/diagram/Genetics-01.htm.
- **Genetics** at http://www.neok12.com/jigsaw-puzzle/Genetics-03.htm.
- **DNA Replication** at http://johnkyrk.com/DNAreplic.swf.
- **Build a DNA Molecule** at http://learn.genetics.utah.edu/content/begin/dna/builddna/.

Review

1. What are Chargaff's rules?
2. Identify the structure of the DNA molecule.
3. Why is DNA replication said to be semi-conservative?
4. Create a diagram that shows how DNA replication occurs.
5. Explain why complementary base pairing is necessary to maintain the double helix shape of the DNA molecule.

References

1. CK-12 Foundation. . CC-BY-NC-SA 3.0
2. DNA image by Michael Ströck; staircase image copyright 3drendering, 2010; composite created by CK-12 Foundation. . DNA image under GNU-FDL 1.2; staircase image used under license from Shutterstock.com
3. Madeleine Price Ball. . CC-BY-SA 2.5

CHAPTER 4 RNA

- Describe the structure of RNA, and identify the three main types of RNA.

How does the information move from the nucleus, where the DNA is located, to the cytoplasm, where the ribosomes are?

RNA, the other nucleic acid, that's how. Specifically mRNA. RNA, the middle player in the central dogma. This image is an abstract representation of tRNA. Without tRNA, mRNA, and rRNA, proteins cannot be made.

RNA

DNA alone cannot "tell" your cells how to make proteins. It needs the help of **RNA**, ribonucleic acid, the other main player in the central dogma of molecular biology. Remember, DNA "lives" in the nucleus, but proteins are made on the ribosomes in the cytoplasm. How does the genetic information get from the nucleus to the cytoplasm? RNA is the answer.

RNA vs. DNA

RNA, like DNA, is a nucleic acid. However, RNA differs from DNA in several ways. In addition to being smaller than DNA, RNA also

- consists of one nucleotide chain instead of two,
- contains the nitrogen base uracil (U) instead of thymine,
- contains the sugar ribose instead of deoxyribose.

Types of RNA

There are three main types of RNA, all of which are involved in making proteins.

1. **Messenger RNA (mRNA)** copies the genetic instructions from DNA in the nucleus, and carries them to the cytoplasm.
2. **Ribosomal RNA (rRNA)** helps form ribosomes, where proteins are assembled.
3. **Transfer RNA (tRNA)** brings amino acids to ribosomes, where they are joined together to form proteins.

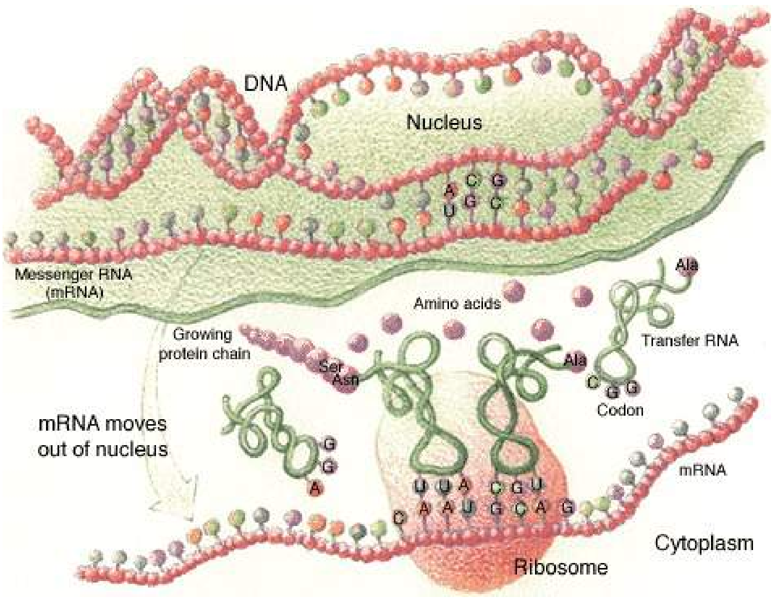


FIGURE 4.1
Shown are the three types of RNA and their roles: (1) mRNA contains the genetic message, (2) tRNA transfers the amino acids to the ribosome, (3) rRNA is the main component of the ribosome. More on the roles of the RNAs will be discussed in the "Protein Synthesis" concepts.

Summary

- RNA differs from DNA in several ways.
- There are three main types of RNA: messenger RNA (mRNA), ribosomal RNA (rRNA), and transfer RNA (tRNA).
- Each type plays a different in role in making proteins.

Making Connections

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Click image to the left for more content.

Practice I

Use this resource to answer the questions that follow.

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

1. List three structural differences between DNA and RNA.
2. What is the function of mRNA?

Practice II

- **About RNA** at http://johnkyrk.com/DNAtranscription.html.

Review

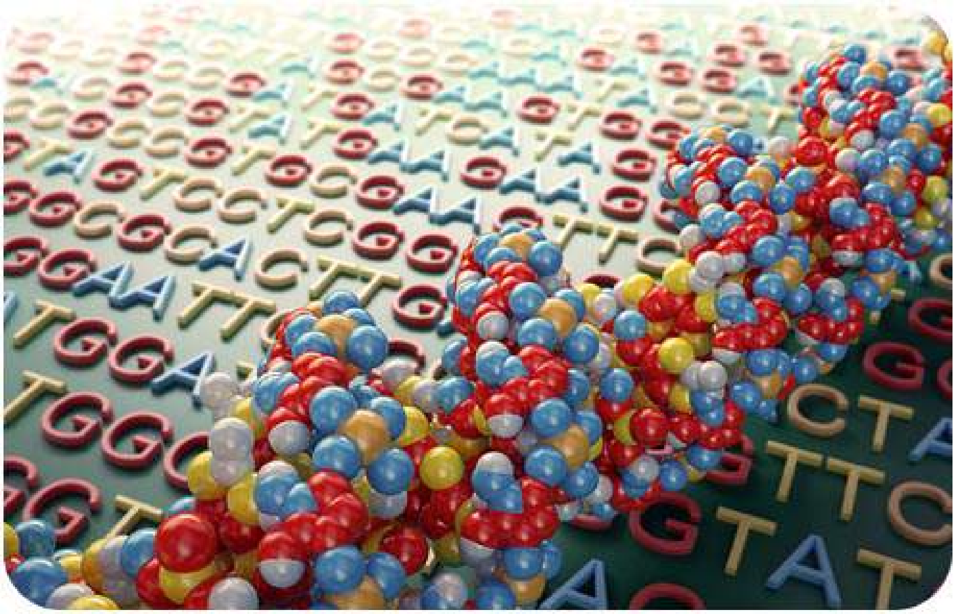
1. What are the three main types of RNA?
2. Compare and contrast DNA and RNA.

References

1. Marilee Bailey, courtesy of U.S. Department of Energy. . Public Domain

CHAPTER 5 Genetic Code

- Describe the genetic code.



How do you go from four letters to 20 amino acids?

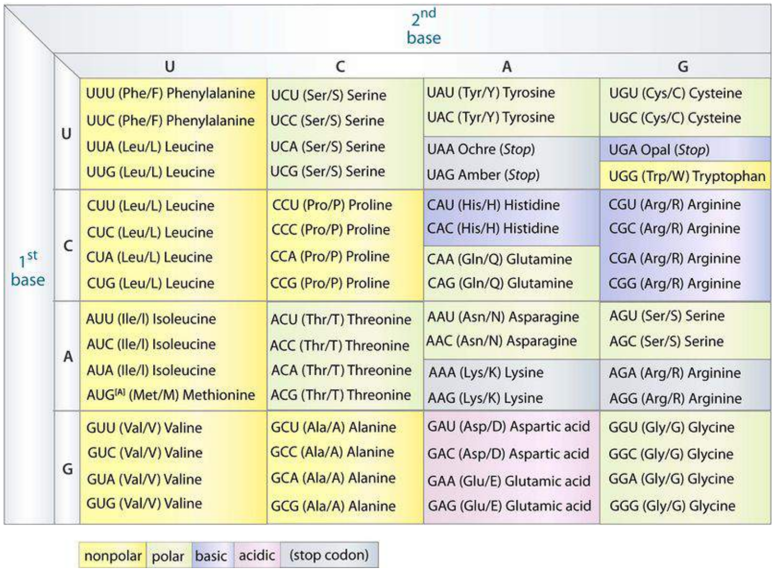
You need a code. And the code that changes the information embedded in DNA and RNA into ordered amino acids and proteins is the genetic code. And every living organism uses the same genetic code.

The Genetic Code

How is the information in a gene encoded? The answer is the genetic code. The **genetic code** consists of the sequence of nitrogen bases—A, C, G, U—in an mRNA chain. The four bases make up the "letters" of the genetic code. The letters are combined in groups of three to form code "words," called **codons**. Each codon stands for (encodes) one amino acid, unless it codes for a start or stop signal. There are 20 common amino acids in proteins. There are 64 possible codons, more than enough to code for the 20 amino acids. The genetic code is shown in **Figure** 5.1. To see how scientists cracked the genetic code, go to this link: http://www.dnalc.org/view/16494-Animation-22-DNA-words-are-three-letters-long-.html.

Reading the Genetic Code

As shown in **Figure** 5.1, the codon AUG codes for the amino acid methionine. This codon is also the **start codon** that begins translation. The start codon establishes the reading frame of mRNA. The **reading frame** is the way the letters are divided into codons. After the AUG start codon, the next three letters are read as the second codon. The next three letters after that are read as the third codon, and so on. This is illustrated in **Figure** 5.2. The mRNA molecule is read, codon by codon, until a **stop codon** is reached. UAG, UGA, and UAA are all stop codons. They do not code for any amino acids. Stop codons are also known as termination codons.



1st base \ 2nd base	U	C	A	G
U	UUU (Phe/F) Phenylalanine UUC (Phe/F) Phenylalanine UUA (Leu/L) Leucine UUG (Leu/L) Leucine	UCU (Ser/S) Serine UCC (Ser/S) Serine UCA (Ser/S) Serine UCG (Ser/S) Serine	UAU (Tyr/Y) Tyrosine UAC (Tyr/Y) Tyrosine UAA Ochre (*Stop*) UAG Amber (*Stop*)	UGU (Cys/C) Cysteine UGC (Cys/C) Cysteine UGA Opal (*Stop*) UGG (Trp/W) Tryptophan
C	CUU (Leu/L) Leucine CUC (Leu/L) Leucine CUA (Leu/L) Leucine CUG (Leu/L) Leucine	CCU (Pro/P) Proline CCC (Pro/P) Proline CCA (Pro/P) Proline CCG (Pro/P) Proline	CAU (His/H) Histidine CAC (His/H) Histidine CAA (Gln/Q) Glutamine CAG (Gln/Q) Glutamine	CGU (Arg/R) Arginine CGC (Arg/R) Arginine CGA (Arg/R) Arginine CGG (Arg/R) Arginine
A	AUU (Ile/I) Isoleucine AUC (Ile/I) Isoleucine AUA (Ile/I) Isoleucine AUG[A] (Met/M) Methionine	ACU (Thr/T) Threonine ACC (Thr/T) Threonine ACA (Thr/T) Threonine ACG (Thr/T) Threonine	AAU (Asn/N) Asparagine AAC (Asn/N) Asparagine AAA (Lys/K) Lysine AAG (Lys/K) Lysine	AGU (Ser/S) Serine AGC (Ser/S) Serine AGA (Arg/R) Arginine AGG (Arg/R) Arginine
G	GUU (Val/V) Valine GUC (Val/V) Valine GUA (Val/V) Valine GUG (Val/V) Valine	GCU (Ala/A) Alanine GCC (Ala/A) Alanine GCA (Ala/A) Alanine GCG (Ala/A) Alanine	GAU (Asp/D) Aspartic acid GAC (Asp/D) Aspartic acid GAA (Glu/E) Glutamic acid GAG (Glu/E) Glutamic acid	GGU (Gly/G) Glycine GGC (Gly/G) Glycine GGA (Gly/G) Glycine GGG (Gly/G) Glycine

nonpolar | polar | basic | acidic | (stop codon)

FIGURE 5.1

The Genetic Code. To find the amino acid for a particular codon, find the cell in the table for the first and second bases of the codon. Then, within that cell, find the codon with the correct third base. For example CUG codes for leucine, AAG codes for lysine, and GGG codes for glycine.

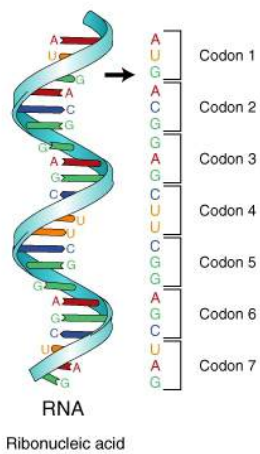


FIGURE 5.2

Reading the Genetic Code. The genetic code is read three bases at a time. Codons are the code words of the genetic code. Which amino acid does codon 2 in the drawing stand for?

Characteristics of the Genetic Code

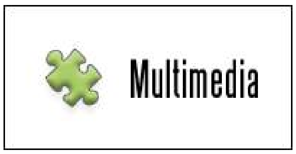
The genetic code has a number of important characteristics.

- The genetic code is universal. All known living organisms use the same genetic code. This shows that all organisms share a common evolutionary history.
- The genetic code is unambiguous. Each codon codes for just one amino acid (or start or stop). What might happen if codons encoded more than one amino acid?
- The genetic code is redundant. Most amino acids are encoded by more than one codon. In **Figure** 5.1, how many codons code for the amino acid threonine? What might be an advantage of having more than one codon for the same amino acid?

Summary

- The genetic code consists of the sequence of bases in DNA or RNA.
- Groups of three bases form codons, and each codon stands for one amino acid (or start or stop).
- The codons are read in sequence following the start codon until a stop codon is reached.
- The genetic code is universal, unambiguous, and redundant.

Making Connections



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Click image to the left for more content.

Practice I

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Decoding RNA**

1. What is a polypeptide?
2. How do the 4 nucleotides code for 20 amino acids?
3. What is the meaning of a "triplet code"?
4. Describe the 4 properties of codons.
5. Describe how the genetic code was "cracked."
6. What is the start codon?
7. How many stop codons are there? What do these codons signal?
8. What is a reading frame? Why are reading frames important?
9. What amino acid do the following codons encode: UUC, UCU, CUU?

Practice II

- **Transcribe and Translate a Gene** at http://learn.genetics.utah.edu/content/begin/dna/transcribe/.

Review

1. What is the genetic code? What are codons?

2. Use the genetic code to translate the following segment of RNA into a sequence of five amino acids: GUC-GCG-CAU-AGC-AAG

3. The genetic code is universal, unambiguous, and redundant. Explain what this means and why it is important.

References

1. CK-12 Foundation. . CC-BY-NC-SA 3.0
2. TransControl. . GNU-FDL 1.2

CHAPTER 6 Transcription of DNA to RNA

- Give an overview of transcription.

How does a cell use the information in its DNA?

To transcribe means "to paraphrase or summarize in writing." The information in DNA is transcribed - or summarized - into a smaller version - RNA - that can be used by the cell. This process is called transcription.

Transcription

The process in which cells make proteins is called **protein synthesis**. It actually consists of two processes: **transcription** and **translation**. Transcription takes place in the nucleus. It uses DNA as a template to make an RNA molecule. RNA then leaves the nucleus and goes to a ribosome in the cytoplasm, where translation occurs. Translation reads the genetic code in mRNA and makes a protein.

Transcription is the first part of the central dogma of molecular biology: $DNA \rightarrow RNA$. It is the transfer of genetic instructions in DNA to messenger RNA (mRNA). During transcription, a strand of mRNA is made that is complementary to a strand of DNA. **Figure** 6.1 shows how this occurs. You can watch an animation of the process at this link: http://www.biostudio.com/d_%20Transcription.htm.

- A detailed video about transcription is available at this link: http://vcell.ndsu.edu/animations/transcription/movie-flash.htm.

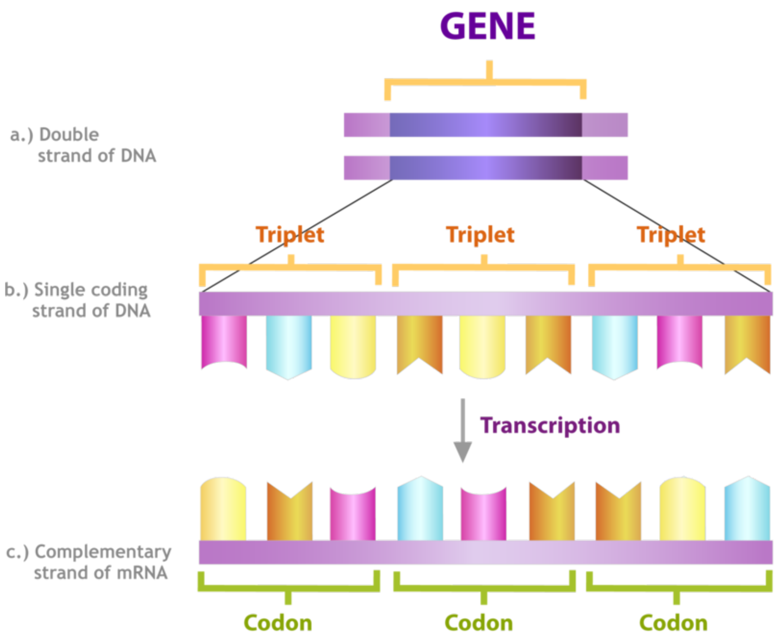


FIGURE 6.1
Overview of Transcription. Transcription uses the sequence of bases in a strand of DNA to make a complementary strand of mRNA. Triplets are groups of three successive nucleotide bases in DNA. Codons are complementary groups of bases in mRNA.

Steps of Transcription

Transcription takes place in three steps: initiation, elongation, and termination. The steps are illustrated in **Figure** 6.2.

1. **Initiation** is the beginning of transcription. It occurs when the enzyme **RNA polymerase** binds to a region of a gene called the **promoter**. This signals the DNA to unwind so the enzyme can "read" the bases in one of the DNA strands. The enzyme is now ready to make a strand of mRNA with a complementary sequence of bases.
2. **Elongation** is the addition of nucleotides to the mRNA strand.
3. **Termination** is the ending of transcription, and occurs when RNA polymerase crosses a stop (termination) sequence in the gene. The mRNA strand is complete, and it detaches from DNA.

Processing mRNA

In eukaryotes, the new mRNA is not yet ready for translation. It must go through additional processing before it leaves the nucleus. This may include splicing, editing, and polyadenylation. These processes modify the mRNA in various ways. Such modifications allow a single gene to be used to make more than one protein.

- **Splicing** removes **introns** from mRNA (see **Figure** 6.3). Introns are regions that do not code for proteins. The remaining mRNA consists only of regions that do code for proteins, which are called **exons**. You can watch

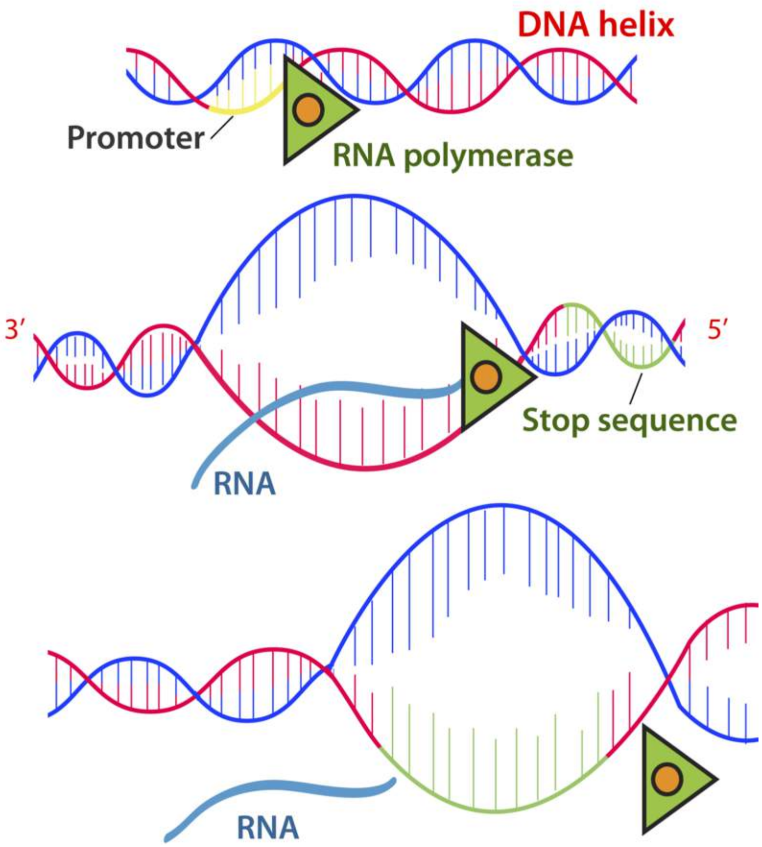


FIGURE 6.2
Steps of Transcription. Transcription occurs in the three steps - initiation, elongation, and termination - shown here.

a video showing splicing in more detail at this link: http://vcell.ndsu.edu/animations/mrnasplicing/movie-flash.htm.

- **Editing** changes some of the nucleotides in mRNA. For example, the human protein called APOB, which helps transport lipids in the blood, has two different forms because of editing. One form is smaller than the other because editing adds a premature stop signal in mRNA.
- **Polyadenylation** adds a "tail" to the mRNA. The tail consists of a string of As (adenine bases). It signals the end of mRNA. It is also involved in exporting mRNA from the nucleus. In addition, the tail protects mRNA from enzymes that might break it down.

Summary

- Transcription is the DNA → RNA part of the central dogma of molecular biology.
- Transcription occurs in the nucleus.
- During transcription, a copy of mRNA is made that is complementary to a strand of DNA. In eukaryotes, mRNA may be modified before it leaves the nucleus.

Practice I

Use these resources to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **The Initiation of Transcription**

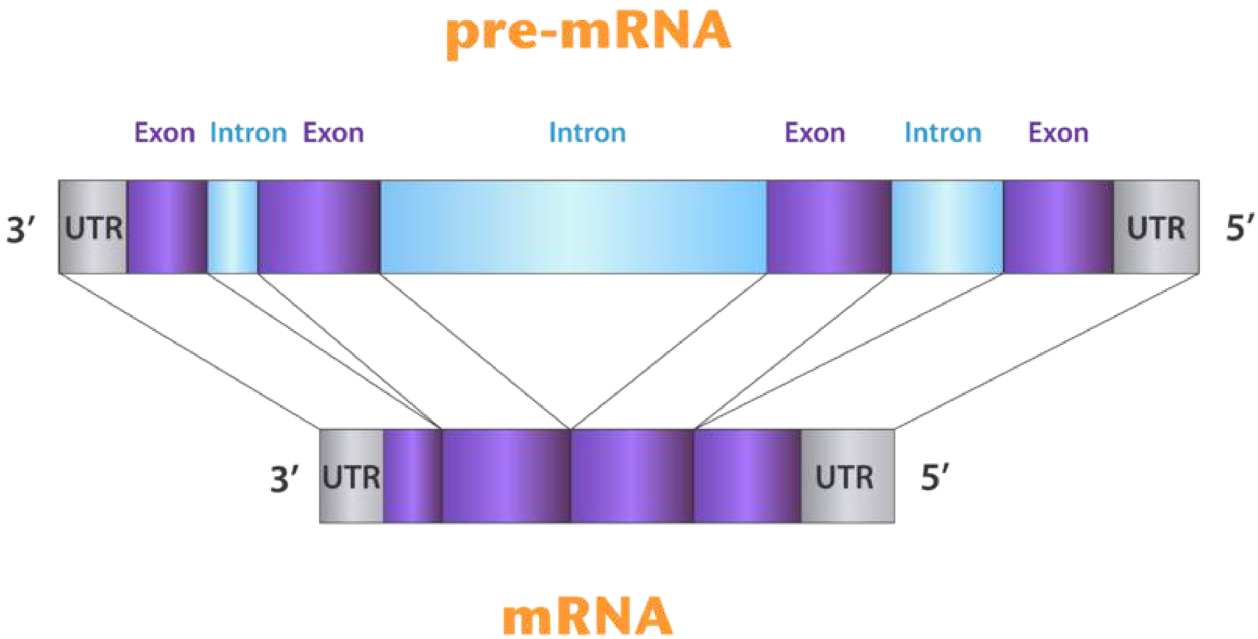


FIGURE 6.3

Splicing. Splicing removes introns from mRNA. UTR is an untranslated region of the mRNA.

1. What is a transcription unit?
2. Describe the importance of the template strand.
3. What enzyme is used in transcription? What does this enzyme do?
4. What are the promoter and initiation site?
5. Describe the TATA box.
6. How does RNA polymerase bind to the DNA?

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Elongation, Termination, and Processing**

1. Describe elongation of the RNA during transcription.
2. What must happen to the RNA prior to translation? Why?
3. Distinguish between an intron and exon.
4. What is the role of the GTP cap?

Practice II

- **Protein Synthesis** at http://www.wisc-online.com/Objects/ViewObject.aspx?ID=AP1302
- **DNA Transcription** at http://johnkyrk.com/DNAtranscription.html
- **How Do Cells Make Proteins?** at http://ca.pbslearningmedia.org/content/lsps07.sci.life.stru.lpbiosystems/#content/4dd2fb6badd2c73bce006585

- **What is a Gene?** at http://learn.genetics.utah.edu/content/begin/dna/
- **Transcribe and Translate a Gene** at http://learn.genetics.utah.edu/content/begin/dna/transcribe/

Review

1. What is protein synthesis?
2. Describe transcription.
3. How may mRNA be modified before it leaves the nucleus?

References

1. CK-12 Foundation. . CC-BY-NC-SA 3.0
2. CK-12 Foundation. . CC-BY-NC-SA 3.0
3. CK-12 Foundation. . CC-BY-NC-SA 3.0

CHAPTER 7 Translation of RNA to Protein

- Describe the process of translation.

How does the cell translate a message?

The mRNA is the message sent from the nucleus to the ribosome. 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** 7.1) how to create a specific protein.

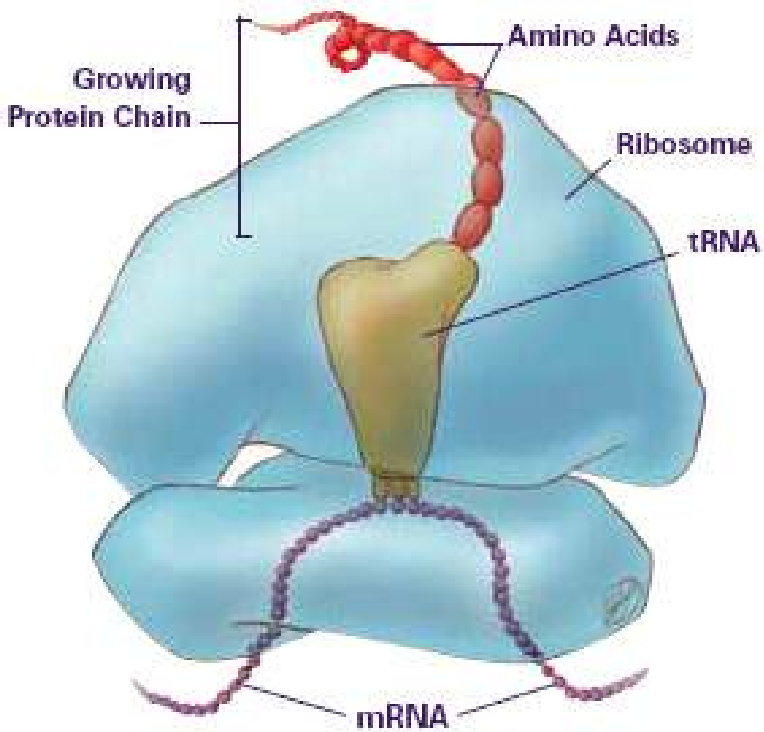


FIGURE 7.1
Ribosomes translate RNA into a protein with a specific amino acid sequence. The tRNA binds and brings to the ribosome the amino acid encoded by the mRNA.

The process of reading the mRNA code in the ribosome to make a protein is called **translation** (**Figure** 7.2): 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.

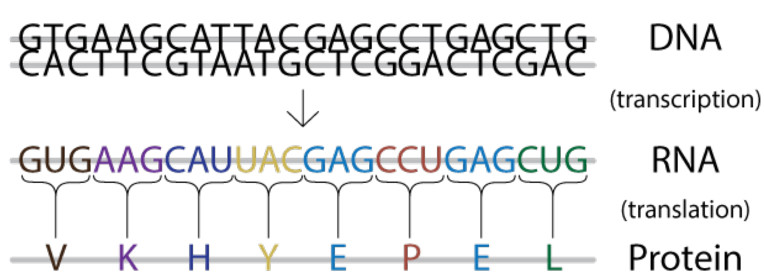


FIGURE 7.2
This summary of how genes are expressed shows that DNA is transcribed into RNA, which is translated, in turn, to protein. The one letter code represents amino acids.

The following are the steps involved in translation:

- mRNA travels to the ribosome from the nucleus.

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. 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.
- 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** 7.3) is used to determine which amino acids correspond to which codons.

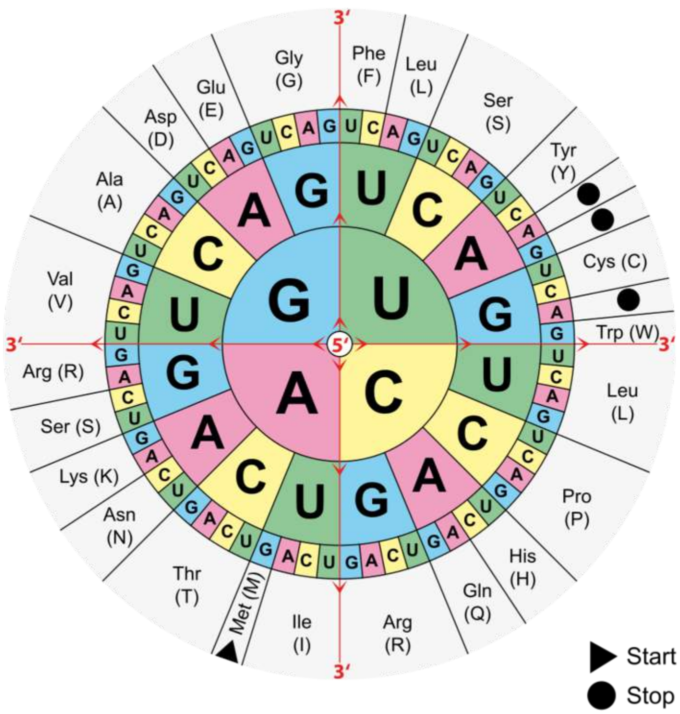


FIGURE 7.3

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.

Vocabulary

- **anticodon**: Sequence on a tRNA molecule that specifically binds to a codon; ensures the proper amino acid is brought to the ribosome.
- **codon**: Triplet (3) of bases in the mRNA that codes for a specific amino acid.
- **ribosome**: Organelle responsible for making proteins.
- **stop codon**: One of three codons that does not encode for an amino acid; signifies the end of translation.
- **translation**: Process of reading the mRNA code in the ribosome to make a protein.

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.

Practice

Use the resources below to answer the following questions.

- **Cell Translation** at http://www.teachersdomain.org/asset/lsps07_int_celltrans/

1. What reads the sequence of the mRNA? What are three nucleotides that code of an amino acid called?
2. What brings amino acids to the translation site? Where does it find these amino acids?
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?

Go to this site to make a protein. Practice and see how fast you can transcribe DNA and translate mRNA.

- **Transcribe and Translate a Gene** at http://learn.genetics.utah.edu/units/basics/transcribe/

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 amino acids are used to make proteins?

Review

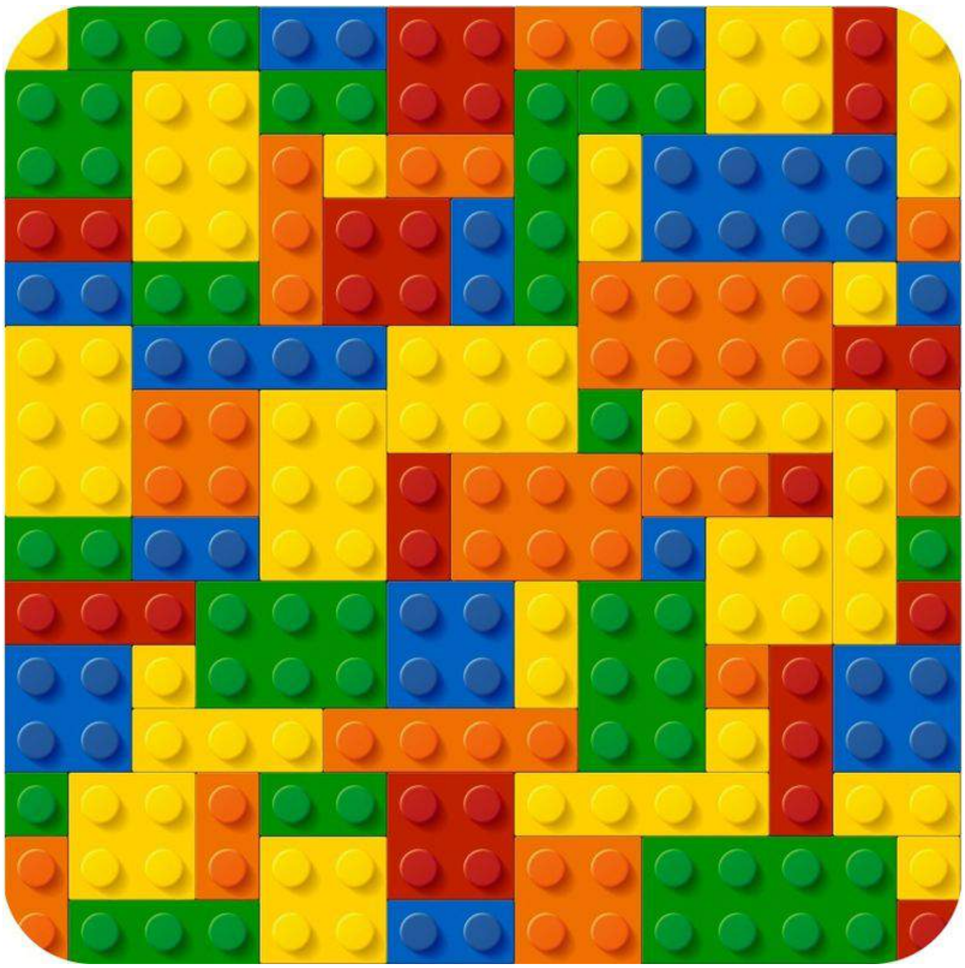
1. What is translation?
2. What would happen if the stop codon was mutated to encode for another amino acid?
3. Given the DNA sequence, ATGTTAGCCTTA, what is the mRNA sequence? What is the amino acid sequence?

References

1. Courtesy of the National Institute of General Medical Sciences (NIGMS). . Public Domain
2. CK-12 Foundation - Zachary Wilson. . CC-BY-NC-SA 3.0
3. Mouagip (Wikimedia). . Public Domain

CHAPTER 8 Protein Synthesis and Gene Expression

- Describe the purpose of protein synthesis.



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

The DNA sequence contains the instructions to place units called **amino acids** into a specific order. When these amino acid are assembled in that specific order, proteins are made. In short, DNA contains the instructions to create 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** 8.1). Units of DNA that contain code for the creation of a protein are called **genes**.

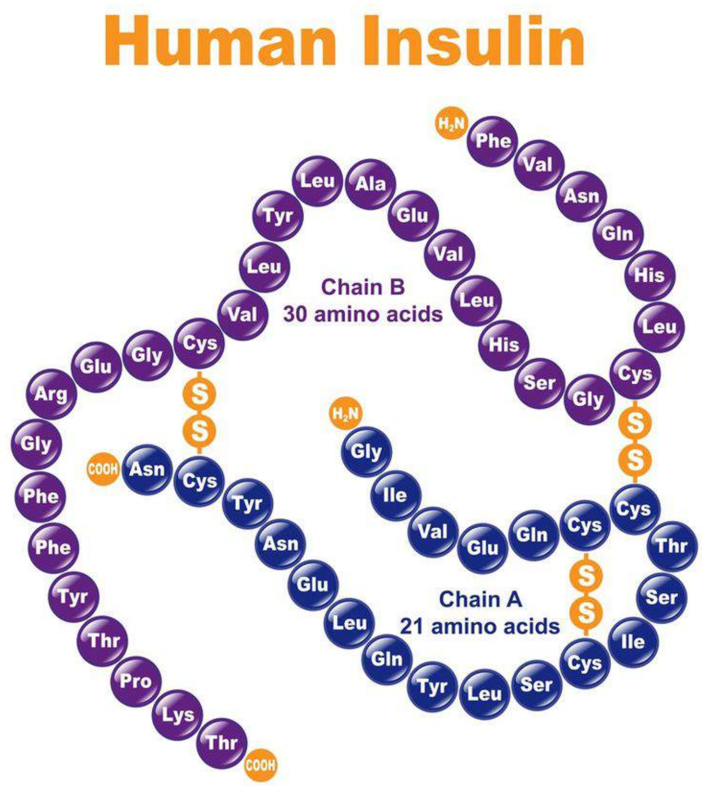


FIGURE 8.1

Insulin. Each blue or purple bead represents a different amino acid.

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.

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.

Vocabulary

- **amino acid**: Building blocks of proteins.
- **gene**: Unit of DNA that contains code for the creation of one protein.
- **gene expression**: Process of using a gene to make a gene product.

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.

Practice

Use the resource below to answer the questions that follow.

- **Protein Synthesis** at http://www.biostudio.com/demo_freeman_protein_synthesis.htm

1. What is the molecule that assembles the protein?
2. What is the molecule that delivers the amino acids?
3. What initiates protein synthesis?

Review

1. What is a gene?
2. If every human cell has the same genes, how can they look so different?

References

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CHAPTER 9 Gene Expression

- Identify general mechanisms that regulate gene expression.

Can your expression change at any moment?

As you know, a person's expression can change moment by moment. The expression that is demonstrated is usually appropriate for that moment's feelings. Gene expression is the use of a gene whose product is necessary for that moment. It may be a moment during development, it may be a moment of increased anxiety, or it may be in response to an environmental change. Whenever a particular protein is needed, gene expression provides it.

Gene Expression

Each of your cells has at least 20,000 genes. In fact, all of your cells have the same genes. Do all of your cells make the same proteins? Obviously not. If they did, then all your cells would be alike. Instead, you have cells with different structures and functions. This is because different cells make different proteins. They do this by using, or expressing, different genes. Using a gene to make a protein is called **gene expression**.

How Gene Expression is Regulated

Gene expression is regulated to ensure that the correct proteins are made when and where they are needed. Regulation may occur at any point in the expression of a gene, from the start of transcription to the processing of a protein after translation. Following is a list of stages where gene expression is regulated:

- Chemical and structural modification of DNA or chromatin
- Transcription
- Translation
- Post-transcriptional modification
- RNA transport
- mRNA degradation
- Post-translational modifications

As shown in **Figure** 9.1, transcription is controlled by **regulatory proteins** binding to the DNA. Specifically, gene regulation at the level of transcription controls when transcription occurs as well as how much RNA is created. A regulatory protein, or a **transcription factor**, is a protein involved in regulating gene expression. It is usually bound to a **cis-regulatory element**, which is part of the DNA. Regulatory proteins often must be bound to a cis-regulatory element to switch a gene on (**activator**), or to turn a gene off (**repressor**).

Transcription of a gene by RNA polymerase can be regulated by at least five mechanisms:

- Specificity factors (proteins) alter the specificity of RNA polymerase for a promoter or set of promoters, making it more or less likely to bind to the promoter and begin transcription.
- Activator proteins enhance the interaction between RNA polymerase and a particular promoter.
- Repressor proteins bind to non-coding sequences on the DNA that are close to or overlap the promoter region, impeding RNA polymerase's progress along the strand.
- Basal factors are transcription factors that help position RNA polymerase at the start of a gene.
- **Enhancers** are sites on the DNA strand that are bound by activators in order to loop the DNA, bringing a specific transcription factor to the initiation complex. An **initiation complex** is composed of RNA polymerase and transcription factors.

As the organism grows more sophisticated, gene regulation becomes more complex, though prokaryotic organisms possess some highly regulated systems. Some human genes are controlled by many activators and repressors working together. Obviously, a mutation in a cis-regulatory region, such as the promoter, can greatly affect the proper expression of a gene. It may keep the gene permanently off, such that no protein can be made, or it can keep the gene permanently on, such that the corresponding protein is constantly made. Both of these can have detremental effects on the cell.

Summary

- Gene transcription is controlled by regulatory proteins that bind to regulatory elements on DNA.
- The proteins usually either activate or repress transcription.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **The Regulation of Gene Expression**

1. What percentage of its genes does a typical human cell express?

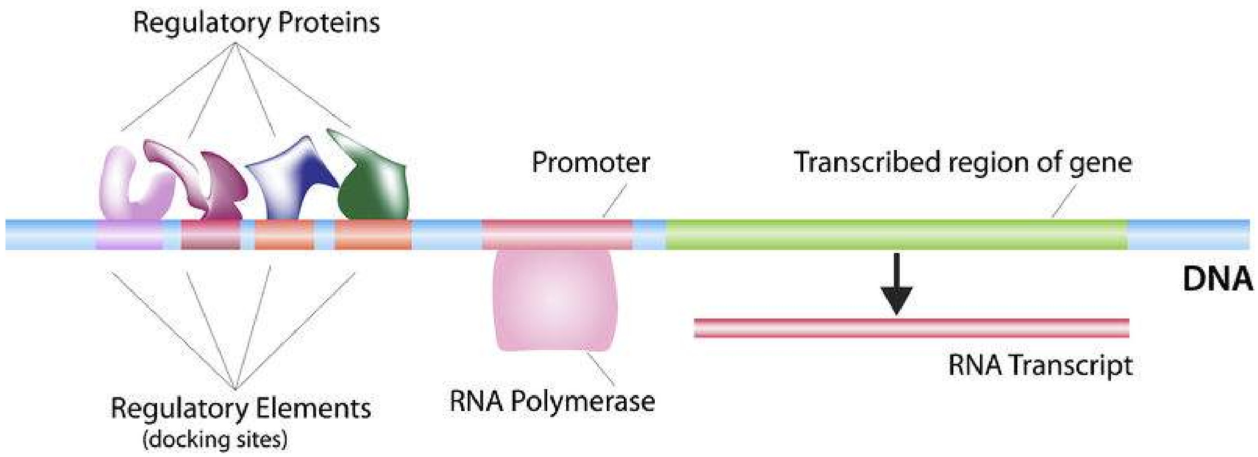

FIGURE 9.1
Regulation of Transcription. Regulatory proteins bind to regulatory elements to control transcription. The regulatory elements are embedded within the DNA.

2. List three ways gene expression may be regulated.
3. Draw a diagram of an enhancer interacting with its promoter.
4. Compare euchromatin to heterochromatin.
5. Discuss how chromosomal rearrangements may effect gene expression.

Review

1. What is gene expression?

2. Describe how regulatory proteins regulate gene expression.

References

1. CK-12 Foundation. . CC-BY-NC-SA 3.0

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Ecology

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Contents

CHAPTER 1 Introduction to Ecology

- Define ecology.
- Distinguish between abiotic and biotic factors.

Do organisms live in isolation?

No, organisms are not separated from their environment or from other organisms. They interact in many ways with their surroundings. For example, this deer may be drinking from this stream or eating nearby plants. Ecology is the study of these interactions.

Introduction to Ecology

Life Science can be studied at many different levels. You can study small things like cells. Or you can study big things like a group of animals. You can also study the **biosphere,** which is any area in which organisms live. The study of the biosphere is part of **ecology**, the study of how living organisms interact with each other and with their environment.

Research in Ecology

Ecology involves many different fields, including geology, soil science, geography, meteorology, genetics, chemistry, and physics. You can also divide ecology into the study of different organisms, such as animal ecology, plant ecology, insect ecology, and so on.

Ecologists also study biomes. A **biome** is a large community of plants and animals that live in the same place. For example, ecologists can study the biomes as diverse as the Arctic, the tropics, or the desert (**Figure** 1.1). They may want to know why different species live in different biomes. They may want to know what would make a particular biome or ecosystem stable. Can you think of other aspects of a biome or ecosystem that ecologists could study?

Ecologists do two types of research:

FIGURE 1.1
An example of a biome, the Atacama Desert, in Chile.

1. Field studies.
2. Laboratory studies.

Field studies involve collecting data outside in the natural world. An ecologist who completes a field study may travel to a tropical rain forest to study, count, and classify all of the insects that live in a certain area. Laboratory studies involve working inside, usually in a controlled environment. Sometimes, ecologists collect data from the field, and then they analyze that data in the lab. Also, they use computer programs to predict what will happen to organisms that live in a specific area. For example, they may make predictions about what happens to insects in the rainforest after a fire.

Organisms and Environments

All organisms have the ability to grow and reproduce. To grow and reproduce, organisms must get materials and energy from the environment. Plants obtain their energy from the sun through **photosynthesis**, whereas animals obtain their energy from other organisms. Either way, these plants and animals, as well as the bacteria and fungi, are constantly interacting with other species as well as the non-living parts of their ecosystem.

An organism's environment includes two types of factors:

1. **Abiotic factors** are the parts of the environment that are not living, such as sunlight, climate, soil, water, and air.
2. **Biotic factors** are the parts of the environment that are alive, or were alive and then died, such as plants, animals, and their remains. Biotic factors also include bacteria, fungi and protists.

Ecology studies the interactions between biotic factors, such as organisms like plants and animals, and abiotic factors. For example, all animals (biotic factors) breathe in oxygen (abiotic factor). All plants (biotic factor) absorb carbon dioxide (abiotic factor) and need water (abiotic factor) to survive.

Can you think of another way that abiotic and biotic factors interact with each other?

Vocabulary

- **abiotic factor**: Aspect of the environment that is not a living organism, such as soil, water or air.

- **biome**: Large community of plants and animals distinguished by the dominant forms of animal and plant life and the climate.
- **biotic factor**: Components of the environment that are living, or were alive and then died, such as plants or animals.
- **biosphere**: Part of the planet and atmosphere with living organisms.
- **ecology**: Study of how living organisms interact with each other and with their environment.
- **photosynthesis**: Process by which specific organisms (including all plants) use the sun's energy to make their own food from carbon dioxide and water; process that converts the energy of the sun, or solar energy, into carbohydrates, a type of chemical energy.

Summary

- Ecology is the study of how living organisms interact with each other and with their environment.
- Abiotic factors are the parts of the environment that have never been alive, while biotic factors are the parts of the environment that are alive, or were alive and then died.

Practice

Use the resource below to answer the questions that follow.

- **A Study in Stream Ecology** at USGS http://gallery.usgs.gov/videos/449#.UKWeJId9KSo (6:57)

Adobe Flash

MEDIA

Click image to the left for more content.

1. What are some of the abiotic factors that scientists monitor when dealing with stream ecosystems?
2. What are some of the biotic factors that scientists monitor when dealing with stream ecosystems?
3. Remembering what you've learned about the scientific process, why is it valuable for scientists to use the same procedures and gather the same information across different streams and a wide ranging geography? What does this allow them to do? How does this affect the strength and applicability of their research?
4. What is a "benchmark" in ecology? Why are they essential?
5. Why is it important to have a reference stream if you want to gauge the effects of *Homo sapiens* on streams? What characteristics should this reference stream have?
6. How does water pollution seem to be affecting diversity in some streams? What data would be necessary to prove the pollution is the causative agent affecting stream biodiversity?

Review

1. What do ecologists study?
2. In a forest, what are some biotic factors present? Abiotic factors?

References

1. Courtesy of NASA. . Public Domain

CHAPTER 2

Levels of Ecological Organization

- Describe the levels of organization in ecology.

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 who 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.
- An **ecosystem** includes the living organisms (all the populations) in an area and the non-living aspects of the environment (**Figure** 2.1). An ecosystem is made of the biotic and abiotic factors in an area.

FIGURE 2.1

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** 2.2). The biosphere includes most of Earth, including part of the oceans and the atmosphere.

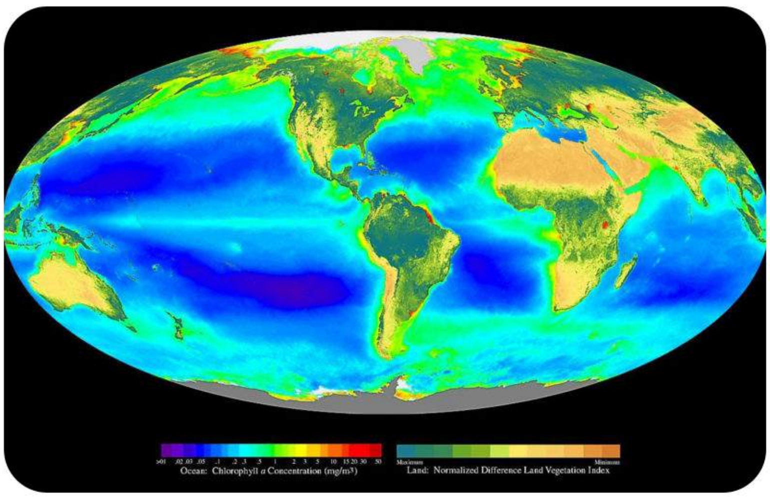


FIGURE 2.2

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** 2.1, using the zebra (*Equus zebra*) as an example.

TABLE 2.1: Ecological Ecosystems

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?
Biosphere	How does carbon dioxide in the air affect global temperature?

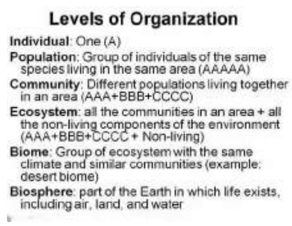
Vocabulary

- **biosphere**: Region of the earth that is home to living things.
- **community**: All of the populations of different species that live in the same area and interact with one another.
- **ecosystem**: All the living things in an area interacting with all of the non-living parts of the environment.
- **population**: Group of organisms belonging to the same species that live in the same area and interact with one another.
- **species**: Group of individuals that are genetically related and can breed to produce fertile young.

Practice

Use the resource below to answer the questions that follow.

- **Ecology Levels and Populations** at http://www.youtube.com/watch?v=1JSS8XIYcgU (5:31)



MEDIA

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1. What is the relationship between an individual and a community?
2. What characteristics define a population? Why is identification of characteristics important to compare populations?
3. Why is the distinction between a community and an ecosystem important to ecologists? What kinds of questions could be answered by looking at the community level of organization? What kinds of questions could be answered by looking at the ecosystem level of organization? When answering this question keep in mind the need to control variables in scientific experiments.

Review

1. How is an ecosystem different from a community?
2. How is a population different from a community?

References

1. Courtesy of NASA. . Public Domain
2. SeaWiFS Project, NASA/Goddard Space Flight Center and ORBIMAGE. . Public Domain

CHAPTER 3 Habitat and Niche

- Define habitat and niche and describe their role in the 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** 3.1).

FIGURE 3.1
The Konik horse. This horse filled the niche left by the Tarpan, a horse that became extinct in the early 1900s in southern Russia.

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. 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** 3.2).

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. A habitat should not be confused with an ecosystem: the habitat is the actual place of the ecosystem, whereas the ecosystem includes both the **biotic** and abiotic factors in the habitat.

FIGURE 3.2
Kudzu, a Japanese vine, introduced intentionally to the southeastern United States, has out-competed the native vegetation.

FIGURE 3.3
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.

Vocabulary

- **abiotic factor**: Aspect of the environment that is not a living organism, such as soil, water, or air.
- **biotic factor**: Components of the environment that are living, or were alive and then died, such as plants or animals.
- **habitat** : Natural home or environment of an organism; the physical environment in which a species lives.

FIGURE 3.4
The above image shows wetland reeds, another type of habitat.

- **niche**: Role a species plays in the ecosystem.

Summary

- The role a species plays in the ecosystem is called its niche.
- A habitat is the physical environment in which a species lives.

Practice

Use the resource below to answer the questions that follow.

- **Competition, Predation, Symbiosis** at http://www.youtube.com/watch?v=D1aRSeT-mQE (3:20)

MEDIA
Click image to the left for more content.

1. Niches and relationships between organisms are generally developed over a long period of time. How do you think rapid changes in the chracteristics of niches affect the animals occupying that niche?
2. Do you think rapid or gradual changes in niches have a greater potential to affect organisms? Think carefully and realize there may not be only one 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. Name three factors that can be used to describe a habitat.

References

1. Image copyright Ellen Beijers, 2012. . Used under license from Shutterstock.com
2. Galen Parks Smith (Wikimedia: GSmith). . CC-BY 2.5
3. Courtesy of Shane Anderson, NOAA. . Public Domain
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CHAPTER 4 Producers

- Explain where all the energy in an ecosystem comes from.
- Describe how energy enters an ecosystem.

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 the bear eats an 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** 4.1), 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.

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 4.1

Producers include plants (a), algae (b), and diatoms (c).

Vocabulary

- **chemosynthesis**: Process of using the energy in chemical compounds to make food; characteristic of produc-

ers in ecosystems without sunlight.
- **energy**: Ability to do work.
- **glucose**: Simple sugar molecule with the chemical formula $C_6H_{12}O_6$.
- **photosynthesis**: Process by which specific organisms (including all plants) use the sun's energy to make their own food from carbon dioxide and water; process that converts the energy of the sun, or solar energy, into carbohydrates, a type of chemical energy.
- **phytoplankton**: Tiny photosynthetic organisms that are producers in aquatic ecosystems.
- **predator-prey relationship**: Interaction between two organisms of unlike species; one organism acts as predator that captures and feeds on the other organism, which serves as the prey.
- **producer**: Organism that produces food (glucose) for itself and other organisms.

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.

Practice

Use the resource below to answer the questions that follow.

- **Producers and Consumers** at http://www.youtube.com/watch?v=P0a97kS_3SA (1:59)

MEDIA

Click image to the left for more content.

1. Can producers function without sunlight? Why or why not? Explain your answer fully.
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 energy in an ecosystem ultimately come from?
2. What "ingredients" are needed for the process of photosynthesis?

References

1. (a) Jan Tik; (b) qorize (Flickr); (c) Courtesy of Prof. Gordon T. Taylor, Stony Brook University/NSF Polar Programs. . (a) CC-BY 2.0; (b) CC-BY 2.0; (c) Public Domain

CHAPTER 5 Consumers and Decomposers

- 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** 5.1) is an 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** 5.1).

- **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.

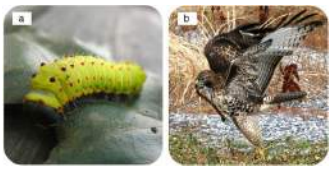


FIGURE 5.1
Examples of consumers are caterpillars (herbivores) and hawks (carnivore).

Decomposers and Stability

Decomposers (**Figure** 5.2) 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.

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 5.2
Examples of decomposers are bacteria (a) and fungi (b).

Vocabulary

- **carnivore**: Organism that feeds on other animals.
- **consumer**: Organism that must consume other organisms to obtain food for energy.
- **decomposer**: Organism that obtains nutrients and energy by breaking down dead organisms and animal wastes.
- **herbivore**: Animal that eats producers to obtain energy.
- **omnivore**: Animal that eats both producers and consumers.
- **producer**: Organism that produces food for itself and other organisms.

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.

Practice

Use the resource below to answer the questions that follow.

- **Decomposers** at http://www.youtube.com/watch?v=Z6V0a_7N1Mw (3:19)

MEDIA

Click image to the left for more content.

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's the term for a consumer that eats both leaves and fish?
2. What are the different types of consumers?
3. Why are decomposers important in the ecosystem?

References

1. (a) Benny Mazur (Flickr: Benimoto); (b) Steve Jurvetson (Flickr: jurvetson). . CC-BY 2.0
2. (a) Umberto Salvagnin (Flickr: kaibara87); (b) takomabibelot (Flickr). . CC-BY 2.0

Chapter 6 Ecosystems

- Distinguish between abiotic and biotic factors.
- Define ecosystem and other ecological concepts.

What lives in the forest?

Take a close look at this ecosystem. Obviously there are deer and many types of plants. But there are organisms that live there that cannot be seen in the picture. Many other animals, such as rabbits, mice, and countless insects. There are also bacteria and fungi. Add in the nonliving aspects of the area, such as the water, and you have an ecosystem.

The Ecosystem

Ecology is the study of how living things interact with each other and with their environment. It is a major branch of biology, but has areas of overlap with geography, geology, climatology, and other sciences. The study of ecology begins with two fundamental concepts in ecology: the ecosystem and their organisms.

Organisms are individual living things. Despite their tremendous diversity, all organisms have the same basic needs: energy and matter. These must be obtained from the environment. Therefore, organisms are not closed systems. They depend on and are influenced by their environment. The environment includes two types of factors: abiotic and biotic.

1. **Abiotic factors** are the nonliving aspects of the environment. They include factors such as sunlight, soil, temperature, and water.
2. **Biotic factors** are the living aspects of the environment. They consist of other organisms, including members of the same and different species.

An **ecosystem** is a unit of nature and the focus of study in ecology. It consists of all the biotic and abiotic factors in an area and their interactions. Ecosystems can vary in size. A lake could be considered an ecosystem. So could a

FIGURE 6.1
A desert ecosystem. What are some of the biotic and abiotic factors in this desert ecosystem?

dead log on a forest floor. Both the lake and log contain a variety of species that interact with each other and with abiotic factors. Another example of an ecosystem is pictured in **Figure** 6.1.

When it comes to energy, ecosystems are not closed. They need constant inputs of energy. Most ecosystems get energy from sunlight. A small minority get energy from chemical compounds. Unlike energy, matter is not constantly added to ecosystems. Instead, it is recycled. Water and elements such as carbon and nitrogen are used over and over again.

Niche

One of the most important concepts associated with the ecosystem is the niche. A **niche** refers to the role of a species in its ecosystem. It includes all the ways that the species interacts with the biotic and abiotic factors of the environment. Two important aspects of a species' niche are the food it eats and how the food is obtained. Look at **Figure** 6.2. It shows pictures of birds that occupy different niches. Each species eats a different type of food and obtains the food in a different way.

Habitat

Another aspect of a species' niche is its habitat. The **habitat** is the physical environment in which a species lives and to which it is adapted. A habitat's features are determined mainly by abiotic factors such as temperature and rainfall. These factors also influence the traits of the organisms that live there.

Competitive Exclusion Principle

A given habitat may contain many different species, but each species must have a different niche. Two different species cannot occupy the same niche in the same place for very long. This is known as the **competitive exclusion principle**. If two species were to occupy the same niche, what do you think would happen? They would compete with one another for the same food and other resources in the environment. Eventually, one species would be likely to outcompete and replace the other.

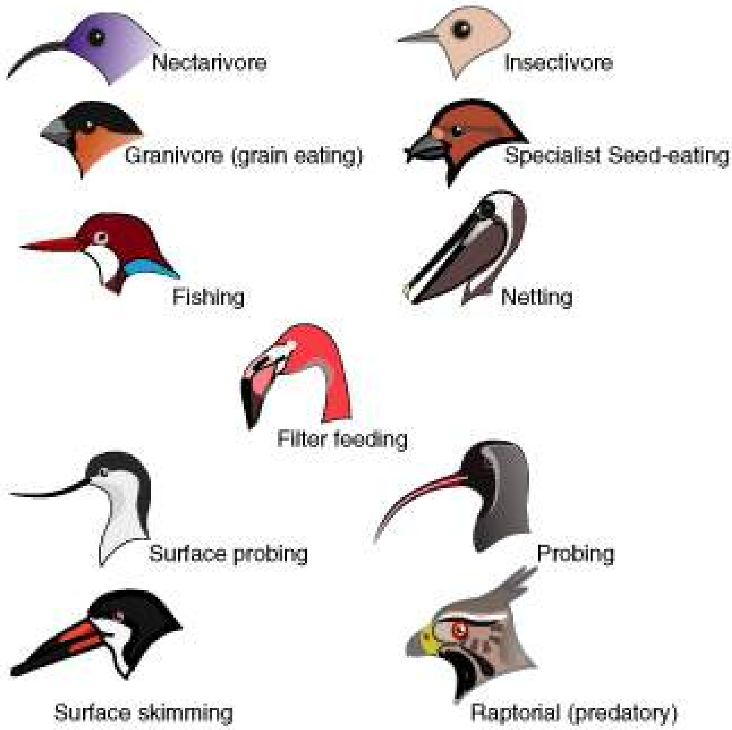


FIGURE 6.2

Bird Niches. Each of these species of birds has a beak that suits it for its niche. For example, the long slender beak of the nectarivore allows it to sip liquid nectar from flowers. The short sturdy beak of the granivore allows it to crush hard, tough grains.

Summary

- Ecology is the study of how living things interact with each other and with their environment.
- The environment includes abiotic (nonliving) and biotic (living) factors.
- An ecosystem consists of all the biotic and abiotic factors in an area and their interactions.
- A niche refers to the role of a species in its ecosystem.
- A habitat is the physical environment in which a species lives and to which it is adapted.
- Two different species cannot occupy the same niche in the same place for very long.

Practice I

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **The Natural Setting: Overview**

1. Define ecology and ecosystem.
2. Distinguish between a population and a community.
3. Compare a biome to the biosphere.

Practice II

- **Experiment with Ecosystems** at http://www.concord.org/activities/experiment-ecosystems.
- **Identify and Label Ecosystems, Food Chain** at http://www.neok12.com/diagram/Ecosystems-01.htm.

Review

1. Define biotic and abiotic factors of the environment. Give an example of each.
2. How do ecologists define the term *ecosystem*?
3. State the competitive exclusion principle.
4. Compare and contrast the ecosystem concepts of *niche* and *habitat*.

References

1. Tomas Castelazo. . CC-BY-SA 2.5
2. L Shyamal. . CC-BY-SA 2.5

Chapter 7 Flow of Energy

- Describe how energy flows through ecosystems.

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** 7.1).
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.

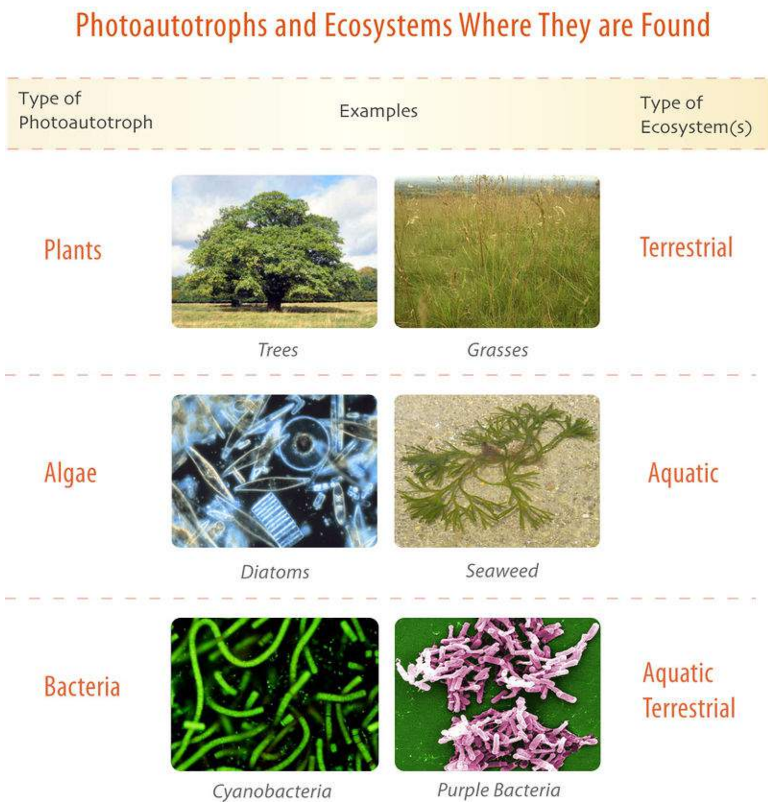


FIGURE 7.1
Different types of photoautotrophs are important in different ecosystems.

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** 7.2. 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.

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

FIGURE 7.2

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?

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** 7.3). In water, detritivores include "bottom feeders" such as sea cucumbers and catfish.
- **Saprotrophs** are the final step in decomposition. They feed on any remaining organic matter that is left after other decomposers do their work. Saprotrophs include fungi and single-celled protozoa. Fungi are the only organisms that can decompose wood.

FIGURE 7.3
Dung Beetle. This dung beetle is rolling a ball of feces to its nest to feed its young.

KQED: Banana Slugs: The Ultimate Recyclers

One of the most beloved and iconic native species within the old growth redwood forests of California is the Pacific Banana Slug. These slimy friends of the forest are the ultimate recyclers. Feeding on fallen leaves, mushrooms or even dead animals, they play a pivotal role in replenishing the soil. QUEST goes to Henry Cowell Redwoods State Park near Santa Cruz, California on a hunt to find *Ariolomax dolichophallus*, a bright yellow slug with a very big personality. See http://www.kqed.org/quest/television/science-on-the-spot-banana-slugs-unpeeled for more information.

MEDIA
Click image to the left for more content.

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.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Energy Flow**

1. Describe the role of autotrophs.
2. Is energy recycled?
3. What is the role of photosynthesis?
4. What is the difference between primary productivity and secondary productivity?
5. What is the relationship between gross primary productivity and net primary productivity?
6. What is biomass?
7. How much energy is lost at each trophic level?

Review

1. Identify three different types of consumers. Name an example of each type.

2. What can you infer about an ecosystem that depends on chemoautotrophs for food?

References

1. Tree: Haabet; Grass: Polishname; Diatoms: Gordon T. Taylor/Stony Brook University/National Oceanic and Atmospheric Administration; Seaweed: Flyingdream; Cyanobacteria: Barry H. Rosen/US Geological Survey; Purple bacteria: Janice Carr/Centers for Disease Control and Prevention; Composite created by CK-12 Foundation. . All images are under the public domain
2. Image copyright Chai Kian Shin, 2010. . Used under license from Shutterstock.com
3. Dewet. . CC-BY-SA 2.0

CHAPTER 8 Food Chains and Food Webs

- Explain how food chains and webs model feeding relationships.

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 are diagrams that represent feeding relationships. Essentially, they show who eats whom. In this way, they model how energy and matter move through ecosystems.

Food Chains

A **food chain** represents a single pathway by which energy and matter flow through an ecosystem. An example is shown in **Figure** 8.1. Food chains are generally simpler than what really happens in nature. Most organisms consume—and are consumed by—more than one species.

A musical summary of food chains can be heard at http://www.youtube.com/watch?v=TE6wqG4nb3M (2:46).

Food Webs

A **food web** represents multiple pathways through which energy and matter flow through an ecosystem. It includes many intersecting food chains. It demonstrates that most organisms eat, and are eaten, by more than one species. An example is shown in **Figure** 8.2.

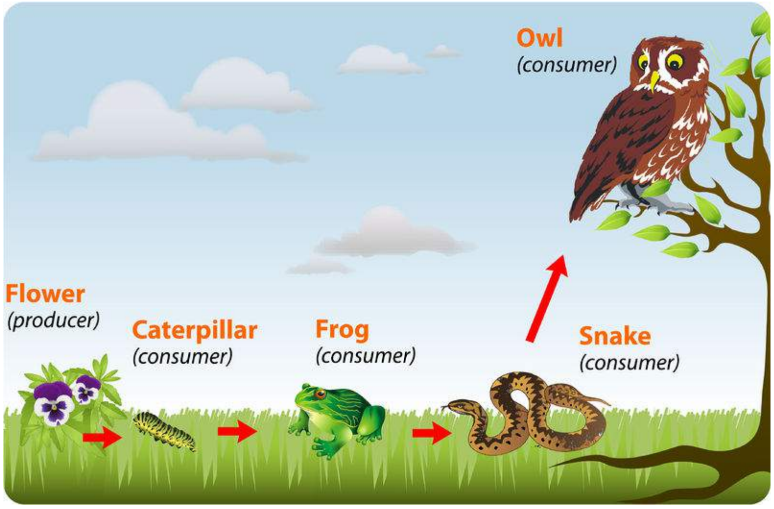


FIGURE 8.1
This food chain includes producers and consumers. How could you add decomposers to the food chain?

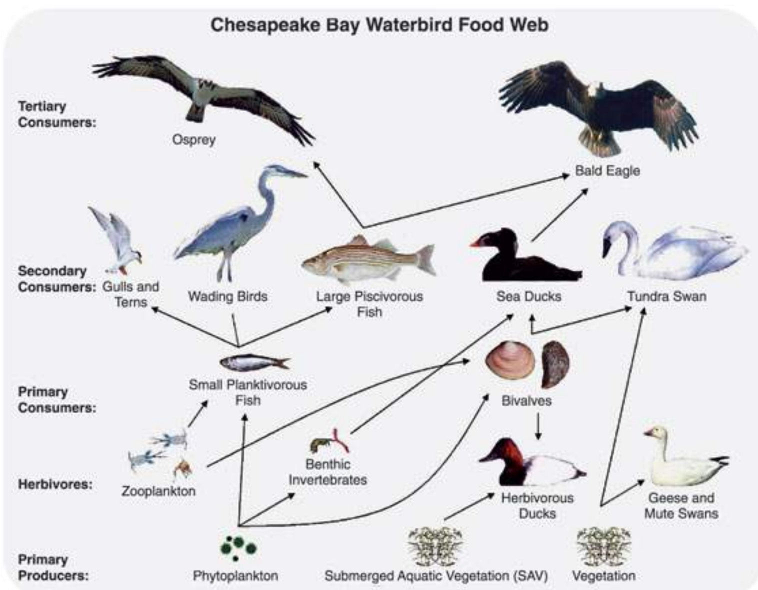


FIGURE 8.2
This food web consists of several different food chains. Which organisms are producers in all of the food chains included in the food web?

Summary

- Food chains and food webs are diagrams that represent feeding relationships.
- Food chains and webs model how energy and matter move through ecosystems.

Practice I

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Feeding Relationships**

1. What are trophic levels?
2. Describe primary producers.

3. Differentiate between primary, secondary, and tertiary consumers.
4. Define detritus and detritivore.
5. What is a food chain? What is a food web?

Practice II

- **Ecosystem Terms** at http://www.neok12.com/quiz/ECOSYS03.

Review

1. Draw a terrestrial food chain that includes four feeding levels.

2. Describe the role of decomposers in food webs.

References

1. Flower image copyright Laurent Renault, 2010; caterpillar image copyright ngstyle, 2010; frog image copyright zaharch, 2010; snake image copyright ananas, 2010; owl image ; tree image copyright sabri deniz kizil, 2010; composite created by CK-12 Foundation. . Used under licenses from Shuttesrtock.com
2. Courtesy of US Geological Survey. . Public Domain

Chapter 9 Trophic Levels

- Identify trophic levels in a food chain or web.

Why are pyramids important in ecology?

The classic example of a pyramid is shown here. But the pyramid structure can also represent the decrease in a measured substance from the lowest level on up. In ecology, pyramids model the use of energy from the producers through the ecosystem.

Trophic Levels

The feeding positions in a food chain or web are called **trophic levels**. The different trophic levels are defined in the **Table** 9.1. Examples are also given in the table. All food chains and webs have at least two or three trophic levels. Generally, there are a maximum of four trophic levels.

TABLE 9.1: Trophic Levels

Trophic Level	Where It Gets Food	Example
1st Trophic Level: Producer	Makes its own food	Plants make food
2nd Trophic Level: Primary Consumer	Consumes producers	Mice eat plant seeds
3rd Trophic Level: Secondary Consumer	Consumes primary consumers	Snakes eat mice
4th Trophic Level: Tertiary Consumer	Consumes secondary consumers	Hawks eat snakes

Many consumers feed at more than one trophic level. Humans, for example, are primary consumers when they eat plants such as vegetables. They are secondary consumers when they eat cows. They are tertiary consumers when they eat salmon.

Trophic Levels and Energy

Energy is passed up a food chain or web from lower to higher trophic levels. However, generally only about 10 percent of the energy at one level is available to the next level. This is represented by the **ecological pyramid** in **Figure** 9.1. What happens to the other 90 percent of energy? It is used for metabolic processes or given off to the environment as heat. This loss of energy explains why there are rarely more than four trophic levels in a food chain or web. Sometimes there may be a fifth trophic level, but usually there's not enough energy left to support any additional levels.

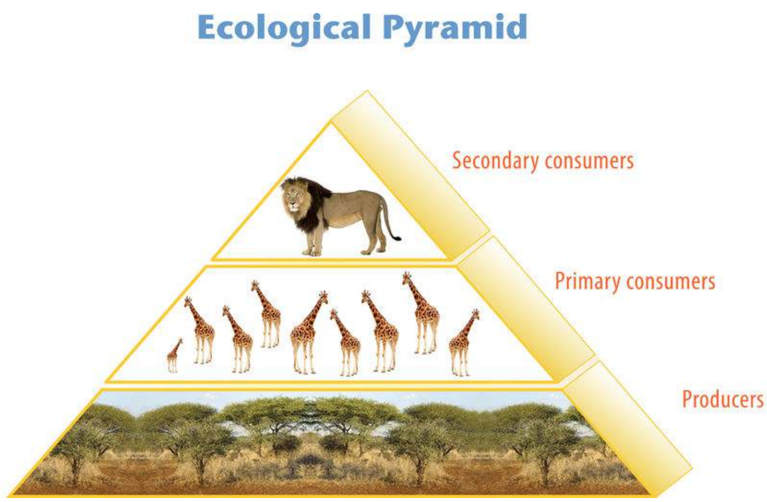


FIGURE 9.1
Ecological Pyramid. This pyramid shows how energy and biomass decrease from lower to higher trophic levels. Assume that producers in this pyramid have 1,000,000 kilocalories of energy. How much energy is available to primary consumers?

Ecological pyramids can demonstrate the decrease in energy, biomass or numbers within an ecosystem. Energy pyramids are discussed at http://www.youtube.com/watch?v=8T2nEMzk6_E&feature=related (1:44).

Trophic Levels and Biomass

With less energy at higher trophic levels, there are usually fewer organisms as well. Organisms tend to be larger in size at higher trophic levels, but their smaller numbers result in less biomass. **Biomass** is the total mass of organisms at a trophic level. The decrease in biomass from lower to higher levels is also represented by **Figure** 9.1.

Summary

- The different feeding positions in a food chain or web are called trophic levels.
- Generally, there are no more than four trophic levels because energy and biomass decrease from lower to higher levels.
- For a summary of Trophic Levels and Producer vs. Consumer, see http://www.youtube.com/watch?v=qUZkWZ12A8s.

Practice

Use these resources to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Feeding Relationships**

1. Define trophic level.
2. What is the role of organisms in the first trophic level?
3. What are the main primary producers in aquatic ecosystems?
4. Give examples of primary consumers and secondary consumers.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Energy Flow**

1. Discuss the importance of primary producers.
2. Define biomass.
3. What is meant by ecological efficiency?
4. Compare a pyramid of productivity to a biomass pyramid and a pyramid of numbers.
5. What is shown in each type of ecological pyramid?

Review

1. What is a trophic level?

2. Draw a terrestrial food chain that includes four trophic levels. Identify the trophic level of each organism in the food chain.

3. Explain how energy limits the number of trophic levels in a food chain or web.

References

1. Images of lion and landscape copyright by Eric Isselée, 2010; image of giraffe copyright Kletr, 2010; composite created by CK-12 Foundation. . Used under licenses from Shutterstock.com

CHAPTER 10 Competition

- Explain why interspecific competition leads to extinction or greater specialization.

Does there have to be a winner?

When animals compete? Yes. Animals, or other organisms, will compete when both want the same thing. One must "lose" so the winner can have the resource. But competition doesn't necessarily involve physical altercations.

Competition

Competition is a relationship between organisms that strive for the same resources in the same place. The resources might be food, water, or space. There are two different types of competition:

1. **Intraspecific competition** occurs between members of the same species. For example, two male birds of the same species might compete for mates in the same area. This type of competition is a basic factor in natural selection. It leads to the evolution of better adaptations within a species.
2. **Interspecific competition** occurs between members of different species. For example, predators of different species might compete for the same prey.

Interspecific Competition and Extinction

Interspecific competition often leads to **extinction**. The species that is less well adapted may get fewer of the resources that both species need. As a result, members of that species are less likely to survive, and the species may go extinct.

Interspecific Competition and Specialization

Instead of extinction, interspecific competition may lead to greater specialization. **Specialization** occurs when competing species evolve different adaptations. For example, they may evolve adaptations that allow them to use different food sources. **Figure** 10.1 describes an example.

FIGURE 10.1
Specialization lets different species of anole lizards live in the same area without competing.

Summary

- Competition is a relationship between organisms that strive for the same resources in the same place.
- Intraspecific competition occurs between members of the same species. It improves the species' adaptations.
- Interspecific competition occurs between members of different species. It may lead to one species going extinct or both becoming more specialized.

Practice I

Use this resource to answer the questions that follow.

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

1. What are the three general types of interactions within a community?
2. Define competition.
3. What are some of the resources organisms compete for?
4. What is the main outcome of competition? (*Hint*: affects the niche)
5. Describe an example of interspecific competition.
6. Why might intraspecific competition occur?

Practice II

- **Competition** at http://www.concord.org/activities/competition.

Review

1. What is competition?
2. Compare and contrast the evolutionary effects of intraspecific and interspecific competition.

References

1. Ground Anole image: pondhawk; Tree Anole image copyright Dewitt, 2010. . Ground Anole image: CC-BY 2.0; Tree Anole image used under license from Shutterstock.com

CHAPTER 11 Symbiosis

- Compare and contrast mutualism, commensalism, and parasitism.

Do interactions between species always result in harm?

A commensal shrimp on another sea organism, possibly a sea cucumber. As commensal shrimp they neither bring a benefit nor have a negative effect on their host.

Symbiotic Relationships

Symbiosis is a close relationship between two species in which at least one species benefits. For the other species, the relationship may be positive, negative, or neutral. There are three basic types of symbiosis: mutualism, commensalism, and parasitism.

Mutualism

Mutualism is a symbiotic relationship in which both species benefit. An example of mutualism involves goby fish and shrimp (see **Figure** 11.1). The nearly blind shrimp and the fish spend most of their time together. The shrimp maintains a burrow in the sand in which both the fish and shrimp live. When a predator comes near, the fish touches the shrimp with its tail as a warning. Then, both fish and shrimp retreat to the burrow until the predator is gone. From their relationship, the shrimp gets a warning of approaching danger. The fish gets a safe retreat and a place to lay its eggs.

FIGURE 11.1
The multicolored shrimp in the front and the green goby fish behind it have a mutualistic relationship.

Commensalism

Commensalism is a symbiotic relationship in which one species benefits while the other species is not affected. One species typically uses the other for a purpose other than food. For example, mites attach themselves to larger flying insects to get a "free ride." Hermit crabs use the shells of dead snails for homes.

Parasitism

Parasitism is a symbiotic relationship in which one species (the **parasite**) benefits while the other species (the **host**) is harmed. Many species of animals are parasites, at least during some stage of their life. Most species are also hosts to one or more parasites. Some parasites live on the surface of their host. Others live inside their host. They may enter the host through a break in the skin or in food or water. For example, roundworms are parasites of mammals, including humans, cats, and dogs (see **Figure** 11.2). The worms produce huge numbers of eggs, which are passed in the host's feces to the environment. Other individuals may be infected by swallowing the eggs in contaminated food or water.

Some parasites kill their host, but most do not. It's easy to see why. If a parasite kills its host, the parasite is also likely to die. Instead, parasites usually cause relatively minor damage to their host.

Summary

- Symbiosis is a close relationship between two species in which at least one species benefits.
- Mutualism is a symbiotic relationship in which both species benefit.
- Commensalism is a symbiotic relationship in which one species benefits while the other species is not affected.
- Parasitism is a symbiotic relationship in which one species (the parasite) benefits while the other species (the host) is harmed.

FIGURE 11.2

Canine Roundworm. The roundworm above, found in a puppy's intestine, might eventually fill a dog's intestine unless it gets medical treatment.

Practice

Use this resource to answer the questions that follow.

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

1. What are the three types of symbiotic relationships?
2. Describe the three symbiotic relationships.
3. Describe an example of a symbiotic relationship involving humans.
4. Describe a symbiotic relationship involving plants and bacteria.

Review

1. Define mutualism and commensalism.

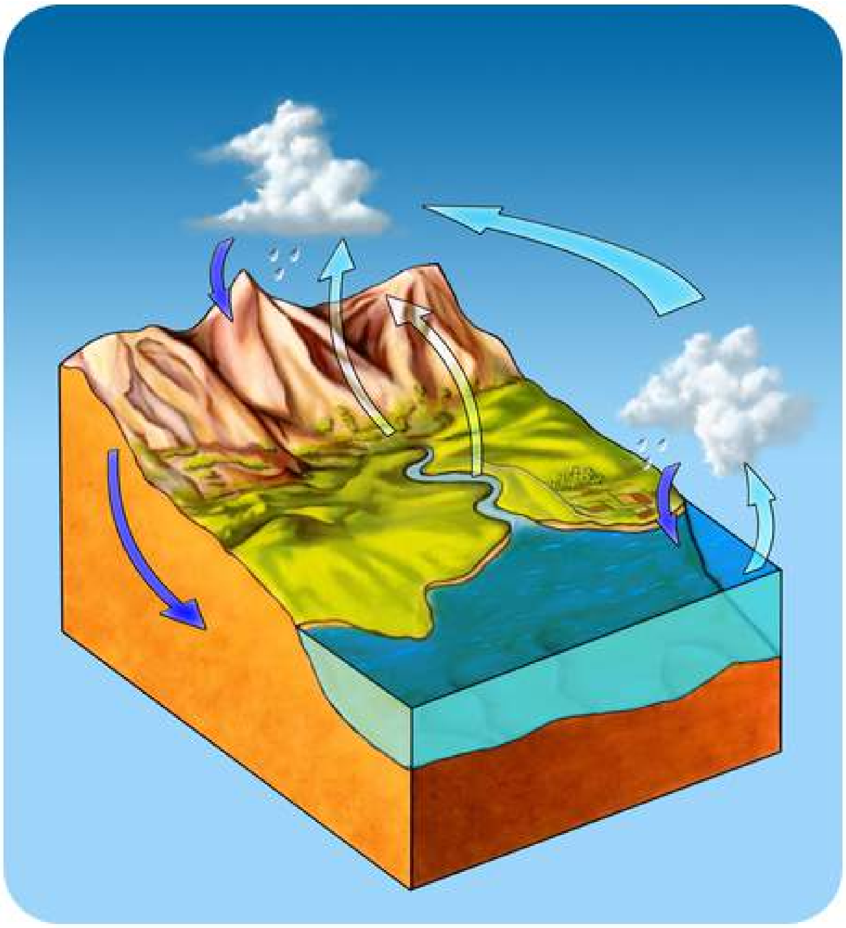
2. Explain why most parasites do not kill their host. Why is it in their own best interest to keep their host alive?

References

1. Haplochromis. . CC-BY-SA 3.0
2. Joel Mills. . CC-BY-SA 2.5

CHAPTER 12 Water Cycle

- Describe the water cycle and its processes.



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** 12.1.

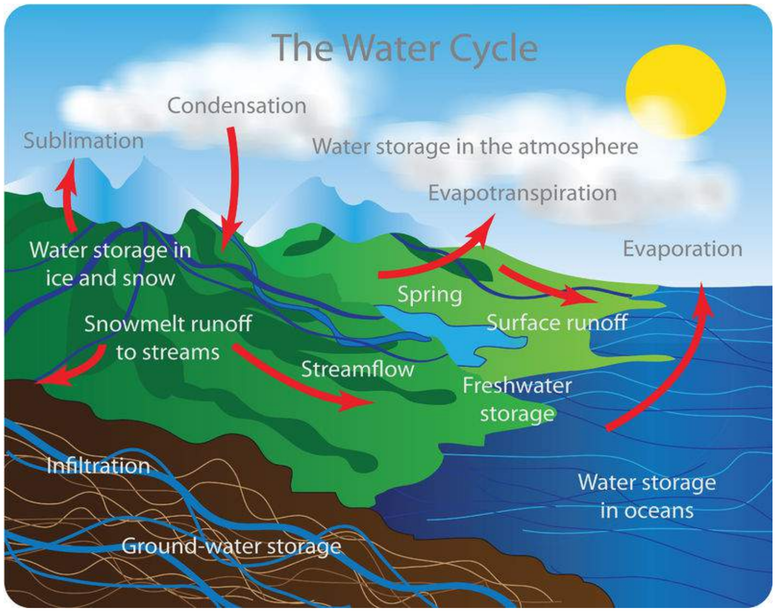


FIGURE 12.1
Like other biogeochemical cycles, there is no beginning or end to the water cycle. It just keeps repeating.

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** 12.2).

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**.

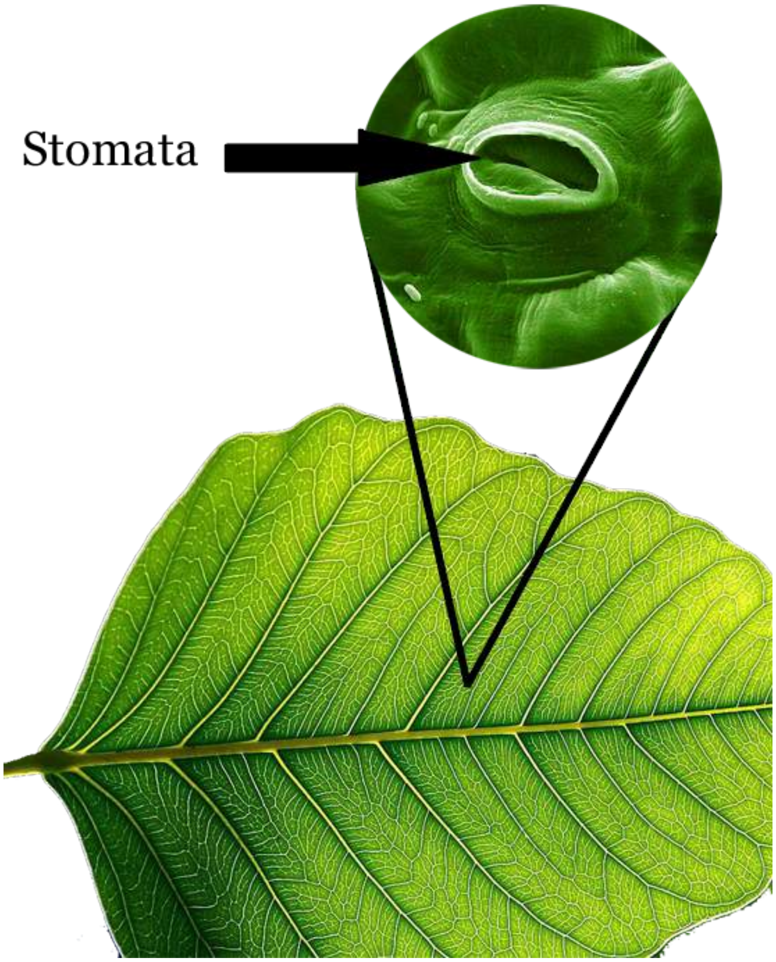


FIGURE 12.2
Plant leaves have many tiny stomata. They release water vapor into the air.

Groundwater may seep out of the ground at a spring or into a body of water such as the ocean. Some groundwater may be taken up by plant roots. Some may flow deeper underground to an **aquifer**. This is an underground layer of rock that stores water, sometimes for thousands of years.

The water cycle is demonstrated at http://www.youtube.com/watch?v=iohKd5FWZOE&feature=related (4:00).

The "Water Cycle Jump" can be viewed at http://www.youtube.com/watch?v=BayExatv8lE. (1:31).

KQED: Tracking Raindrops

We all rely on the water cycle, but how does it actually work? Scientists at University of California Berkeley are embarking on a new project to understand how global warming is affecting our fresh water supply. And they're doing it by tracking individual raindrops in Mendocino and north of Lake Tahoe. See http://www.kqed.org/quest/television/tracking-raindrops for more information.

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.

Practice I

Use these resources to answer the questions that follow.

- http://www.hippocampus.org/Earth Science → Environmental Science → Search: **Water Cycle**

1. Describe the role of each of the following in the water cycle:
    a. condensation
    b. surface runoff
    c. groundwater movement
    d. evaporation
    e. transpiration

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **The Water Cycle**

1. How much of Earth's surface is covered by water?
2. Describe the water cycle.
3. In addition to recycling water, what are the additional roles of the water cycle?

Practice II

- **Label the Diagram of Water Cycle** at http://www.neok12.com/diagram/Water-Cycle-01.htm.

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.

References

1. CK-12 Foundation. . CC-BY-NC-SA 3.0
2. Stomata: Photohound; Leaf: Jon Sullivan/pdphoto.org. . Both images are in the public domain

CHAPTER 13 Carbon Cycle

- Give an overview of the carbon cycle.

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** 13.1.

The carbon cycle is discussed in the following video: http://www.youtube.com/watch?v=0Vwa6qtEih8 (1:56).

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** 13.1.

TABLE 13.1:

Form of Carbon	Chemical Formula	State	Main Reservoir
Carbon Dioxide	CO_2	Gas	Atmosphere
Carbonic Acid	H_2CO_3	Liquid	Ocean

TABLE 13.1: (continued)

Form of Carbon	Chemical Formula	State	Main Reservoir
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

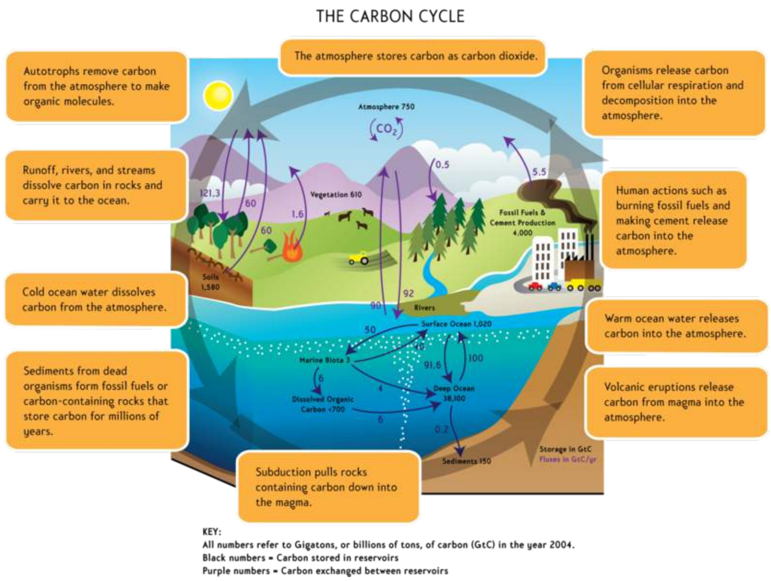


FIGURE 13.1

The Carbon Cycle. Carbon moves from one reservoir to another in the carbon cycle. What role do organisms play in this cycle?

KEY: C = Carbon, O = Oxygen, H = Hydrogen

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.
- Carbon dioxide is also removed when ocean water cools and dissolves more carbon dioxide from the air.

Because of human activities, there is more carbon dioxide in the atmosphere today than in the past hundreds of thousands of years. Burning fossil fuels and producing concrete has released great quantities of carbon dioxide into the atmosphere. Cutting forests and clearing land has also increased carbon dioxide into the atmosphere because these activities reduce the number of autotrophic organisms that use up carbon dioxide in photosynthesis. In addition, clearing often involves burning, which releases carbon dioxide that was previously stored in autotrophs.

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.

Practice I

Use these resources to answer the questions that follow.

- http://www.hippocampus.org/Earth Science → Environmental Science → Search: **Carbon Cycle**

1. Describe the role of each of the following in the carbon cycle:
   a. photosynthesis
   b. respiration
   c. diffusion
   d. decomposition
   e. combustion
   f. sedimentation
   g. volcanism
   h. weathering

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **The Carbon Cycle**

1. What is the role of carbon in organic compounds?
2. How is carbon used in primary producers?
3. How is CO_2 returned to the atmosphere by living organisms?
4. How much CO_2 is removed from the atmosphere by plants?
5. What are fossil fuels? How are they formed?
6. What is $CaCO_3$? What is its role in the carbon cycle?
7. Why is the amount of atmospheric CO_2 lowest during the Northern Hemisphere summer?

Practice II

- **Label the Diagram of Carbon Cycle** at http://www.neok12.com/diagram/Carbon-Cycle-01.htm.

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.

References

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CHAPTER 14 Nitrogen Cycle

- Outline the steps of 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** 14.1 shows how nitrogen cycles through a terrestrial ecosystem. Nitrogen passes through a similar cycle in aquatic ecosystems.

Plants cannot use nitrogen gas from the air to make organic compounds for themselves and other organisms. The nitrogen gas must be changed to a form called nitrates, which plants can absorb through their roots. The process of changing nitrogen gas to nitrates is called **nitrogen fixation**. It is carried out by nitrogen-fixing bacteria. The bacteria live in soil and roots of legumes, such as peas.

When plants and other organisms die, decomposers break down their remains. In the process, they release nitrogen in the form of ammonium ions. 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.

See *The Nitrogen Cycle: An Aquatic Perspective* at http://www.youtube.com/watch?v=pdY4I-EaqJA&feature=fvw (5:08) for a summary of this cycle. The cycle is also summarized at http://www.youtube.com/watch?v=w03iO_Yu9Xw&feature=related (2:04).

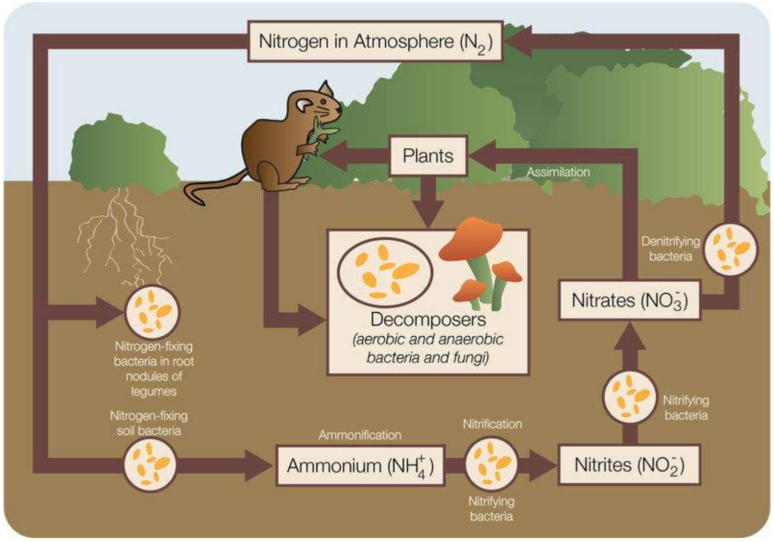

FIGURE 14.1

Nitrogen Cycle in a Terrestrial Ecosystem. Nitrogen cycles between the atmosphere and living things.

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.

Practice

Use these resources to answer the questions that follow.

- http://www.hippocampus.org/Earth Science → Environmental Science → Search: **Nitrogen Cycle**

1. Describe the role of each of the following in the nitrogen cycle:
   a. nitrogen fixation
   b. nitrification
   c. uptake
   d. decomposition and excretion
   e. ammonification
   f. denitrification
   g. weathering

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **The Nitrogen Cycle**

1. In which compounds is nitrogen found?
2. In plants, which are the unusable and usable forms of nitrogen?
3. What is nitrogen fixation? Describe this process.
4. What happens during ammonification?
5. Compare nitrification and denitrification.

Review

1. What is nitrogen fixation?

2. Explain why bacteria are essential parts of the nitrogen cycle.

References

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CHAPTER 15 Population Size, Density, and Distribution

- Define population size, density, and dispersion.

Is this any way to live?

It is if you're a penguin. This population of penguins is made of all the individuals of the same species of penguins who live together. They seem to exist in a very crowded - or densely populated - environment, and in a random configuration.

Population Size, Density, and Distribution

Communities are made up of populations of different species. In biology, a **population** is a group of organisms of the same species that live in the same area. The population is the unit of natural selection and evolution. How large a population is and how fast it is growing are often used as measures of its health.

Population size is the number of individuals in a population. For example, a population of insects might consist of 100 individual insects, or many more. Population size influences the chances of a species surviving or going extinct. Generally, very small populations are at greatest risk of extinction. However, the size of a population may be less important than its density.

Population Density

Population density is the average number of individuals in a population per unit of area or volume. For example, a population of 100 insects that live in an area of 100 square meters has a density of 1 insect per square meter. If the same population lives in an area of only 1 square meter, what is its density? Which population is more crowded? How might crowding affect the health of a population?

Population Distribution

Population density just represents the average number of individuals per unit of area or volume. Often, individuals in a population are not spread out evenly. Instead, they may live in clumps or some other pattern (see **Figure** 15.1). The pattern may reflect characteristics of the species or its environment. **Population distribution** describes how the individuals are distributed, or spread throughout their habitat.

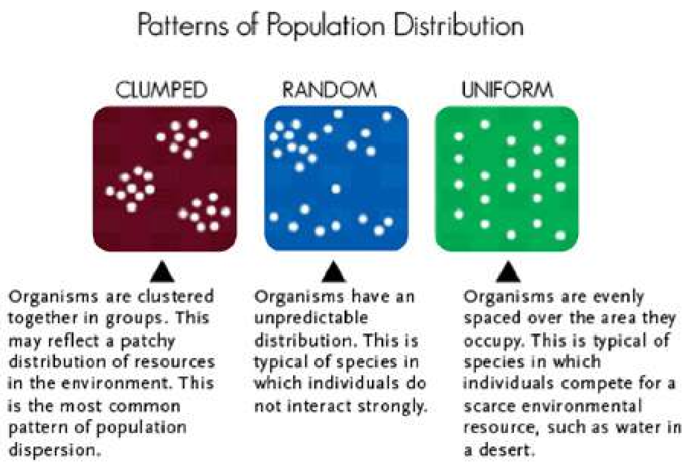


FIGURE 15.1

Patterns of Population Distribution. What factors influence the pattern of a population over space?

Summary

- Population size is the number of individuals in a population.
- Population density is the average number of individuals per unit of area or volume.
- The pattern of spacing of individuals in a population may be affected by the characteristics of a species or its environment.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Population Distribution**

1. Distinguish between clumped, uniform, and random distributions.
2. Discuss causes of clumped distributions.
3. Why might a uniform distribution result?
4. Define population density and demographics.

Review

1. What is population density?

2. What are the differences between population density and distribution?

3. A population of 820 insects lives in a 1.2-acre area. They gather nectar from a population of 560 flowering plants. The plants live in a 0.2-acre area. Which population has greater density, the insects or the plants? Why?

4. What can you infer about a species that has a random pattern of distribution over space? A uniform pattern?

References

1. CK-12 Foundation. . CC-BY-NC-SA 3.0

CHAPTER 16 Population Structure

- Relate population pyramids and survivorship curves to population structure.

Young vs. old. Does it matter?

When it comes to populations, yes it does. The age structure (and the sex structure) of a population influences population growth. Can you explain why?

Population Structure

Population growth is the change in the size of the population over time. An important factor in population growth is **age-sex structure**. This is the number of individuals of each sex and age in the population. The age-sex structure influences population growth. This is because younger people are more likely to reproduce, while older people have higher rates of dying.

Population Pyramids

Age-sex structure is represented by a **population pyramid**. This is a bar graph, like the one **Figure** 16.1. In this example, the bars become narrower from younger to older ages. Can you explain why?

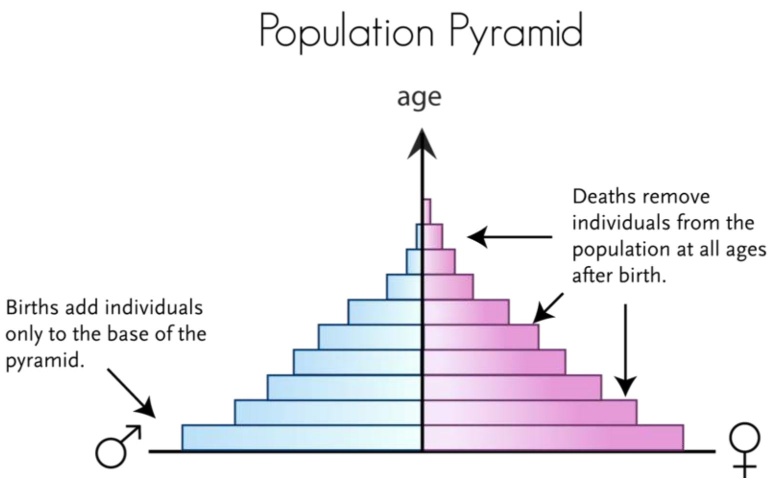


FIGURE 16.1
A population pyramid represents the age-sex structure of a population.

Survivorship Curves

Another way to show how deaths affect populations is with **survivorship curves**. These are graphs that represent the number of individuals still alive at each age. Examples are shown in **Figure** 16.2.

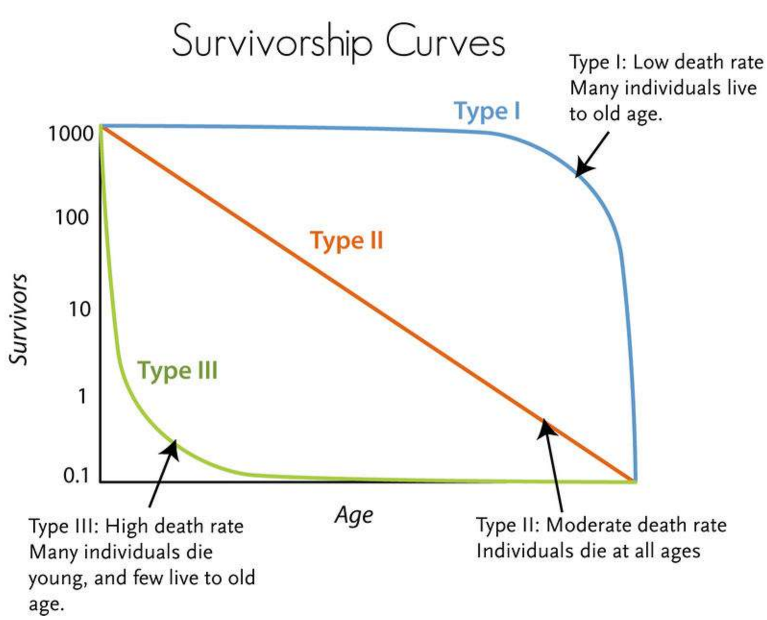


FIGURE 16.2
Survivorship curves reflect death rates at different ages.

The three types of curves shown in the figure actually represent different strategies species use to adapt to their environment:

- Type I: Parents produce relatively few offspring and provide them with a lot of care. As a result, most of the offspring survive to adulthood so they can reproduce. This pattern is typical of large animals, including humans.
- Type II: Parents produce moderate numbers of offspring and provide some parental care. Deaths occur more uniformly throughout life. This pattern occurs in some birds and many asexual species.
- Type III: Parents produce many offspring but provide them with little or no care. As a result, relatively few offspring survive to adulthood. This pattern is typical of plants, invertebrates, and many species of fish.

See http://www.youtube.com/watch?v=xkAnO8VjCz0 for an overview of survivorship curves.

The Type I strategy occurs more often in stable environments. The Type III strategy is more likely in unstable environments. Can you explain why?

Summary

- The age-sex structure of a population is the number of individuals of each sex and age in the population.
- Age-sex structure influences population growth. It is represented by a population pyramid.
- The number of survivors at each age is plotted on a survivorship curve.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Population Distribution**

1. Describe the relationship between a life table and a survivorship curve.
2. What is a major factor in determining if offspring survive?
3. What is an age pyramid?

Review

1. Assume that a population pyramid has a very broad base. What does that tell you about the population it represents?

2. Compare and contrast Type I and Type III survivorship curves.

References

1. CK-12 Foundation. . CC-BY-NC-SA 3.0
2. CK-12 Foundation. . CC-BY-NC-SA 3.0

Chapter 17 Population Growth Patterns

- Compare and contrast exponential and logistic growth.

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** 17.1 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.

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** 17.1 represents this pattern of growth, which is called **logistic growth**.

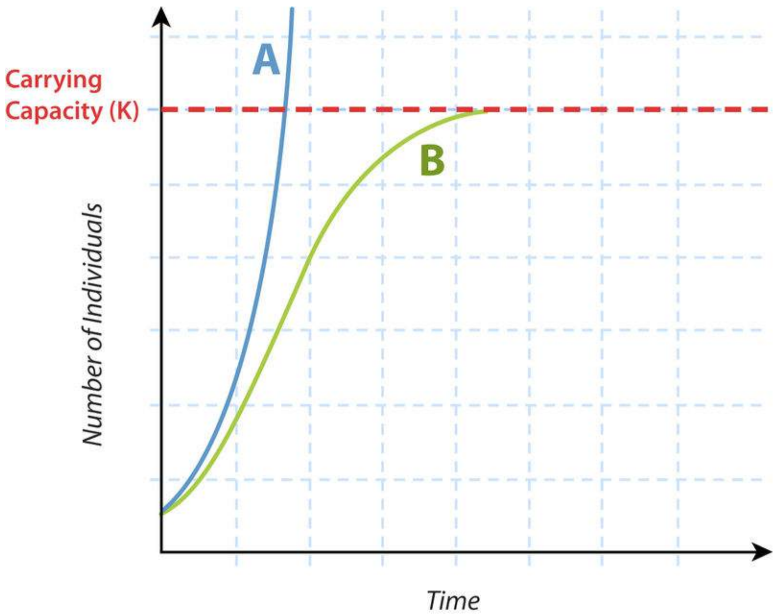


FIGURE 17.1
Exponential and Logistic Growth. Curve A shows exponential growth. Curve B shows logistic growth.

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** 17.1). 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.

K-Selected and *r*-Selected Species

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** 17.1.
- 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** 17.1. (*r* is the population growth rate. See the "Population III: Growth" concept.)

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.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Models of Population Growth**

1. Define carrying capacity.
2. Describe exponential and logistic growth curves.
3. How does logistic growth effect natural selection?
4. Contrast *K*-selected and *r*-selected populations.

Review

1. Describe exponential population growth.

2. What are *K*-selected and *r*-selected species?

References

1. CK-12 Foundation. . CC-BY-NC-SA 3.0

CHAPTER 18 Biodiversity

- Define biodiversity.

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** 18.1. 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**

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

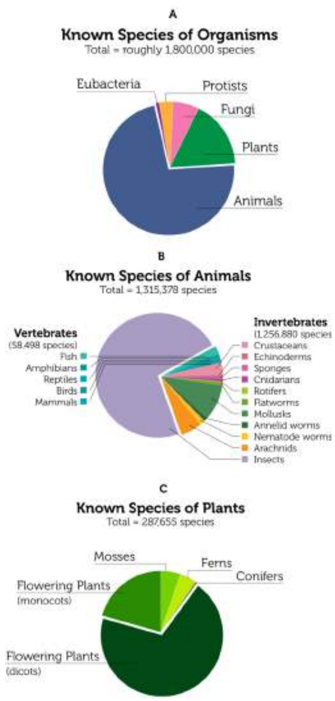


FIGURE 18.1

Known species represent only a fraction of all species that exist on Earth.

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.

A discussion of biodiversity is available at http://www.youtube.com/watch?v=vGxJArebKoc (6:12).

Summary

- Biodiversity refers to the number of species in an ecosystem or the biosphere as a whole.

Practice

Use this resource to answer the questions that follow.

- **Biodiversity** at http://vimeo.com/14105623

1. Define biodiversity.
2. What factors help a region survive?
3. What is genetic biodiversity? Why is it important?
4. What is species diversity? Why is it important?
5. What is ecosystem diversity? Why is it important?
6. What is meant by *interdependent*?

Review

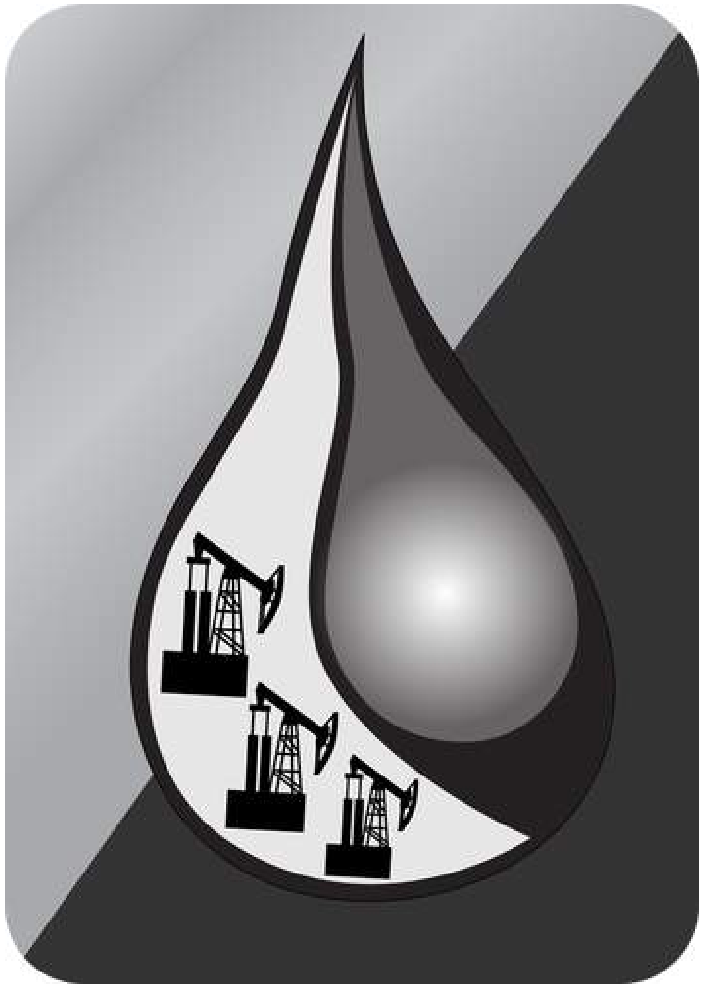
1. What is biodiversity?

References

1. Barbara Akre/CK-12 Foundation based on data from http://cnx.org/content/m12174/latest/ and http://en.wikipedia.org/wiki . CC-BY-NC-SA 3.0

CHAPTER 19 Renewable and Nonrenewable Resources

- Distinguish between renewable and nonrenewable resources.



Renewable or nonrenewable, what's the difference?

That's like asking the difference between having an endless supply and having a limited supply. Will this planet eventually run out of oil? Probably. So oil is a nonrenewable resource.

Renewable and Nonrenewable Resources

A **natural resource** is something supplied by nature that helps support life. When you think of natural resources, you may think of minerals and fossil fuels. However, ecosystems and the services they provide are also natural resources. **Biodiversity** is a natural resource as well.

Renewable Resources

Renewable resources can be replenished by natural processes as quickly as humans use them. Examples include sunlight and wind. They are in no danger of being used up (see **Figure** 19.1). Metals and other minerals are renewable too. They are not destroyed when they are used and can be recycled.

FIGURE 19.1
Wind is a renewable resource. Wind turbines like this one harness just a tiny fraction of wind energy.

Living things are considered to be renewable. This is because they can reproduce to replace themselves. However, they can be over-used or misused to the point of extinction. To be truly renewable, they must be used sustainably. **Sustainable use** is the use of resources in a way that meets the needs of the present and also preserves the resources for future generations.

Nonrenewable Resources

FIGURE 19.2

Nonrenewable resources are natural resources that exist in fixed amounts and can be used up. Examples include fossil fuels such as petroleum, coal, and natural gas. These fuels formed from the remains of plants over hundreds of millions of years. We are using them up far faster than they could ever be replaced. At current rates of use, petroleum will be used up in just a few decades and coal in less than 300 years. Nuclear power is also considered to be a nonrenewable resource because it uses up uranium, which will sooner or later run out. It also produces harmful wastes that are difficult to dispose of safely.

FIGURE 19.3

Summary

- Renewable resources can be replaced by natural processes as quickly as humans use them. Examples include sunlight and wind.
- Nonrenewable resources exist in fixed amounts. They can be used up. Examples include fossil fuels such as coal.

Practice I

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Non-Majors Biology → Search: **Human Impacts on Biogeochemical Cycles**

1. What was the energy source for much of the Industrial Revolution? How were these fuels made?
2. Why are carbon dioxide levels rising in the atmosphere?

Practice II

- **Renewable or Non-renewable Quiz** at http://www.neok12.com/quiz/ENESRC01.

Review

1. Define natural resource.
2. Distinguish between renewable and nonrenewable resources and give examples.
3. Infer factors that determine whether a natural resource is renewable or nonrenewable.

References

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3. Image copyright SeDmi, 2011. . Used under license from Shutterstock.com

CHAPTER 20 Global Climate Change

- Explain global climate change.

Is the Earth really fragile?

Maybe not the planet, but how about the ecosystems? It may soon be hard to argue that global climate change does not exist. Climate change can definitely be seen in numerous ecosystems. So what will we do about it?

Global Climate Change

Another major problem caused by air pollution is global climate change. Gases such as carbon dioxide from the burning of fossil fuels increase the natural greenhouse effect. This raises the temperature of Earth's surface.

What Is the Greenhouse Effect?

The **greenhouse effect** is a natural feature of Earth's atmosphere. It occurs when gases in the atmosphere radiate the sun's heat back down to Earth's surface (see **Figure** 20.1). Otherwise, the heat would escape into space. Without the greenhouse effect, Earth's surface temperature would be far cooler than it is. In fact, it would be too cold to support life as we know it.

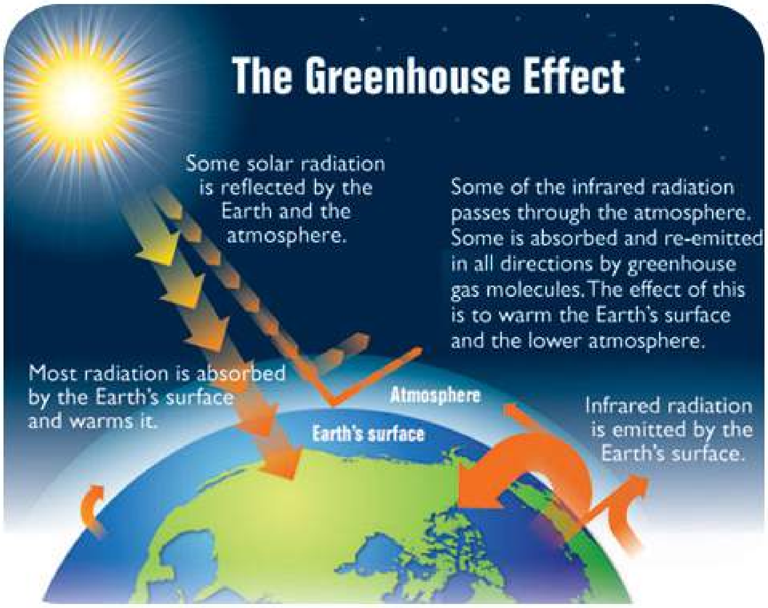

FIGURE 20.1
The Greenhouse Effect. Without greenhouse gases, most of the sun's energy would be radiated from Earth's surface back out to space.

Global Warming

Global warming refers to a recent increase in Earth's average surface temperature (see **Figure** 20.2). During the past century, the temperature has risen by almost 1°C (about 1.3°F). That may not seem like much. But consider that just 10°C is the difference between an ice-free and an ice-covered Earth.

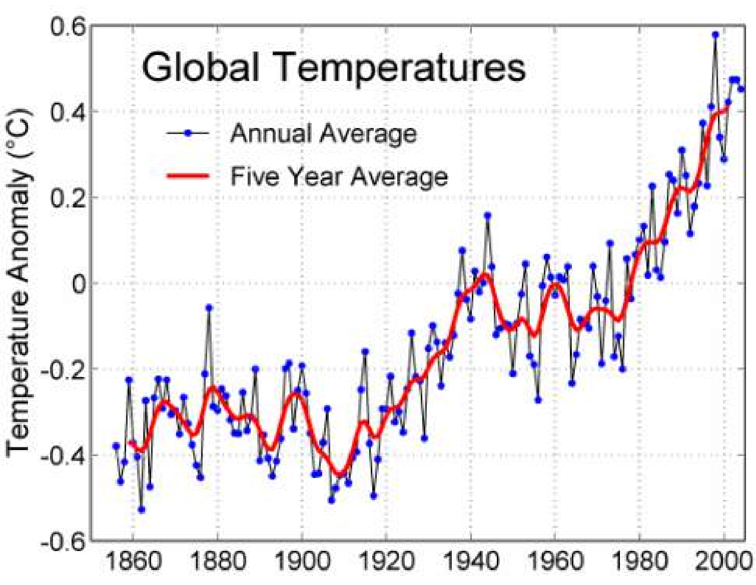

FIGURE 20.2
The average annual temperature on Earth has been rising for the past 100 years.

Most scientists agree that global warming is caused by more carbon dioxide in the atmosphere (see **Figure** 20.3). This increases the greenhouse effect. There is more carbon dioxide mainly because of the burning of fossil fuels.

Destroying forests is another cause. With fewer forests, less carbon dioxide is removed from the atmosphere by photosynthesis.

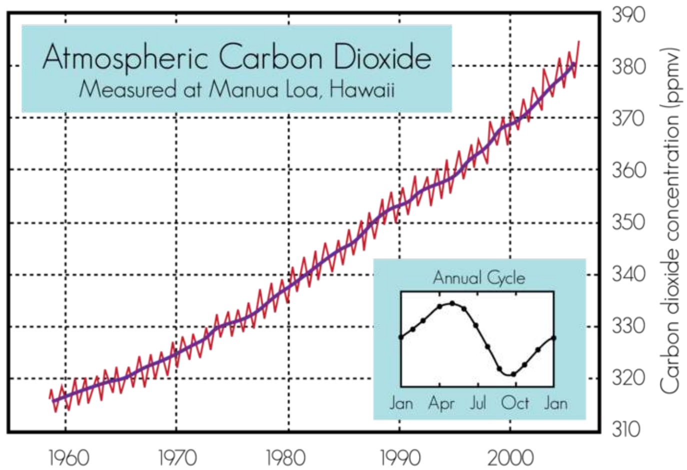

FIGURE 20.3

This graph shows the recent trend in carbon dioxide in the atmosphere.

Effects of Climate Change

How has global warming affected Earth and its life? Some of its effects include:

- Decline in cold-adapted species such as polar bears.
- Melting of glaciers and rising sea levels.
- Coastal flooding and shoreline erosion.
- Heat-related human health problems.
- More droughts and water shortages.
- Changing patterns of precipitation.
- Increasing severity of storms.
- Major crop losses.

These two videos discuss some of the consequences from changes in ecosystems: http://www.youtube.com/watch?v=jHWgWxDWhsA (7:47) and http://www.youtube.com/watch?v=5qblwORXwrg (2:26).

KQED: Climate Watch: California at the Tipping Point

The world's climate is changing and California is now being affected in both dramatic and subtle ways. In 2008, scientists determined that California's temperatures increased by more than 2.1°F during the last century. What's more, the data showed that human activity has played a significant role in that climate change. "What's just 2 degrees?" you may wonder. But, as the science shows, just 2 degrees is extremely significant.

What does all this temperature change mean? For starters, declining mountain snowpack and prolonged drought conditions could pose a threat to limited water supplies. Heat waves are projected to be longer, bringing increased danger from wildfires and heat-related deaths. Rising sea levels due to temperature shifts jeopardize life in coastal areas, both for human communities and the plants and animals that rely on intertidal and rich wetland ecosystems.

Also, more precipitation is expected to fall as rain rather than snow, thereby increasing the risk of floods. And, as heat increases the formation of smog, poor air quality could get even worse.

Climate change may also profoundly affect the economy in California and elsewhere. Shorter ski seasons and damage to the marine ecosystem mean a reduction in tourism. Water shortages mean issues with the commercial and recreational fishing industry, and higher temperatures will affect crop growth and quality, weakening the agricultural industry, to name just a few of the economic issues associated with climate change.

Get an in-depth look at the science behind climate change at http://www.kqed.org/quest/television/climate-watch-california-at-the-tipping-point-part-one.

MEDIA
Click image to the left for more content.

KQED: Giant Redwoods and Global Warming

Forest ecologist Steve Sillett is leading a team of scientists as they climb and measure every branch of some of the last and tallest old growth redwoods in California. Their goal is to learn how these ancient giants have historically responded to climatic shifts and to monitor how they are being impacted today by global warming. See http://www.kqed.org/quest/television/science-on-the-spot-measuring-redwood-giants for additional information.

MEDIA
Click image to the left for more content.

KQED: Acidic Seas

Melting glaciers, rising temperatures, and droughts are all impacts of global warming. But how does global warming actually affect the oceans? The ocean acts like a giant sponge, absorbing carbon dioxide emissions from the air. And as we add more and more carbon dioxide to air by burning fossil fuels, the ocean is absorbing it. On one level, it's done us a big favor. Scientists say that we would be experiencing much more extreme climate change were it not for the ocean's ability to remove the heat-trapping gas. However, these emissions are causing the oceans to become more acidic. Changing pH levels threaten entire marine food webs, from coral reefs to salmon. See http://www.kqed.org/quest/radio/acidic-seas for additional information.

MEDIA
Click image to the left for more content.

What Can Be Done?

Efforts to reduce future global warming mainly involve energy use. We need to use less energy, for example, by driving more fuel-efficient cars. We also need to switch to energy sources that produce less carbon dioxide, such as solar and wind energy. At the same time, we can increase the amount of carbon dioxide that is removed from air. We can stop destroying forests and plant new ones.

Summary

- Gases such as carbon dioxide from the burning of fossil fuels increase the natural greenhouse effect. This is raising the temperature of Earth's surface, and is called global warming.

Practice I

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Environmental Degradation**

1. What is global warming?
2. How does the burning of fossil fuels lead to global warming?
3. Describe the role of water vapor in global warming.
4. What causes sea levels to rise?

Practice II

- Greenhouse effect interactive simulation: http://phet.colorado.edu/en/simulation/greenhouse

MEDIA

Click image to the left for more content.

- http://www.hippocampus.org/Biology → Non-Majors Biology → Search: **Global Challenges and Opportunities**

Review

1. How does air pollution contribute to global warming?

2. Apply lesson concepts to explain the relationship between the above graphs.

References

1. US EPA. . Public Domain
2. Robert A. Rohde/Global Warming Art. . GNU-FDL 1.2
3. Sémhur, modified by CK-12 Foundation. . CC-BY-SA 3.0

CK-12 FlexBook

Evolution

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Contents

CHAPTER 1 History of Life

- Explain how scientists learn about the history of life on Earth.

How do we learn about the past?

We study the remains of things that existed many years ago. The Ruins of Pompeii have given archeologists, historians, and other scholars a tremendous amount of information about life two thousand years ago. This section discusses studying things that are many thousands of years older than these remains.

Learning About the Past

Much of what we know about the history of life on Earth is based on the fossil record. Detailed knowledge of modern organisms also helps us understand how life evolved.

The Fossil Record

Fossils are the preserved remains or traces of organisms that lived in the past. The soft parts of organisms almost always decompose quickly after death. On occasion, the hard parts—mainly bones, teeth, or shells—remain long enough to mineralize and form fossils. An example of a complete fossil skeleton is shown in **Figure** 1.1. The **fossil record** is the record of life that unfolded over four billion years and pieced back together through the analysis of fossils.

To be preserved as fossils, remains must be covered quickly by sediments or preserved in some other way. For example, they may be frozen in glaciers or trapped in tree resin, like the frog in **Figure** 1.2. Sometimes traces of organisms—such as footprints or burrows—are preserved (see the fossil footprints in **Figure** 1.2). The conditions required for fossils to form rarely occur. Therefore, the chance of an organism being preserved as a fossil is very low. You can watch a video at the following link to see in more detail how fossils form: http://www.youtube.com/watch?v=A5i5Qrp6sJU.

FIGURE 1.1
Extinct Lion Fossil. This fossilized skeleton represents an extinct lion species. It is rare for fossils to be so complete and well preserved as this one.

FIGURE 1.2
The photo on the left shows an ancient frog trapped in hardened tree resin, or amber. The photo on the right shows the fossil footprints of a dinosaur.

In order for fossils to "tell" us the story of life, they must be dated. Then they can help scientists reconstruct how life changed over time. Fossils can be dated in two different ways: relative dating and absolute dating. Both are described below. You can also learn more about dating methods in the video at this link: http://www.youtube.com/watch?v=jM7vZ-9bBc0.

- **Relative dating** determines which of two fossils is older or younger than the other, but not their age in years. Relative dating is based on the positions of fossils in rock layers. Lower layers were laid down earlier, so they are assumed to contain older fossils. This is illustrated in **Figure** 1.3.
- **Absolute dating** determines about how long ago a fossil organism lived. This gives the fossil an approximate age in years. Absolute dating is often based on the amount of carbon-14 or other radioactive element that remains in a fossil. You can learn more about carbon-14 dating by watching the animation at this link: http://www.absorblearning.com/media/attachment.action?quick=bo&att=832.

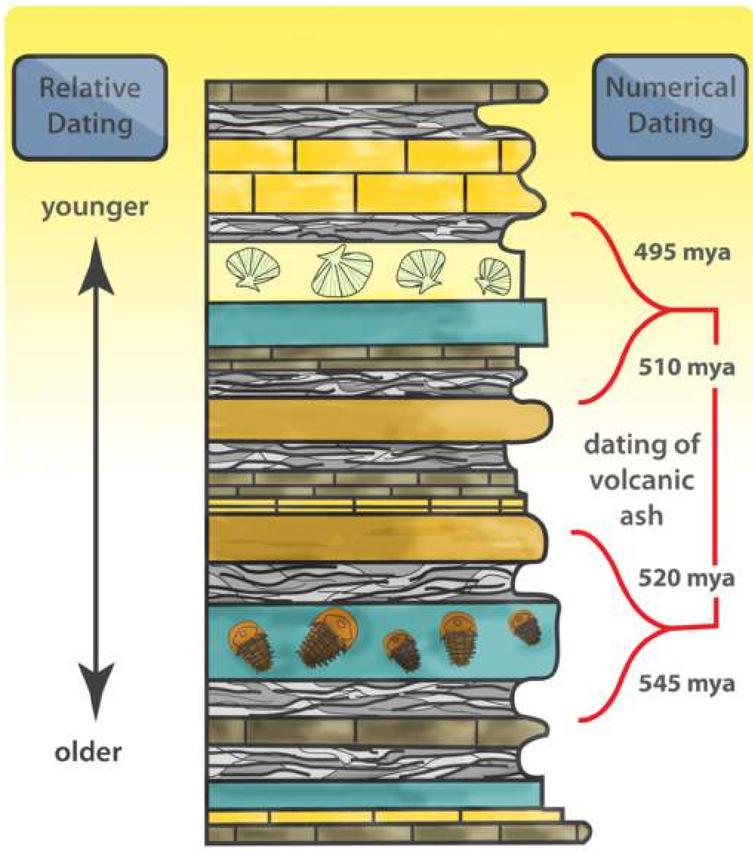


FIGURE 1.3
Relative Dating Using Rock Layers. Relative dating establishes which of two fossils is older than the other. It is based on the rock layers in which the fossils formed.

Molecular Clocks

Evidence from the fossil record can be combined with data from molecular clocks. A **molecular clock** uses DNA sequences (or the proteins they encode) to estimate relatedness among species. Molecular clocks estimate the time in geologic history when related species diverged from a common ancestor. Molecular clocks are based on the assumption that mutations accumulate through time at a steady average rate for a given region of DNA. Species that have accumulated greater differences in their DNA sequences are assumed to have diverged from their common ancestor in the more distant past. Molecular clocks based on different regions of DNA may be used together for more accuracy. Consider the example in **Table** 1.1. The table shows how similar the DNA of several animal species is to human DNA. Based on these data, which organism do you think shared the most recent common ancestor with humans?

TABLE 1.1: Comparing DNA: Humans and Other Animals

Organism	Similarity with Human DNA (percent)
Chimpanzee	98
Mouse	85
Chicken	60
Fruit Fly	44

Geologic Time Scale

Another tool for understanding the history of Earth and its life is the **geologic time scale**, shown in **Figure** 1.4. The geologic time scale divides Earth's history into divisions (such as eons, eras, and periods) that are based on major changes in geology, climate, and the evolution of life. It organizes Earth's history and the evolution of life on the basis of important events instead of time alone. It also allows more focus to be placed on recent events, about which we know the most.

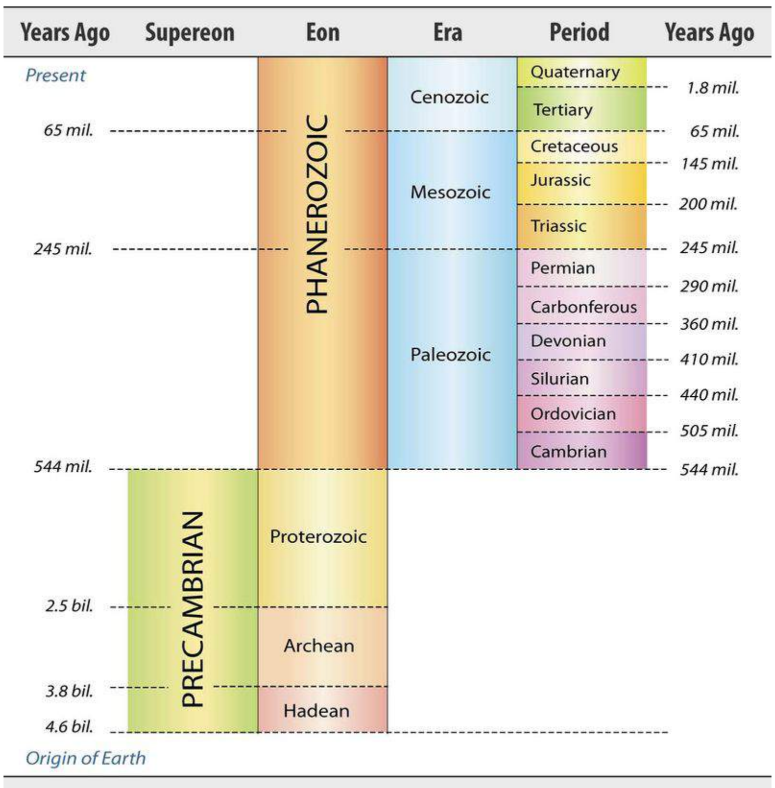


FIGURE 1.4
Geologic Time Scale. The geologic time scale divides Earth's history into units that reflect major changes in Earth and its life forms. During which eon did Earth form? What is the present era?

Summary

- Much of what we know about the history of life on Earth is based on the fossil record.
- Molecular clocks are used to estimate how long it has been since two species diverged from a common ancestor.
- The geologic time scale is another important tool for understanding the history of life on Earth.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **The History of Life on Earth**

1. What are the most important clues to understanding the history of life on Earth?
2. Compare relative dating to radiometric dating.

Use the time slider in this resource to answer the questions that follow.

- **Evolution** at http://johnkyrk.com/evolution.swf.

1. When did the Big Bang occur?
2. When did the sun ignite?
3. When did the Earth form?
4. When did the first cells appear?

Review

1. What are fossils?

2. Describe how fossils form.

3. This table shows DNA sequence comparisons for some hypothetical species. Based on the data, describe evolutionary relationships between Species A and the other four species. Explain your answer.

TABLE 1.2: **DNA Similarities**

Species	**DNA Similarity with Species A**
Species B	42%
Species C	85%
Species D	67%
Species E	91%

4. Compare and contrast relative and absolute dating.

References

1. Karora. . Public Domain
2. Frog in resin image copyright Galyna Andrushko, 2010; Fossil footprint image copyright Anton Foltin, 2010. . Both images used under licenses from Shutterstock.com
3. CK-12 Foundation. . CC-BY-NC-SA 3.0
4. CK-12 Foundation. . CC-BY-NC-SA 3.0

CHAPTER 2 First Organic Molecules

- Outline how the first organic molecules arose.

How do you make large molecules?

From smaller ones. The first organic molecules were probably very simple carbon-based molecules made of few atoms. These molecules then combined with other simple molecules to form more complex molecules. Over many years and probably trillions and trillions of chemical reactions, more complex molecules, and more stable molecules, formed.

The First Organic Molecules

All living things consist of **organic molecules**, centered around the element carbon. Therefore, it is likely that organic molecules evolved before cells, perhaps as long as 4 billion years ago. How did these building blocks of life first form? Scientists think that lightning sparked chemical reactions in Earth's early atmosphere. The early atmosphere contained gases such as ammonia, methane, water vapor, and carbon dioxide. Scientists hypothesize that this created a "soup" of organic molecules from inorganic chemicals. In 1953, scientists Stanley Miller and Harold Urey used their imaginations to test this hypothesis. They created a simulation experiment to see if organic molecules could arise in this way (see **Figure** 2.1). They used a mixture of gases to represent Earth's early atmosphere. Then, they passed sparks through the gases to represent lightning. Within a week, several simple organic molecules had formed. You can watch a dramatization of Miller and Urey's experiment at this link: http://www.youtube.com/watch?v=j9ZRHoawyOg.

Which Organic Molecule Came First?

Living things need organic molecules to store genetic information and to carry out the chemical work of cells. Modern organisms use DNA to store genetic information and proteins to catalyze chemical reactions. So, did DNA

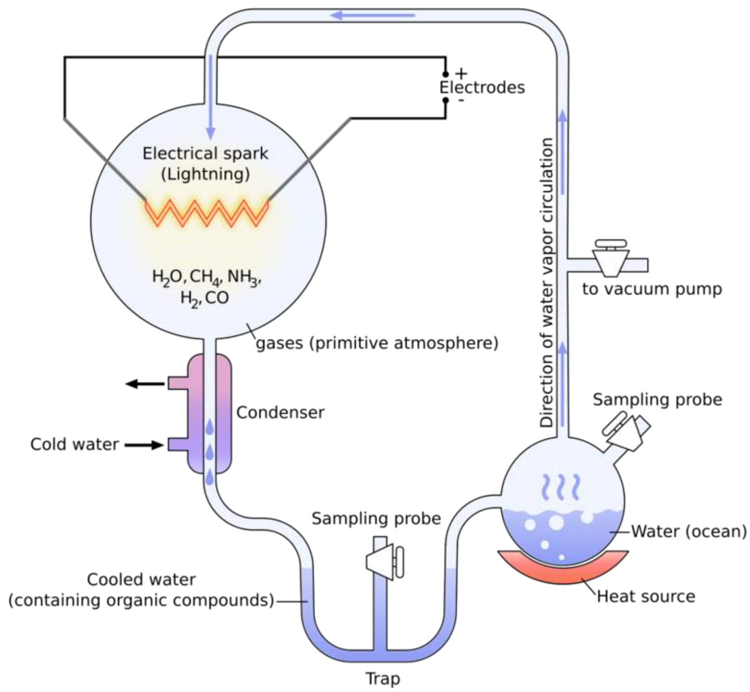


FIGURE 2.1

Miller and Urey's Experiment. Miller and Urey demonstrated that organic molecules could form under simulated conditions of early Earth. What assumptions were their simulation based upon?

or proteins evolve first? This is like asking whether the chicken or the egg came first. DNA encodes proteins and proteins are needed to make DNA, so each type of organic molecule needs the other for its own existence. How could either of these two molecules have evolved before the other? Did some other organic molecule evolve first, instead of DNA or proteins?

RNA World Hypothesis

Some scientists speculate that RNA may have been the first organic molecule to evolve. In fact, they think that early life was based solely on RNA and that DNA and proteins evolved later. This is called the **RNA world hypothesis.** Why RNA? It can encode genetic instructions (like DNA), and some RNAs can carry out chemical reactions (like proteins). Therefore, it solves the chicken-and-egg problem of which of these two molecules came first. Other evidence also suggests that RNA may be the most ancient of the organic molecules. You can learn more about the RNA world hypothesis and the evidence for it at this link: http://www.youtube.com/watch?v=sAkgb3yNgqg.

Summary

- The first organic molecules formed about 4 billion years ago.
- This may have happened when lightning sparked chemical reactions in Earth's early atmosphere.
- RNA may have been the first organic molecule to form as well as the basis of early life.

Practice

Use the time slider in this resource to answer the questions that follow.

- **Evolution** at http://johnkyrk.com/evolution.swf.

1. When did the element carbon form?
2. When did the first chemicals appear in Earth's atmosphere and on its surface?
3. List 5 of these early chemicals.
4. When did the first organic molecules appear?
5. What were these first organic molecules?

Review

1. Describe Miller and Urey's experiment. What did it demonstrate?

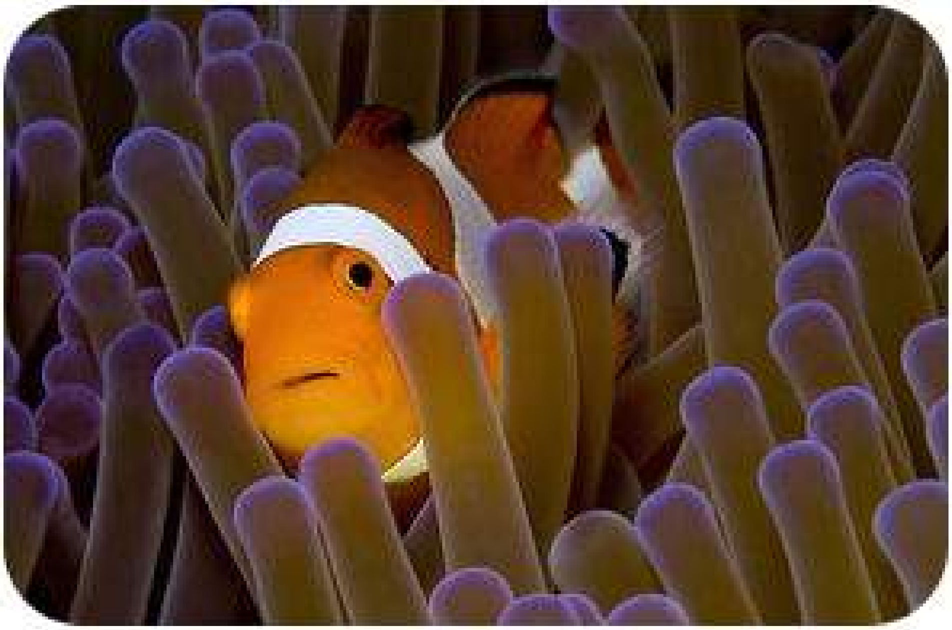
2. State the RNA world hypothesis.

References

1. YassineMrabet. . CC-BY-SA 3.0

CHAPTER 3 Evolution of Eukaryotes

- Explain how eukaryotes are thought to have evolved.



Why can this fish live in these tentacles, but other fish cannot?

Anemones and Clown Fish have a well-known symbiotic relationship. In the ocean, the Clown Fish are protected from predator fish by the stinging tentacles of the anemone, and the anemone receives protection from polyp-eating fish, which the Clown Fish chases away. But what about symbiotic relationships at a much smaller scale? Is it possible for two single-celled organisms to have a symbiotic relationship? As you will find out, yes it is!

Evolution of Eukaryotes

Our own eukaryotic cells protect DNA in chromosomes with a nuclear membrane, make ATP with mitochondria, move with flagella (in the case of sperm cells), and feed on cells which make our food with chloroplasts. All multicellular organisms and the unicellular Protists share this cellular intricacy. Bacterial (prokaryotic) cells are orders of magnitude smaller and have none of this complexity. What quantum leap in evolution created this vast chasm of difference?

The first **eukaryotic cells** - cells with a **nucleus** an internal membrane-bound **organelles** - probably evolved about 2 billion years ago. This is explained by the **endosymbiotic theory**. As shown in the **Figure** 3.1, **endosymbiosis** came about when large cells engulfed small cells. The small cells were not digested by the large cells. Instead, they lived within the large cells and evolved into organelles.

The large and small cells formed a **symbiotic relationship** in which both cells benefited. Some of the small cells were able to break down the large cell's wastes for energy. They supplied energy not only to themselves but also to the large cell. They became the mitochondria of eukaryotic cells. Other small cells were able to use sunlight to make food. They shared the food with the large cell. They became the chloroplasts of eukaryotic cells.

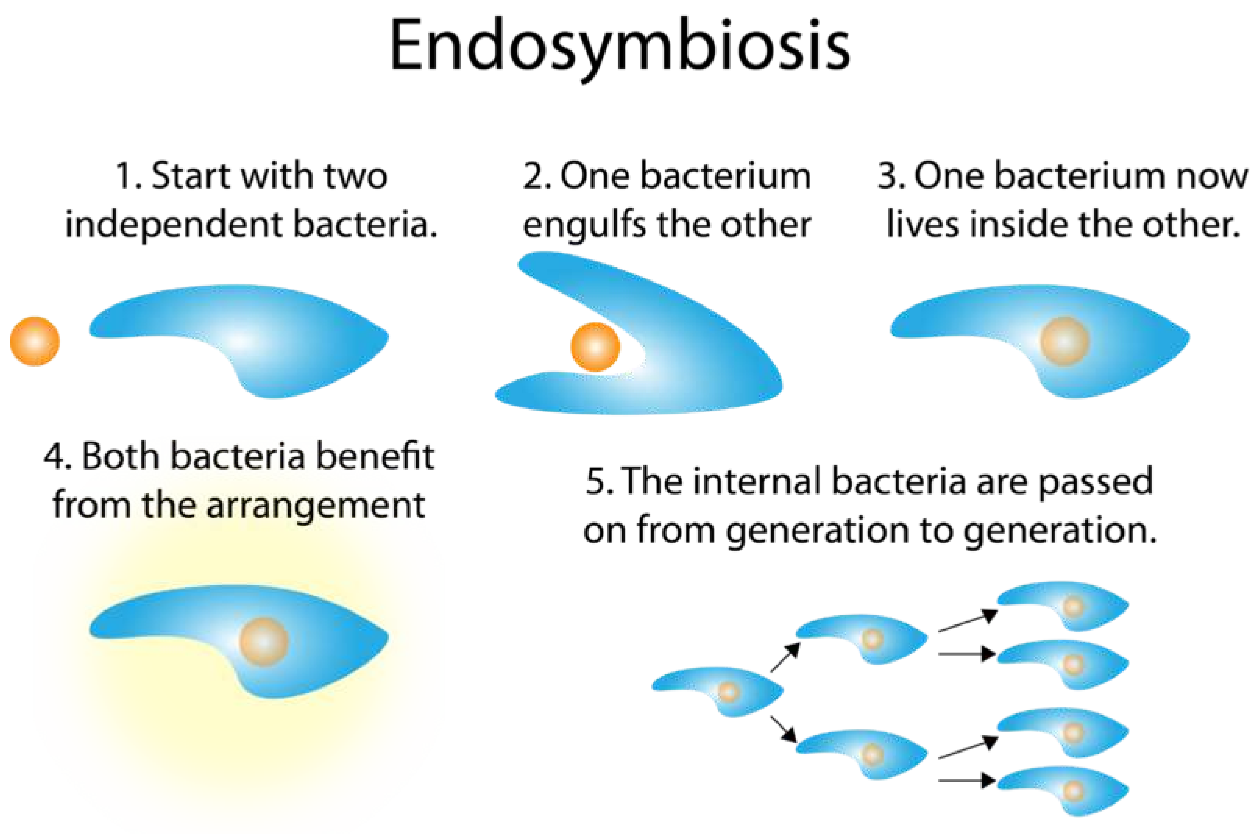


FIGURE 3.1
From Independent Cell to Organelle. The endosymbiotic theory explains how eukaryotic cells evolved.

Mitochondria and Chloroplasts

What is the evidence for this evolutionary pathway? Biochemistry and electron microscopy provide convincing support. The mitochondria and chloroplasts within our eukaryotic cells share the following features with prokaryotic cells:

- Their organelle DNA is short and circular, and the DNA sequences do not match DNA sequences found in the nucleus.
- Molecules that make up organelle membranes resemble those in prokaryotic membranes – and differ from those in eukaryotic membranes.
- Ribosomes in these organelles are similar to those of bacterial ribosomes, and different from eukaryotic ribosomes.
- Reproduction is by binary fission, not by mitosis.
- Biochemical pathways and structures show closer relationships to prokaryotes.
- Two or more membranes surround these organelles.

The "host" cell membrane and biochemistry are more similar to those of Archaebacteria, so scientists believe eukaryotes descended more directly from that major group (**Figure** 3.2). The timing of this dramatic evolutionary event (more likely a series of events) is not clear. The oldest fossil clearly related to modern eukaryotes is a red alga dating back to 1.2 billion years ago. However, many scientists place the appearance of eukaryotic cells at about 2 billion years. Some time within Proterozoic Eon, then, all three major groups of life – Bacteria, Archaea, and Eukaryotes – became well established.

What Does it all Mean?

Eukaryotic cells, made possible by endosymbiosis, were powerful and efficient. That power and efficiency gave them the potential to evolve new characteristics: multicellularity, cell specialization, and large size. They were the key to the spectacular diversity of animals, plants, and fungi that populate our world today. Nevertheless, as we close the history of early life, reflect once more on the remarkable but often unsung patterns and processes of early evolution. Often, as humans, we focus our attention on plants and animals, and ignore bacteria. Our human senses cannot directly perceive the unimaginable variety of single cells, the architecture of organic molecules, or the intricacy of biochemical pathways. Let your study of early evolution give you a new perspective – a window into the beauty and diversity of unseen worlds, now and throughout Earth's history. In addition to the mitochondria that call your 100 trillion cells home, your body contains more bacterial cells than human cells. You, mitochondria, and your resident bacteria share common ancestry – a continuous history of the gift of life.

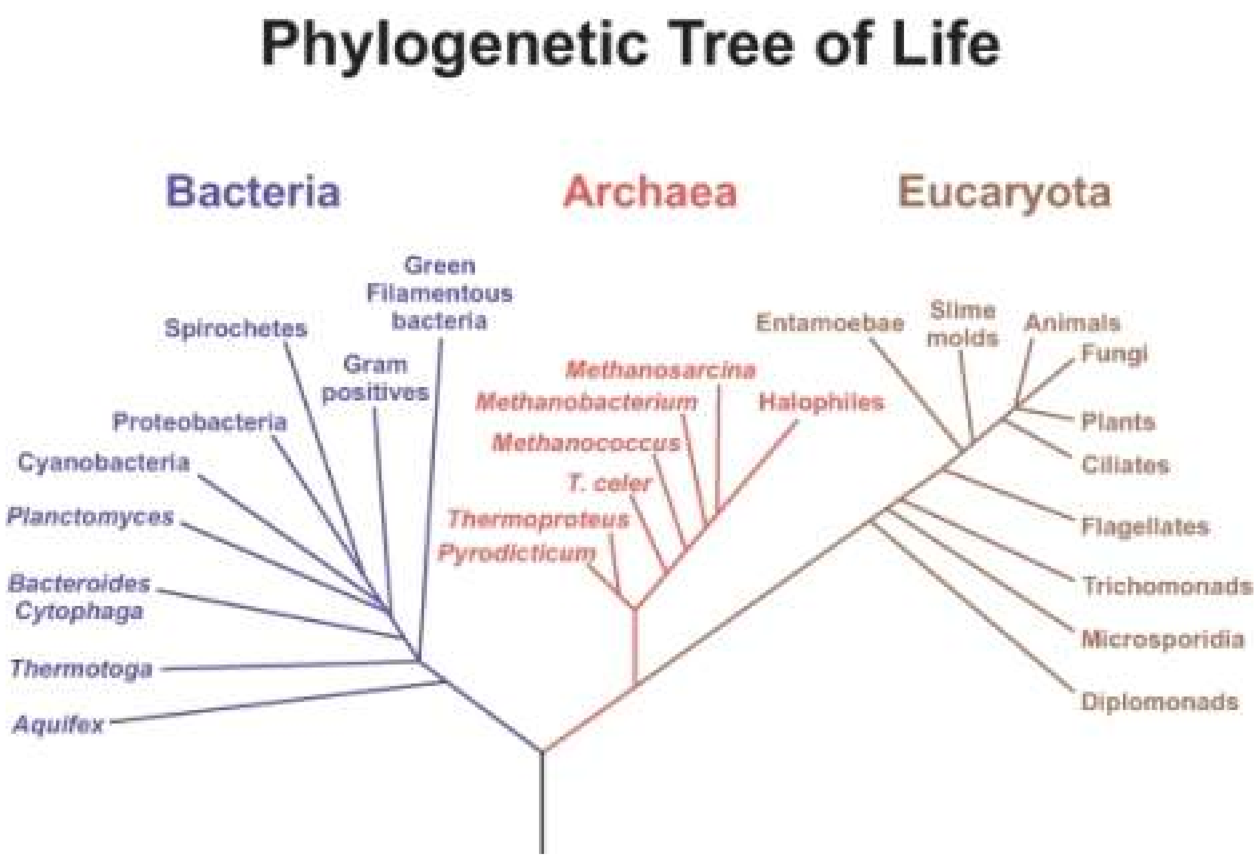


FIGURE 3.2

The three major domains of life had evolved by 1.5 billion years ago. Biochemical similarities show that eukaryotes share more recent common ancestors with the Archaea, but our organelles probably descended from bacteria by endosymbiosis.

Summary

- Eukaryotic cells probably evolved about 2 billion years ago. Their evolution is explained by endosymbiotic theory.
- Mitochondria and chloroplasts evolved from prokaryotic organisms.
- Eukaryotic cells would go on to evolve into the diversity of eukaryotes we know today.

Practice

Use the time slider in this resource to answer the questions that follow.

- **Evolution** at http://johnkyrk.com/evolution.swf.

1. When did cells begin to "swallow" other cells?
2. When did respiration develop?
3. The rapid rise in atmospheric oxygen favored which cells?
4. When did eukaryotic cells first form? What distinguished these cells from their predecessors?

Review

1. Describe the endosymbiotic theory.

2. Discuss the evidence for the evolution of mitochondria and chloroplasts.

References

1. CK-12 Foundation. . CC-BY-NC-SA 3.0
2. Eric Gaba. . Public Domain

CHAPTER 4 Evolution of Life

- Explain how life on Earth evolves.

Are dinosaurs evidence of past life forms?

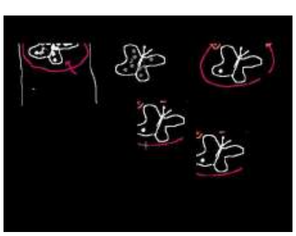
Evolution can be described as *a change in species over time*. Dinosaur fossils are significant evidence of evolution and of past life on Earth.

Evolution of Life

The diversity of life on Earth today is the result of evolution. Life began on Earth at least 3.5 to 4 billion years ago, and it has been evolving ever since. At first, all living things on Earth were simple, single-celled organisms. Much later, the first multicellular organisms evolved, and after that, Earth's biodiversity greatly increased. **Figure** 4.1 shows a timeline of the history of life on Earth. You can also find an interactive timeline of the history of life at the link below. http://www.johnkyrk.com/evolution.html

Today, scientists accept the evolution of life on Earth as a fact. There is too much evidence supporting evolution to doubt it. However, that wasn't always the case.

An introduction to evolution and natural selection can be viewed at http://www.youtube.com/watch?v=GcjgWov7mTM.



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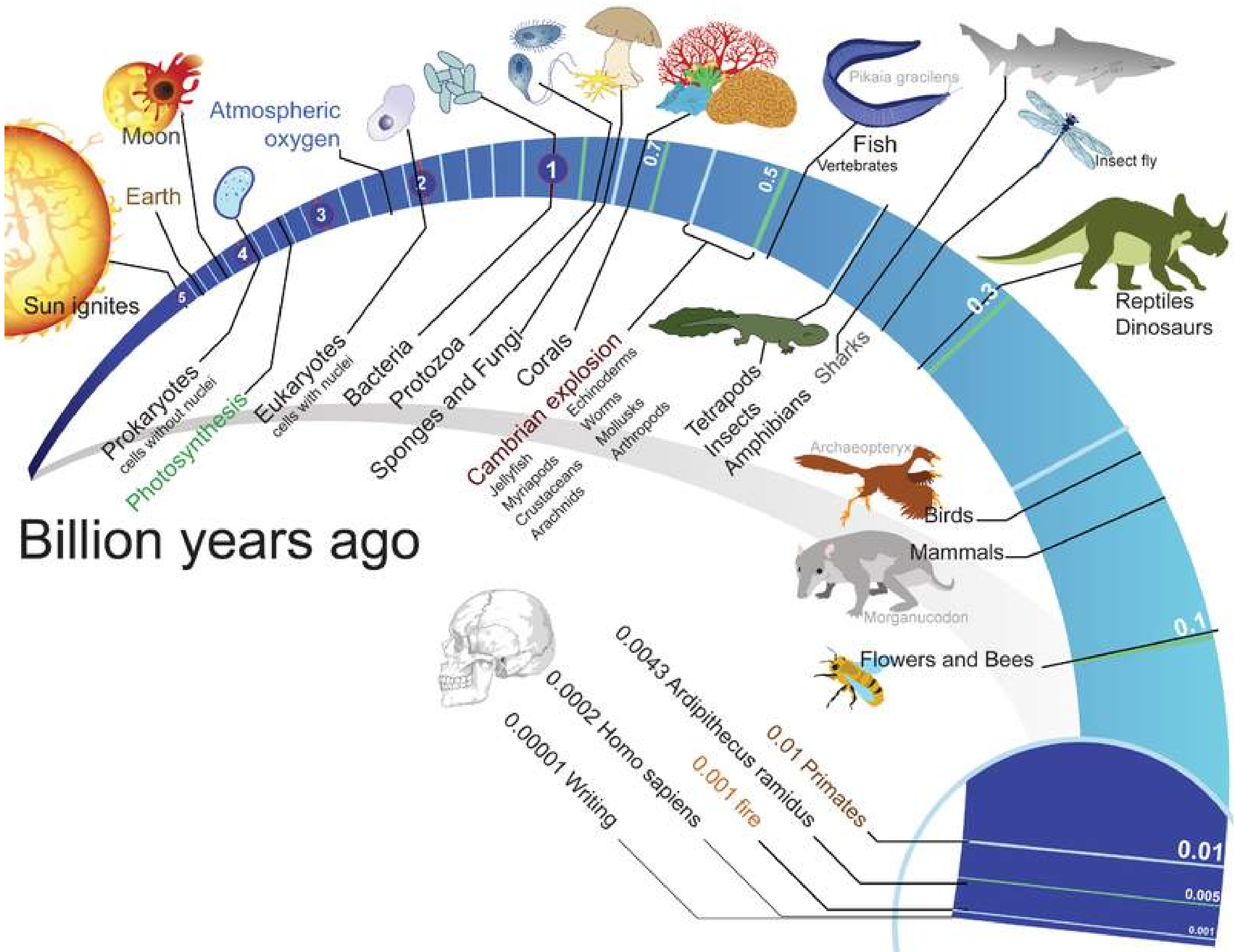

FIGURE 4.1

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

As you view *Introduction to Evolution and Natural Selection,* focus on these concepts:

1. the relationship between evolution and natural selection,
2. the relationship between natural selection and variation,
3. the evolution of the peppered moth.

Darwin and the Theory of Evolution

The idea of evolution has been around for centuries. In fact, it goes all the way back to the ancient Greek philosopher Aristotle. However, evolution is most often associated with Charles Darwin. Darwin published a book on evolution in 1859 titled *On the Origin of Species*. In the book, Darwin stated the theory of evolution by natural selection. He also presented a great deal of evidence that evolution occurs.

Evolution is a change in the characteristics of living things over time. As described by Darwin, evolution occurs by a process called **natural selection**. In natural selection, some members of a species produce more offspring than others, so they pass "advantageous traits" to their offspring. Over many generations, this can lead to major changes in the characteristics of the species. Evolution explains how living things are changing today and how modern living things have descended from ancient life forms that no longer exist on Earth. As living things evolve, they generally become better suited for their environment. This is because they evolve adaptations. An **adaptation** is a trait that helps an organism survive and reproduce in a given environment. Despite all the evidence Darwin presented, his theory was not well-received at first. Many people found it hard to accept the idea that humans had evolved from an ape-like ancestor, and they saw evolution as a challenge to their religious beliefs. Look at the cartoon in **Figure** 4.2. Drawn in 1871, it depicts Darwin himself as an ape. The cartoon reflects how many people felt about Darwin and his theory during his own time. Darwin had actually expected this type of reaction to his theory and had waited a long time before publishing his book for this reason. It was only when another scientist, named Alfred Wallace, developed essentially the same theory of evolution that Darwin put his book into print.

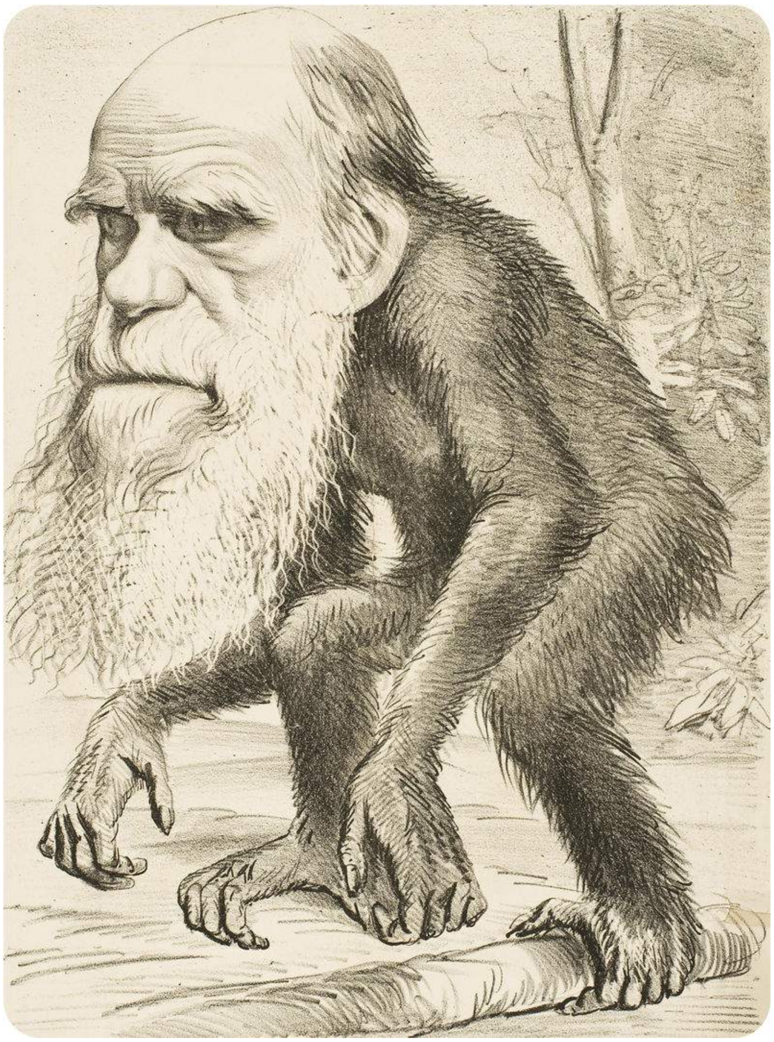

FIGURE 4.2

Charles Darwin's name is linked with the theory of evolution. This cartoon from the 1870s makes fun of both Darwin and his theory.

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

Evolutionary Theory After Darwin

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

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

Misconceptions About Evolution

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

Summary

- Life began on Earth at least 3.5 to 4 billion years ago, and it has been evolving ever since.
- Darwin stated the theory of evolution by natural selection, presenting a great deal of evidence to support his theory.
- Evolution is a change in the characteristics of living things over time. Evolution occurs by natural selection.
- Characteristics of organisms are passed from one generation to the next through their genes.

Making Connections

MEDIA

Click image to the left for more content.

Practice

Use this resource to answer the questions that follow.

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

1. Who was Charles Darwin?
2. What did Darwin conclude about homologous structures?
3. Why are some traits more likely to be passed to the next generation?
4. What is the outcome of natural selection?

Review

1. What is evolution?
2. What is natural selection?
3. Explain the theory of evolution.

References

1. Mariana Ruiz Villarreal [Wikimedia: LadyofHats]. . Public Domain
2. . . Public Domain

CHAPTER 5 Natural Selection

- Explain how natural selection works.

How is this deer mouse well adapted for life in the forest?

Notice how its dark coloring would allow the deer mouse to easily hide from predators on the darkened forest floor. On the other hand, deer mice that live in the nearby Sand Hills are a lighter, sand-like color. What caused the deer mice to be so well adapted to their unique environments? Natural selection.

Natural Selection

The theory of evolution by natural selection means that the inherited traits of a population change over time. **Inherited traits** are features that are passed from one generation to the next. For example, your eye color is an inherited trait. You inherited your eye color from your parents. Inherited traits are different from **acquired traits**, or traits that organisms develop over a lifetime, such as strong muscles from working out (**Figure** 5.1).

Natural selection explains how organisms in a population develop traits that allow them to survive and reproduce. Natural selection means that traits that offer an advantage will most likely be passed on to offspring. Evolution occurs by natural selection. Take the giant tortoises on the Galápagos Islands as an example. If a short-necked tortoise lives on an island with fruit located at a high level, will the short-necked tortoise survive? No, it will not, because it will not be able to reach the food it needs to survive. If all of the short necked tortoises die, and the long-necked tortoises survive, then, over time, only the long-necked trait will be passed down to offspring. All of the tortoises with long-necks will be "naturally selected" to survive.

Every plant and animal depends on its traits to survive. Survival may include getting food, building homes, and attracting mates. Traits that allow a plant, animal, or other organism to survive and reproduce in its environment are called **adaptations**.

Natural selection occurs when:

1. There is some variation in the inherited traits of organisms within a species.

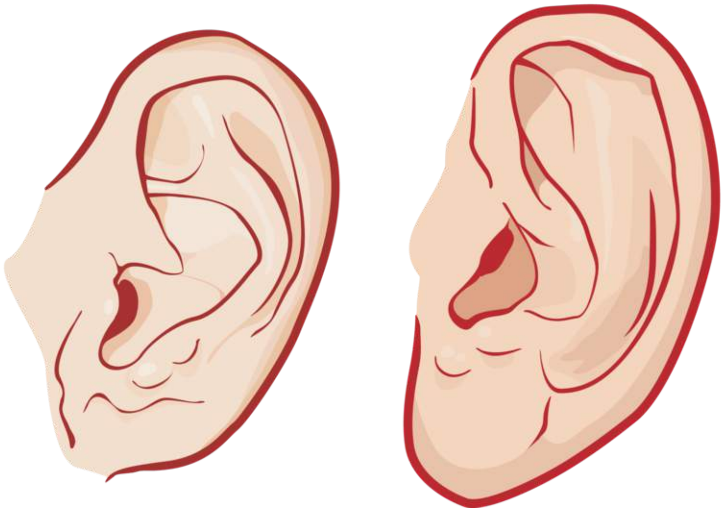

FIGURE 5.1
Human earlobes may be attached or free. You inherited the particular shape of your earlobes from your parents. Inherited traits are influenced by genes, which are passed on to offspring and future generations. Things not influenced by genes are not passed on to your offspring. Natural selection only operates on traits like earlobe shape that have a genetic basis, not on traits that are acquired, like a summer tan.

2. Some of these traits will give individuals an advantage over others in surviving and reproducing.
3. These individuals will be likely to have more offspring.

Imagine how in the Arctic, dark fur makes a rabbit easy for foxes to spot and catch in the snow. Therefore, white fur is a beneficial trait that improves the chance that a rabbit will survive, reproduce, and pass the trait of white fur on to its offspring (**Figure** 5.2). Through this process of natural selection, dark fur rabbits will become uncommon over time. Rabbits will adapt to have white fur.

FIGURE 5.2
The white fur of the Artic hares may make it more difficult for fox and other predators to locate hares against the white snow.

Why So Many Species?

Scientists estimate that there are between 5 million and 30 million species on the planet. But why are there so many? As environments change over time, organisms must constantly adapt to those environments. Diversity of species increases the chance that at least some organisms adapt and survive any major changes in the environment. For example, if a natural disaster kills all of the large organisms on the planet, then the small organisms will continue to survive.

Vocabulary

- **acquired trait**: Trait that organisms develops over a lifetime.
- **adaptation**: Trait that enhances an organism's ability to survive and reproduce in its environment.
- **inherited trait**: Feature passed from one generation to the next.
- **natural selection**: Process by which organisms with traits that better enable them to adapt to their environment will tend to survive and reproduce in greater numbers, allowing these favorable traits to be passed on to the next generations.

Summary

- Evolution occurs by natural selection, the process by which organisms with traits that better enable them to adapt to their environment will tend to survive and reproduce in greater numbers.
- Natural selection occurs when there is some variation in the inherited traits, some of these traits will give individuals an advantage over others, and the individuals with certain traits will be more likely to have more offspring.

Practice

Use the resource below to answer the questions that follow.

- **Sources of Variation** at http://learn.genetics.utah.edu/content/variation/sources/

1. Are all members of your family exactly alike? Are all members of a species exactly alike?
2. What is an important base of variation in species? Are all forms of a gene the same?
3. What are common mutations in DNA? How common are these mutations?
4. Do most mutations that are passed on to future generations come from the environment? What is the relationship between mutations and the environment?
5. How does recombination in sexually reproducing organisms ensure that every generation will have mutations or changes in the inherited DNA?
6. At what frequency (not at all, low, medium, or high) does recombination of DNA occur in asexually reproducing populations?

Review

1. What's the difference between an acquired and inherited trait?
2. What is required for natural selection to take place?

References

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2. Courtesy of the U.S. Fish and Wildlife Service. . Public Domain

CHAPTER 6 Living Species

- Explain how evidence from living species gives clues about evolution.

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** 6.1 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.

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** 6.2, look similar on the outside. They also have the same function. However, wings evolved independently in the two groups of animals. This is apparent when you compare the pattern of bones inside the wings.

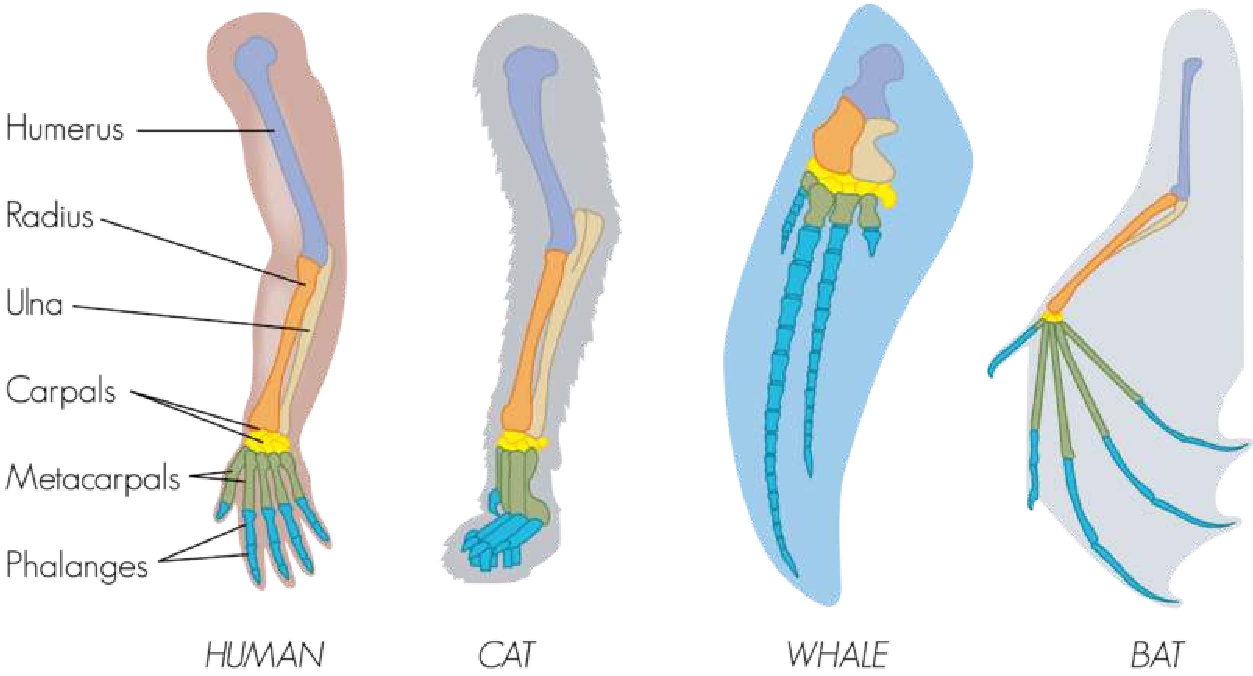

FIGURE 6.1

The forelimbs of all mammals have the same basic bone structure.

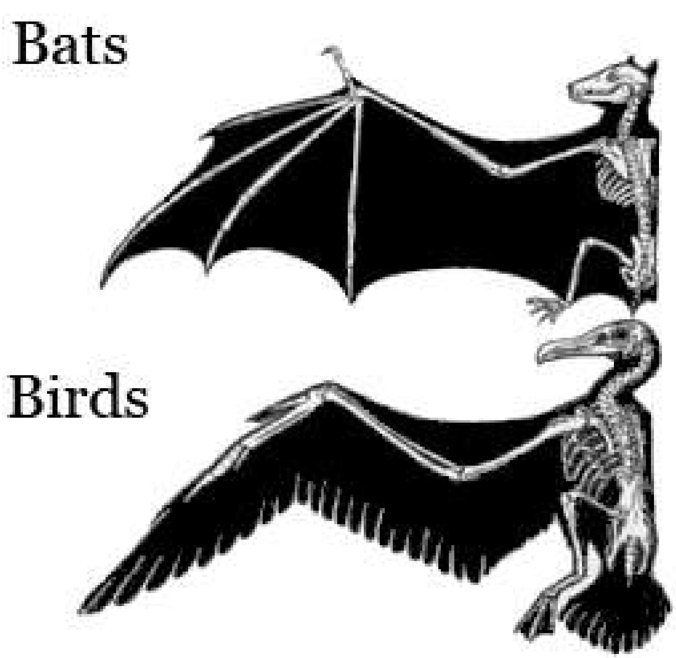

FIGURE 6.2

Wings of bats and birds serve the same function. Look closely at the bones inside the wings. The differences show they developed from different ancestors.

Comparative Embryology

Comparative embryology is the study of the similarities and differences in the embryos of different species. Similarities in embryos are evidence of common ancestry. All vertebrate embryos, for example, have gill slits and tails. All of the animals in the figure, except for fish, lose their gill slits by adulthood. Some of them also lose their tail. In humans, the tail is reduced to the tail bone. Thus, similarities organisms share as embryos may be gone by adulthood. This is why it is valuable to compare organisms in the embryonic stage. See http://www.pbs.org/wgbh/evolution/library/04/2/pdf/l_042_03.pdf for additional information and a comparative diagram of human, monkey, pig, chicken and salamander embryos.

Vestigial Structures

Structures like the human tail bone are called **vestigial structures**. Evolution has reduced their size because the structures are no longer used. The human appendix is another example of a vestigial structure. It is a tiny remnant of a once-larger organ. In a distant ancestor, it was needed to digest food. It serves no purpose in humans today. Why do you think structures that are no longer used shrink in size? Why might a full-sized, unused structure reduce an organism's fitness?

Comparing DNA

Darwin could compare only the anatomy and embryos of living things. Today, scientists can compare their DNA. Similar DNA sequences are the strongest evidence for evolution from a common ancestor. Look at the cladogram in the **Figure** 6.3. It shows how humans and apes are related based on their DNA sequences.

Evolution and molecules are discussed at http://www.youtube.com/watch?v=nvJFI3ChOUU (3:52).

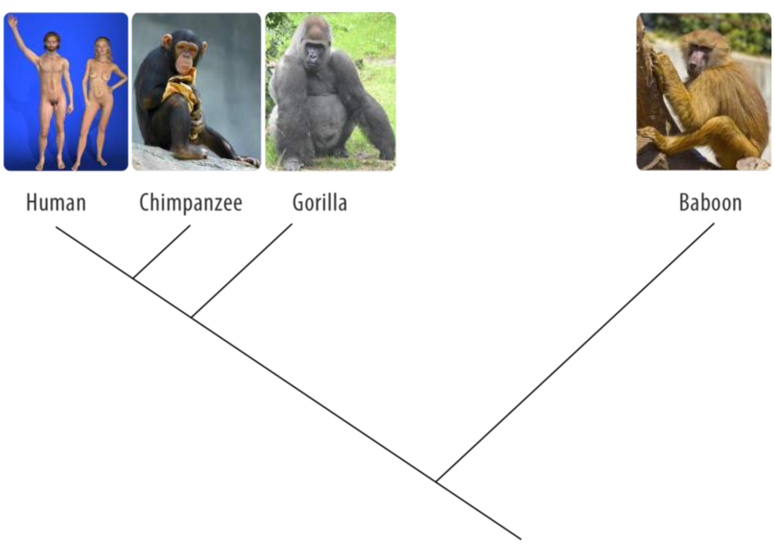

FIGURE 6.3
Cladogram of Humans and Apes. This cladogram is based on DNA comparisons. It shows how humans are related to apes by descent from common ancestors.

Using various types of information to understand evolutionary relationships is discussed in the following videos: http://www.youtube.com/watch?v=aZc1t2Os6UU (3:38), http://www.youtube.com/watch?v=6IRz85QNjz0 (6:45), http://www.youtube.com/watch?v=JgyTVT3dqGY&feature=related (10:51).

KQED: The Reverse Evolution Machine

In search of the common ancestor of all mammals, University of California Santa Cruz scientist David Haussler is pulling a complete reversal. Instead of studying fossils, he's comparing the genomes of living mammals to construct a map of our common ancestors' DNA. His technique holds promise for providing a better picture of how life evolved. See http://www.kqed.org/quest/television/the-reverse-evolution-machine for more information.

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.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **The Evidence for Evolution**

1. What is a vestigial structure? Provide an example.
2. Name a fundamental cell process conserved from yeast to humans.

Review

1. What are vestigial structures? Give an example.

2. Compare and contrast homologous and analogous structures. What do they reveal about evolution?

3. Why does comparative embryology show similarities between organisms that do not appear to be similar as adults?

4. Humans and apes have five fingers they can use to grasp objects. Do you think these are analogous or homologous structures? Explain.

References

1. CK-12 Foundation. . CC-BY-NC-SA 3.0
2. John Romanes, modified by CK-12 Foundation. . Public Domain
3. Left to right: Ernst Wilhelm Zwergelstern; Aaron Logan; Mark Pellegrini; Image copyright Fernando Cortes, 2010. . Left to right: GNU-FDL; CC-BY-2.5; GNU-FDL; Used under license from Shutterstock.com

CHAPTER 7 Origin of Species

- Describe two ways in which a new species can develop.

Where did this diversity of life come from?

If you have ever been to the beach, then you realize there is not just one species of marine life. The wide variety of shells that wash up on the beach indicate that there are many forms of life in the ocean. This wide diversity of life requires that many new species have appeared over time. But how does a new species come into being?

The Origin of Species

The creation of a new species is called **speciation**. Most new species develop naturally. But humans have also artificially created new breeds and species for thousands of years.

New species develop naturally through the process of **natural selection**. Due to natural selection, organisms with traits that better enable them to adapt to their environment will tend to survive and reproduce in greater numbers. Natural selection causes beneficial heritable traits to become more common in a population and unfavorable heritable traits to become less common. For example, a giraffe's neck is beneficial because it allows the giraffe to reach leaves high in trees. Natural selection caused this beneficial trait to become more common than short necks.

As new changes in the DNA sequence are constantly being generated in a population's gene pool, some of these changes will be beneficial and result in traits that allow adaptation and survival. Natural selection causes evolution of a species as these beneficial traits become more common within a population.

Artificial Selection

Artificial selection occurs when humans select which plants or animals to breed in order to pass on specific traits to the next generation. For example, a farmer may choose to breed only cows that produce the best milk. Farmers would also avoid breeding cows that produce less milk. In this way, selective breeding of the cows would increase milk quality and quantity.

Humans have also artificially bred dogs to create new breeds (**Figure** 7.1).

FIGURE 7.1
Artificial Selection: Humans used artificial selection to create these different breeds. Both dog breeds are descended from the same wolves, and their genes are almost identical.

Reproductive Isolation

There are two main ways that speciation happens naturally. Both processes create new species by reproductively isolating populations of the same species from each other. Organisms can be geographically isolated or isolated by a behavior. Either way, they will no longer be able to mate. Over a long period of time, usually thousands of years, each of the isolated populations evolves in a different direction, forming distinct species.

How do you think scientists test whether two populations are separate species? They bring species from two populations back together again. If the two populations do not mate and produce fertile offspring, they are separate species.

Geographic Isolation

Allopatric speciation occurs when groups from the same species are geographically isolated for long periods. Imagine all the ways that plants or animals could be isolated from each other:

- Emergence of a mountain range.
- Formation of a canyon.
- New rivers or streams.

Here are two examples of allopatric speciation:

- Darwin observed thirteen distinct finch species on the Galápagos Islands that had evolved from the same ancestor. Different finch populations lived on separate islands with different environments. They evolved to best adapt to those particular environments. Later, scientists were able to determine which finches had evolved into distinct species by bringing members of each population together. The birds that could not mate were a separate species.

- When the Grand Canyon in Arizona formed, two populations of one squirrel species were separated by the giant canyon. After thousands of years of isolation from each other, the squirrel populations on the northern wall of the canyon looked and behaved differently from those on the southern wall (**Figure** 7.2). North rim squirrels have white tails and black bellies. Squirrels on the south rim have white bellies and dark tails. They cannot mate with each other, so they are different species.

FIGURE 7.2

Abert squirrel (*left*) on the southern rim of the Grand Canyon. Kaibab squirrel (*right*) found on northern rim of the Grand Canyon.

Isolation without Physical Separation

Sympatric speciation occurs when groups from the same species stop mating because of something other than physical or geographic separation. The behavior of two groups that live in the same region is an example of such separation. The separation may be caused by different mating seasons, for example. Sympatric speciation is more difficult to identify.

Here are two examples of sympatric speciation:

- Some scientists suspect that two groups of orcas (killer whales) live in the same part of the Pacific Ocean part of the year but do not mate. The two groups hunt different prey species, eat different foods, sing different songs, and have different social interactions (**Figure** 7.3).

- Two groups of Galápagos Island finch species lived in the same space, but each had his or her own distinct mating signals. Members of each group selected mates according to different beak structures and bird calls. The behavioral differences kept the groups separated until they formed different species.

FIGURE 7.3
Scientists suspect that two types of orca whales live in the same part of the Pacific Ocean for part of the year, but they do not mate.

Vocabulary

- **allopatric speciation**: New species is formed when groups from the same species are geographically isolated for long periods of time.
- **artificial selection**: Selective breeding of plants or animals by humans to pass specific traits on to the next generation.
- **natural selection**: Process by which organisms with traits that better enable them to adapt to their environment will tend to survive and reproduce in greater numbers, causing beneficial heritable traits to become more common in a population.
- **speciation**: Creation of a new species.
- **sympatric speciation**: New species is formed when groups from the same species stop mating because of something other than physical separation.

Summary

- Speciation, the creation of a new species, can happen through natural selection or artificial selection.
- Reproductive isolation is necessary for speciation to occur, and this can happen through a geographic barrier (allopatric speciation) or without a geographic barrier (sympatric speciation).
- Different behaviors can result in sympatric speciation.

Practice

Use the resource below to answer the questions that follow.

- **Allopatric Speciation** at http://www.pbs.org/wgbh/evolution/library/05/2/l_052_03.html.

1. What is allopatric speciation?
2. How did scientists determine if the shrimp were two different species?

- **Diatoms The Evolution of a New Species - Richard Dawkins Foundation** at http://wrl.it/show/197403/12898467 (2:10)

1. What is a diatom?
2. Where is *Stephanodiscus yellowstonensis* found?
3. What technique did scientists use to determine what diatoms occurred historically in the lake where *Stephanodiscus yellowstonensis* now occurs?
4. What were the environmental conditions when *Stephanodiscus niagarae* lived in the lake?
5. What has happened to the diatoms in the lake as the climate has changed over the last 14,000 years?
6. Do you think the changes seen in the diatoms demonstrates it has become a new species? Why or why not? Be specific in your reasoning.

Review

1. Compare and contrast natural selection and artificial selection.
2. Compare and contrast allopatric speciation and sympatric speciation.

References

1. Image copyright Erik Lam, 2012. . Used under license from Shutterstock.com
2. Abert squirrel: Courtesy of Sally King and the National Park Service; Kaibab squirrel: Stavenn (Wikimedia). . Abert squirrel: Public Domain; Kaibab squirrel: CC-BY 2.5
3. Image copyright Ferderic B, 2010. . Used under license from Shutterstock.com

CHAPTER 8 Forces of Evolution

- Describe two ways that new species may originate.

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.

Forces of Evolution

The conditions for Hardy-Weinberg equilibrium are unlikely to be met in real populations. The Hardy-Weinberg theorem also describes populations in which allele frequencies are not changing. By definition, such populations are not evolving. How does the theorem help us understand evolution in the real world?

From the theorem, we can infer factors that cause allele frequencies to change. These factors are the "forces of evolution." There are four such forces: mutation, gene flow, genetic drift, and natural selection. Natural selection will be discussed in the "Evolution II: Natural Selection" concept.

Mutation

Mutation creates new genetic variation in a gene pool. It is how all new alleles first arise. In sexually reproducing species, the mutations that matter for evolution are those that occur in gametes. Only these mutations can be passed to offspring. For any given gene, the chance of a mutation occurring in a given gamete is very low. Thus, mutations alone do not have much effect on allele frequencies. However, mutations provide the genetic variation needed for other forces of evolution to act.

Gene Flow

Gene flow occurs when individuals move into or out of a population. If the rate of migration is high, this can have a significant effect on allele frequencies. The allele frequencies of both the population they leave and the population they enter may change.

During the Vietnam War in the 1960s and 1970s, many American servicemen had children with Vietnamese women. Most of the servicemen returned to the United States after the war. However, they left copies of their genes behind in their offspring. In this way, they changed the allele frequencies in the Vietnamese gene pool. Was the gene pool of the American population also affected? Why or why not?

Genetic Drift

Genetic drift is a random change in allele frequencies that occurs in a small population. When a small number of parents produce just a few offspring, allele frequencies in the offspring may differ, by chance, from allele frequencies in the parents. This is like tossing a coin. If you toss a coin just a few times, you may, by chance, get more or less than the expected 50 percent heads or tails. In a small population, you may also, by chance, get different allele frequencies than expected in the next generation. In this way, allele frequencies may drift over time. There are two special conditions under which genetic drift occurs. They are called bottleneck effect and founder effect.

1. **Bottleneck effect** occurs when a population suddenly gets much smaller. This might happen because of a natural disaster such as a forest fire. By chance, allele frequencies of the survivors may be different from those of the original population.
2. **Founder effect** occurs when a few individuals start, or found, a new population. By chance, allele frequencies of the founders may be different from allele frequencies of the population they left. An example is described in the **Figure** 8.1.

Summary

- There are four forces of evolution: mutation, gene flow, genetic drift, and natural selection.
- Mutation creates new genetic variation in a gene pool.
- Gene flow and genetic drift alter allele frequencies in a gene pool.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **The Process of Genetic Change**

1. What drives evolution?
2. Describe genetic drift.

FIGURE 8.1

Founder Effect in the Amish Population. The Amish population in the U.S. and Canada had a small number of founders. How has this affected the Amish gene pool?

3. Distinguish between the bottleneck effect and the founder effect.
4. What is gene flow?
5. What is meant by nonrandom mating?
6. Why may inbreeding be dangerous?
7. Describe sexual selection.
8. Describe natural selection.

Review

1. Identify the four forces of evolution.
2. Why is mutation needed for evolution to occur, even though it usually has little effect on allele frequencies?
3. What is founder effect? Give an example.
4. Explain why genetic drift is most likely to occur in a small population.

References

1. Horse and buggy image copyright Nancy Hixson, 2010; hands image G Baujat and M Le Merrer; composite created by CK-12 Foundation. . Horse and buggy image used under license from Shutterstock.com; hands image CC-BY 2.0

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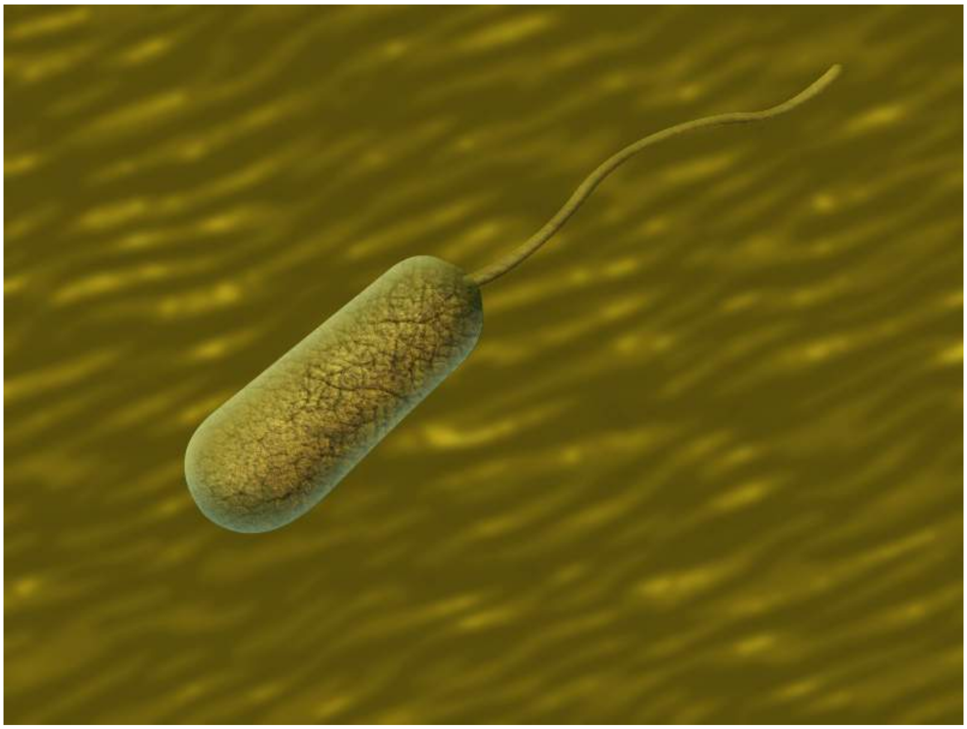
CONCEPT 1 Prokaryote Evolution

- Outline the evolution of prokaryotes.



What are the most numerous organisms on the planet?

Bacteria. And all it takes is one to quickly grow, under just the right conditions, into millions and billions. Luckily, we know how to control bacteria when necessary. But bacteria do serve many important purposes. In fact, we could not survive without them.

Evolution of Prokaryotes

No doubt you've had a sore throat before, and you've probably eaten cheese or yogurt. If so, then you've encountered the fascinating world of prokaryotes. **Prokaryotes** are single-celled organisms that lack a nucleus. They also lack other membrane-bound organelles. Prokaryotes are tiny and sometimes bothersome, but they are the most numerous organisms on Earth. Without them, the world would be a very different place.

An overview of bacteria can be seen at http://www.youtube.com/watch?v=TDoGrbpJJ14 .

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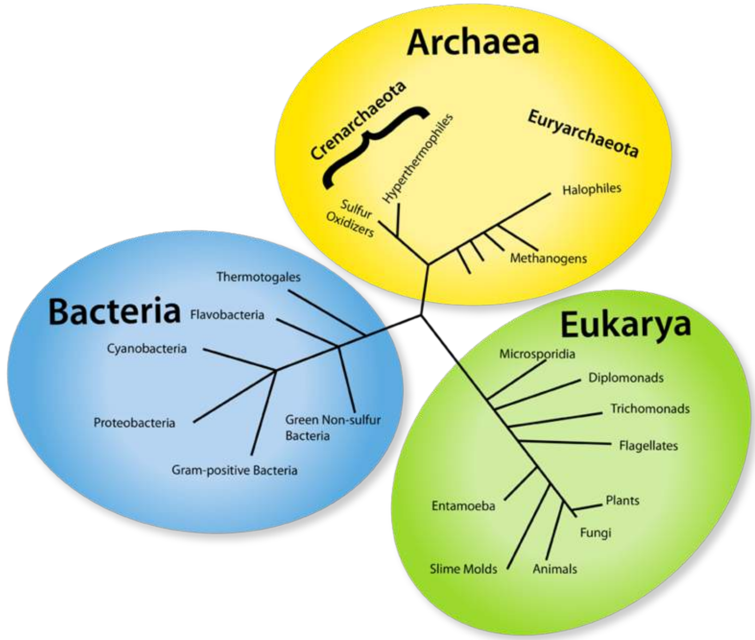

FIGURE 1.1

The Three Domains of Life. All living things are grouped in three domains. The domains Bacteria and Archaea consist of prokaryotes. The Eukarya domain consists of eukaryotes.

Prokaryotes are currently placed in two domains. A **domain** is the highest **taxon**, just above the **kingdom**. The prokaryote domains are **Bacteria** and **Archaea** (see **Figure** 1.1). The third domain is **Eukarya**. It includes all eukaryotes. Unlike prokaryotes, eukaryotes have a nucleus in their cells.

It's not clear how the three domains are related. Archaea were once thought to be offshoots of Bacteria that were adapted to extreme environments. For their part, Bacteria were considered to be ancestors of Eukarya. Scientists now know that Archaea share several traits with Eukarya that Bacteria do not share (see **Table** 1.1). How can this be explained? One hypothesis is that Eukarya arose when an Archaean cell fused with a Bacterial cell. The two cells became the nucleus and cytoplasm of a new Eukaryan cell. How well does this hypothesis fit the evidence in **Table** 1.1 ?

TABLE 1.1: Comparison of Bacteria, Archaea, and Eukarya

Characteristic	Bacteria	Archaea	Eukarya
Flagella	Unique to Bacteria	Unique to Archaea	Unique to Eukarya
Cell Membrane	Unique to Bacteria	Like Bacteria and Eukarya	Unique to Eukarya
Protein Synthesis	Unique to Bacteria	Like Eukarya	Like Archaea
Introns	Absent in most	Present	Present
Peptidoglycan (in cell wall)	Present	Absent in most	Absent

Summary

- Prokaryotes include Bacteria and Archaea. An individual prokaryote consists of a single cell without a nucleus.
- Bacteria live in virtually all environments on Earth.
- Archaea live everywhere on Earth, including extreme environments.

Practice

Use this resource to answer the questions that follow.

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

CONCEPT 2 Prokaryote Classification

- Outline the classification of prokaryotes.

With so many different bacteria, how are they all classified?

By shape? By size? By some other criteria? As you can imagine, classifying bacteria is probably not an easy task. Bacteria are classified by their traits, some of which have to do with their shape, others with the cell wall, and even additional traits.

The Prokaryotic Domains

Domain Bacteria

Bacteria are the most diverse and abundant group of organisms on Earth. They live in almost all environments. They are found in the ocean, the soil, and the intestines of animals. They are even found in rocks deep below Earth's surface. Any surface that has not been sterilized is likely to be covered with bacteria. The total number of bacteria in the world is amazing. It's estimated to be 5×10^{30}, or five million trillion trillion. You have more bacteria in and on your body than you have body cells!

Bacteria called **cyanobacteria** are very important. They are bluish green in color (see **Figure** 2.1) because they contain chlorophyll. They make food through photosynthesis and release oxygen into the air. These bacteria were probably responsible for adding oxygen to the air on early Earth. This changed the planet's atmosphere. It also

FIGURE 2.1
Cyanobacteria Bloom. The green streaks in this lake consist of trillions of cyanobacteria. Excessive nutrients in the water led to overgrowth of the bacteria.

changed the direction of evolution. Ancient cyanobacteria also may have evolved into the chloroplasts of plant cells.

Thousands of species of bacteria have been discovered, and many more are thought to exist. The known species can be classified on the basis of various traits. One classification is based on differences in their cell walls and outer membranes. It groups bacteria into **Gram-positive** and **Gram-negative** bacteria, as described in **Figure** 2.2 .

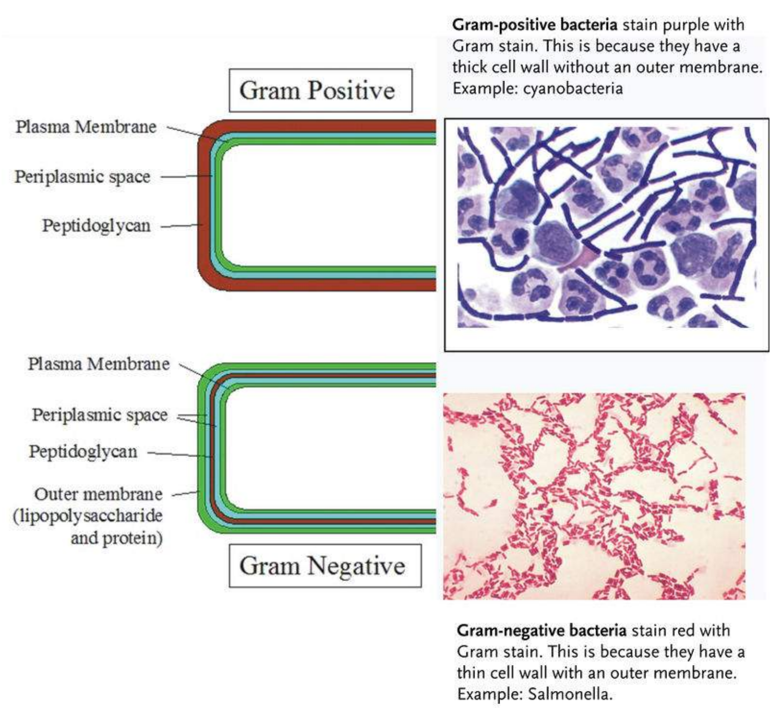

FIGURE 2.2
Classification of Bacteria. Different types of bacteria stain a different color when stained with Gram stain. This makes them easy to identify.

Domain Archaea

Scientists still know relatively little about Archaea. This is partly because they are hard to grow in the lab. Many live inside the bodies of animals, including humans. However, none are known for certain to cause disease.

Archaea were first discovered in extreme environments. For example, some were found in hot springs. Others were found around deep sea vents. Such Archaea are called **extremophiles** , or "lovers of extremes." **Figure** 2.3 describes three different types of Archaean extremophiles. The places where some of them live are thought to be similar to the environment on ancient Earth. This suggests that they may have evolved very early in Earth's history.

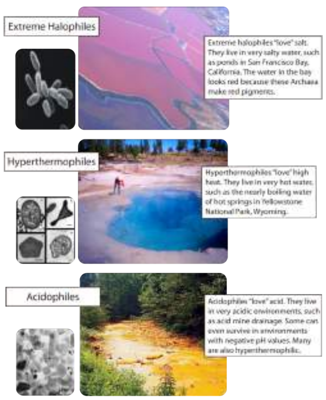

FIGURE 2.3

Extremophile Archaea. Many Archaea are specialized to live in extreme environments. Just three types are described here.

Archaea are now known to live just about everywhere on Earth. They are particularly numerous in the ocean. Archaea in plankton may be one of the most abundant types of organisms on the planet. Archaea are also thought to play important roles in the carbon and nitrogen cycles. For these reasons, Archaea are now recognized as a major aspect of life on Earth.

Summary

- Bacteria live in virtually all environments on Earth.
- Archaea live everywhere on Earth, including extreme environments.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Two Domains: Bacteria and Archaea**

1. How do eubacteria and archaebacteria differ? Describe these differences.
2. Describe the extreme environments of archaebacteria.

Review

1. Distinguish between Gram-positive and Gram-negative bacteria, and give an example of each.

2. Summarize the evolutionary significance of cyanobacteria.

3. What are extremophiles? Name three types.

4. Compare and contrast Archaea and Bacteria.

References

1. Courtesy of Jesse Allen/NASA. . Public Domain
2. Gram cell wall: User:JulianOnions/Wikimedia Commons; Gram-positive: JA Jernigan et al./Centers for Disease Control and Prevention; Gram-negative: William A. Clark/Centers for Disease and Control. . Public Domain
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CONCEPT 3 Prokaryote Metabolism

- Identify different types of metabolism found in prokaryotes.

What do bacteria need to grow?

Like most everything else, they need food. Given the right conditions, bacteria can grow from just a few cells to millions or billions overnight.

Prokaryote Metabolism

Like all living things, prokaryotes need energy and carbon. They meet these needs in a variety of ways. In fact, prokaryotes have just about every possible type of **metabolism** . They may get energy from light (photo) or chemical compounds (chemo). They may get carbon from carbon dioxide (**autotroph**) or other living things (**heterotroph**). Most prokaryotes are **chemoheterotrophs** . They depend on other organisms for both energy and carbon. Many break down organic wastes and the remains of dead organisms. They play vital roles as decomposers and help recycle carbon and nitrogen. **Photoautotrophs** are important producers. They are especially important in aquatic ecosystems.

Classification of Prokaryotes Based on Metabolism

Two major nutritional needs can be used to group prokaryotes. These are (1) carbon metabolism, their source of carbon for building organic molecules within the cells, and (2) energy metabolism, their source of energy used for growth.

In terms of carbon metabolism, prokaryotes are classified as either heterotrophic or autotrophic:

- Heterotrophic organisms use organic compounds, usually from other organisms, as carbon sources.
- Autotrophic organisms use carbon dioxide (CO_2) as their only source or their main source of carbon. Many autotrophic bacteria are photosynthetic, and get their carbon from the carbon dioxide in the atmosphere.

Energy metabolism in prokaryotes is classified as one of the following:

- Phototrophic organisms capture light energy from the sun and convert it into chemical energy inside their cells.
- Chemotrophic organisms break down either organic or inorganic molecules to supply energy for the cell. Some chemotrophic organisms can also use their organic energy-supplying molecules as a carbon supply, which would make them chemoheterotrophs.
- **Photoheterotrophs** are organisms that capture light energy to convert to chemical energy in the cells, but they get carbon from organic sources (other organisms). Examples are purple non-sulfur bacteria, green non-sulfur bacteria and heliobacteria.
- Chemoheterotrophs are organisms that get their energy source and carbon source from organic sources. Chemoheterotrophs must consume organic building blocks that they are unable to make themselves. Most get their energy from organic molecules such as sugars. This nutritional mode is very common among eukaryotes, including humans.
- Photoautotrophs are cells that capture light energy, and use carbon dioxide as their carbon source. There are many photoautotrophic prokaryotes, which include cyanobacteria. Photoautotrophic prokaryotes use similar compounds to those of plants to trap light energy.
- **Chemoautotrophs** are cells that break down inorganic molecules to supply energy for the cell, and use carbon dioxide as a carbon source. Chemoautotrophs include prokaryotes that break down hydrogen sulfide (H_2S the "rotten egg" smelling gas), and ammonia (NH_4). *Nitrosomonas*, a species of soil bacterium, oxidizes NH_4^+ to nitrite (NO_2^-). This reaction releases energy that the bacteria use. Many chemoautotrophs also live in extreme environments such as deep sea vents.

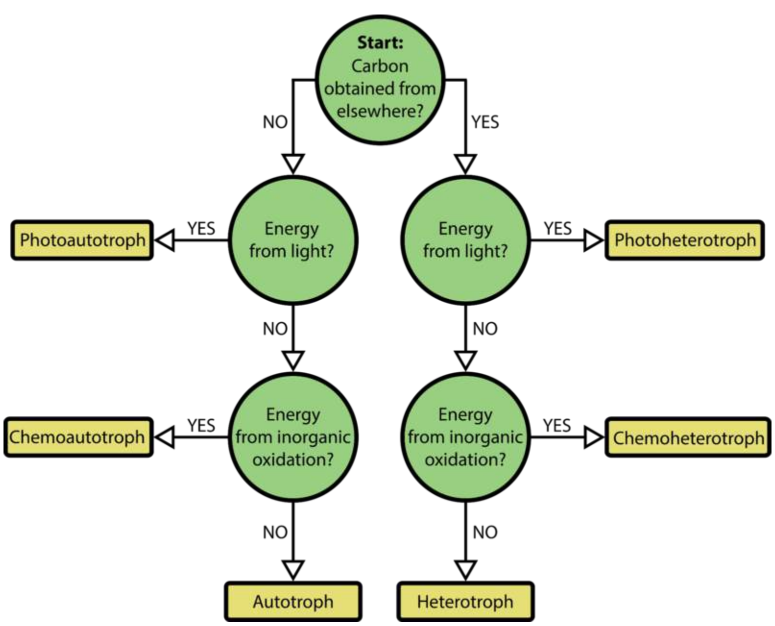


FIGURE 3.1

This flowchart helps to determine if a species is an autotroph or a heterotroph, a phototroph or a chemotroph. For example, "Obtain carbon elsewhere?" asks if the source of carbon is another organism. If the answer is "yes", the organism is heterotrophic. If the answer is "no," the organisms is autotrophic.

Summary

- Prokaryotes fulfill their carbon and energy needs in various ways. They may be photoautotrophs, chemoautotrophs, photoheterotrophs, or chemoheterotrophs.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Prokaryotic Lifestyles**

1. What is nutrition?
2. Distinguish between autotrophs and heterotrophs.
3. Distinguish between phototrophs and chemotrophs.
4. What is a photoautotroph?
5. Describe chemoheterotrophs.

Review

1. Compare and contrast prokaryotic metabolism.

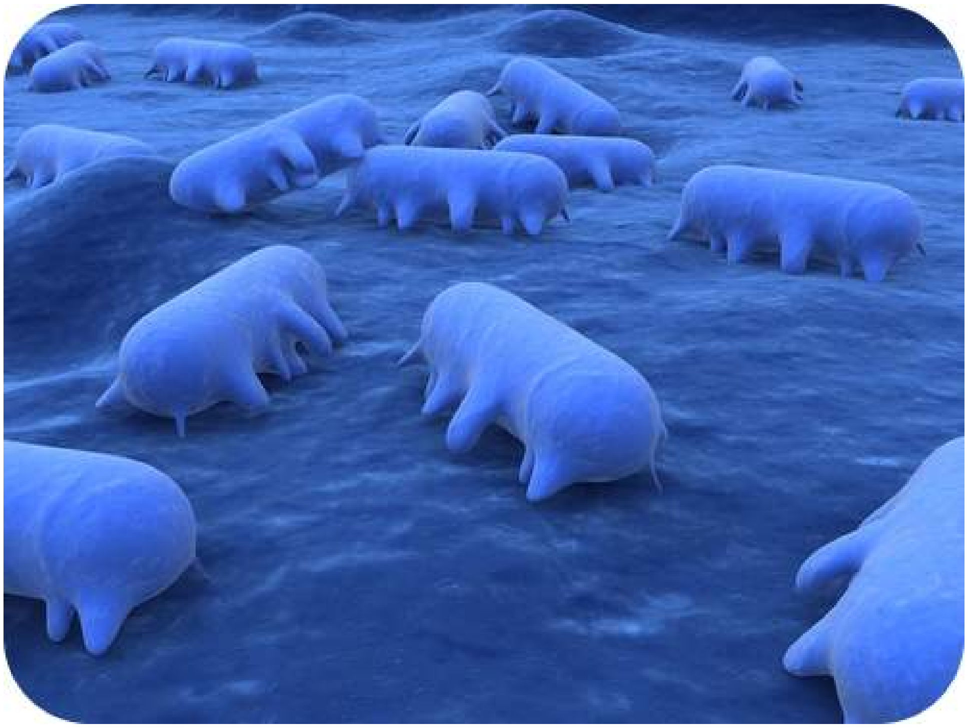
2. Which type of prokaryotes are producers, and which are consumers?

References

1. Laura Guerin. . CC BY-NC 3.0

CONCEPT 4 Prokaryote Habitats

- Describe the range of prokaryote habitats.



Where do you find lots of bacteria?

Practically all surfaces. Bacteria can live and grow in practically any environment. It is this ability that has made bacteria the most numerous species on the planet.

Prokaryote Habitats

Prokaryotes have a wide range of metabolisms, and this determines where they live. They live in a particular habitat because they are able to "eat" whatever is around them. For example, there are bacteria and archaea that break down hydrogen sulfide to produce ATP. Hydrogen sulfide is the gas that gives rotten eggs and sewage their distinctive smell. It is poisonous to animals, but some prokaryotes depend on it for life.

Organisms that are **obligate aerobes** need oxygen to live. That is, they use oxygen as a terminal electron acceptor while making ATP (see the "Cellular Respiration" concept). Humans are obligate aerobes, and so are *Mycobacterium tuberculosis* bacteria. *M. tuberculosis* causes tuberculosis (TB). Obligate aerobes are found only in places with molecular oxygen.

An **anaerobic** organism is any organism that does not need oxygen for growth and even dies in its presence. **Obligate anaerobes** will die when exposed to atmospheric levels of oxygen. *Clostridium perfringens* bacteria, which are commonly found in soil around the world, are obligate anaerobes. Infection of a wound by *C. perfringens* bacteria causes the disease gas gangrene. Obligate anaerobes use molecules other than oxygen as terminal electron acceptors.

Facultative anaerobic organisms, which are usually prokaryotic, make ATP by aerobic respiration, if oxygen is present, but can also survive without oxygen. In the absence of oxygen they switch to the process of fermentation to make ATP. **Fermentation** is a type of heterotrophic metabolism that uses organic carbon instead of oxygen as a terminal electron acceptor. Examples of facultative anaerobic bacteria are the *Staphylococci* , *Escherichia coli* , *Corynebacterium* , and *Listeria* species. Many bacteria that cause human diseases are facultative anaerobic organisms.

Temperature

Like most organisms, prokaryotes live and grow best within certain temperature ranges. Prokaryotes can be classified by their temperature preferences, as shown in the **Table** 4.1 . Which type of prokaryote would you expect to find inside the human body?

Thermophiles live at relatively high temperatures, above 45°C (113°F). Thermophiles are found in geothermally heated regions of the Earth, such as hot springs like the Morning Glory pool in Yellowstone National Park (see **Figure** 4.1), and deep sea hydrothermal vents. Some thermophiles live in decaying plant matter such as peat bogs and compost. Many thermophiles are archaea. Extreme thermophiles (or **hyperthermophiles**), live in temperatures hotter than 80°C (176°F).

Psychrophiles grow and reproduce in cold temperatures. The optimal growth temperature of some psychrophiles is 15°C or lower; they cannot grow in temperatures above 20°C. The environments that psychrophiles inhabit are found all over Earth. Psychrophiles live in such places as permafrost soils, deep-ocean waters, Arctic and Antarctic glaciers and snowfields.

Mesophiles grow best in moderate temperature, typically between 25°C and 40°C (77°F and 104°F). Mesophiles are often found living in or on the bodies of humans or other animals. The optimal growth temperature of many pathogenic mesophiles is 37°C (98°F), the normal human body temperature. Mesophilic organisms have important uses in food preparation, including cheese, yogurt, beer and wine.

TABLE 4.1: Classification of Prokaryotes by Temperature

Type of Prokaryote	Preferred Temperature	Where It Might Be Found
Thermophile	above 45°C (113°F)	in compost
Mesophile	about 37°C (98°F)	inside animals
Psychrophile	below 20°C (68°F)	in the deep ocean

FIGURE 4.1

The Morning Glory pool of Yellowstone National Park in the United States is a geothermal pool whose waters are heated to high temperatures by magma deep underground. Hyperthermophilic organisms, such as members of the archaeal genus *Sulfolobus* can live at temperatures between 60°C-80°C and a pH of 3.

Summary

- Aerobic prokaryotes live in habitats with oxygen.
- Anaerobic prokaryotes live in habitats without oxygen.
- Prokaryotes may also be adapted to habitats that are hot, moderate, or cold in temperature.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Prokaryotic Lifestyles**

1. Distinguish between aerobes, facultative anaerobes, and obligate anaerobes.
2. Describe the habitats of obligate anaerobes.

Review

1. Apply lesson concepts to explain why many prokaryotes are adapted for living at the normal internal temperature of the human body.

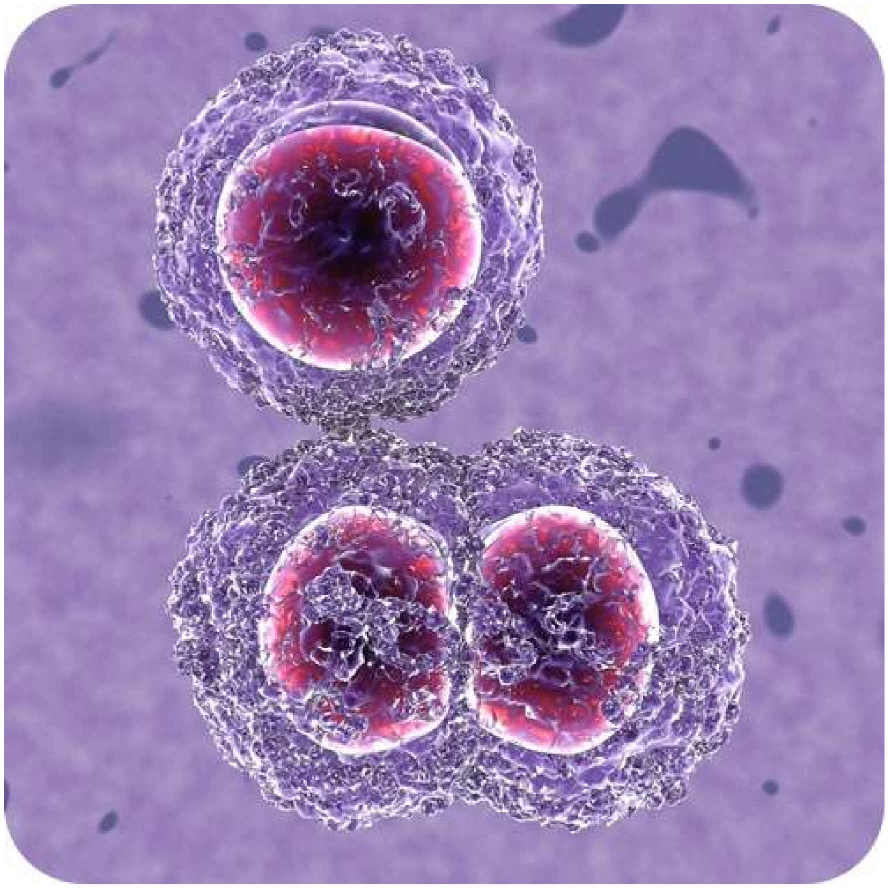
2. Compare psychrophiles to thermophiles.

References

1. Courtesy of the National Park Service. . Public Domain

CONCEPT 5 Prokaryote Reproduction

- Explain how prokaryotes reproduce.



How do bacteria reproduce?

Essentially, they grow and divide. Show here is an example of Methicillin-resistant *Staphylococcus aureus* , or MRSA, bacteria. Notice how one bacterium is dividing into two.

Reproduction in Prokaryotes

Unlike multicellular organisms, increases in the size of prokaryotes (cell growth) and their reproduction by cell division are tightly linked. Prokaryotes grow to a fixed size and then reproduce through **binary fission.** For a discussion of exponential growth and bacteria see http://www.youtube.com/watch?v=-3MI0ZX5WRc (10:43).

Binary Fission

Binary fission is a type of asexual reproduction. It occurs when a parent cell splits into two identical daughter cells. This can result in very rapid population growth. For example, under ideal conditions, bacterial populations can double every 20 minutes. Such rapid population growth is an adaptation to an unstable environment. Can you explain why?

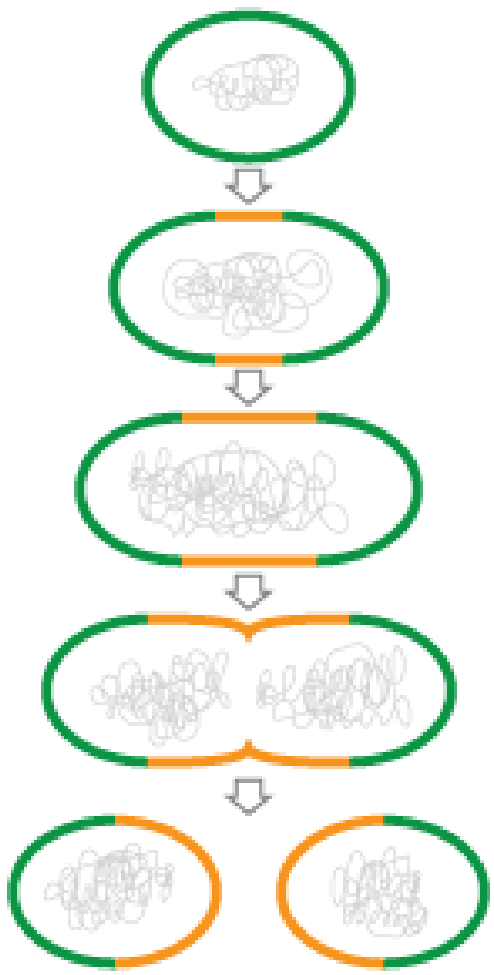


FIGURE 5.1
Schematic diagram of cellular growth (elongation) and binary fission of bacilli. Blue and red lines indicate old and newly-synthesized bacterial cell wall, respectively. The DNA inside the bacterium is copied and the daughter cells receive an exact copy of the parent DNA. Fission involves a cytoskeletal protein FtsZ that forms a ring at the site of cell division.

Genetic Transfer

In asexual reproduction, all the offspring are exactly the same. This is the biggest drawback of this type of reproduction. Why? Lack of genetic variation increases the risk of extinction. Without variety, there may be no organisms that can survive a major change in the environment.

Prokaryotes have a different way to increase genetic variation. It's called **genetic transfer** or **bacterial conjugation** . It can occur in two ways. One way is when cells "grab" stray pieces of DNA from their environment. The other way is when cells directly exchange DNA (usually plasmids) with other cells. For example, as shown in **Figure** 5.2 , the donor cell makes a structure called an **F pilus** , or sex pilus. The F pilus attaches one cell to another cell. The membranes of the two cells merge and genetic material, usually a **plasmid** , moves into the recipient cell. Genetic transfer makes bacteria very useful in biotechnology. It can be used to create bacterial cells that carry new genes.

Summary

- Prokaryotic cells grow to a certain size. Then they divide by binary fission. This is a type of asexual reproduction.
- Binary fission produces genetically identical offspring.

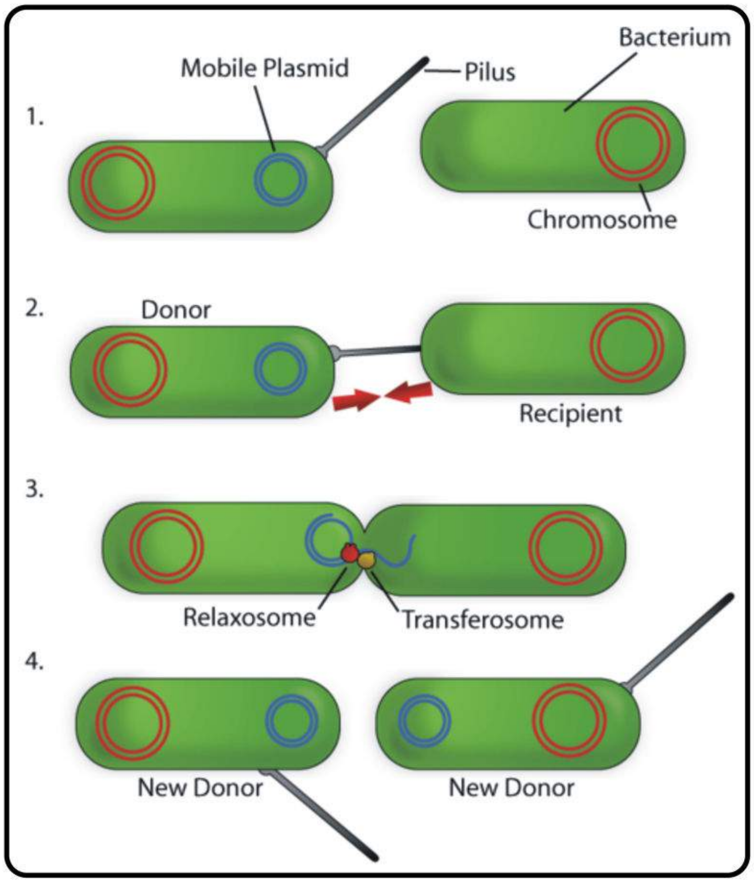


FIGURE 5.2
A flowchart showing bacterial conjugation. The donor cell makes a structure called an F pilus, or sex pilus. The F pilus attaches one cell to another cell. The membranes of the two cells merge and genetic material, usually a plasmid, moves into the recipient cell.

- Genetic transfer increases genetic variation in prokaryotes.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Prokaryotic Lifestyles**

1. Describe the steps of binary fission.
2. How quickly can some prokaryotes reproduce?
3. What is the source of most genetic variation in prokaryotes?
4. Describe the processes of transformation and conjugation.
5. What is transduction?

Review

1. What is binary fission?

2. Why might genetic transfer be important for the survival of prokaryote species?

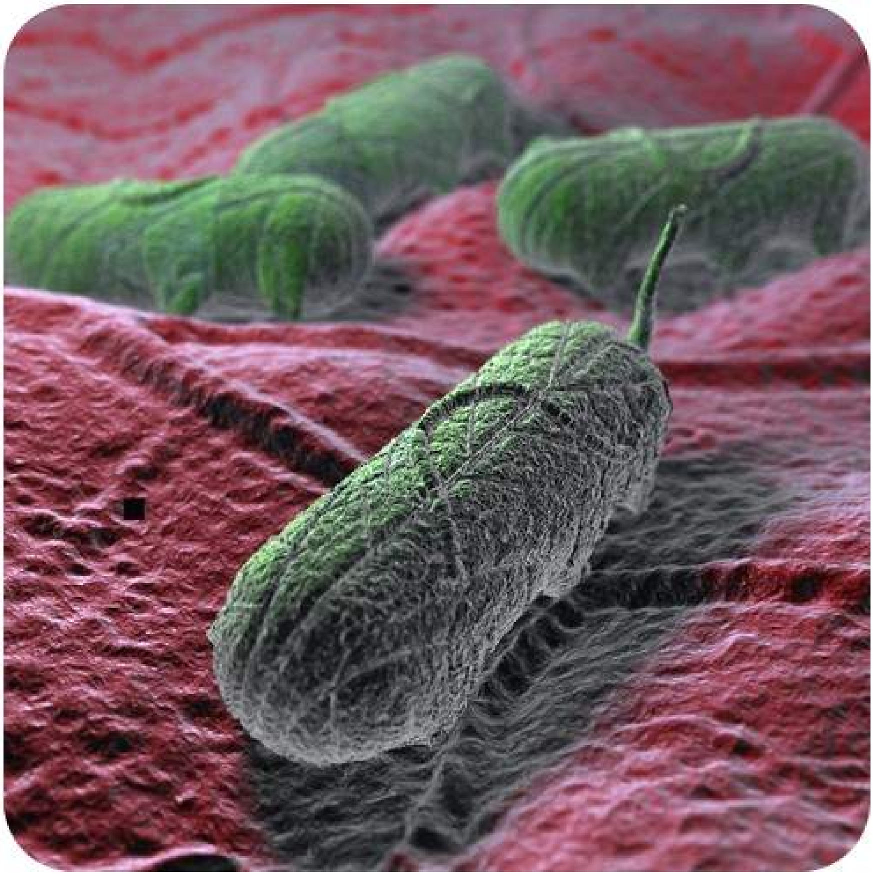
3. Why might genetic transfer make genetic comparisons of prokaryotes difficult to interpret in studies of their evolution?

References

1. Zachary Wilson. . CC BY-NC 3.0
2. Mike Jones. A flowchart showing bacterial conjugation.. CC-BY-SA 2.5

Concept 6 Bacteria and Humans

- Identify important relationships between bacteria and humans.



Can you guess what organisms are pictured here?

Are they fat green worms on a red leaf? Here's a clue: There are more organisms like these than any other on Earth. Here's another clue: Each organism consists of a single cell without a nucleus.

The organisms are bacteria called *Salmonella* . If the word Salmonella rings a bell, that's probably because *Salmonella* causes human diseases such as food poisoning. Many other types of bacteria also cause human diseases. But not all bacteria are harmful to people. In fact, we could not survive without many of the trillions of bacteria that live in or on the human body.

Bacteria and Humans

Bacteria and humans have many important relationships. Bacteria make our lives easier in a number of ways. In fact, we could not survive without them. On the other hand, bacteria can also make us sick.

Benefits of Bacteria

Bacteria provide vital ecosystem services. They are important decomposers. They are also needed for the carbon and nitrogen cycles. There are billions of bacteria inside the human intestines. They help digest food, make vitamins, and play other important roles. Humans also use bacteria in many other ways, including:

- Creating products, such as ethanol and enzymes.
- Making drugs, such as antibiotics and vaccines.
- Making biogas, such as methane.
- Cleaning up oil spills and toxic wastes.
- Killing plant pests.
- Transferring normal genes to human cells in gene therapy.
- Fermenting foods (see **Figure** 6.1).

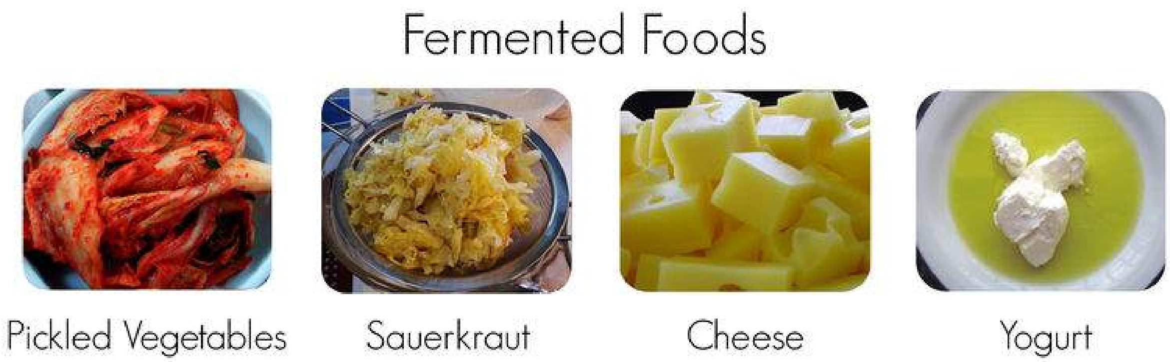


FIGURE 6.1

Fermented Foods. Fermentation is a type of respiration that doesn't use oxygen. Fermentation by bacteria is used in brewing and baking. It is also used to make the foods pictured here.

Bacteria and Disease

You have ten times as many bacteria as human cells in your body. Most of these bacteria are harmless. However, bacteria can also cause disease. Examples of bacterial diseases include tetanus, syphilis, and food poisoning. Bacteria may spread directly from one person to another. For example, they can spread through touching, coughing, or sneezing. They may also spread via food, water, or objects.

Another way bacteria and other pathogens can spread is by vectors. A **vector** is an organism that spreads pathogens from host to host. Insects are the most common vectors of human diseases. **Figure** 6.2 shows two examples.

Humans have literally walked into some new bacterial diseases. When people come into contact with wild populations, they may become part of natural cycles of disease transmission. Consider Lyme disease. It's caused by bacteria that normally infect small, wild mammals, such as mice. A tick bites a mouse and picks up the bacteria. The tick may then bite a human who invades the natural habitat. Through the bite, the bacteria are transmitted to the human host.

Controlling Bacteria

Bacteria in food or water usually can be killed by heating it to a high temperature (generally, at least 71°C, or 160°F). Bacteria on many surfaces can be killed with chlorine bleach or other disinfectants. Bacterial infections in people can be treated with **antibiotic drugs** . For example, if you ever had "strep" throat, you were probably treated with an antibiotic.

FIGURE 6.2

Bacterial Disease Vectors. Ticks spread bacteria that cause Lyme disease. Deerflies spread bacteria that cause tularemia.

Antibiotics have saved many lives. However, misuse and over-use of the drugs have led to **antibiotic resistance** in bacteria. **Figure** 6.3 shows how antibiotic resistance evolves. Some strains of bacteria are now resistant to most common antibiotics. These infections are very difficult to treat.

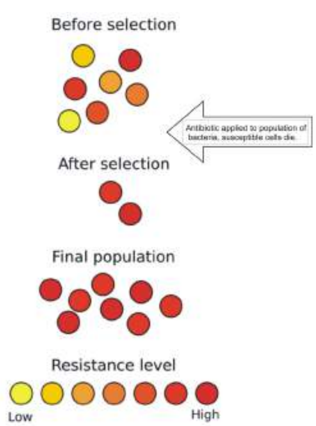


FIGURE 6.3

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

Summary

- Bacteria and humans have many important relationships. Bacteria provide humans with a number of services. They also cause human diseases.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Prokaryotic Lifestyles**

1. Give 4 examples of human diseases caused by bacteria.
2. How do some bacteria cause their symptoms?
3. How can some bacteria be beneficial?
4. How are bacteria used to treat sewage?
5. How is *E. coli* used in research?

Review

1. How can bacteria cause disease?

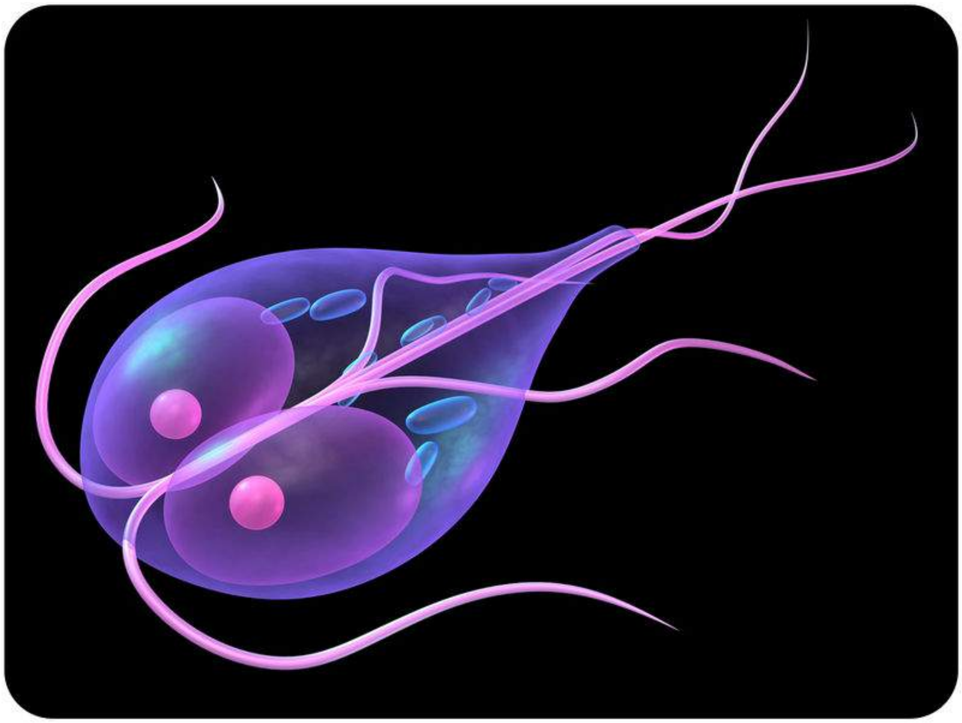
2. List several benefits of bacteria.

References

1. Left to right: Flickr:LWY; Flickr:dustingrzesik; Christian Bauer; User:Omernos/Wikimedia Commons. . Left to right: CC BY 2.0; CC BY 2.0; CC BY 2.0; Public Domain
2. Tick: Courtesy of Centers for Disease Control and Prevention; Deerfly: User:Pudding4Brains/Wikimedia Commons. . Public Domain
3. User:Wykis/Wikimedia Commons, modified by CK-12 Foundation. . Public Domain

Concept 7 Protist Kingdom

- Describe the protist kingdom.



Prokaryote or eukaryote?

This organism consists of a single cell with several flagella. Is it a prokaryote, such as a bacterium? Actually, it's larger than a prokaryotic cell, and it also has a nucleus. Therefore, this organism belongs to the domain Eukarya, the domain that includes humans. This particular eukaryote is one of the smallest, simplest organisms in the domain, called a protist. It's scientific name is *Giardia lamblia.* As a human parasite, it can make us sick.

Kingdom Protista

Protists are a group of all the eukaryotes that are not fungi, animals, or plants. As a result, it is a very diverse group of organisms. The eukaryotes that make up this kingdom, Kingdom **Protista** , do not have much in common besides a relatively simple organization. Protists can look very different from each other. Some are tiny and unicellular, like an **amoeba** , and some are large and multicellular, like **seaweed** . However, multicellular protists do not have highly specialized tissues or organs. This simple cellular-level organization distinguishes protists from other eukaryotes, such as fungi, animals, and plants. There are thought to be between 60,000 and 200,000 protist species, and many have yet to be identified. Protists live in almost any environment that contains liquid water. Many protists, such as the **algae** , are photosynthetic and are vital primary producers in ecosystems. Other protists are responsible for a range of serious human diseases, such as **malaria** and sleeping sickness.

The term protista was first used by Ernst Haeckel in 1866. Protists were traditionally placed into one of several groups based on similarities to a plant, animal, or fungus: the animal-like **protozoa** , the plant-like **protophyta** (mostly algae), and the fungus-like **slime molds** and **water molds** . These traditional subdivisions, which were largely based on non-scientific characteristics, have been replaced by classifications based on **phylogenetics** (evolutionary relatedness among organisms). However, the older terms are still used as informal names to describe the general characteristics of various protists.

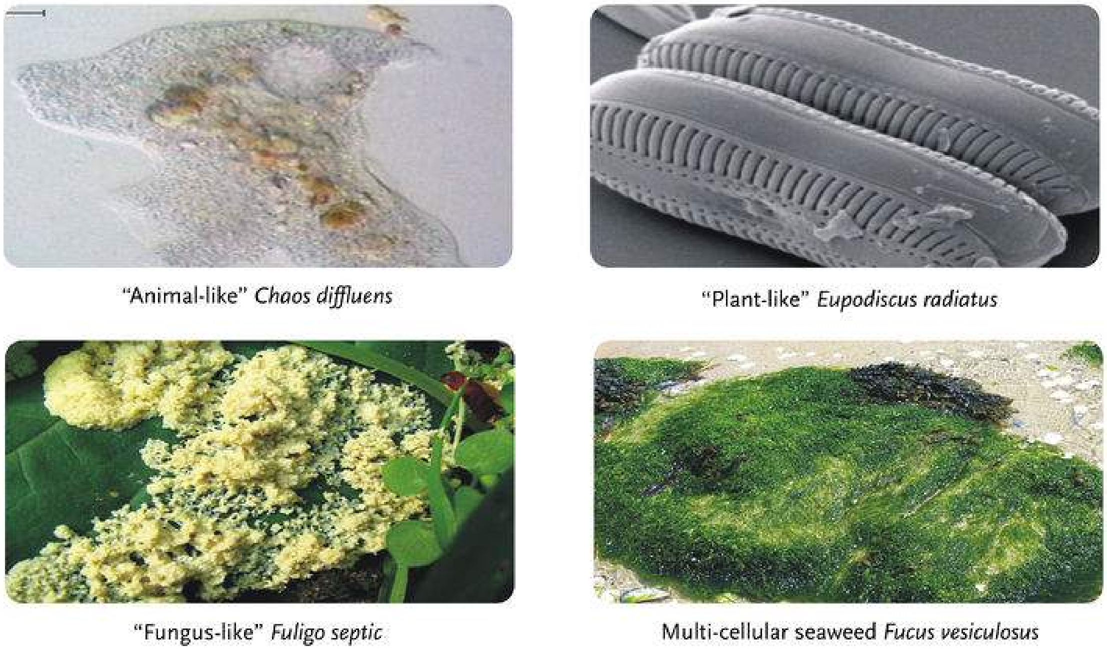


FIGURE 7.1

Protists range from single-celled amoebas to multicellular seaweed. Protists may be similar to animals, plants, or fungi.

Summary

- Kingdom Protista includes all eukaryotes that are not animals, plants, or fungi.
- Kingdom Protista is very diverse. It consists of both single-celled and multicellular organisms.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **The Kingdom Protista**

1. What were the first eukaryotes and when did they arise?
2. Describe endosymbiosis.
3. What is kelp?
4. Describe an amoeba.

Review

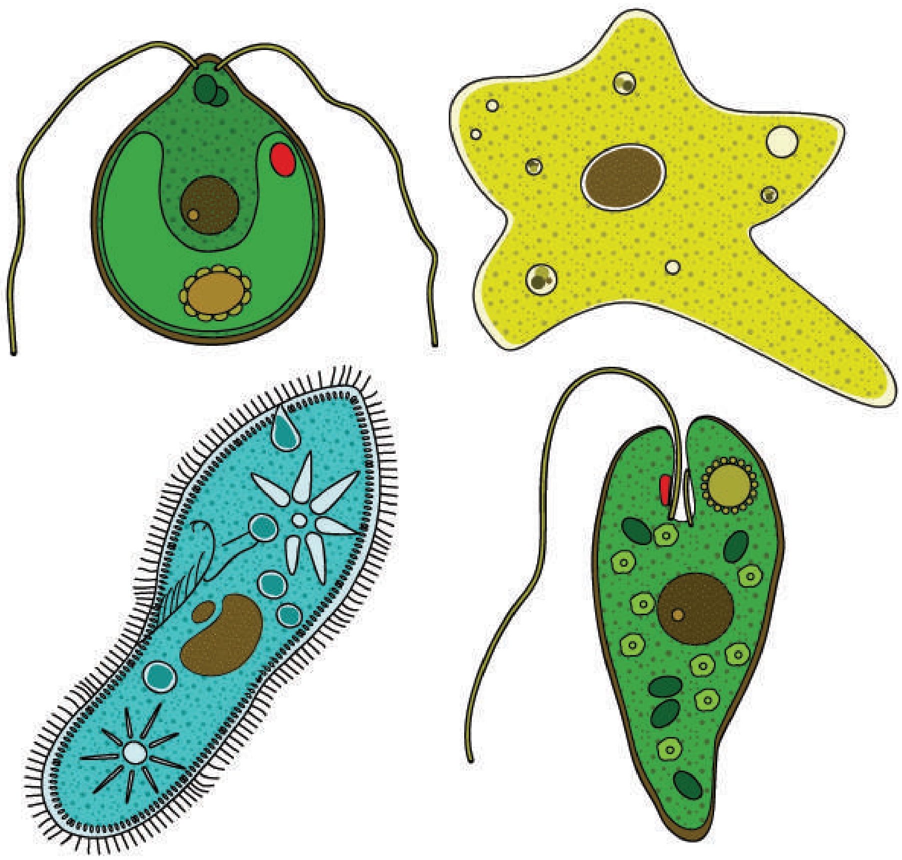
1. What are protists?
2. Compare unicellular protists to multicellular protists.
3. How are protists classified?

References

1. Chaos diffluens: Ralf Wagner; Eupodiscus radiatus: Mary Ann Tiffany, San Diego State University; Fuligo septic: Kpjas; Fucus vesiculosus: Luis Miguel Bugallo Sánchez. . Chaos diffluens: GNU-FDL 1.2; Eupodiscus radiatus: CC-BY 2.5; Fuligo septic: CC-BY-SA 2.0; Fucus vesiculosus: GNU-FDL 1.2

CONCEPT 8 Protist Characteristics

- Describe the main features of the protists.



Animal? Bacteria? Plant? Fungi? What do these figures represent?

None of the above! These organisms may be single-celled like bacteria, and they may look like a fungus. They also may hunt for food like an animal or photosynthesize like a plant. And, yet, they do not fit into any of these groups. These organisms are protists!

What are Protists?

Protists are **eukaryotes** , which means their cells have a nucleus and other membrane-bound organelles. Most protists are single-celled. Other than these features, they have very little in common. You can think about protists as all eukaryotic organisms that are neither animals, nor plants, nor fungi.

Although Ernst Haeckel set up the Kingdom *Protista* in 1866, this kingdom was not accepted by the scientific world until the 1960s. These unique organisms can be so different from each other that sometimes Protista is called the "junk drawer kingdom." Just like a "junk drawer," which contains items that don't fit into any other category, this kingdom contains the eukaryotes that cannot be put into any other kingdom. Therefore, protists can seem very different from one another.

Unicellular or Multicellular?

Most protists are so small that they can be seen only with a microscope. Protists are mostly unicellular (one-celled) eukaryotes. A few protists are multicellular (many-celled) and surprisingly large. For example, kelp is a multicellular protist that can grow to be over 100-meters long (**Figure** 8.1). Multicellular protists, however, do not show cellular specialization or differentiation into tissues. That means their cells all look the same and, for the most part, function the same. On the other hand, your cells often are much different from each other and have special jobs.

FIGURE 8.1
Kelp is an example of a muticellular protist.

Characteristics of Protists

A few characteristics are common between protists.

1. They are eukaryotic, which means they have a nucleus.
2. Most have mitochondria.
3. They can be parasites.
4. They all prefer aquatic or moist environments.

Classification of Protists

For classification, the protists are divided into three groups:

1. Animal-like protists, which are heterotrophs and have the ability to move.
2. Plant-like protists, which are autotrophs that photosynthesize.
3. Fungi-like protists, which are heterotrophs, and they have cells with cell walls and reproduce by forming spores.

But remember, protists are not animals, nor plants, nor fungi (**Figure** 8.2).

Vocabulary

- **eukaryote** : Organism with cells (or cell) that have a nucleus and membrane-bound organelles.
- **protist** : Eukaryote that is not a plant, animal, or fungus.

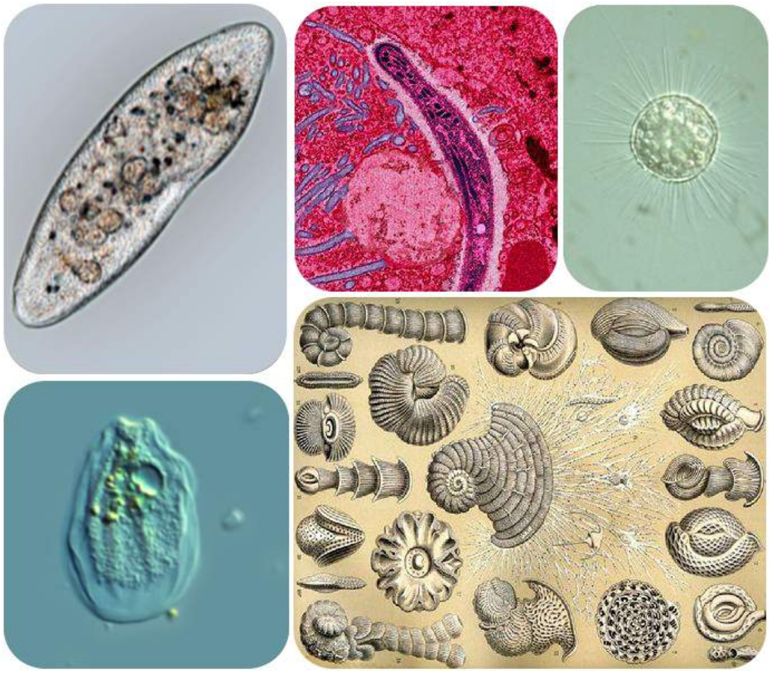


FIGURE 8.2

Protists come in many different shapes.

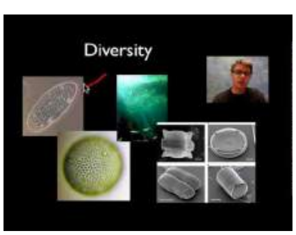
Summary

- Protists are a diverse kingdom, including all eukaryotic organisms that are neither animals, nor plants, nor fungi.
- For classification, the protists are divided into three groups: animal-like protists, plant-like protists, and fungi-like protists.

Practice

Use the resource below to answer the questions that follow.

- **Protists** at http://www.youtube.com/watch?v=8deF3Rw4ti4 (5:07)



MEDIA

Click image to the left for more content.

1. What defines the Kingdom Protista?
2. Are relationships between protist clearly defined? Why or why not?
3. What are phototrophs? Are they the same as autotrophs? How do they obtain their food?
4. What are organotrophs? Are they the same as heterotrophs? How do they obtain their food?
5. Do all protists reproduce in the same manner?

Review

1. What do protists tend to have in common?
2. How are protists generally classified?

References

1. Image copyright Janelle Lugge, 2012. . Used under license from Shutterstock.com
2. Clockwise from top left: Leo Papandreou (Flickr: manual crank); Image by Ute Frevert, false color by Margaret Shear; Yuiuji Tsukii; Ernst Haeckel; Antonio Guillén (Flickr: PROYECTO AGUA** /** WATER PROJECT). Protists come in many different shapes. Clockwise from top left: CC-BY-NC-SA 2.0; CC-BY 2.5; Public Domain; Public Domain; CC-BY-NC-SA 2.0

CONCEPT 9 Fungi Classification

- Explain how the fungi are classified.

What's growing on this orange?

Mold, of course! Did you know that mold is a type of fungus? There are many different types of fungi besides molds, however.

Fungi Classification

Scientists used to think that fungi were members of the plant kingdom. They thought this because fungi had several similarities to plants. For example:

- Fungi and plants have similar structures.
- Plants and fungi live in the same kinds of habitats, such as growing in soil.
- Plants and fungi both have a cell wall, which animals do not have.

How Fungi and Plants Differ

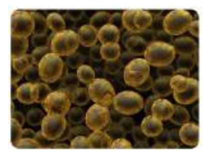
However, there are a number of characteristics that make fungi different from plants:

1. Fungi cannot make their own food like plants can, since they do not have chloroplasts and cannot carry out photosynthesis. Fungi are more like animals because they are **heterotrophs** . They have to obtain their food from outside sources.
2. The cell walls in many species of fungi contain chitin. **Chitin** is tough carbohydrate found in the shells of animals such as beetles and lobsters. The cell wall of a plant is made of cellulose, not chitin.
3. Unlike many plants, most fungi do not have structures that transfer water and nutrients.

The Types of Fungi

The Kingdom Fungi can be broken down into several phyla. Each phyla has some unique traits. And even within the same phyla there are many differences among the fungi. Various types of fungi are pictured below (**Table** 9.1). Notice how different each of these organisms are from one another.

TABLE 9.1: Common Types of Fungi

Type of Fungi	Example
Molds	
Mushrooms	
Single-celled yeasts	

Vocabulary

- **chitin** : Tough carbohydrate found in the shells of animals and cell walls of fungi.
- **heterotroph** : Organism which obtains carbon from outside sources.

Summary

- Fungi are no longer classified as plants.
- Although fungi have cell walls like plants, the cell walls are made of chitin instead of cellulose.
- Types of fungi include molds, yeasts, and mushrooms.

Practice

Use the resources below to answer the questions that follow.

- **The Fungi Kingdom** at http://www.wisc-online.com/Objects/ViewObject.aspx?ID=bio304

1. How many of the existing fungi do scientist feel they have identified?
2. What are the characteristics of Chrytid fungi?
3. What are the characteristics of Zygomycetes?

4. What are the characteristics of Basidiomycetes?
5. What are the characteristics of Ascomycetes?
6. Compare and contrast the four above groups of fungi. How are they the same? How do they differ?

- **Asomycete Fungi** at http://www.youtube.com/watch?v=ioBGnZwRjsQ (5:52)

MEDIA
Click image to the left for more content.

1. In what kind of habitats do you find Ascomycete fungi?
2. How large is their fruiting body?
3. Do you think you can find Ascomycerte in marine environments? Why or why not?
4. What characteristics do scientists use to distinguish between different species of fungi?

Review

1. What do plants and fungi have in common?
2. How are fungi more like animals than plants?

Concept 10 Fungi

- Describe the characteristics of the fungi.

What does this fungus have in common with mold?

This colorful bracket fungus doesn't look much like mold. But they have a lot in common. They both break down organic matter to obtain nutrients. They both reproduce by spores. They are both eukaryotic, but they are not plants, and they are definitely not animals. They are both fungi.

What are Fungi?

Ever notice blue-green mold growing on a loaf of bread? Do you like your pizza with mushrooms? Has a physician ever prescribed an antibiotic for you?

If so, then you have encountered **fungi** . Fungi are organisms that belong to the Kingdom Fungi (**Figure** 10.1). Our environment needs fungi. Fungi help decompose matter to release nutrients and make nutritious food for other organisms. Fungi are all around us and are useful in many ways.

FIGURE 10.1
These many different kinds of organisms demonstrate the huge diversity within the Kingdom Fungi.

Classification of the Fungi

If you had to guess, would you say a fungus is a plant or an animal? Scientists used to debate about which kingdom to place fungi in. Finally they decided that fungi were plants. But they were wrong. Now, scientists know that fungi are not plants at all. Fungi are very different from plants.

The main difference between plants and fungi is how they obtain energy. Plants are **autotrophs** , meaning that they make their own "food" using the energy from sunlight. Fungi are **heterotrophs** , which means that they obtain their "food" from outside of themselves. In other words, they must "eat" their food like animals do.

Yeasts, molds, and mushrooms are all different kinds of fungi. There may be as many as 1.5 million species of fungi (**Figure** 10.2). You can easily see bread mold and mushrooms without a microscope, but most fungi you cannot see. Fungi are either too small to be seen without a microscope, or they live where you cannot see them easily—deep in the soil, under decaying logs, or inside plants or animals. Some fungi even live in, or on top of, other fungi.

Fungi are Good Eaters

Fungi can grow fast because they are such good eaters. Fungi have lots of surface area, and this large surface area “eats.” Surface area is how much exposed area an organism has, compared to their overall volume. Most of a mushroom’s surface area is actually underground. If you see a mushroom in your yard, that is just a small part of a larger fungus growing underground.

These are the steps involved in fungi "eating":

1. Fungi squirt special enzymes into their environment.

FIGURE 10.2
The blue in this blue cheese is actually mold, which is a fungus.

2. The enzymes help digest large organic molecules, similar to cutting up your food before you eat.
3. Cells of the fungi then absorb the broken-down nutrients.

Vocabulary

- **autotroph** : Organism that makes its own food.
- **fungi** : Eukaryotic organisms that include yeasts, molds, and mushrooms.
- **heterotroph** : Organism that cannot make its own food and, therefore, must seek food outside itself.

Summary

- Fungi are heterotrophs, meaning they obtain food from outside themselves.
- Common fungi include yeasts, molds, and mushrooms.

Practice

Use the resources below to answer the questions that follow.

- **Planet World - Fungi** at http://www.youtube.com/watch?v=5_rprVa-RY4 (3:03)

MEDIA
Click image to the left for more content.

1. What are some of the ways fungi differ from plants?

2. How many spores can a fungi disperse per day? What methods of dispersal do they use?
3. How do fungi benefit trees? How do they affect where trees can live?

- **Fungi: What They Eat** at http://archives.microbeworld.org/microbes/fungi/eat.aspx

1. Some fungi "hunt" for prey.
   a. What structure do they use to form "nooses"?
   b. How do they close these nooses?
   c. How do they "consume" their prey?
   d. What hunting technique do some fungi use other than nooses or loops?
   e. What other organisms can you think of that hunt in a similar manner?
2. What is a lichen? What does a lichen do to increase the types of habitats in which it can live?

Review

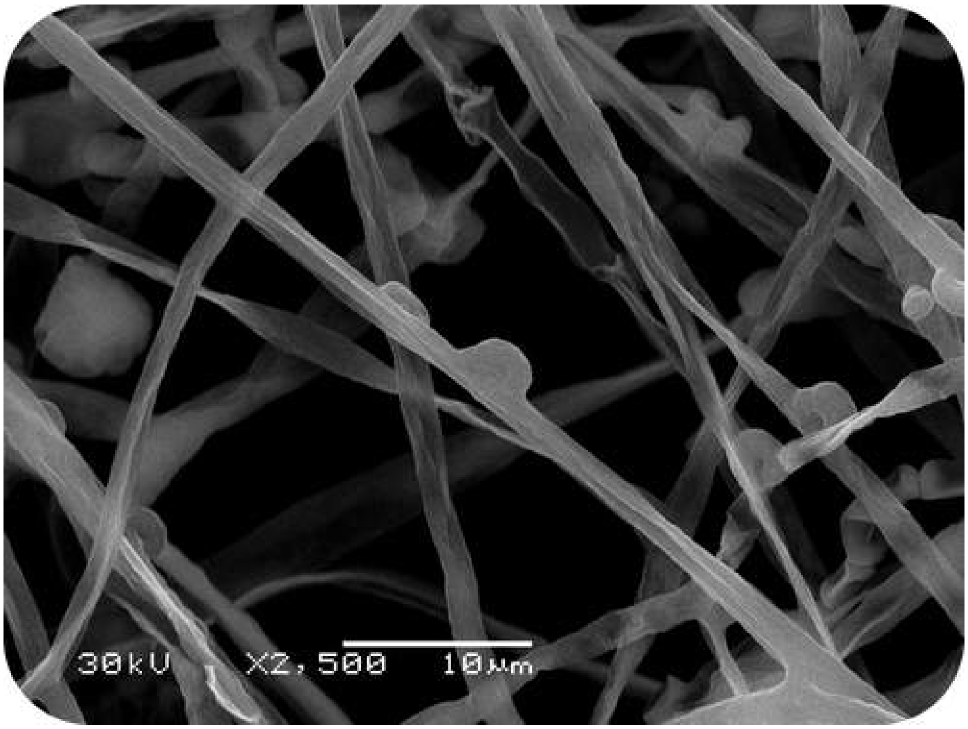
1. How are fungi different from plants.
2. What are some common examples of fungi?

References

1. Clockwise from top left: Tim Bekaert (Wikimedia: Tbc); Velela (Wikimedia); Maestrosync (Wikimedia); Jason Hollinger (Flickr: pellaea); Nick Saltmarsh (Flickr: Nick Saltmarsh). . Clockwise from top left: Public Domain; Public Domain; Public Domain; CC-BY 2.0; CC-BY 2.0
2. Jon Sullivan/PD Photo.org. The blue in this blue cheese is actually mold. Public Domain

CONCEPT 11 Fungi Reproduction

- Describe fungi reproduction.



How do fungi reproduce? Sexually or asexually?

How about both? That would suggest that fungi can produce both diploid and haploid cells, which they can. Shown above are fungi mycelia and haploid spores. Spores allow fungi to reproduce through unfavorable conditions.

Reproduction of Fungi

The majority of fungi can reproduce both asexually and sexually. This allows them to adjust to conditions in the environment. They can spread quickly through asexual reproduction when conditions are stable. They can increase their genetic variation through sexual reproduction when conditions are changing and variation may help them survive.

Asexual Reproduction

Almost all fungi reproduce asexually by producing spores. A fungal **spore** is a haploid cell produced by mitosis from a haploid parent cell. It is genetically identical to the parent cell. Fungal spores can develop into new haploid individuals without being fertilized.

Spores may be dispersed by moving water, wind, or other organisms. Some fungi even have "cannons" that "shoot" the spores far from the parent organism. This helps to ensure that the offspring will not have to compete with the parent for space or other resources. You are probably familiar with puffballs, like the one in **Figure** 11.1 . They release a cloud of spores when knocked or stepped on. Wherever the spores happen to land, they do not germinate until conditions are favorable for growth. Then they develop into new **hyphae** .

FIGURE 11.1
Puffballs release spores when disturbed.

Yeasts do not produce spores. Instead, they reproduce asexually by budding. **Budding** is the pinching off of an offspring from the parent cell. The offspring cell is genetically identical to the parent. Budding in yeast is pictured in **Figure** 11.2 .

FIGURE 11.2
Yeast reproduce asexually by budding.

Sexual Reproduction

Sexual reproduction also occurs in virtually all fungi. This involves mating between two haploid hyphae. During mating, two haploid parent cells fuse, forming a diploid spore called a **zygospore** . The zygospore is genetically different from the parents. After the zygospore germinates, it can undergo meiosis, forming haploid cells that develop into new hyphae.

Summary

- The majority of fungi can reproduce both asexually and sexually. This allows them to adjust to conditions in the environment.
- Yeast reproduce asexually by budding. Other fungi reproduce asexually by producing spores.
- Sexual reproduction occurs when spores from two parents fuse and form a zygospore.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Characteristics of Fungi**

1. How do most fungi disperse their offspring?
2. When do fungi reproduce asexually?
3. Using an illustration, explain sexual reproduction in fungi.
4. What is a mating type?
5. What is the dikaryotic stage?

Review

1. Identify ways that fungal spores may be dispersed.

2. Compare and contrast a fungal spore and zygospore.

References

1. Image copyright siloto, 2010. . Used under license from Shutterstock.com
2. Courtesy of National Institute of Allergy and Infectious Diseases/National Institutes of Health. . Public Domain

CK-12 FlexBook

Mutations

Sherry Wantz
Douglas Wilkin, Ph.D.
Jean Brainard, Ph.D.

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

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Printed: June 12, 2013

Contents

CHAPTER 1 Mutation Types

- Compare and contrast types of mutations.

What causes albinism?

This rare albino alligator must have the specific "instructions," or DNA, to have this quality. The cause of albinism is a mutation in a gene for melanin, a protein found in skin and eyes. Such a mutation may result in no melanin production at all or a significant decline in the amount of melanin.

Mutations

A change in the sequence of bases in DNA or RNA is called a **mutation**. Does the word mutation make you think of science fiction and bug-eyed monsters? Think again. Everyone has mutations. In fact, most people have dozens or even hundreds of mutations in their DNA. Mutations are essential for evolution to occur. They are the ultimate source of all new genetic material - new **alleles** - in a species. Although most mutations have no effect on the organisms in which they occur, some mutations are beneficial. Even harmful mutations rarely cause drastic changes in organisms.

Types of Mutations

There are a variety of types of mutations. Two major categories of mutations are germline mutations and somatic mutations.

- **Germline mutations** occur in gametes. These mutations are especially significant because they can be transmitted to offspring and every cell in the offspring will have the mutation.
- **Somatic mutations** occur in other cells of the body. These mutations may have little effect on the organism because they are confined to just one cell and its daughter cells. Somatic mutations cannot be passed on to offspring.

Mutations also differ in the way that the genetic material is changed. Mutations may change the structure of a chromosome or just change a single nucleotide.

Chromosomal Alterations

Chromosomal alterations are mutations that change chromosome structure. They occur when a section of a chromosome breaks off and rejoins incorrectly or does not rejoin at all. Possible ways these mutations can occur are illustrated in **Figure** 1.1. Go to this link for a video about chromosomal alterations: http://www.youtube.com/watch?v=OrXRSqa_3lU&feature=related (2:18).

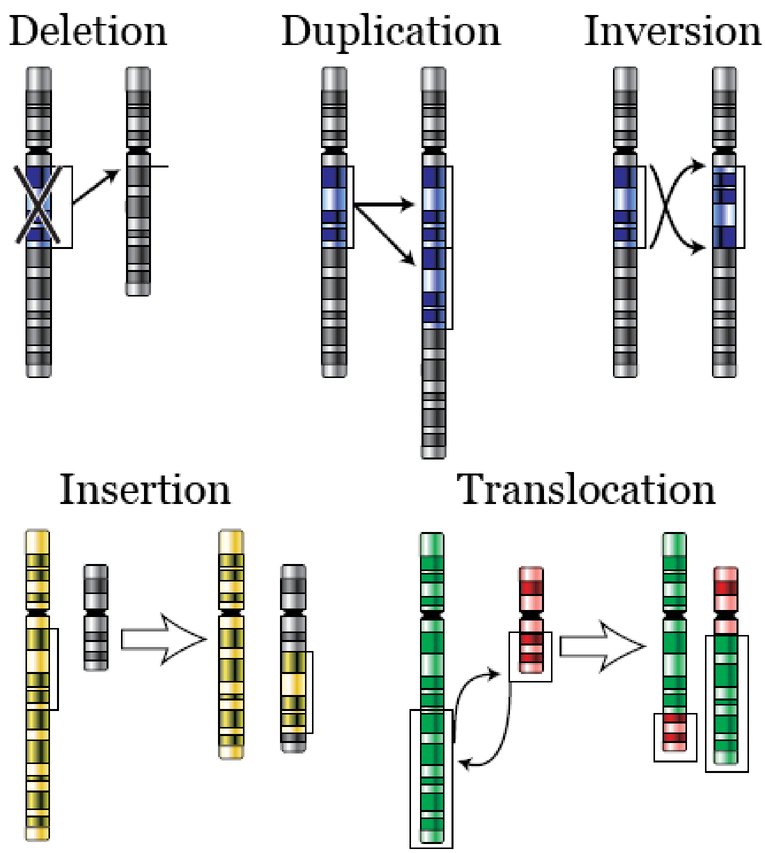

FIGURE 1.1
Chromosomal Alterations. Chromosomal alterations are major changes in the genetic material.

Chromosomal alterations are very serious. They often result in the death of the organism in which they occur. If the organism survives, it may be affected in multiple ways. An example of a human chromosomal alteration is the mutation that causes Down Syndrome. It is a duplication mutation that leads to developmental delays and other abnormalities.

Point Mutations

A **point mutation** is a change in a single nucleotide in DNA. This type of mutation is usually less serious than a chromosomal alteration. An example of a point mutation is a mutation that changes the codon UUU to the codon UCU. Point mutations can be silent, missense, or nonsense mutations, as shown in **Table** 1.1. The effects of point mutations depend on how they change the genetic code. You can watch an animation about nonsense mutations at this link: http://www.biostudio.com/d_%20Nonsense%20Suppression%20I%20Nonsense%20Mutation.htm.

TABLE 1.1: Point Mutations and Their Effects

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

Frameshift Mutations

A **frameshift mutation** is a deletion or insertion of one or more nucleotides that changes the **reading frame** of the base sequence. Deletions remove nucleotides, and insertions add nucleotides. Consider the following sequence of bases in RNA:

AUG-AAU-ACG-GCU = start-asparagine-threonine-alanine

Now, assume an insertion occurs in this sequence. Let's say an **A** nucleotide is inserted after the start codon **AUG**:

AUG-AAA-UAC-GGC-U = start-lysine-tyrosine-glycine

Even though the rest of the sequence is unchanged, this insertion changes the reading frame and thus all of the codons that follow it. As this example shows, a frameshift mutation can dramatically change how the codons in mRNA are read. This can have a drastic effect on the protein product.

Summary

- Germline mutations occur in gametes. Somatic mutations occur in other body cells.
- Chromosomal alterations are mutations that change chromosome structure.
- Point mutations change a single nucleotide.
- Frameshift mutations are additions or deletions of nucleotides that cause a shift in the reading frame.

Making Connections

MEDIA

Click image to the left for more content.

Practice

Use this resource to answer the questions that follow.

- **Mutations are changes in genetic information** at http://www.dnaftb.org/27/animation.html.

1. What is a point mutation?
2. What are the effects of a point mutation?
3. What is a frameshift mutation?

4. What causes a frameshift?
5. Who identified point mutations?

Review

1. Identify three types of chromosomal alterations.

2. Distinguish among silent, missense, and nonsense point mutations.

3. What is a frameshift mutation? What causes this type of mutation?

4. Assume that a point mutation changes the codon AUU to AUC. Why is this a neutral mutation?

5. Look at the mutation shown below. The base A was inserted following the start codon AUG. Describe how this mutation affects the encoded amino acid sequence. AUG-GUC-CCU-AAA $\rightarrow$ AUG-AGU-CCC-UAA-A

6. Compare and contrast germline mutations and somatic mutations.

References

1. Dietzel65. . Public Domain

CHAPTER 2 Mutation Causes

- Identify causes of mutation.

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** 2.1. For a video about mutagens, go the link below. http://www.youtube.com/watch?v=0wrNxCGKCws&feature=related (0:36)

Spontaneous Mutations

There are five common types of spontaneous mutations. These are described in the **Table** 2.1.

TABLE 2.1:

Mutation	Description
Tautomerism	a base is changed by the repositioning of a hydrogen atom
Depurination	loss of a purine base (A or G)

TABLE 2.1: (continued)

Mutation	Description
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

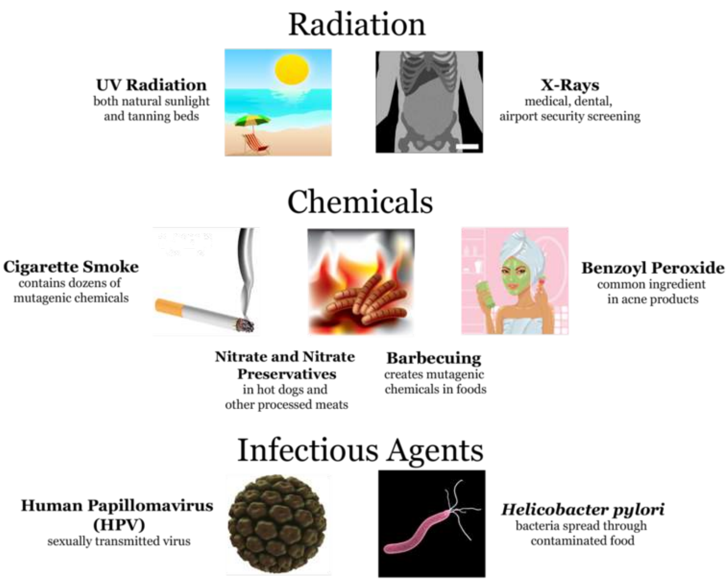

FIGURE 2.1

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?

Summary

- Mutations are caused by environmental factors known as mutagens.
- Types of mutagens include radiation, chemicals, and infectious agents.
- Mutations may be spontaneous in nature.

Making Connections

MEDIA

Click image to the left for more content.

Practice

Use this resource to answer the questions that follow.

- **What Causes DNA Mutations?** at http://learn.genetics.utah.edu/archive/sloozeworm/mutationbg.html.

1. Mutations in DNA sequences generally occur through two processes. What are they?
2. How might ultraviolet light cause a mutation?
3. How can nuclear radiation damage DNA?
4. How often does DNA polymerase make a mistake?
5. Are all of the mistakes by DNA polymerase incorporated into DNA? Why or why not?

Review

1. Define mutation and mutagen.
2. List three examples of mutagens.
3. Distinguish between a transition and a transversion.

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. Birds nest inside the cracked concrete *sarcophagus* shielding in the shattered remains of the nuclear reactor. 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.

References

1. A) Beach Image Copyright Alexander Sabilin, 2010; B) X-ray Image Copyright VALIK-NOVIK, 2010; C) Cigarette Image Copyright robertosch, 2010; D) BBQ Image Copyright valeriya_gold, 2010; E) Facial Cream Image Copyright Lena Rozova, 2010; F) HPV Image Copyright Sebastian Kaulitzki, 2010; G) H. pylori Image Copyright 3drenderings, 2010. . All images used under licenses from Shutterstock.com

CHAPTER 3 Mutation Effects

- Explain how mutations may affect the organisms in which they occur.

Is this rat hairless?

Yes. Why? The result of a mutation, a change in the DNA sequence. The effects of mutations can vary widely, from being beneficial, to having no effect, to having lethal consequences, and every possibility in between.

Effects of Mutations

The majority of mutations have neither negative nor positive effects on the organism in which they occur. These mutations are called **neutral mutations**. Examples include silent point mutations. They are neutral because they do not change the amino acids in the proteins they encode.

Many other mutations have no effect on the organism because they are repaired before protein synthesis occurs. Cells have multiple repair mechanisms to fix mutations in DNA. One way DNA can be repaired is illustrated in **Figure** 3.1. If a cell's DNA is permanently damaged and cannot be repaired, the cell is likely to be prevented from dividing.

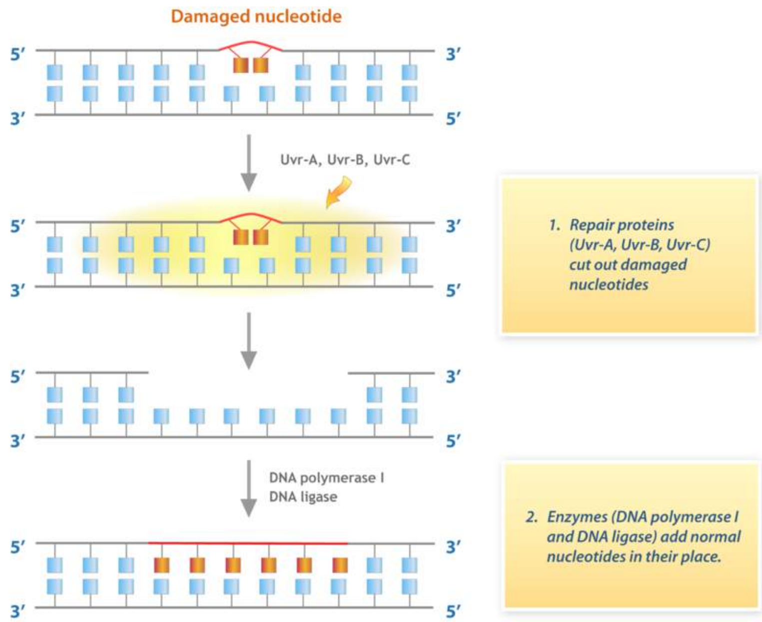

FIGURE 3.1

DNA Repair Pathway. This flow chart shows one way that damaged DNA is repaired in E. coli bacteria.

Beneficial Mutations

Some mutations have a positive effect on the organism in which they occur. They are called **beneficial mutations**. They lead to new versions of proteins that help organisms adapt to changes in their environment. Beneficial mutations are essential for evolution to occur. They increase an organism's changes of surviving or reproducing, so they are likely to become more common over time. There are several well-known examples of beneficial mutations. Here are just two:

1. Mutations in many bacteria that allow them to survive in the presence of antibiotic drugs. The mutations lead to **antibiotic-resistant** strains of bacteria.
2. A unique mutation is found in people in a small town in Italy. The mutation protects them from developing atherosclerosis, which is the dangerous buildup of fatty materials in blood vessels. The individual in which the mutation first appeared has even been identified.

Harmful Mutations

Imagine making a random change in a complicated machine such as a car engine. The chance that the random change would improve the functioning of the car is very small. The change is far more likely to result in a car that does not run well or perhaps does not run at all. By the same token, any random change in a gene's DNA is likely to result in a protein that does not function normally or may not function at all. Such mutations are likely to be harmful. Harmful mutations may cause genetic disorders or cancer.

- A **genetic disorder** is a disease caused by a mutation in one or a few genes. A human example is cystic fibrosis. A mutation in a single gene causes the body to produce thick, sticky mucus that clogs the lungs and blocks ducts in digestive organs. You can watch a video about cystic fibrosis and other genetic disorders at this link: http://www.youtube.com/watch?v=8s4he3wLgkM&feature=PlayList&p=397710758E9BCB24&playnext_from=PL&playnext=1&index=17 (9:31).
- **Cancer** is a disease in which cells grow out of control and form abnormal masses of cells. It is generally caused by mutations in genes that regulate the cell cycle. Because of the mutations, cells with damaged DNA

are allowed to divide without limits. Cancer genes can be inherited. You can learn more about hereditary cancer by watching the video at the following link: http://www.youtube.com/watch?v=LWk5FplsKwM (4:29)

Summary

- Mutations are essential for evolution to occur because they increase genetic variation and the potential for individuals to differ.
- The majority of mutations are neutral in their effects on the organisms in which they occur.
- Beneficial mutations may become more common through natural selection.
- Harmful mutations may cause genetic disorders or cancer.

Making Connections

MEDIA

Click image to the left for more content.

Practice I

Use these resources to answer the questions that follow.

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

1. Define genetic disorders.
2. What are the two primary types of genetic aberrations?

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

1. What are the results of a mutation or defect in a single gene?
2. Describe the causes and effects of cystic fibrosis, Huntington's Disease, and hemophilia.

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

1. What is a chromosomal disorder?
2. When and how do chromosomal errors occur?
3. Describe Cri-du-chat Syndrome and Down Syndrome.

Practice II

- **Test Neurofibromin Activity in a Cell** at http://learn.genetics.utah.edu/content/begin/dna/neurofibromin/.

Review

1. Why are mutations essential for evolution to occur?

2. What is a genetic disorder?

3. What is cancer?

References

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Plants

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Printed: June 7, 2013

Contents

CHAPTER 1 Plant Classification

- Explain how plants are classified.

Do all plants grow from seeds?

No, there are actually a few plants that do not make seeds. Whether or not a plant makes seeds is one criteria used to classify plants. How else could you distinguish between plants?

Plant Classification

Plants are formally divided into 12 phyla (plural for phylum), and these phyla are gathered into four groups (**Figure** 1.1). These four groups are based on the evolutionary history of significant features in plants:

1. **Nonvascular plants** evolved first. They are distinct from the algae because they keep the embryo inside of the reproductive structure after fertilization. These plants do not have vascular tissue to transport nutrients, water, and food.
2. **Seedless vascular plants** evolved to have vascular tissue after the nonvascular plants but do not have seeds.
3. **Gymnosperms** evolved to have seeds but do not have flowers.
4. Flowering plants, or **angiosperms**, evolved to have vascular tissue, seeds, and flowers.

Vocabulary

- **angiosperm**: Flowering plant with vascular tissue, seeds, and flowers.
- **gymnosperm**: Plant with vascular tissue and seeds but no flowers.
- **nonvascular plant**: Plant without vascular tissue.
- **seedless vascular plant**: Plant with vascular tissue but no seeds or flowers.

FIGURE 1.1
The plant kingdom contains a diversity of organisms.

Summary

- Nonvascular plants were the first plants to evolve and do not have vascular tissue.
- Seedless vascular plants have vascular tissue but do not have seeds.
- Gymnosperms have seeds but do not have flowers.
- Angiosperms have vascular tissue, seeds, and flowers.

Practice

Use the resource below to answer the questions that follow.

- **Plant Body Systems and Classification Part 1** at http://www.youtube.com/watch?v=6FnPVFPSt3A (7:21)

MEDIA

Click image to the left for more content.

1. What plant group/groups are included in non-vascular plants
2. What group/groups of plants have seeds?
3. What group/groups of plants have fruit?
4. Where do you usually find non-vascular plants? Why?
5. From what group of plants do we get "softwood"?

Review

1. What distinguishes the gymnosperms from other plants?
2. List the following major features of plants in the order they evolved: seeds, vascular tissue, flowers.

References

1. Clockwise from top left: David Gardiner Garcia; Mark Robinson (Flickr: me'nthedogs); Petr Kosina; Flickr: Akra_ciel; John Tann; Flickr: Flickred!; Flickr: helen.2006; Courtesy of Bruce Fritz, Agricultural Research Service; Flickr: CrazyModKimberli; Amadej Trnkoczy (Flickr: amadej2008); Pietro Zanarini (Flickr: zipckr); Flickr: buttersweet; Kristine Paulus; Maja Dumat (Flickr: blumenbiene). . Clockwise from top left: CC-BY-NC 2.0; CC-BY-NC 2.0; CC-BY-NC 2.0; CC-BY 2.0; CC-BY 2.0; CC-BY-NC 2.0; CC-BY-NC-SA 2.0; Public Domain; CC-BY-NC-SA 2.0; CC-BY-NC-SA 2.0; CC-BY 2.0; CC-BY-NC-SA 2.0; CC-BY 2.0; CC-BY 2.0

Chapter 2 Plants' Adaptations for Life on Land

- Describe plants' major adaptations for life on land.

Where did plants come from?

Plants have not always been around on land. For a long time, life was confined to water. The first plants evolved from green algae that looked somewhat like the *Chara* pictured above.

Plants' Adaptations for Life on Land

The first photosynthetic organisms lived in the water. So, where did plants come from? Evidence shows that plants evolved from freshwater green algae, a protist (**Figure** 2.1). The similarities between green algae and plants is one piece of evidence. They both have cellulose in their cell walls, and they share many of the same chemicals that give them color. So what separates green algae from green plants?

There are four main ways that plants adapted to life on land and, as a result, became different from algae:

1. In plants, the embryo develops inside of the female plant after fertilization. Algae do not keep the embryo inside of themselves but release it into water. This was the first feature to evolve that separated plants from green algae. This is also the only adaptation shared by all plants.
2. Over time, plants had to evolve from living in water to living on land. In early plants, a waxy layer called a **cuticle** evolved to help seal water in the plant and prevent water loss. However, the cuticle also prevents gases from entering and leaving the plant easily. Recall that the exchange of gasses—taking in carbon dioxide and releasing oxygen—occurs during photosynthesis.

FIGURE 2.1
The ancestor of plants is green algae. This picture shows a close up of algae on the beach.

3. To allow the plant to retain water and exchange gases, small pores (holes) in the leaves called **stomata** also evolved (**Figure** 2.2). The stomata can open and close depending on weather conditions. When it's hot and dry, the stomata close to keep water inside of the plant. When the weather cools down, the stomata can open again to let carbon dioxide in and oxygen out.
4. A later adaption for life on land was the evolution of vascular tissue. **Vascular tissue** is specialized tissue that transports water, nutrients, and food in plants. In algae, vascular tissue is not necessary since the entire body is in contact with the water, and the water simply enters the algae. But on land, water may only be found deep in the ground. Vascular tissues take water and nutrients from the ground up into the plant, while also taking food down from the leaves into the rest of the plant. The two vascular tissues are xylem and phloem. **Xylem** is responsible for the transport of water and nutrients from the roots to the rest of the plant. **Phloem** carries the sugars made in the leaves to the parts of the plant where they are needed.

Vocabulary

- **cuticle**: Waxy layer that prevents water loss.
- **phloem**: Tube that carries the sugars from the leaves to the other parts of the plant.
- **stomata**: Small pores (holes) in the leaves.
- **vascular tissue**: Specialized tissue that transports water, nutrients, and food in plants.
- **xylem**: Tube that transports water and nutrients from the roots to the rest of the plant.

Summary

- Plants evolved from freshwater green algae.
- Plants have evolved several adaptations to life on land, including embryo retention, a cuticle, stomata, and vascular tissue.

Practice

Use the resources below to answer the questions that follow.

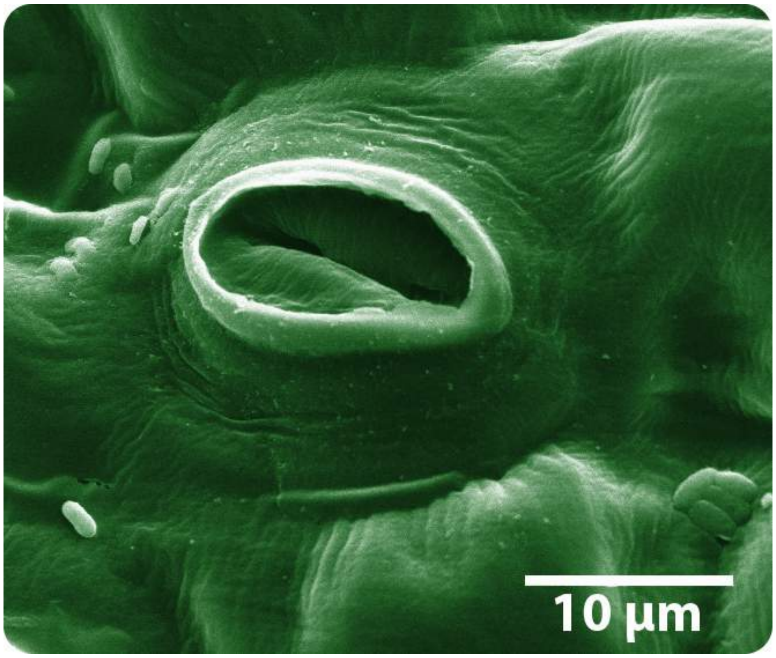

FIGURE 2.2
Stomata are pores in leaves that allow gasses to pass through, but they can be closed to conserve water.

- **The Role of Xylem Tissue and Stomata** at http://www.youtube.com/watch?v=QBMkiLIyETc (3:34)

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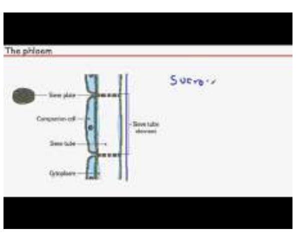
- **The Phloem** at http://www.youtube.com/watch?v=M4onP3_4ERU (3:03)



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1. In what groups of plants do you find xylem and phloem? Hint: refer to previous lesson if necessary.
2. What are the main components of sap?
3. Compare and contrast xylem and phloem.
    a. What does each transport?
    b. How are their structures similar?
    c. How are their structures different?
4. What is "transpirational pull"? How is it key to the functioning of xylem?

Review

1. How are plants different from green algae? How are they the same?
2. What is the purpose of vascular tissue?

References

1. Flickr: solarshakti. . CC-BY 2.0
2. Dartmouth Electron Microscope Facility, colorized by Photohound (Wikimedia). . Public Domain

CHAPTER 3 Gymnosperms

- Define and give examples of gymnosperms.

What does "gymnasium" mean?

Today a gymnasium means a place for playing indoor sports. In ancient Greece, sports were done in the nude, so the word "gymnasium" is based on the Greek word for naked (gymnos). The root word is the same for "gymnosperm," which means "naked seed." Gymnosperms are those plants that do not have a fruit encasing the seed.

Gymnosperms

Gymnosperms have seeds, but they do not produce fruit. Instead, the seeds of gymnosperms are usually found in cones.

There are four phyla of gymnosperms:

1. Conifers
2. Cycads
3. Ginkgoes
4. Gnetophytes

Conifers

Conifers, members of the phylum *Coniferophyta*, are probably the gymnosperms that are most familiar to you. Conifers include trees such as pines, firs, spruces, cedars, and the coastal redwood trees in California, which are the tallest living vascular plants.

Conifers have their reproductive structures in cones, but they are not the only plants to have that trait (**Figure** 3.1). Conifer pollen cones are usually very small, while the seed cones are larger. **Pollen** contains gametophytes that produce the male gamete of seed plants. The pollen, which is a powder-like substance, is carried by the wind to fertilize the seed cones that contain the female gamete (**Figure** 3.2).

FIGURE 3.1
A red pine, which bears seeds in cones, is an example of a conifer.

FIGURE 3.2
The end of a pine tree branch bears the male cones that produce the pollen.

Conifers have many uses. They are important sources of lumber and are also used to make paper. Resins, the sticky substance you might see oozing out of a wound on a pine tree, are collected from conifers to make a variety of products, such as the solvent turpentine and the rosin used by musicians and baseball players. The sticky rosin improves the pitcher's hold on the ball or increases the friction between the bow and the strings to help create music from a violin or other stringed instrument.

Cycads

Cycads, in the phylum *Cycadophyta*, are also gymnosperms. They have large, finely-divided leaves and grow as short shrubs and trees in tropical regions. Like conifers, they produce cones, but the seed cones and pollen cones are always on separate plants (**Figure** 3.3). One type of cycad, the Sago Palm, is a popular landscape plant. During the Age of the Dinosaurs (about 65 to 200 million years ago), cycads were the dominant plants. So you can imagine dinosaurs grazing on cycad seeds and roaming through cycad forests.

FIGURE 3.3
Cycads bear their pollen and seeds in cones on separate plants.

Ginkgoes

Ginkgoes, in the phylum *Ginkgophyta*, are unique because they are the only species left in the phylum. Many other species in the fossil record have gone extinct (**Figure** 3.4). The ginkgo tree is sometimes called a "living fossil" because it is the last species from its phylum.

One reason the ginkgo tree may have survived is because it was often grown around Buddhist temples, especially in China. The ginkgo tree is also a popular landscape tree today in American cities because it can live in polluted areas better than most plants.

Ginkgoes, like cycads, has separate female and male plants. The male trees are usually preferred for landscaping because the seeds produced by the female plants smell terrible when they ripen.

Gnetophytes

Gnetophytes, in the phylum *Gnetophyta*, are a very small and unusual group of plants. *Ephedra* is an important member of this group, since this desert shrub produces the ephedrine used to treat asthma and other conditions. *Welwitschia* produces extremely long leaves and is found in the deserts of southwestern Africa (**Figure** 3.5). Overall, there are about 70 different species in this diverse phylum.

FIGURE 3.4
Ginkgo trees are gymnosperms with broad leaves.

FIGURE 3.5
One type of gnetophyte is *Welwitschia*.

Vocabulary

- **conifer**: Plant that bears seeds in cones and has evergreen needlelike or scalelike leaves.
- **cycad**: Palmlike plant bearing large male or female cones and found in tropical regions.
- **ginkgo**: Chinese tree with broad, fan-shaped leaves.
- **gnetophyte**: Subdivision of woody plants consisting of three living genera and approximately 70 species; link between conifers and angiosperms.
- **pollen**: Powder-like substance; it contains gametophytes that produce the male gamete of seed plants.

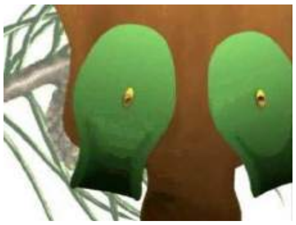
Summary

- Gymnosperms have seeds, but they do not produce fruit; the seeds of gymnosperms are usually found in cones.
- There are four phyla of gymnosperms: conifers, cycads, ginkgoes, and gnetophytes.

Practice

Use the resources below to answer the questions that follow.

- **Seed Production in Gymnosperm** at http://www.youtube.com/watch?v=D9byVQxvMXs (1:37)



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- **Gymnosperms** at http://www.youtube.com/watch?v=zKnrlUI85ys (4:31)

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1. Which division of gymnosperm has the most living species?
2. Where are cycads most abundant?
3. Where are conifers most abundant?
4. What are the characteristics of conifers? Explain their patterns of abundance.
5. What climate change led to conifers becoming more abundant than ferns? When did this occur?

Review

1. What features define the gymnosperms?
2. How are the conifers different from the cycads?

References

1. Keith Kanoti, Maine Forest Service, USA. . CC-BY 3.0
2. John Haslam (Flickr: foxypar4). . CC-BY 2.0
3. Glenn Fleishman. . CC-BY 2.0
4. Flickr: .Bambo.. . CC-BY-NC-SA 2.0
5. Matthew Reyes (Flickr: motorbikematt). One type of gnetophyte is "Welwitschia". CC-BY-NC 2.0

CHAPTER 4 Angiosperms

- Define angiosperms and the parts of the flower.

Why do plants make fruit?

When this bird eats a berry, it also consumes the seeds contained inside. The bird may fly for many miles before digestion is complete and the seeds are excreted. This allows the plant to spread its seeds to a new location. For this reason, plants that make fruits have been very successful.

Angiosperms

Angiosperms, in the phylum *Anthophyta*, are the most successful phylum of plants. This category also contains the largest number of individual plants (**Figure** 4.1). Angiosperms evolved the structure of the flower, so they are also called the flowering plants. Angiosperms live in a variety of different environments. A water lily, an oak tree, and a barrel cactus, although different, are all angiosperms.

The Parts of a Flower

Even though flowers may look very different from each other, they do have some structures in common. The structures are explained in the picture below (**Figure** 4.2).

- The green outside of a flower that often looks like a leaf is called the **sepal** (**Figure** 4.3). All of the sepals together are called the **calyx**, which is usually green and protects the flower before it opens.
- All of the petals (**Figure** 4.3) together are called the **corolla**. They are bright and colorful to attract a particular **pollinator**, an animal that carries pollen from one flower to another. Examples of pollinators include birds and insects.

FIGURE 4.1
Angiosperms are the flowering plants.

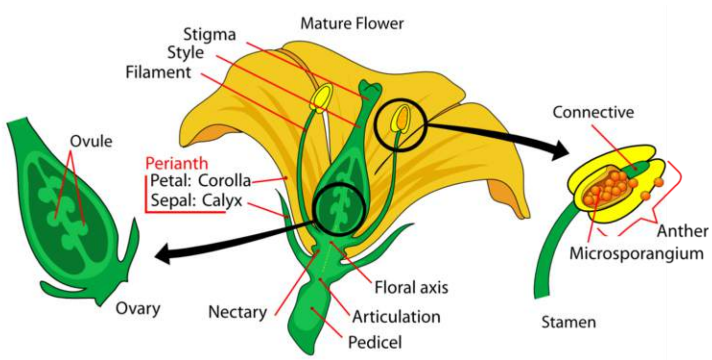

FIGURE 4.2
A complete flower has sepals, petals, stamens, and one or more carpels.

- The next structure is the **stamen**, consisting of the stalk-like **filament** that holds up the **anther**, or pollen sac. The **pollen** is the male gametophyte.
- At the very center is the **carpel,** which is divided into three different parts: (1) the sticky **stigma**, where the pollen lands, (2) the tube of the **style**, and (3) the large, bottom part, known as the **ovary**.

The ovary holds the **ovules**, the female gametophytes. When the ovules are fertilized, the ovule becomes the seed and the ovary becomes the fruit.

The following table summarizes the parts of the flower (**Table** 4.1).

TABLE 4.1: Parts of a Flower

Flower part	Definition
sepals	The green outside of the flower.
calyx	All of the sepals together, or the outside of the flower.
corolla	The petals of a flower collectively.
stamens	The part of the flower that produces pollen.
filament	Stalk that holds up the anther.

TABLE 4.1: (continued)

Flower part	Definition
anther	The structure that contains pollen in a flower.
carpel	"Female" part of the flower; includes the stigma, style, and ovary.
stigma	The part of the carpel where the pollen must land for fertilization to occur.
style	Tube that makes up part of the carpel.
ovary	Large bottom part of the carpel where the ovules are contained.
ovules	Part of the ovary that is the female gametophyte and that after fertilization becomes the seed.

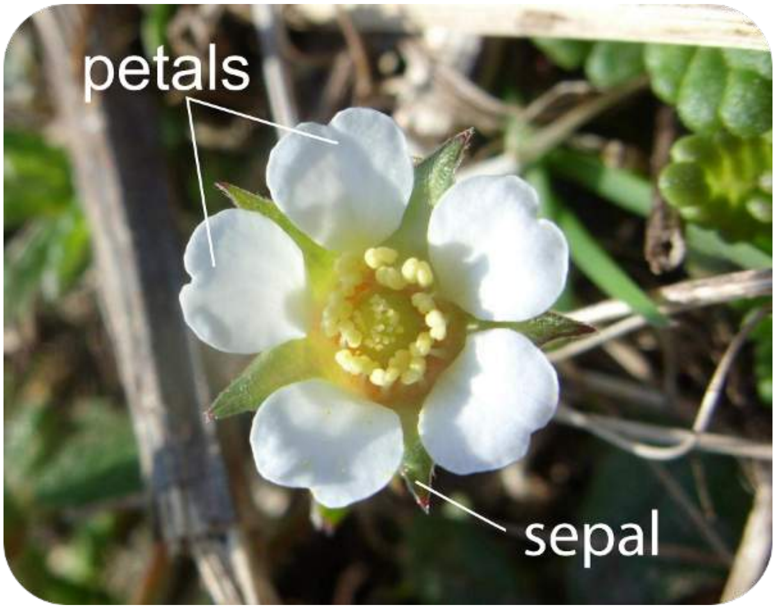

FIGURE 4.3
This image shows the difference between a petal and a sepal.

How Do Angiosperms Reproduce?

Flowering plants can reproduce two different ways:

1. Self-pollination: Pollen falls on the stigma of the same flower. This way, a seed will be produced that can turn into a genetically identical plant.
2. Cross-fertilization: Pollen from one flower travels to a stigma of a flower on another plant. Pollen travels from flower to flower by wind or by animals. Flowers that are pollinated by animals such as birds, butterflies, or bees are often colorful and provide nectar, a sugary reward, for their animal pollinators.

Why Are Angiosperms Important to Humans?

Angiosperms are important to humans in many ways, but the most significant role of angiosperms is as food. Wheat, rye, corn, and other grains are all harvested from flowering plants. Starchy foods, such as potatoes, and legumes, such as beans, are also angiosperms. And, as mentioned previously, fruits are a product of angiosperms that increase seed dispersal and are nutritious.

There are also many non-food uses of angiosperms that are important to society. For example, cotton and other plants are used to make cloth, and hardwood trees are used for lumber.

Vocabulary

- **angiosperms**: Plants that produce flowers and fruits.
- **anther**: Structure that contains pollen in a flower.
- **calyx**: All of the sepals together, or the outside of the flower.
- **carpel**: “Female” part of the flower; it includes the stigma, style, and ovary.
- **corolla**: Petals of a flower collectively.
- **cross-fertilization**: Pollen from one flower travels to a stigma of a flower on another plant.
- **filament**: Stalk that holds up the anther.
- **ovary**: Large, bottom part of the carpel where the ovules are contained.

- **ovules**: Part of the ovary that is the female gametophyte; after fertilization, ovules become the seed.
- **pollen**: Powder-like substance; it contains gametophytes that produce the male gamete of seed plants.
- **pollinator**: Animal, such as a bird or an insect, that carries pollen from one flower to another.
- **self-pollination**: Pollen falls on the stigma of the same flower.
- **sepal**: Green outside of the flower.
- **stamen**: Part of the flower that produces pollen.
- **stigma**: Part of the carpel on which the pollen must land for fertilization to occur.
- **style**: Tube that makes up part of the carpel.

Summary

- Angiosperms are plants that produce flowers and fruit.
- Angiosperms can be self-pollinated, meaning pollen falls on the stigma of the same flower, or cross-fertilized, during which pollen from one flower travels to a stigma of a flower on another plant.

Practice

Use the resource below to answer the questions that follow.

- **Angiosperms: The Secrets of Flowers** at http://www.youtube.com/watch?v=sr4Khc7BUzA (5:46)

MEDIA
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1. How many species of angiosperms exist today?
2. How many species of gymnosperm exist today?
3. When did angiosperms become the most abundant type of plant on the planet?
4. When do angiosperms grow fruit?
5. Where are the sex organs of angiosperms located?
6. What is the difference between a superior and inferior ovary?

Review

1. How are angiosperms like gymnosperms? How are they different?
2. What makes up the female part of the flower? The male part?

References

1. Flickr: reebs*. Angiosperms are the flowering plants. CC-BY 2.0
2. Mariana Ruiz Villarreal (LadyofHats). . Public Domain
3. Flickr: joysaphine. . CC-BY-NC 2.0

CHAPTER 5 Plant Hormones

- List the major types of plant hormones and the main functions of each.

How do fruits know when to fall?

Fruits, such as these peaches, do not leave their trees until it's the right time. The seeds are mature, and the fruit is ripe. But what tells the fruits it's time to drop? The signal that is sent through the tree is a type of hormone. Hormones also send signals through your body.

Plant Hormones

Plants may not move, but that does not mean they don't respond to their environment. Plants can sense gravity, light, touch, and seasonal changes. For example, you might have noticed how a house plant bends toward a bright window. Plants can sense and then grow toward the source of light. Scientists say that plants are able to respond to "stimuli," or something—usually in the environment—that results in a response. For instance, light is the stimulus, and the plant moving toward the light is the "response."

Hormones are special chemical messengers that help plants respond to stimuli in their environment. In order for plants to respond to the environment, their cells must be able to communicate with other cells. Hormones send messages between the cells. Animals, like humans, also have hormones, such as testosterone or estrogen, to carry messages from cell to cell. In both plants and animals, hormones travel from cell to cell in response to a stimulus; they also activate a specific response.

Types of Plant Hormones

Five different types of plant hormones are involved in the main responses of plants, and they each have different functions (**Table** 5.1).

TABLE 5.1: Plant Hormones

Hormone	Function
Ethylene	Fruit ripening and abscission
Gibberellins	Break the dormancy of seeds and buds; promote growth
Cytokinins	Promote cell division; prevent senescence
Abscisic Acid	Close the stomata; maintain dormancy
Auxins	Involved in tropisms and apical dominance

Ethylene

The hormone **ethylene** has two functions. It (1) helps ripen fruit and (2) is involved in the process of **abscission**, the dropping of leaves, fruits, and flowers. When a flower is done blooming or a fruit is ripe and ready to be eaten, ethylene causes the petals or fruit to fall from a plant (**Figure** 5.1 and **Figure** 5.2).

Ethylene is an unusual plant hormone because it is a gas. That means it can move through the air, and a ripening apple can cause another apple to ripen, or even over-ripen. That's why one rotten apple spoils the whole barrel! Some farmers spray their green peppers with ethylene gas to cause them to ripen faster and become red peppers.

You can try to see how ethylene works by putting a ripe apple or banana with another unripe fruit in a closed container or paper bag. What do you think will happen to the unripe fruit?

FIGURE 5.1
The hormone ethylene is signaling these tomatoes to ripen.

Gibberellins

Gibberellins are hormones that cause the plant to grow. When gibberellins are applied to plants by scientists, the stems grow longer. Some gardeners or horticulture scientists add gibberellins to increase the growth of plants.

FIGURE 5.2
The hormone ethylene causes flower petals to fall from a plant, a process known as abscission.

Dwarf plants (small plants), on the other hand, have low levels of gibberellins (**Figure** 5.3). Another function of gibberellins is to stop **dormancy** (resting time) of seeds and buds. Gibberellins signal that it's time for a seed to **germinate** (sprout) or for a bud to open.

FIGURE 5.3
Dwarf plants like this bonsai tree often have unusually low concentrations of gibberellins.

Cytokinins

Cytokinins are hormones that cause plant cells to divide. Cytokinins were discovered from attempts to grow plant tissue in artificial environments (**Figure** 5.4). Cytokinins prevent the process of aging. So florists sometimes apply cytokinins to cut flowers, so they do not get old and die.

FIGURE 5.4
Cytokinins promote cell division and are necessary for growing plants in tissue culture. A small piece of a plant is placed in sterile conditions to regenerate a new plant.

Abscisic Acid

Abscisic acid is misnamed because it was once believed to play a role in abscission (the dropping of leaves, fruits, and flowers), but we now know abscission is caused by ethylene. The actual role of abscisic acid is to close the stomata, the tiny openings in leaves that allow substances to enter and leave, and to maintain dormancy. When a plant is stressed due to lack of water, abscisic acid tells the stomata to close. This prevents water loss through the stomata.

When the environment is not good for a seed to germinate, abscisic acid signals for the dormancy period of the seed to continue. Abscisic acid also tells the buds of plants to stay in the dormancy stage. When conditions improve, the levels of abscisic acid drop and the levels of gibberellins increase, signaling that is time to break dormancy (**Figure** 5.5).

Auxins

Auxins are hormones that play a role in plant growth. Auxins produced at the tip of the plant are involved in **apical dominance**, when the main central stem grows more strongly than other stems and branches. When the tip of the plant is removed, the auxins are no longer present, and the side branches begin to grow. This is why pruning a plant by cutting off the main branches helps produce a fuller plant with more branches. You actually need to cut branches off of a plant for it to grow more branches! Auxins are also involved in tropisms, responses to stimuli in the environment

Vocabulary

- **abscisic acid**: Hormone involved in the closing of the stomata and maintaining dormancy.

FIGURE 5.5
A decrease in levels of abscisic acid allows these buds to break dormancy and put out leaves.

- **abscission**: Dropping of leaves, fruits, and flowers.
- **apical dominance**: How the main central stem grows more strongly than other stems and branches.
- **auxin**: Hormone involved in tropisms and apical dominance.
- **cytokinin**: Hormone that promotes cell division and prevents senescence.
- **dormancy**: Resting stage.
- **ethylene**: Hormone involved in fruit ripening and abscission.
- **germinate**: Causing a seed to start to sprout.
- **gibberellin**: Hormone involved in breaking the dormancy of seeds and buds and promoting growth.
- **hormone**: Chemical messengers that allow organisms to respond to stimuli in their environment.

Summary

- Plant hormones are chemical signals that control different processes in plants.
- Plant hormones include ethylene, gibberellins, cytokinins, abscisic acid, and auxins.

Practice

Use the resource below to answer the questions that follow.

- **Plant Hormones** at http://www.youtube.com/watch?v=ZbRiKlIYa-k (5:39)

1. What hormones stimulate plant growth?
2. What hormones inhibit plant growth?
3. Why is it important for a plant to be able to both stimulate and inhibit growth? Think carefully and explain your answer fully.
4. Do you think hormones are more important to plants or mammals? Explain your thinking and support your reasoning.

Review

1. Explain how hormones are involved in seed germination.
2. What hormone is involved in fruit ripening?

References

1. Todd Petit (Flickr: starmist1). . CC-BY 2.0
2. Sarah Cady. . CC-BY-NC-SA 2.0
3. Sheila Thomson (Flickr: sheilaellen). . CC-BY 2.0
4. Image copyright Zenphotography, 2011. . Used under license from Shutterstock.com
5. Martin LaBar. . CC-BY-NC 2.0

CHAPTER 6 Seeds and Seed Dispersal

- Describe the importance of the seed, and explain how seeds are dispersed.

Why are seeds important?

Many important crops, such as corn, are planted and harvested as seeds. These seeds are important sources of food. For example, corn is ground into feed for chickens and cows. And corn syrup is used to sweeten beverages and candy.

Seeds and Seed Dispersal

Plants seem to grow wherever they can. How? Plants can't move on their own. So how does a plant start growing in a new area?

What is a Seed?

If you've ever seen a plant grow from a tiny seed, then you might realize that seeds are amazing structures. A **seed** is a plant ovule containing an embryo. The seed allows a plant embryo to survive droughts, harsh winters, and other conditions that would kill an adult plant. The tiny plant embryo can simply stay **dormant**, in a resting state, and wait for the perfect environment to begin to grow. In fact, some seeds can stay dormant for hundreds of years!

Another impressive feature of the seed is that it stores food for the young plant after it sprouts. This greatly increases the chances that the tiny plant will survive. So being able to produce a seed is a beneficial adaptation, and, as a result, seed plants have been very successful. Although the seedless plants were here on Earth first, today there are many more seed plants than seedless plants.

How are Seed Plants Successful?

For a seed plant species to be successful, the seeds must be **dispersed**, or scattered around in various directions. If the seeds are spread out in many different areas, there is a better chance that some of the seeds will find the right conditions to grow. But how do seeds travel to places they have never been before? To aid with seed dispersal, some plants have evolved special features that help their seeds travel over long distances.

One such strategy is to allow the wind to carry the seeds. With special adaptations in the seeds, the seeds can be carried long distances by the wind. For example, you might have noticed how the "fluff" of a dandelion moves in the wind. Each piece of fluff carries a seed to a new location. If you look under the scales of pine cone, you will see tiny seeds with "wings" that allow these seeds to be carried away by the wind. Maple trees also have specialized fruits with wing-like parts that help seed dispersal (**Figure** 6.1).

FIGURE 6.1
Maple trees have fruits with “wings” that help the wind disperse the seeds.

Some flowering plants grow fleshy fruit that helps disperse their seeds. When animals eat the fruit, the seeds pass through an animal’s digestive tract unharmed. The seeds germinate after they are passed out with the animal’s feces. Berries, citrus fruits, cherries, apples, and a variety of other types of fruits are all adapted to be attractive to animals, so the animals will eat them and disperse the seed (**Figure** 6.2). Some non-fleshy fruits are specially adapted for animals to carry them on their fur. You might have returned from a walk in the woods to find burrs stuck to your socks. These burrs are actually specialized fruits designed to carry seeds to a new location.

Vocabulary

- **disperse**: To scatter in different directions.
- **dormant**: In a resting state.
- **seed**: Plant ovule containing an embryo.

Summary

- The seed contains a dormant embryo and stored food.
- Fruits are adapted to disperse seeds with the help of animals or the wind.

Practice

Use the resource below to answer the questions that follow.

FIGURE 6.2
Fleshy fruits aid in seed dispersal, since animals eat the fruits and carry the seeds to a new location.

- **Fruit and Seed Dispersal** at http://www.youtube.com/watch?v=mGAeS8JuyBM (6:08)

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Click image to the left for more content.

1. What are four mechanisms of seed and fruit dispersal?
2. What is the difference between a true fruit and a false fruit?
3. What mechanism of fruit and seed dispersal was not available to plants before the development of angiosperms?
4. Name five ways that animals disperse fruit and seeds?
5. What causes the "explosion" for the explosive dispersal of seeds?

Review

1. Why was the evolution of the seed so beneficial to plants?
2. What are two ways that fruits are adapted to disperse seeds?

References

1. Laura Harris (Flickr: Imajilon). . CC-BY 2.0
2. Flickr: heydrienne. . CC-BY 2.0

CHAPTER 7 Roots

- Outline the structure, function, and growth of roots.

Now those are some serious roots. But what exactly are roots?

There are taproots and fibrous roots, primary roots and secondary roots. And they always seem to know which way to grow. Roots are very special plant organs. How and why?

Roots

Plants have specialized organs that help them survive and reproduce in a great diversity of habitats. Major organs of most plants include roots, stems, and leaves.

Roots are important organs in all vascular plants. Most vascular plants have two types of roots: **primary roots** that grow downward and **secondary roots** that branch out to the side. Together, all the roots of a plant make up a **root system**.

Root Systems

There are two basic types of root systems in plants: taproot systems and fibrous root systems. Both are illustrated in **Figure** 7.1.

- **Taproot systems** feature a single, thick primary root, called the **taproot**, with smaller secondary roots growing out from the sides. The taproot may penetrate as many as 60 meters (almost 200 feet) below the ground surface. It can plumb very deep water sources and store a lot of food to help the plant survive drought and other environmental extremes. The taproot also anchors the plant very securely in the ground.
- **Fibrous root systems** have many small branching roots, called **fibrous roots**, but no large primary root. The huge number of threadlike roots increases the surface area for absorption of water and minerals, but fibrous roots anchor the plant less securely.

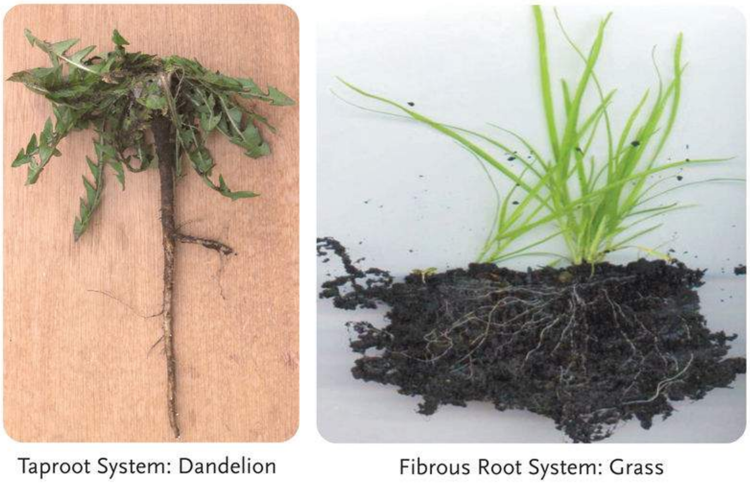

FIGURE 7.1
Dandelions have taproot systems; grasses have fibrous root systems.

Root Structures and Functions

As shown in **Figure** 7.2, the tip of a root is called the **root cap**. It consists of specialized cells that help regulate primary growth of the root at the tip. Above the root cap is primary meristem, where growth in length occurs.

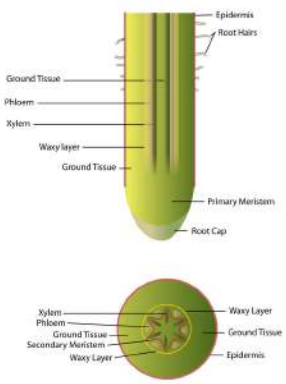

FIGURE 7.2
A root is a complex organ consisting of several types of tissue. What is the function of each tissue type?

Above the meristem, the rest of the root is covered with a single layer of epidermal cells. These cells may have **root hairs** that increase the surface area for the absorption of water and minerals from the soil. Beneath the epidermis is ground tissue, which may be filled with stored starch. Bundles of vascular tissues form the center of the root. Waxy layers waterproof the vascular tissues so they don't leak, making them more efficient at carrying fluids. Secondary meristem is located within and around the vascular tissues. This is where growth in thickness occurs.

The structure of roots helps them perform their primary functions. What do roots do? They have three major jobs: absorbing water and minerals, anchoring and supporting the plant, and storing food.

1. Absorbing water and minerals: Thin-walled epidermal cells and root hairs are well suited to absorb water and dissolved minerals from the soil. The roots of many plants also have a mycorrhizal relationship with fungi for greater absorption.
2. Anchoring and supporting the plant: Root systems help anchor plants to the ground, allowing plants to grow tall without toppling over. A tough covering may replace the epidermis in older roots, making them ropelike and even stronger. As shown in **Figure** 7.3, some roots have unusual specializations for anchoring plants.

3. Storing food: In many plants, ground tissues in roots store food produced by the leaves during photosynthesis. The bloodroot shown in **Figure** 7.3 stores food in its roots over the winter.

FIGURE 7.3
Mangrove roots are like stilts, allowing mangrove trees to rise high above the water. The trunk and leaves are above water even at high tide. A bloodroot plant uses food stored over the winter to grow flowers in the early spring.

Root Growth

Roots have primary and secondary meristems for growth in length and width. As roots grow longer, they always grow down into the ground. Even if you turn a plant upside down, its roots will try to grow downward. How do roots "know" which way to grow? How can they tell down from up? Specialized cells in root caps are able to detect gravity. The cells direct meristem in the tips of roots to grow downward toward the center of Earth. This is generally adaptive for land plants. Can you explain why?

As roots grow thicker, they can't absorb water and minerals as well. However, they may be even better at transporting fluids, anchoring the plant, and storing food (see **Figure** 7.4).

Summary

- Roots absorb water and minerals and transport them to stems. They also anchor and support a plant, and store food.
- A root system consists of primary and secondary roots.
- Each root is made of dermal, ground, and vascular tissues.
- Roots grow in length and width from primary and secondary meristem.

FIGURE 7.4
Secondary growth of sweet potato roots provides more space to store food. Roots store sugar from photosynthesis as starch. What other starchy roots do people eat?

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology→ Non-Majors Biology → Search: **Plant Organs and Systems**

1. Which organs comprise the plant's vegetative system?
2. Describe the roles of the organs of the vegetative system.
3. Compare primary roots to lateral roots.
4. What is the main role of roots?
5. What are additional roles of roots?

Review

1. What are root hairs? What is their role?
2. Identify three major functions of roots.
3. Contrast a taproot system with a fibrous root system.
4. Explain how roots "know" which way to grow.

References

1. Taproot: Rasbak; Fibrous: Tobias Geberth. . Taproot: GNU-FDL 1.2; Fibrous: CC-BY-SA 2.5
2. Top: Cehagenmerak; Bottom: JoJan; modified by CK-12 Foundation. . Top: GNU-FDL 1.2; Bottom: GNU-FDL 1.2.
3. Mangrove: Cesar Paes Barreto; Bloodroot: William Curtis. . Mangrove: The copyright holder of this work allows anyone to use it for any purpose including unrestricted redistribution, commercial use, and modification; Bloodroot: Public Domain
4. Miya. . GNU-FDL 1.2

Chapter 8 Stems

- Outline the structure, function and growth of stems.

How does water get up? How does sugar move down?

What structures hold the plant upright? Are tree trunks also stems? Of course they are. Trees don't start out big and tall - they grow from small plants to large trees. And it is these stems that allow them to grow upright. So, obviously the stem is very important and has numerous functions.

Stems

In vascular plants, **stems** are the organs that hold plants upright so they can get the sunlight and air they need. Stems also bear leaves, flowers, cones, and secondary stems. These structures grow at points called **nodes** (shown in **Figure** 8.1). At each node, there is a bud of meristem tissue that can divide and specialize to form a particular structure.

Another vital function of stems is transporting water and minerals from roots to leaves and carrying food from leaves to the rest of the plant. Without this connection between roots and leaves, plants could not survive high above ground in the air. In many plants, stems also store food or water during cold or dry seasons.

Stem Diversity

Stems show variation because many stems are specialized. **Figure** 8.2 shows examples of stem specialization. With specialized stems, plants can exploit a diversity of niches in virtually all terrestrial ecosystems.

Stem Tissues and Functions

Like roots, the stems of vascular plants are made of dermal, vascular, and ground tissues.

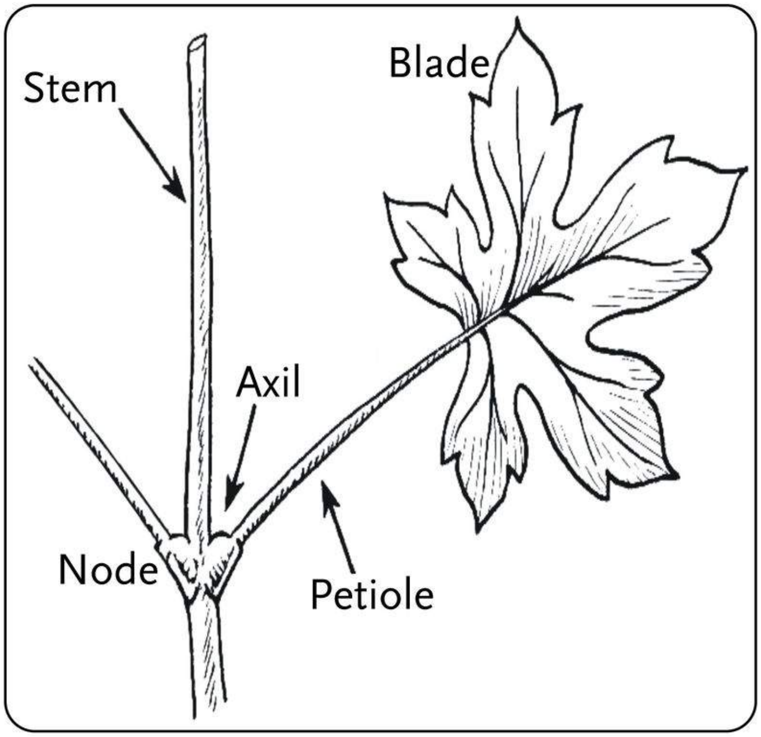

FIGURE 8.1
The stem of a vascular plant has nodes where leaves and other structures may grow.

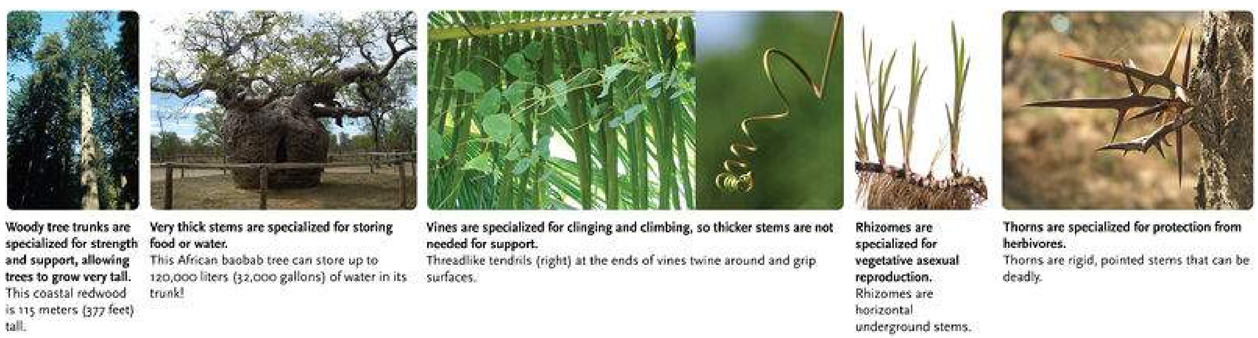

FIGURE 8.2
Stem specializations such as these let plants grow in many different habitats.

- A single-celled layer of epidermis protects and waterproofs the stem and controls gas exchange.
- In trees, some of the epidermal tissue is replaced by bark. **Bark** is a combination of tissues that provides a tough, woody external covering on the stems of trees. The inner part of bark is alive and growing; the outer part is dead and provides strength, support, and protection.
- Ground tissue forms the interior of the stem. The large **central vacuoles** of ground tissue cells fill with water to support the plant. The cells may also store food.
- Bundles of vascular tissue run through the ground tissue of a stem and transport fluids. Plants may vary in

how these bundles are arranged.

Stem Growth

The stems of all vascular plants get longer through primary growth. This occurs in primary meristem at the tips and nodes of the stems. Most stems also grow in thickness through secondary growth. This occurs in secondary meristem, which is located in and around the vascular tissues. Secondary growth forms secondary vascular tissues and bark. In many trees, the yearly growth of new vascular tissues results in an annual growth ring like the one in **Figure** 8.3. When a tree is cut down, the rings in the trunk can be counted to estimate the tree's age.

FIGURE 8.3
The number of rings in this cross-section of tree trunk show how many years the tree lived. What does each ring represent?

Summary

- Stems hold plants upright, bear leaves and other structures, and transport fluids between roots and leaves.
- Like roots, stems contain dermal, ground, and vascular tissues.
- Trees have woody stems covered with bark.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology→ Non-Majors Biology → Search: **Plant Organs and Systems**

1. Which organs comprise the plant's vegetative system?
2. Where are stems located?

3. What are the roles of stems?

Review

1. Describe two types of specialized stems. What is each type of stem specialized for?
2. What is bark? What purposes does it serve?
3. Apply lesson concepts to predict how the stem of a desert plant might be specialized for its environment.

References

1. Pearson Scott Foresman. . Public Domain
2. From left to right: courtesy of National Park Service; Whinging Pom; Arria Belli; Jon Sullivan; image copyright dabjola, 2010; Luis Fernández García;. . From left to right: Public Domain; CC-BY-SA 2.0; GNU-FDL 1.2; Public Domain; used under license from Shuttesrtock.com; CC-BY-SA 2.1 Spain;
3. MPF. . GNU-FDL 1.2

CHAPTER 9 Leaves

- Describe the structure and function of leaves.

Could life exist without the leaf?

A leaf looks so simple. But it is actually a very complex structure. And it may be one of the most important organs in all kingdoms. Life as we know it could not exist without leaves. Why? One word: photosynthesis.

Leaves

Plants have specialized organs that help them survive and reproduce in a great diversity of habitats. Major organs of most plants include roots, stems, and leaves. **Leaves** are the keys not only to plant life but to all terrestrial life. The primary role of leaves is to collect sunlight and make food by **photosynthesis**. Despite the fundamental importance of the work they do, there is great diversity in the leaves of plants. However, given the diversity of habitats in which plants live, it's not surprising that there is no single best way to collect solar energy for photosynthesis.

Leaf Variation

Leaves may vary in size, shape, and their arrangement on stems. Nonflowering vascular plants have three basic types of leaves: **microphylls** ("tiny leaves"), **fronds**, and **needles**. **Figure** 9.1 describes each type.

FIGURE 9.1
Leaf variation in nonflowering plants reflects their evolutionary origins. Can you explain how?

Flowering vascular plants also have diverse leaves. However, the leaves of all flowering plants have two basic parts in common: the blade and petiole (See opening image). The **blade** of the leaf is the relatively wide, flat part of the leaf that gathers sunlight and undergoes photosynthesis. The **petiole** is the part that attaches the leaf to a stem of the plant. This occurs at a node.

Flowering plant leaves vary in how the leaves are arranged on the stem and how the blade is divided. This is illustrated in **Figure** 9.2. Generally, the form and arrangement of leaves maximizes light exposure while conserving water, reducing wind resistance, or benefiting the plant in some other way in its particular habitat.

- Leaves arranged in whorls encircle upright stems at intervals. They collect sunlight from all directions.
- Leaves arranged in basal rosettes take advantage of warm temperatures near the ground.
- Leaves arranged in alternate or opposing pairs collect light from above. They are typically found on plants with a single, upright stem.
- The blades of simple leaves are not divided. This provides the maximum surface area for collecting sunlight.
- The blades of compound leaves are divided into many smaller leaflets. This reduces wind resistance and water loss.

Seasonal Changes in Leaves

Even if you don't live in a place where leaves turn color in the fall, no doubt you've seen photos of their "fall colors" (see **Figure** 9.3). The leaves of many plants turn from green to other, glorious colors during autumn each year. The change is triggered by shorter days and cooler temperatures. Leaves respond to these environmental stimuli by producing less **chlorophyll**. This allows other leaf pigments—such as oranges and yellows—to be seen.

After leaves turn color in the fall, they may all fall off the plant for the winter. Plants that shed their leaves seasonally each year are called **deciduous** plants. Shedding leaves is a strategy for reducing water loss during seasons of extreme dryness. On the downside, the plant must grow new leaves in the spring, and that takes a lot of energy and matter. Some plants may "bank" energy over the winter by storing food. That way, they are ready to grow new leaves as soon as spring arrives.

Evergreen plants have a different strategy for adapting to seasonal dryness. They don't waste energy and matter growing new leaves each year. Instead, they keep their leaves and stay green year-round. However, to reduce water loss, they have needle-like leaves with very thick cuticle. On the downside, needle-like leaves reduce the surface area for collecting sunlight. This is one reason that needles may be especially rich in chlorophyll, as you can see from the dark green pine needles in **Figure** 9.4. This is also an important adaptation for low levels of sunlight, allowing evergreens to live far from the equator.

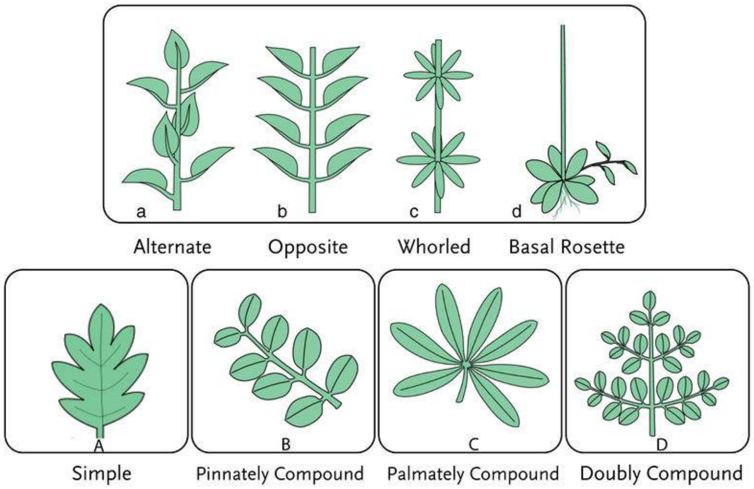

FIGURE 9.2
Leaf variation in flowering plants may include variations in the arrangement of leaves and the divisions of the blade.

FIGURE 9.3
A deciduous tree goes through dramatic seasonal changes each year. Can you identify the seasons in the photo?

Summary

- The primary function of leaves is to collect sunlight and make food by photosynthesis.
- In a deciduous plant, leaves seasonally turn color and fall off the plant. They are replaced with new leaves later in the year.
- An evergreen plant keeps its green leaves year-round. It may have needle-like leaves to reduce water loss.

FIGURE 9.4
Compare the color of the evergreen needles and the deciduous leaf. Why is the darker color of the needles adaptive?

Practice I

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology→ Non-Majors Biology → Search: **Plant Organs and Systems**

1. Which organs comprise the plant's vegetative system?
2. Describe the main role of the leaf.
3. What anther roles do some leaves perform?

Practice II

- **Label the Diagram of Leaf Photosynthesis** at http://www.neok12.com/diagram/Photosynthesis-01.htm.

Review

1. Name the two main parts of an angiosperm leaf. What is the function of each part?

2. Identify strategies used by deciduous and evergreen plants to adapt to seasonal dryness.

3. Devise a model to demonstrate the concept that simple and compound leaves differ in the amount of light they absorb.

4. Relate leaf variation to environmental variation.

References

1. Microphylls: Miika Silfverberg; Fronds (left): André Karwath; Fronds (right): Karora; Needles: MPF. . Microphylls: CC-BY-SA 2.0; Fronds (left); CC-BY-SA 2.5; Fronds (right): Public Domain; Needles: GNU-FDL 1.2
2. Nova and MesserWoland. . GNU-FDL 1.2
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4. Evergreen needles image copyright g215, 2010 and deciduous leaf image copyright rozhenyuk, 2010. . Used under licenses from Shutterstock.com

CHAPTER 10 Plant Responses

- Identify types of plant responses to environmental stimuli.

So what happens to a vineyard in the middle of winter?

The vines cannot die each year. Instead, the plants go into a state of dormancy, almost as if they are taking a long nap.

Plant Responses

Like all organisms, plants detect and respond to stimuli in their environment. Unlike animals, plants can't run, fly, or swim toward food or away from danger. They are usually rooted to the soil. Instead, a plant's primary means of response is to change how it is growing. Plants also don't have a nervous system to control their responses. Instead, their responses are generally controlled by **hormones**, which are chemical messenger molecules.

Plant Tropisms

Plant roots always grow downward because specialized cells in root caps detect and respond to gravity. This is an example of a tropism. A **tropism** is a turning toward or away from a stimulus in the environment. Growing toward gravity is called **geotropism**. Plants also exhibit **phototropism**, or growing toward a light source. This response is controlled by a plant growth hormone called **auxin**. As shown in **Figure** 10.1, auxin stimulates cells on the dark side of a plant to grow longer. This causes the plant to bend toward the light.

Daily and Seasonal Responses

Plants also detect and respond to the daily cycle of light and darkness. For example, some plants open their leaves during the day to collect sunlight and then close their leaves at night to prevent water loss. Environmental stimuli

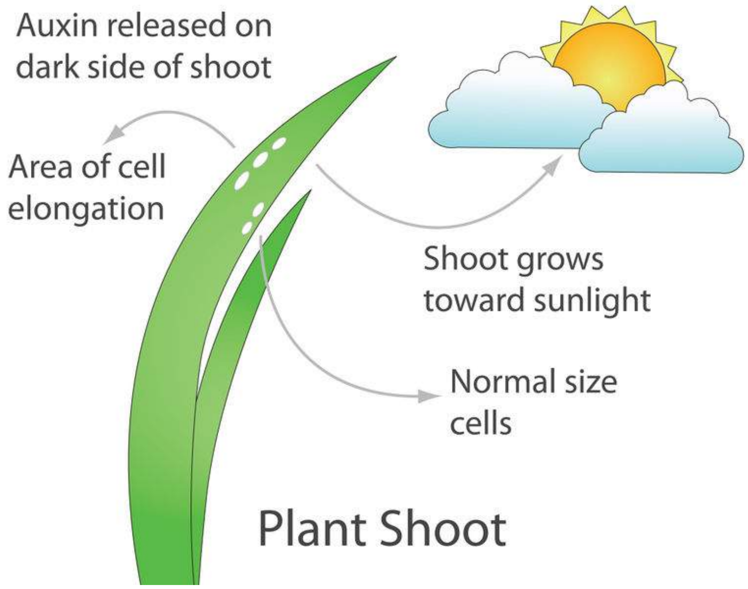

FIGURE 10.1
Phototropism is controlled by the growth hormone auxin.

that indicate changing seasons trigger other responses. Many plants respond to the days growing shorter in the fall by going **dormant**. They suspend growth and development in order to survive the extreme cold and dryness of winter. **Dormancy** ensures that seeds will germinate and plants will grow only when conditions are favorable.

Responses to Disease

Plants don't have immune systems, but they do respond to disease. Typically, their first line of defense is the death of cells surrounding infected tissue. This prevents the infection from spreading. Many plants also produce hormones and toxins to fight pathogens. For example, willow trees produce salicylic acid to kill bacteria. The same compound is used in many acne products for the same reason. Exciting new research suggests that plants may even produce chemicals that warn other plants of threats to their health, allowing the plants to prepare for their own defense. As these and other responses show, plants may be rooted in place, but they are far from helpless.

KQED: Plant Plague: Sudden Oak Death

Devastating over one million oak trees across Northern California in the past ten years, Sudden Oak Death is a killer with no cure. But biologists now are looking to the trees' genetics for a solution. See http://www.kqed.org/quest/television/plant-plague-sudden-oak-death for more information.

Summary

- Like all organisms, plants detect and respond to stimuli in their environment. Their main response is to change how they grow.
- Plant responses are controlled by hormones. Some plant responses are tropisms.
- Plants also respond to daily and seasonal cycles and to disease.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Plant Hormones**

1. What are plant hormones?
2. What is auxin?
3. Describe the process of phototropism.
4. What is a statocyte? What process involves statocytes?
5. What is thigmotropism? What plants utilize this response?
6. What are gibberellins?
7. Compare ethylene to cytokinins.

Review

1. What is the primary way that plants respond to environmental stimuli? What controls their responses?

2. Define tropism. Name one example in plants.

3. State ways that plants respond to disease.

4. Why is it adaptive for plants to detect and respond to daily and seasonal changes?

References

1. CK-12 Foundation. . CC-BY-NC-SA 3.0

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Printed: March 20, 2014

Contents

CHAPTER 1 Mendel's Pea Plants

- Explain why and how Mendel studied pea plants.

What's so interesting about pea plants?

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

Mendel and His Pea Plants

People have long known that the characteristics of living things are similar in parents and their offspring. Whether it's the flower color in pea plants or nose shape in people, it is obvious that offspring resemble their parents. However, it wasn't until the experiments of Gregor Mendel that scientists understood how characteristics are inherited. Mendel's discoveries formed the basis of **genetics**, the science of heredity. That's why Mendel is often called the "father of genetics." It's not common for a single researcher to have such an important impact on science. The importance of

Mendel's work was due to three things: a curious mind, sound scientific methods, and good luck. You'll see why when you read about Mendel's experiments.

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

MEDIA

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Gregor Mendel was born in 1822 and grew up on his parents' farm in Austria. He did well in school and became a monk. He also went to the University of Vienna, where he studied science and math. His professors encouraged him to learn science through experimentation and to use math to make sense of his results. Mendel is best known for his experiments with the pea plant *Pisum sativum* (see **Figure** 1.1). You can watch a video about Mendel and his research at the following link: http://www.metacafe.com/watch/hl-19246625/milestones_in_science_engineering_gregor_mendel_and_classical_genetics/ .

FIGURE 1.1

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

Blending Theory of Inheritance

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

Why Study Pea Plants?

Why did Mendel choose common, garden-variety pea plants for his experiments? Pea plants are a good choice because they are fast growing and easy to raise. They also have several visible characteristics that may vary. These characteristics, which are shown in **Figure** 1.2, include seed form and color, flower color, pod form and color, placement of pods and flowers on stems, and stem length. Each characteristic has two common values. For example, seed form may be round or wrinkled, and flower color may be white or purple (violet).

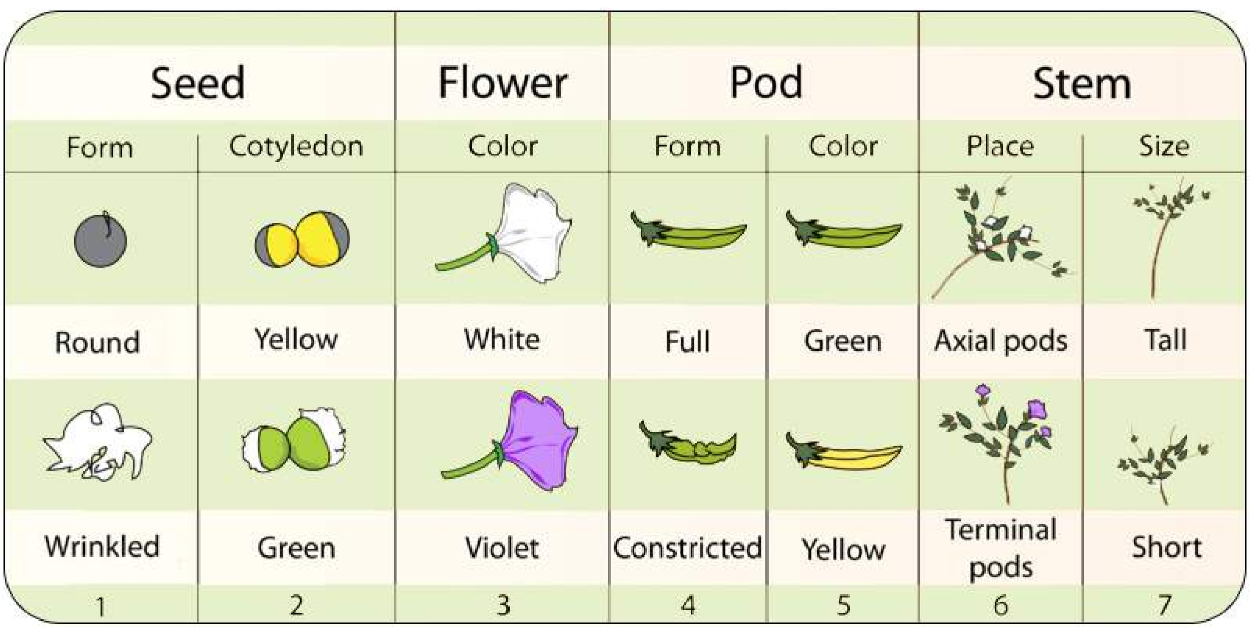

FIGURE 1.2
Mendel investigated seven different characteristics in pea plants. In this chart, cotyledons refer to the tiny leaves inside seeds. Axial pods are located along the stems. Terminal pods are located at the ends of the stems.

Controlling Pollination

To research how characteristics are passed from parents to offspring, Mendel needed to control pollination. **Pollination** is the fertilization step in the sexual reproduction of plants. **Pollen** consists of tiny grains that are the male gametes of plants. They are produced by a male flower part called the **anther** (see **Figure** 1.3). Pollination occurs when pollen is transferred from the anther to the stigma of the same or another flower. The **stigma** is a female part of a flower. It passes the pollen grains to female gametes in the ovary.

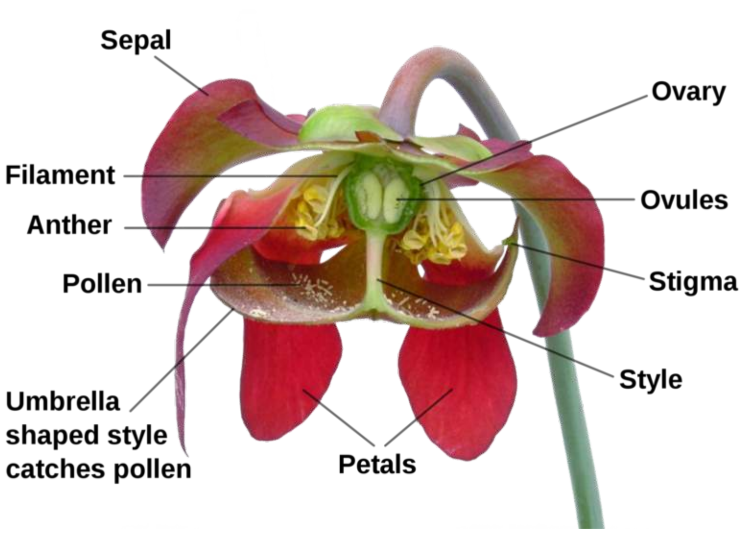

FIGURE 1.3

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

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

Summary

- Gregor Mendel experimented with pea plants to learn how characteristics are passed from parents to offspring.
- Mendel's discoveries formed the basis of genetics, the science of heredity.
- Cross-pollination produces hybrids.

Making Connections

MEDIA

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Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Mendel's Experiments**

1. Why did Mendel choose to work with pea plants?
2. What were the pea plant traits Mendel studied?
3. What are the stamen and carpel?
4. How did Mendel cross-pollinate plants?

Review

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

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

3. How did Mendel control pollination in pea plants?

References

1. . . Public Domain
2. CK-12 Foundation. . CC-BY-SA-NC 3.0
3. Noah Elhardt. . Public Domain

CHAPTER 2 Mendel's Laws and Genetics

- State Mendel's laws of segregation and independent assortment.

Do you look like your parents?

You probably have some characteristics or traits in common with each of your parents. Mendel's work provided the basis to understand the passing of traits from one generation to the next.

Mendel's Laws and Genetics

You might think that Mendel's discoveries would have made a big impact on science as soon as he made them. But you would be wrong. Why? Mendel never published his work. Charles Darwin published his landmark book on evolution in 1859, not long after Mendel had discovered his laws, but Darwin knew nothing of Mendel's discoveries. As a result, Darwin didn't understand heredity. This made his arguments about evolution less convincing to many people. This example shows why it is important for scientists to communicate the results of their investigations.

Rediscovering Mendel's Work

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

Genetics of Inheritance

Today, we known that characteristics of organisms are controlled by genes on chromosomes (see **Figure** 2.1). The position of a gene on a chromosome is called its **locus**. In sexually reproducing organisms, each individual has two copies of the same gene, as there are two versions of the same chromosome (**homologous chromosomes**). One copy comes from each parent. The gene for a characteristic may have different versions, but the different versions are always at the same locus. The different versions are called **alleles**. For example, in pea plants, there is a purple-flower allele (*B*) and a white-flower allele (*b*). Different alleles account for much of the variation in the characteristics of organisms.

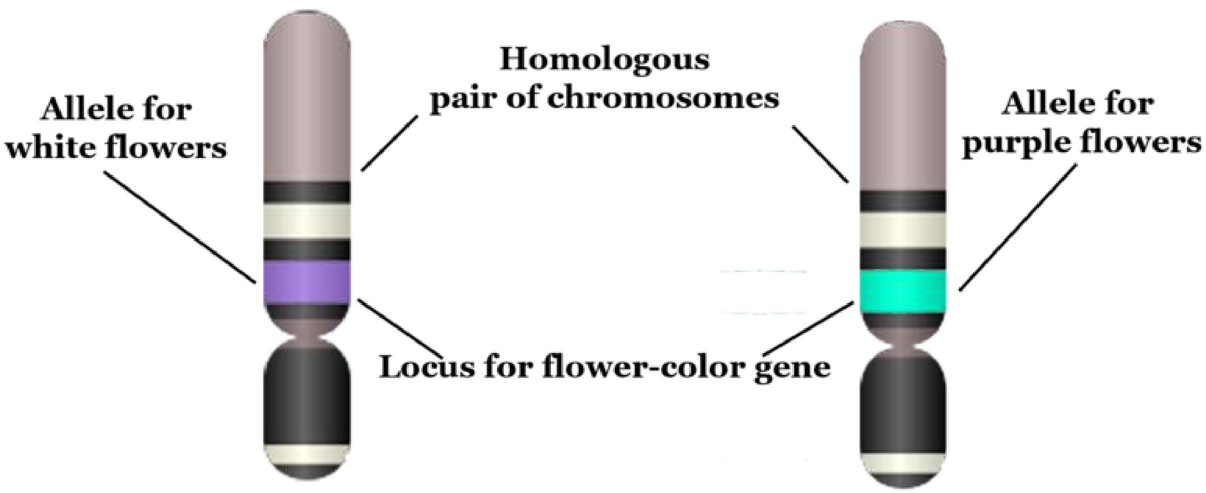


FIGURE 2.1

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

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

Genotype and Phenotype

When gametes unite during fertilization, the resulting zygote inherits two alleles for each gene. One allele comes from each parent. The alleles an individual inherits make up the individual's **genotype**. The two alleles may be the same or different. As shown in **Table** 2.1, an organism with two alleles of the same type (*BB* or *bb*) is called a **homozygote**. An organism with two different alleles (*Bb*) is called a **heterozygote**. This results in three possible genotypes.

TABLE 2.1: Genetics of Flower Color in Pea Plants

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

The expression of an organism's genotype produces its **phenotype**. The phenotype refers to the organism's characteristics, such as purple or white flowers. As you can see from **Table** 2.1, different genotypes may produce the same phenotype. For example, *BB* and *Bb* genotypes both produce plants with purple flowers. Why does this happen? In a *Bb* heterozygote, only the *B* allele is expressed, so the *b* allele doesn't influence the phenotype. In general, when only one of two alleles is expressed in the phenotype, the expressed allele is called the **dominant** allele. The allele that isn't expressed is called the **recessive** allele.

How Mendel Worked Backward to Get Ahead

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

Summary

- Mendel's work was rediscovered in 1900. Soon after that, genes and alleles were discovered. This allowed Mendel's laws to be stated in terms of the inheritance of alleles.
- The gene for a characteristic may have different versions. These different versions of a gene are known as alleles.
- Alleles for different genes assort independently during meiosis.
- The alleles an individual inherits make up the individual's genotype. The individual may be homozygous (two of the same alleles) or heterozygous (two different alleles).
- The expression of an organism's genotype produces its phenotype.
- When only one of two alleles is expressed, the expressed allele is the dominant allele, and the allele that isn't expressed is the recessive allele.
- Mendel used the percentage of phenotypes in offspring to understand how characteristics are inherited.

Making Connections

MEDIA

Click image to the left for more content.

Practice I

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **The Mendelian Model of Inheritance: Summary**

1. What is an allele?
2. Define genotype and phenotype.
3. When is a person heterozygous or homozygous?

Practice II

- **Modern Genetics** at http://www.concord.org/activities/modern-genetics .

Review

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

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

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

References

1. CK-12 Foundation. . CC-BY-NC-SA 3.0

Chapter 3 Probability and Inheritance

- Explain how probability is related to inheritance.

What are the odds of landing on 7 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** 3.1). 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 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.

FIGURE 3.1
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?

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** 3.2). 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.

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.

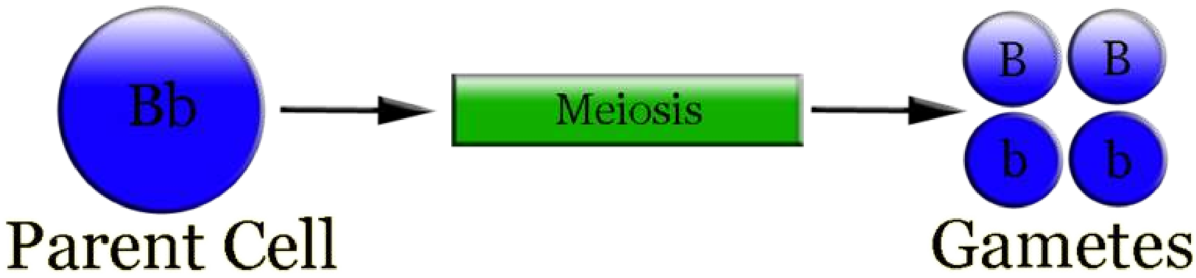
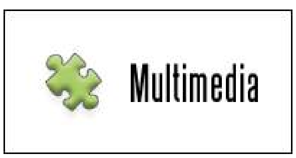


FIGURE 3.2
Formation of Gametes. Paired alleles always separate and go to different gametes during meiosis.

- Probability can be used to predict the chance of gametes and offspring having certain alleles.

Making Connections



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Practice

Use this resource to answer the questions that follow.

- **Fundamentals of Inheritance** at http://www.biologie.uni-hamburg.de/b-online/library/falk/Inherit/Inherit.htm .

1. Define probability as a sentence.
2. Define probability as a fraction.
3. What is the probability of cutting a deck of playing cards and getting an ace?
4. How can you determine the probability of two independent events that occur together?
5. What is the probability that two heterozygous individuals will have offspring with attached earlobes?

Review

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

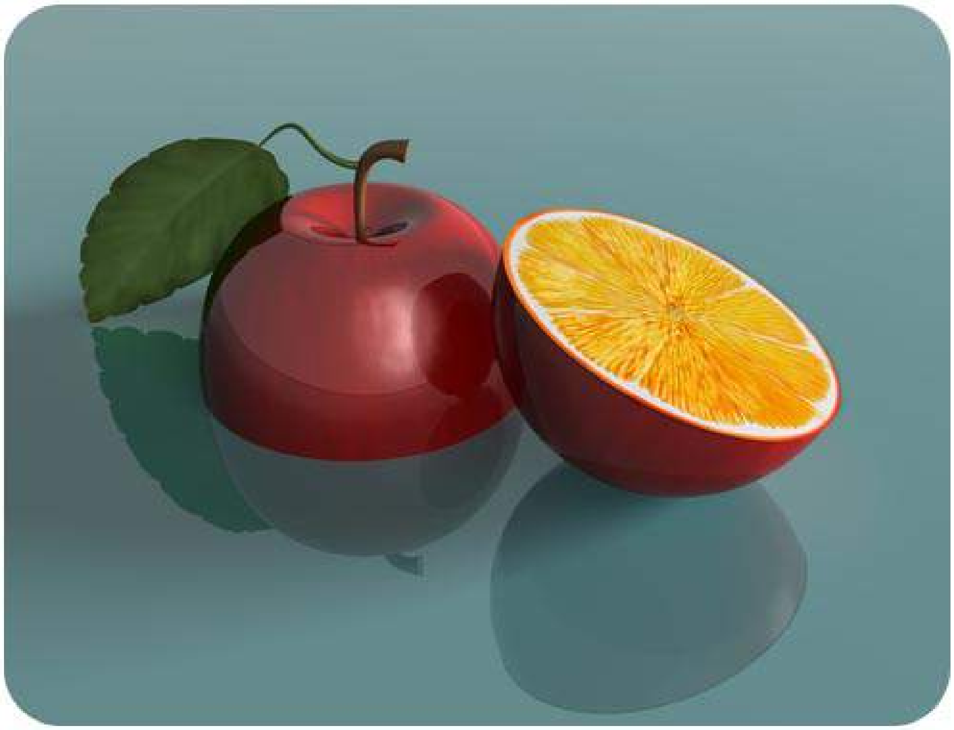
2. How is gamete formation like tossing a coin?

References

1. Image copyright Anyka, 2010. . Used under license from Shutterstock.com.
2. CK-12 Foundation. . CC-BY-NC-SA 3.0

CHAPTER 4 Punnett Squares

- Describe how to use a Punnett square.



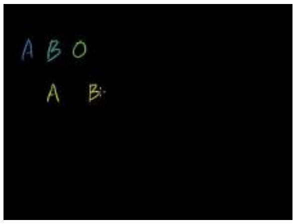
What do you get when you cross an apple and an orange?

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

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



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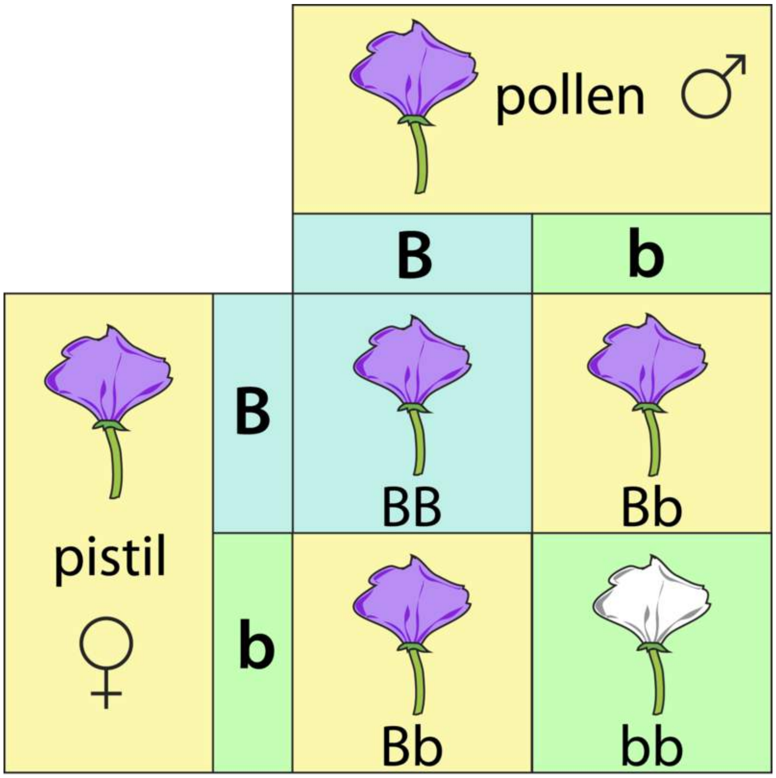

FIGURE 4.1
Punnett Square. This Punnett square shows a cross between two heterozygotes. Do you know where each letter (allele) in all four cells comes from?

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

Predicting Offspring Genotypes

In the cross shown in **Figure** 4.1, 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.

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** 4.2 shows this cross. The question marks (?) in the chart could be either *B* or *b* alleles.

White Flowered Parent

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

FIGURE 4.2

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

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

Punnett Square for Two Characteristics

When you consider more than one characteristic at a time, using a Punnett square is more complicated. This is because many more combinations of alleles are possible. For example, with two genes each having two alleles, an individual has four alleles, and these four alleles can occur in 16 different combinations. This is illustrated for pea plants in **Figure** 4.3. In this cross, known as a **dihybrid cross**, both parents are heterozygous for pod color (*Gg*) and seed color (*Yy*).

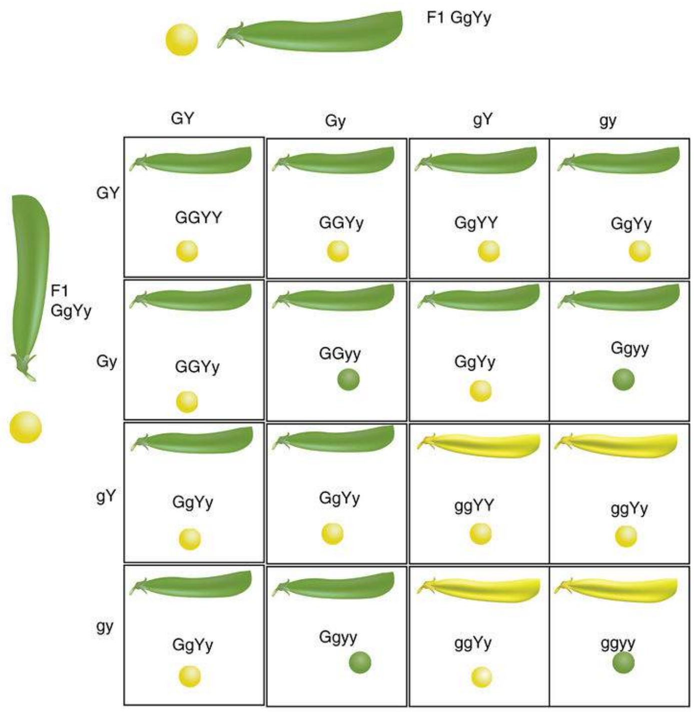

FIGURE 4.3
Punnett Square for Two Characteristics. This Punnett square represents a cross between two pea plants that are heterozygous for two characteristics. *G* represents the dominant allele for green pod color, and *g* represents the recessive allele for yellow pod color. *Y* represents the dominant allele for yellow seed color, and *y* represents the recessive allele for green seed color.

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.

Making Connections

MEDIA
Click image to the left for more content.

Practice I

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Non-Majors Biology → Search: **The Punnett Square**

1. What is a Punnett square?

2. What is the size of a Punnett square used in a dihybrid cross?
3. Define the following terms: alleles, genotype, phenotype, genome.

Practice II

Adobe Flash

MEDIA

Click image to the left for more content.

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. 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, and explain in terms of genotype what each number means. Create a Punnett square to help you answer the question.

References

1. CK-12 Foundation. . CC-BY-NC-SA 3.0
2. CK-12 Foundation. . CC-BY-NC-SA 3.0
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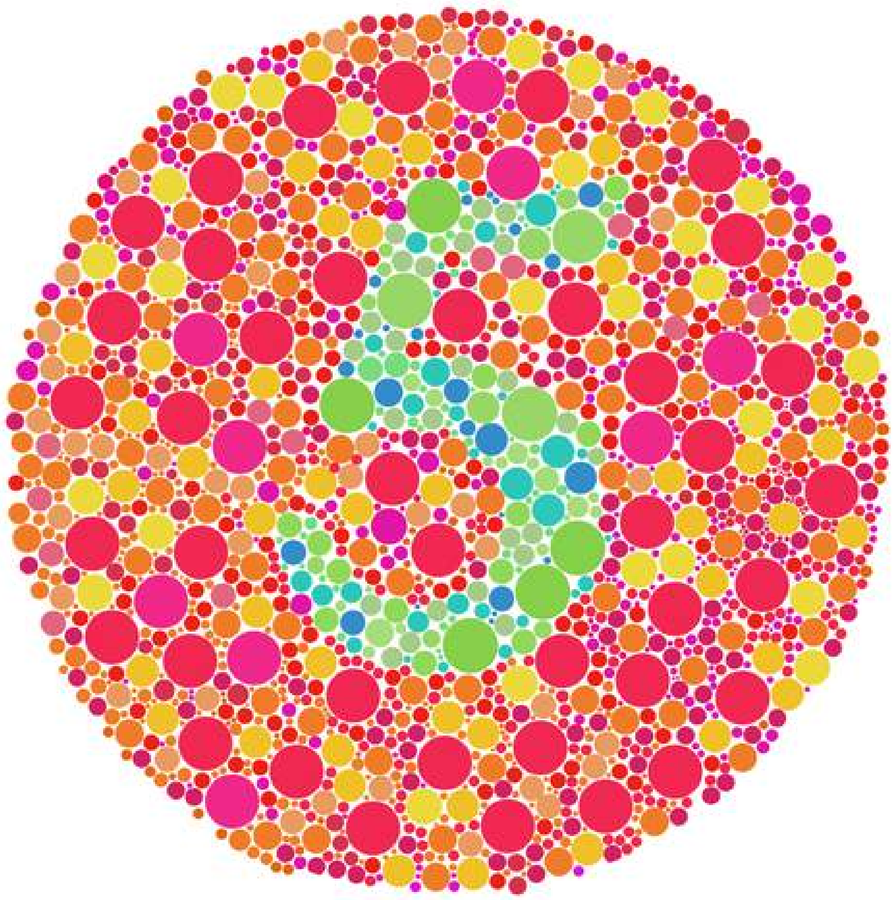
CHAPTER 5 Mendelian Inheritance in Humans

- Describe inheritance in humans for autosomal and X-linked traits.



What number can you see?

Red-green colorblindness is a common inherited trait in humans. About 1 in 10 men have some form of color blindness, however, very few women are color blind. Why?

Mendelian Inheritance in Humans

Characteristics that are encoded in DNA are called **genetic traits**. Different types of human traits are inherited in different ways. Some human traits have simple inheritance patterns like the traits that Gregor Mendel studied in pea plants. Other human traits have more complex inheritance patterns.

Mendelian inheritance refers to the inheritance of traits controlled by a single gene with two alleles, one of which may be dominant to the other. Not many human traits are controlled by a single gene with two alleles, but they are a good starting point for understanding human heredity. How Mendelian traits are inherited depends on whether the traits are controlled by genes on autosomes or the X chromosome.

Autosomal Traits

Autosomal traits are controlled by genes on one of the 22 human autosomes. Consider earlobe attachment. A single autosomal gene with two alleles determines whether you have attached earlobes or free-hanging earlobes. The allele for free-hanging earlobes (F) is dominant to the allele for attached earlobes (f). Other single-gene autosomal traits include widow's peak and hitchhiker's thumb. The dominant and recessive forms of these traits are shown in **Figure** 5.1. Which form of these traits do you have? What are your possible genotypes for the traits? The chart in **Figure** 5.1 is called a **pedigree**. It shows how the earlobe trait was passed from generation to generation within a family. Pedigrees are useful tools for studying inheritance patterns.

You can watch a video explaining how pedigrees are used and what they reveal at this link: http://www.youtube.com/watch?v=HbIHjsn5cHo .

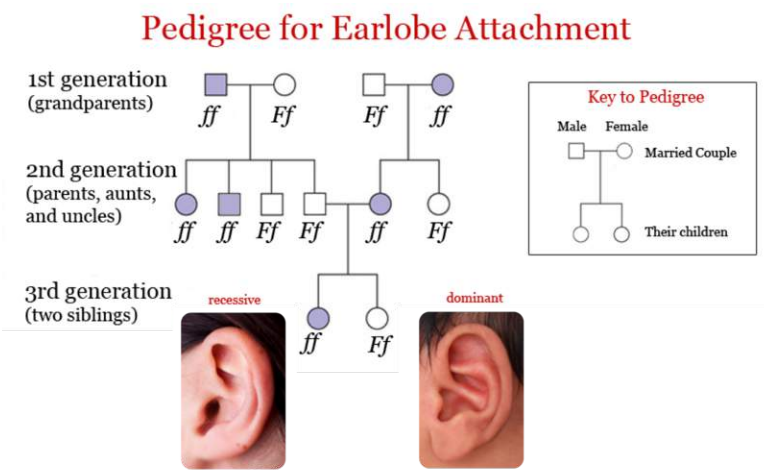


FIGURE 5.1

Having free-hanging earlobes is an autosomal dominant trait. This figure shows the trait and how it was inherited in a family over three generations. Shading indicates people who have the recessive form of the trait. Look at (or feel) your own earlobes. Which form of the trait do you have? Can you tell which genotype you have?

Other single-gene autosomal traits include widow's peak and hitchhiker's thumb. The dominant and recessive forms of these traits are shown in **Figure** 5.2. Which form of these traits do you have? What are your possible genotypes for the traits?

Sex-Linked Traits

Traits controlled by genes on the sex chromosomes are called **sex-linked traits**, or **X-linked traits** in the case of the X chromosome. Single-gene X-linked traits have a different pattern of inheritance than single-gene autosomal traits. Do you know why? It's because males have just one X chromosome. In addition, they always inherit their X chromosome from their mother, and they pass it on to all their daughters but none of their sons. This is illustrated in **Figure** 5.3.

Because males have just one X chromosome, they have only one allele for any X-linked trait. Therefore, a recessive X-linked allele is always expressed in males. Because females have two X chromosomes, they have two alleles for any X-linked trait. Therefore, they must inherit two copies of the recessive allele to express the recessive trait. This explains why X-linked recessive traits are less common in females than males. An example of a recessive X-linked trait is **red-green color blindness**. People with this trait cannot distinguish between the colors red and green. More than one recessive gene on the X chromosome codes for this trait, which is fairly common in males but relatively rare in females (**Figure** 5.4). At the following link, you can watch an animation about another X-linked recessive trait called hemophilia A: http://www.dnalc.org/view/16315-Animation-13-Mendelian-laws-apply-to-human-beings-.html .

FIGURE 5.2
Widow's peak and hitchhiker's thumb are dominant traits controlled by a single autosomal gene.

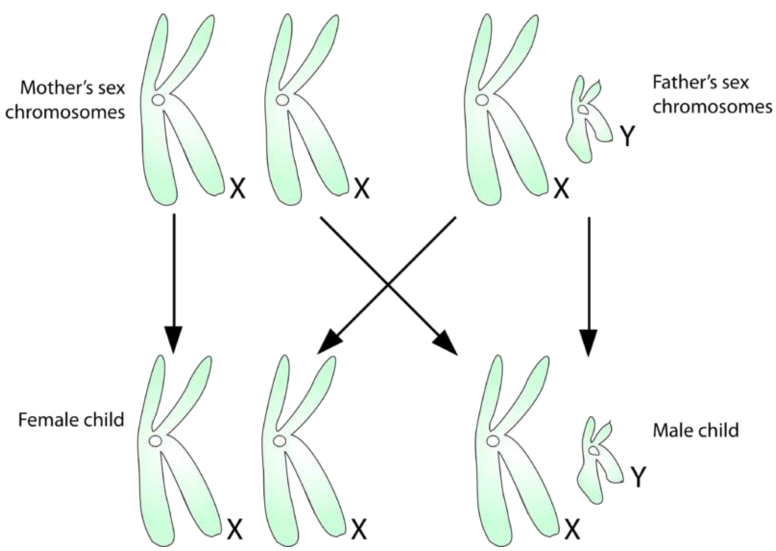


FIGURE 5.3
Inheritance of Sex Chromosomes. Mothers pass only X chromosomes to their children. Fathers always pass their X chromosome to their daughters and their Y chromosome to their sons. Can you explain why fathers always determine the sex of the offspring?

Summary

- A minority of human traits are controlled by single genes with two alleles.
- They have different inheritance patterns depending on whether they are controlled by autosomal or X-linked genes.

Practice I

Use these resources to answer the questions that follow.

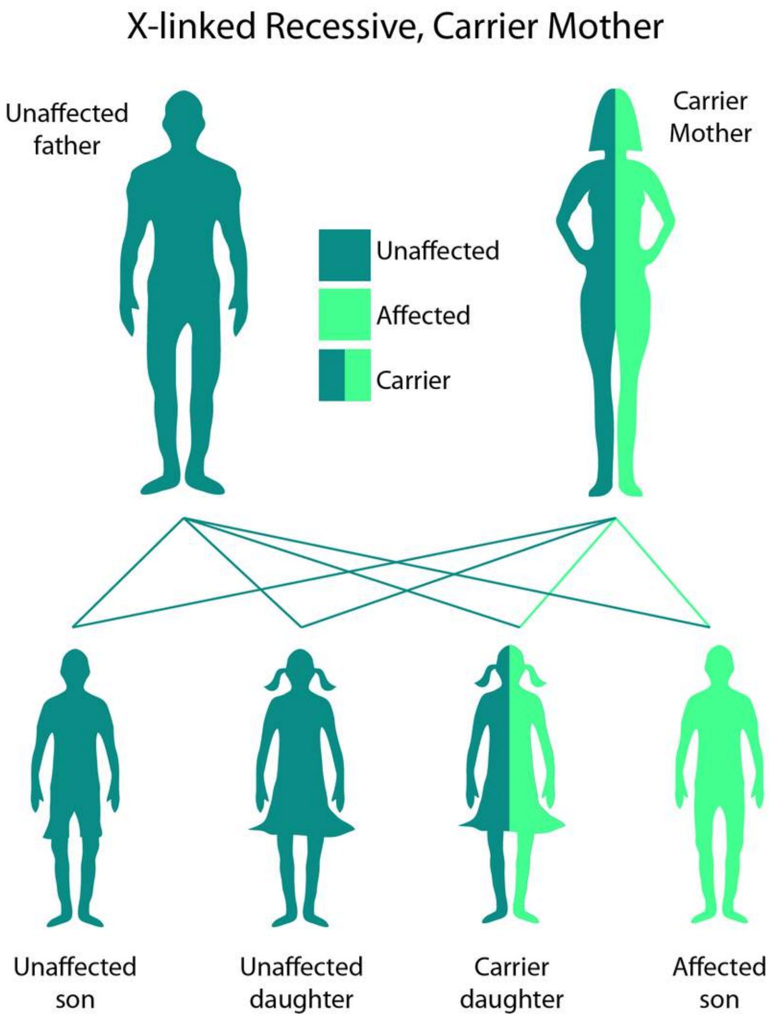


FIGURE 5.4
Pedigree for Color Blindness. Color blindness is an X-linked recessive trait. Mothers pass the recessive allele for the trait to their sons, who pass it to their daughters.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Sex Chromosomes**

1. What is an X-linked gene? Give an example.
2. Will a color blind man always pass the color blind allele to his daughters? Why or why not?
3. How can the son of a color blind man have color blindness?
4. What is meant by a female "carrier"?

- http://www.hippocampus.org/Biology → Non-Majors Biology → Search: **A Case Study**

1. A homozygous freckled man marries a non-freckled woman. If freckles are dominant, will their children have freckles? Explain your answer.
2. Using *F* and *f*, what are the genotypes of the parents? What are the genotypes of their gametes?

Practice II

- **Pedigree Analysis**

MEDIA

Click image to the left for more content.

Review

1. Describe the inheritance pattern for a single-gene autosomal dominant trait, such as free-hanging earlobes.

2. Draw a pedigree for hitchhiker's thumb. Your pedigree should cover at least two generations and include both dominant and recessive forms of the trait. Label the pedigree with genotypes, using the letter H to represent the dominant allele for the trait and the letter h to represent the recessive allele.

References

1. (Recessive ear) Image Copyright Antonio Jorge Nunes, 2010; (Dominant ear) Image Copyright Hywit Dimyadi, 2010; Composite created by CK-12 Foundation. . Ear images used under license from Shutterstock.com
2. From left to right, image copyright Alberto Zornetta, 2011; image copyright IKO, 2011; image copyright Elder, 2010; Vaikunda Raja. . From left to right, the first three images are used under licenses from Shutterstock.com; rightmost image under CC-BY-SA 3.0
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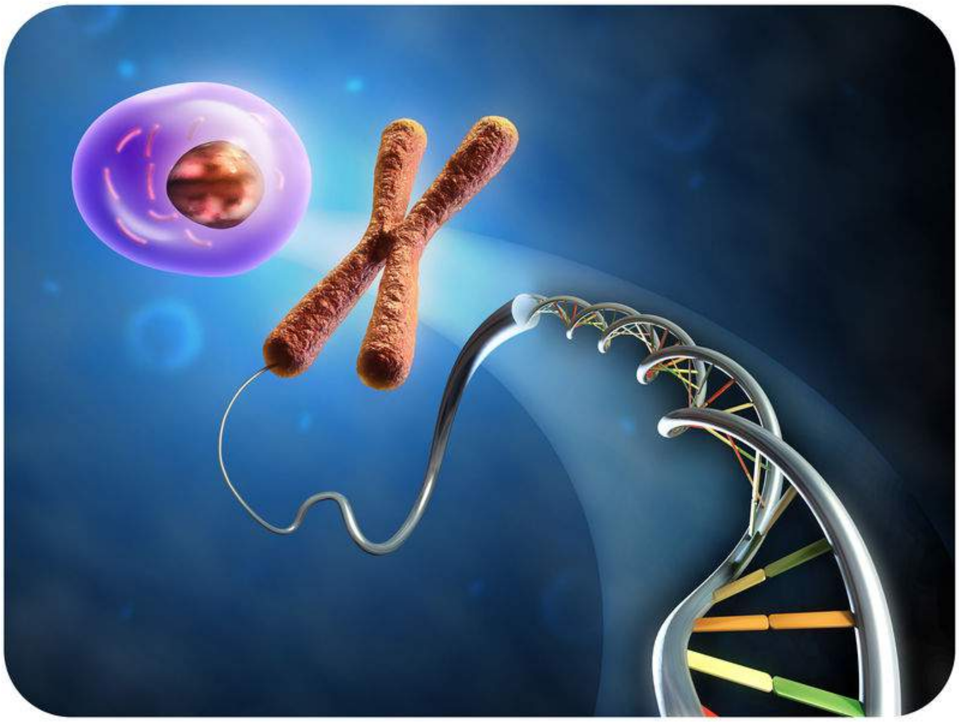
Chapter 6 Modern Genetics

- Compare Mendel's laws with our modern understanding of chromosomes.



Did Mendel know about DNA?

No, people did not understand that DNA is our hereditary material until long after Mendel's time. Our modern understanding of DNA and chromosomes helped to explain how Mendel's rules worked.

Modern Genetics

Mendel laid the foundation for modern genetics, but there were still a lot of questions he left unanswered. What exactly are the dominant and recessive factors that determine how all organisms look? And how do these factors work?

Since Mendel's time, scientists have discovered the answers to these questions. Genetic material is made out of **DNA**. It is the DNA that makes up the hereditary factors that Mendel identified. By applying our modern knowledge of DNA and chromosomes, we can explain Mendel's findings and build on them. In this concept, we will explore the connections between Mendel's work and modern genetics.

Traits, Genes, and Alleles

Recall that our DNA is wound into **chromosomes**. Each of our chromosomes contains a long chain of DNA that encodes hundreds, if not thousands, of genes. Each of these genes can have slightly different versions from individual to individual. These variants of genes are called **alleles**.

For example, remember that for the height gene in pea plants there are two possible factors. These factors are alleles. There is a dominant allele for tallness (T) and a recessive allele for shortness (t).

Genotype and Phenotype

Genotype is a way to describe the combination of alleles that an individual has for a certain gene (**Table** 6.1). For each gene, an organism has two alleles, one on each chromosome of a homologous pair of chromosomes (think of it as one allele from Mom, one allele from Dad). The genotype is represented by letter combinations, such as *TT*, *Tt*, and *tt*.

When an organism has two of the same alleles for a specific gene, it is **homozygous** (homo- means "same") for that gene. An organism can be either homozygous dominant (*TT*) or homozygous recessive (*tt*). If an organism has two different alleles (*Tt*) for a certain gene, it is known as **heterozygous** (hetero- means different).

TABLE 6.1: Genotypes

Genotype	Definition	Example
homozygous	two of the same allele	*TT* or *tt*
heterozygous	one dominant allele and one recessive allele	*Tt*
homozygous dominant	two dominant alleles	*TT*
homozygous recessive	two recessive alleles	*tt*

Phenotype is a way to describe the traits you can see. The genotype is like a recipe for a cake, while the phenotype is like the cake made from the recipe. The genotype expresses the phenotype. For example, the phenotypes of Mendel's pea plants were either tall or short, or they were purple-flowered or white-flowered.

Can organisms with different genotypes have the same phenotypes? Let's see.

What is the phenotype of a pea plant that is homozygous dominant (*TT*) for the tall trait? Tall. What is the phenotype of a pea plant that is heterozygous (*Tt*)? It is also tall. The answer is yes, two different genotypes can result in the same phenotype. Remember, the recessive phenotype will be expressed only when the dominant allele is absent, or when an individual is homozygous recessive (*tt*) (**Figure** 6.1).

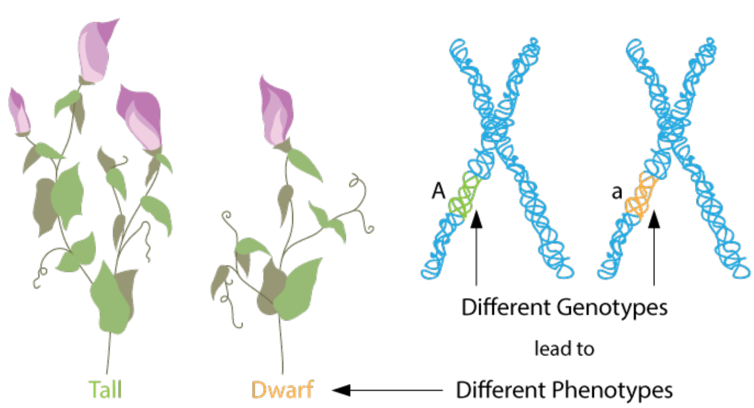


FIGURE 6.1
Different genotypes (*AA*, *Aa*, *aa* or *TT*, *Tt*, *tt*) will lead to different phenotypes, or different appearances of the organism.

Vocabulary

- **allele**: Variant of genes.
- **chromosome**: Structure composed of DNA wrapped around proteins.
- **DNA (deoxyribonucleic acid)**: Hereditary material of a cell.
- **genotype**: Describes the combination of alleles that an individual has for a certain gene.

- **homozygous**: Having two of the same alleles for a specific gene.
- **heterozygous**: Having two different alleles for a specific gene.
- **phenotype**: Describes observable traits.

Summary

- Mendel's hereditary "factors" are variants of genes called alleles.
- Genotype describes the combination of alleles that an individual has for a certain gene, while phenotype describes the traits that you can see.

Practice

Use the resources below to answer the questions that follow.

- **Link Between Genotype and Phenotype** at http://www.sciencelearn.org.nz/Contexts/Uniquely-Me/Sci-Media/Video/Researching-the-link-between-genotype-and-phenotype

1. When geneticists look at genotype, what are they really studying?
2. Why do geneticists like to turn genes off? Explain your answer as fully as you can.
3. If a geneticist turns off a gene and describes "what" happened, is his/her work done? Explain your answer as fully as you can.

- **iPlant Genotype to Phenotype** at http://www.youtube.com/watch?v=nIh0Qy_CZsU (3:49)

MEDIA
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1. Do most of the phenotypes we observe come from a single gene? Given this situation, how valuable to you feel Mendel's work was? Be specific in your reasoning and explain your answer fully.
2. What has led to the rapid analysis of DNA? Where do scientists now hope to apply these tools?
3. What are some of the phenotypic traits that scientists are investigating? Why do you think these traits were chosen?

Review

1. What is the type of allele that only affects the phenotype in the homozygous condition?
2. If two individuals have a certain phenotype, does that mean they must have the same genotype?

References

1. CK-12 Foundation - Zachary Wilson. . CC-BY-NC-SA 3.0

CHAPTER 7 Polygenic Traits

- Explain how polygenic traits are inherited.

Are all people either short or tall?

Unlike Mendel's peas, people do not all fall into two categories: short or tall. Most people, in fact, are somewhere in between. Obviously, Mendel's rules are too simple to explain the inheritance of human height.

Polygenic Traits

Another exception to Mendel's rules is **polygenic inheritance**, which occurs when a trait is controlled by more than one gene. This means that each dominant allele "adds" to the expression of the next dominant allele.

Usually, traits are polygenic when there is wide variation in the trait. For example, humans can be many different sizes. Height is a polygenic trait, controlled by at least three genes with six alleles. If you are dominant for all of the alleles for height, then you will be very tall. There is also a wide range of skin color across people. Skin color is also a polygenic trait.

Polygenic inheritance often results in a bell shaped curve when you analyze the population (**Figure** 7.1). That means that most people fall in the middle of the phenotypic range, such as average height, while very few people are at the extremes, such as very tall or very short. At one end of the curve will be individuals who are recessive for all the alleles; at the other end will be individuals who are dominant for all the alleles. Through the middle of the curve will be individuals who have a combination of dominant and recessive alleles.

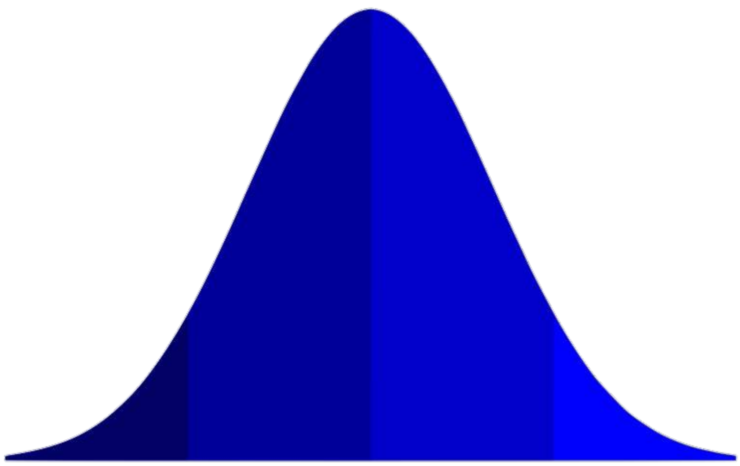


FIGURE 7.1

Polygenic traits tend to result in a distribution that resembles a bell-shaped curve, with few at the extremes and most in the middle. There may be 4 or 6 or more alleles involved in the phenotype. At the left extreme, individuals are completely dominant for all alleles, and at the right extreme, individuals are completely recessive for all alleles. Individuals in the middle have various combinations of recessive and dominant alleles.

Vocabulary

- **polygenic trait**: Trait that is controlled by more than one gene.

Summary

- In polygenic inheritance, a trait is controlled by more than one gene.
- Examples of polygenic inheritance include height or skin color.

Practice

Use the resource below to answer the questions that follow.

- **Genetics and Eye Color** at http://www.youtube.com/watch?v=MjBZaed9yzM (1:49)

MEDIA

Click image to the left for more content.

1. Is eye color a trait controlled by a single gene as it is often taught in schools?
2. Do you think skin color is a polygenic trait? Explain your reasoning, and be as specific as possible.
3. What is an albino? What kind of eyes would they definitely NOT have?
4. Some people have dark hair and blue eyes; what does this say about their ability to produce melanin? Think carefully and explain your answer as fully as you can.

Review

1. How does polygenic inheritance violate Mendel's rules?
2. Give examples of traits governed by polygenic inheritance.

References

1. David Remahl. . The creator of this work allows anyone to use it for any purpose including unrestricted redistribution, commercial use, and modification

CHAPTER 8 Sex-linked Inheritance

- Explain how a baby's gender is determined.
- Explain how sex-linked inheritance works.

Male or female?

One of the exciting things about expecting a child is wondering if the baby will be a boy or a girl. There are many superstitions about how one might influence or predict the outcome. But what really determines if a baby is male or female? We now know that the gender of a baby is determined by a special pair of chromosomes known as the sex chromosomes.

Sex-linked Inheritance

What determines if a baby is a male or female? Recall that you have 23 pairs of chromosomes—and one of those pairs is the **sex chromosomes**. Everyone has two sex chromosomes. Your sex chromosomes can be X or Y. Females have two X chromosomes (XX), while males have one X chromosome and one Y chromosome (XY).

If a baby inherits an X chromosome from the father and an X chromosome from the mother, what will be the child's sex?

The baby will have two X chromosomes, so it will be female. If the father's sperm carries the Y chromosome, the child will be male. Notice that a mother can only pass on an X chromosome, so the sex of the baby is determined by the father. The father has a 50 percent chance of passing on the Y or X chromosome, so there is a 50 percent chance that a child will be male, and there is a 50 percent chance a child will be female.

One special pattern of inheritance that doesn't fit Mendel's rules is **sex-linked inheritance**, referring to the inheritance of traits that are located on genes on the sex chromosomes. Since males and females do not have the same sex chromosomes, there will be differences between the sexes in how these **sex-linked traits**—traits linked to genes located on the sex chromosomes—are expressed.

One example of a sex-linked trait is red-green colorblindness. People with this type of colorblindness cannot tell the difference between red and green. They often see these colors as shades of brown (**Figure** 8.1). Boys are much more likely to be colorblind than girls (**Table** 8.1). This is because colorblindness is a sex-linked, recessive trait.

Boys only have one X chromosome, so if that chromosome carries the gene for colorblindness, they will be colorblind. As girls have two X chromosomes, a girl can have one X chromosome with the colorblind gene and one X chromosome with a normal gene for color vision. Since colorblindness is recessive, the dominant normal gene will mask the recessive colorblind gene. Females with one colorblindness allele and one normal allele are referred to as **carriers**. They carry the allele but do not express it.

How would a female become color-blind? She would have to inherit two genes for colorblindness, which is very unlikely. Many sex-linked traits are inherited in a recessive manner.

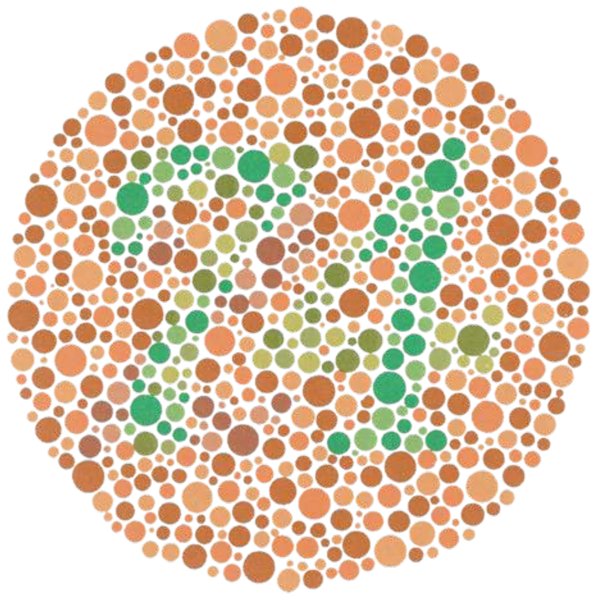


FIGURE 8.1
A person with red-green colorblindness would not be able to see the number.

TABLE 8.1: **Colorblindness**

	$\mathbf{X^c}$	**X**
X	$\mathbf{X^cX}$ (carrier female)	**XX** (normal female)
Y	$\mathbf{X^cY}$ (colorblind male)	**XY** (normal male)

According to this Punnett square (**Table** 8.1), the son of a woman who carries the colorblindness trait and a normal male has a 50% chance of being colorblind.

Vocabulary

- **carrier**: Person who carries the recessive allele for a trait but does not express the trait.
- **sex chromosomes**: Chromosomes that determine the sex of the individual.
- **sex-linked inheritance**: Inheritance of traits that are encoded for in genes on the sex chromosomes.
- **sex-linked trait**: Trait linked to genes located on the sex chromosomes.

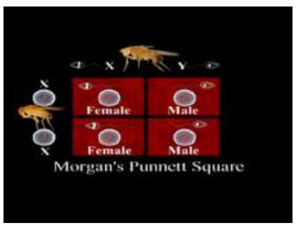
Summary

- Each individual has two sex chromosomes; females have two X chromosomes (XX), while males have one X chromosome and one Y chromosome (XY).
- Sex-linked traits are located on genes on the sex chromosomes.

Practice

Use the resources below to answer the questions that follow.

- **Sex-linked Traits** at http://www.youtube.com/watch?v=H1HaR47Dqfw (5:16)

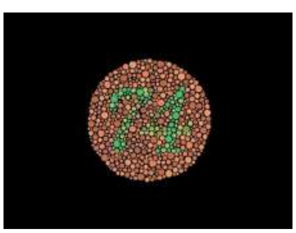


MEDIA
Click image to the left for more content.

1. What was unusual about the F_2 generation in Morgan's crosses?
2. According to Morgan, where is the gene for eye color located?
3. How did Morgan test his hypothesis on the location of the eye color gene?
4. What are three traits that humans have that are related to genes exclusive to the X-chromosome?

The "Morgan" referred to in the above clip is Thomas Hunt Morgan. You can find out more about him and his work here: http://www.nature.com/scitable/topicpage/thomas-hunt-morgan-and-sex-linkage-452 .

- **Inheritance of Sex-linked Traits** at http://www.youtube.com/watch?v=IJqFk-28G08 (4:49)



MEDIA
Click image to the left for more content.

1. What are the three types of color blindness? How are they the same, and how are they different?
2. What is the "Law of Dominance"?
3. Can a woman have colorblindness if her father does not? Explain your answer fully.
4. A woman is color blind but her sister isn't. What does that tell you about her mother?

If you're still puzzled by sex-linked traits you can go to this site for more practice solving problems. Make sure you make good use of the "hints" on the site.

- **Sex-linked genes** at http://www.ksu.edu/biology/pob/genetics/xlinked.htm

Review

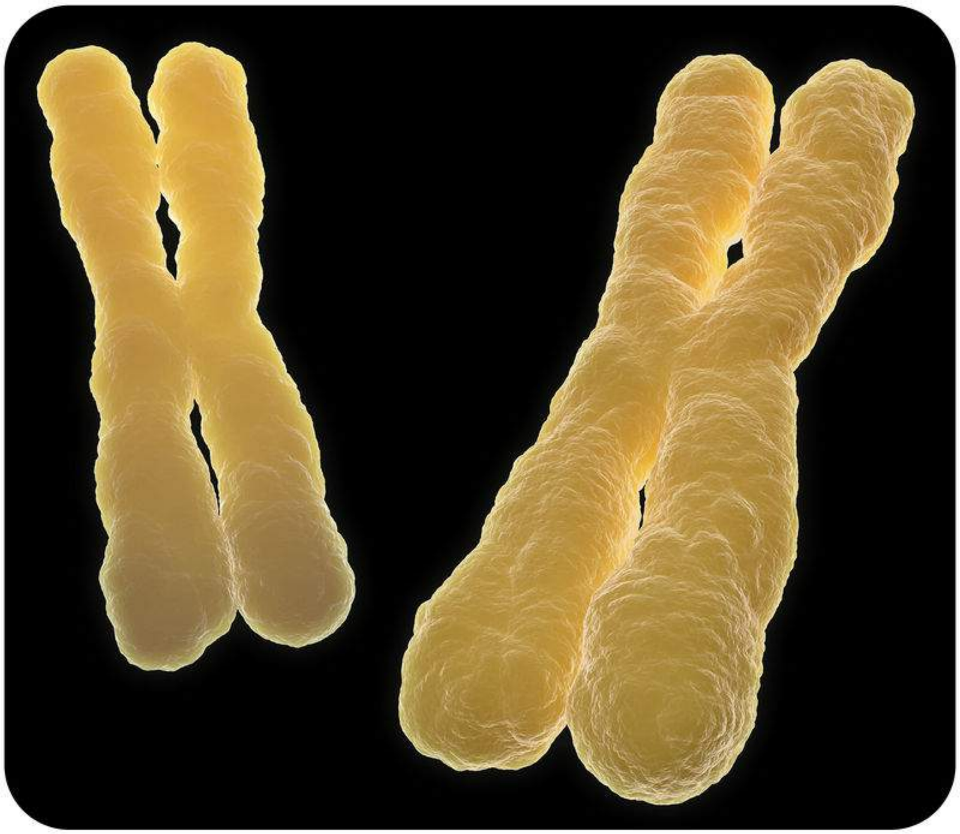
1. Explain why the father determines the sex of the child.
2. A son cannot inherit colorblindness from his father. Why not?

References

1. Unknown. . Public Domain

CHAPTER 9 Chromosomal Disorders

- Explain how changes in chromosomes can cause disorders in humans.



Can you have too many chromosomes?

Yes, it's not a good thing to have extra chromosomes. An extra chromosome can be fatal to an embryo, in fact. In the case of a few chromosomes, however, a baby may be born with an extra chromosome. This child will have a chromosomal disorder.

Chromosomal Disorders

Some children are born with genetic defects that are not carried by a single gene. Instead, an error in a larger part of the chromosome or even in an entire chromosome causes the disorder. Usually the error happens when the egg or sperm is forming. Having extra chromosomes or damaged chromosomes can cause disorders.

Extra Chromosomes

One common example of an extra-chromosome disorder is **Down syndrome** (**Figure** 9.1). Children with Down syndrome are mentally disabled and also have physical deformities. Down syndrome occurs when a baby receives an extra chromosome 21 from one of his or her parents. Usually, a child will receive one chromosome 21 from the mother and one chromosome 21 from the father. In an individual with Down syndrome, however, there are three copies of chromosome 21 (**Figure** 9.2). Therefore, Down syndrome is also known as Trisomy 21.

FIGURE 9.1
A child with Down syndrome.

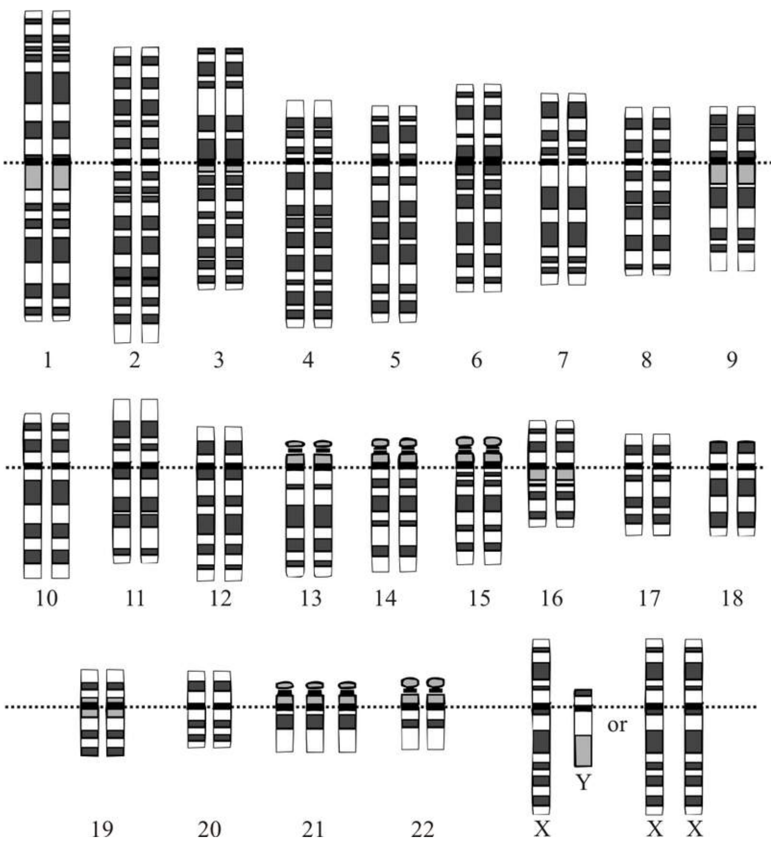


FIGURE 9.2
Chromosomes of a person with Down Syndrome. Notice the extra chromosome 21.

Another example of a chromosomal disorder is **Klinefelter syndrome**, in which a male inherits an extra "X" chromosome. These individuals have an XXY genotype. They have underdeveloped sex organs and elongated limbs. They also have difficulty learning new things.

Outside of chromosome 21 and the sex chromosomes, most embryos with extra chromosomes do not usually survive. Because chromosomes carry many, many genes, a disruption of a chromosome can cause severe problems with the development of a fetus.

Damaged Chromosomes

Chromosomal disorders also occur when part of a chromosome becomes damaged. For example, if a tiny portion of chromosome 5 is missing, the individual will have *cri du chat* (cat's cry) syndrome. These individuals have misshapen facial features, and the infant's cry resembles a cat's cry.

Vocabulary

- **Down syndrome**: Chromosomal disorder that results when an embryo inherits an extra chromosome 21.
- **Klinefelter syndrome**: Chromosomal disorder that results when a male inherits an extra "X" chromosome.

Summary

- Changes in chromosome number can lead to disorders like Down syndrome.
- Chromosomal disorders also occur when part of a chromosome becomes damaged.

Practice

Use the resources below to answer the questions that follow.

- **Down Syndrome** at http://www.ygyh.org/ds/whatisit.htm

1. Are all cases of Down Syndrome the result of inheritance?
2. Do all cases of Down Syndrome have a complete extra chromosome? Explain your answer fully.
3. Why are people with Down Syndrome at a greater risk for Alzheimer's Disease?

- **Understanding Rare Chromosome Disorders** at http://www.youtube.com/watch?v=k4Lps1kIyR0 (8:11)

MEDIA
Click image to the left for more content.

1. What do all people diagnosed with a chromosome disorder share?
2. What is a clinical geneticist? How are they different from a doctor? Think carefully about your answer.
3. What is a karyotype?
4. Do chromosomal disorders always involve extra genetic material?

Review

1. Explain what causes Down Syndrome.
2. How is a chromosomal disorder different from a genetic disorder.

References

1. Image copyright Tomasz Markowski, 2011. A child with Down syndrome.. Used under license from Shutterstock.com
2. Courtesy of the National Human Genome Research Institute. . Public Domain

CHAPTER 10 Human Chromosomes and Genes

- Describe human chromosomes and genes.

Coiled bundles of DNA and proteins, containing hundreds or thousands of genes. What are these things?

Chromosomes. These ensure that each cell receives the proper amount of DNA during cell division. And usually people have 46 of them, 23 from each parent.

Chromosomes and Genes

Each species has a characteristic number of chromosomes. **Chromosomes** are coiled structures made of DNA and proteins called **histones** (**Figure** 10.1). Chromosomes are the form of the genetic material of a cell during cell division. See the "Chromosomes" section for additional information.

The human species is characterized by 23 pairs of chromosomes, as shown in **Figure** 10.2. You can watch a short animation about human chromosomes at this link: http://www.dnalc.org/view/15520-DNA-is-organized-into-46-chromosomes-including-sex-chromosomes-3D-animation.html .

Autosomes

Of the 23 pairs of human chromosomes, 22 pairs are autosomes (numbers 1–22 in **Figure** 10.2). **Autosomes** are chromosomes that contain genes for characteristics that are unrelated to sex. These chromosomes are the same in males and females. The great majority of human genes are located on autosomes. At the link below, you can click on any human chromosome to see which traits its genes control. http://www.ornl.gov/sci/techresources/Human_Genome/posters/chromosome/chooser.shtml

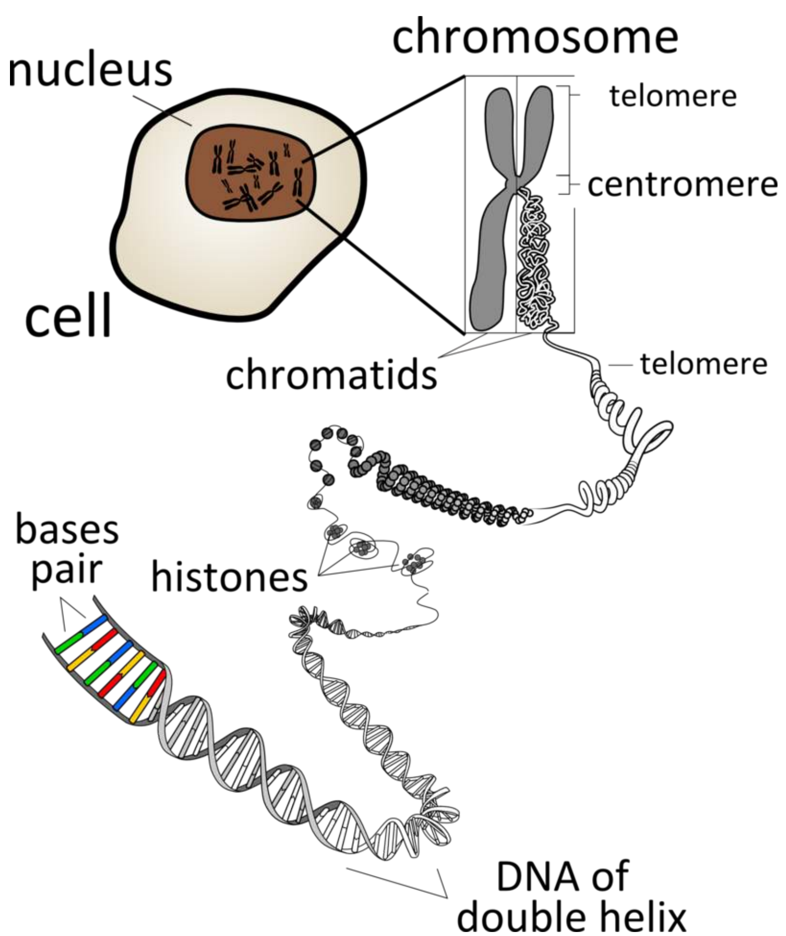


FIGURE 10.1
The human genome has 23 pairs of chromosomes located in the nucleus of somatic cells. Each chromosome is composed of genes and other DNA wound around histones (proteins) into a tightly coiled molecule.

Sex Chromosomes

The remaining pair of human chromosomes consists of the **sex chromosomes**, X and Y. Females have two X chromosomes, and males have one X and one Y chromosome. In females, one of the X chromosomes in each cell is inactivated and known as a Barr body. This ensures that females, like males, have only one functioning copy of the X chromosome in each cell. As you can see from **Figure** above and **Figure** 10.2, the X chromosome is much larger than the Y chromosome. The X chromosome has about 2,000 genes, whereas the Y chromosome has fewer than 100, none of which are essential to survival. Virtually all of the X chromosome genes are unrelated to sex. Only the Y chromosome contains genes that determine sex. A single Y chromosome gene, called **SRY** (which stands for sex-determining region Y gene), triggers an embryo to develop into a male. Without a Y chromosome, an individual develops into a female, so you can think of female as the default sex of the human species. Can you think of a reason why the Y chromosome is so much smaller than the X chromosome? At the link that follows, you can watch an animation that explains why: http://www.hhmi.org/biointeractive/gender/Y_evolution.html .

Human Genes

Humans have an estimated 20,000 to 22,000 genes. This may sound like a lot, but it really isn't. Far simpler species have almost as many genes as humans. However, human cells use splicing and other processes to make multiple proteins from the instructions encoded in a single gene. Of the 3 billion base pairs in the human genome, only about 25 percent make up genes and their regulatory elements. The functions of many of the other base pairs are still unclear. To learn more about the coding and noncoding sequences of human DNA, watch the animation at this link:

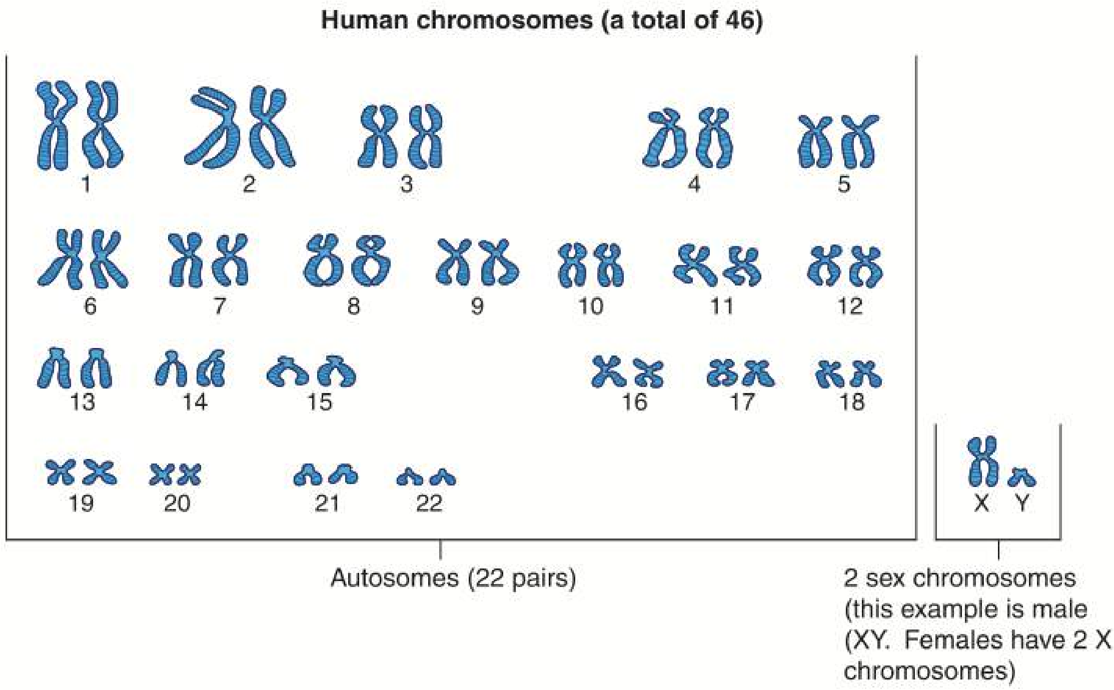


FIGURE 10.2

Human Chromosomes. Humans have 23 pairs of chromosomes. Pairs 1-22 are autosomes. Females have two X chromosomes, and males have an X and a Y chromosome.

http://www.hhmi.org/biointeractive/dna/DNAi_coding_sequences.html .

The majority of human genes have two or more possible **alleles**, which are alternative forms of a gene. Differences in alleles account for the considerable genetic variation among people. In fact, most human genetic variation is the result of differences in individual DNA bases within alleles.

Summary

- Humans have 23 pairs of chromosomes. Of these, 22 pairs are autosomes.
- The X and Y chromosomes are the sex chromosomes. Females have two X chromosomes, and males have one X and one Y.
- Human chromosomes contain a total of 20,000 to 22,000 genes, the majority of which have two or more alleles.

Practice

Use these resources to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **The Chromosome Theory**

1. What is the chromosome theory of inheritance?
2. Distinguish between an autosome and a sex chromosome.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Sex Chromosomes**

1. Genetically, what is the difference between a human male and female?
2. What determines the sex of a baby?
3. Define an X-linked gene.
4. Why is it more likely that a male will display an X-linked trait than a female?

Review

1. Describe human chromosomes.

2. Compare and contrast human autosomes and sex chromosomes.

References

1. KES47. . CC-BY 3.0
2. Image copyright Blamb, 2010. . Used under license from Shutterstock.com

CHAPTER 11 Pedigree Analysis

- Interpret a pedigree.

What's a pedigree?

When you are talking about a pedigree dog, it means the dog is purebred. Through selective breeding, the dog has all the traits of that particular breed. When talking about genetics, however, a pedigree is a chart that helps show family relationships.

Pedigree Analysis

A **pedigree** is a chart that shows the inheritance of a trait over several generations. A pedigree is commonly created for families, and it outlines the inheritance patterns of genetic disorders.

Pictured below is a pedigree displaying recessive inheritance of a disorder through three generations (**Figure** 11.1). From studying a pedigree, scientists can determine the following:

- If the trait is **sex-linked** (on the X or Y chromosome) or **autosomal** (on a chromosome that does not determine sex).
- If the trait is inherited in a dominant or recessive fashion.

Sometimes pedigrees can also help determine whether individuals with the trait are heterozygous or homozygous.

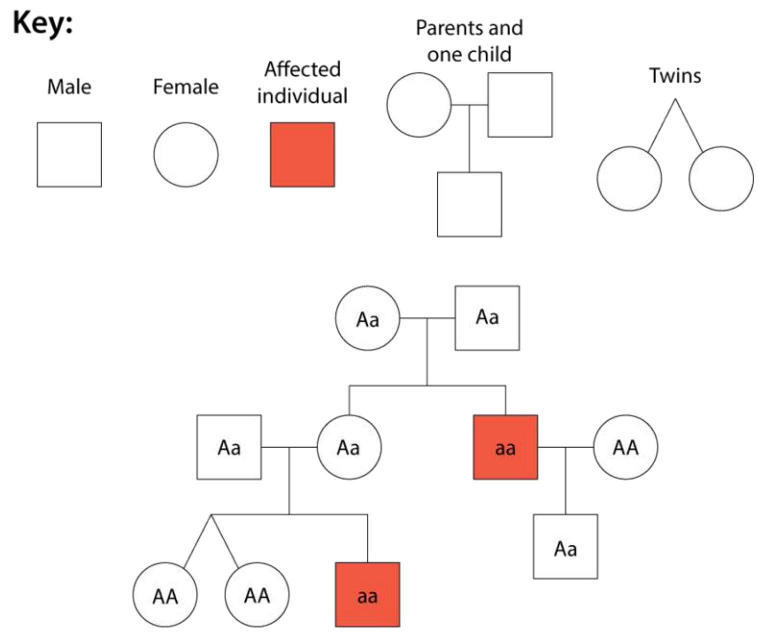


FIGURE 11.1

In a pedigree, squares symbolize males, and circles represent females. A horizontal line joining a male and female indicates that the couple had offspring. Vertical lines indicate offspring which are listed left to right, in order of birth. Shading of the circle or square indicates an individual who has the trait being traced. In this pedigree, the inheritance of the recessive trait is being traced. *A* is the dominant allele, and *a* is the recessive allele.

Vocabulary

- **autosomal**: On any chromosome other than the sex chromosomes.
- **pedigree**: Chart which shows the inheritance of a trait over several generations.
- **sex-linked**: On the X or Y chromosome.

Summary

- A pedigree is a chart which shows the inheritance of a trait over several generations.
- From studying a pedigree, scientists can determine if a trait is sex-linked or autosomal.

Practice

Use the resource below to answer the questions that follow.

- **Find the Gene for Whirling Disorder?** at http://learn.genetics.utah.edu/archive/pedigree/mapgene.html

1. What is Whirling Disorder?
2. On the pedigree, which individuals have Whirling Disorder?
3. Individual 5 does not have Whirling disorder, but what colored pieces does it have that potentially could have carried the gene for Whirling Disorder?
4. Which puzzle piece (gene) is responsible for Whirling Disorder?

Review

1. What is a pedigree?
2. How might a pedigree aid a scientist?

References

1. CK-12 Foundation - Zachary Wilson. . CC-BY-NC-SA 3.0

CHAPTER 12 Genetic Disorders

- Describe how some common human genetic disorders are inherited.

When is a cold not just a cold?

At some point in your life, you're bound to catch a cold. And there are ways to prevent catching a cold. But what if you couldn't prevent an illness? What if you were born with a disease? What if having a disease was actually due to your DNA? These are genetic diseases, and they can be very serious.

Human Genetic Disorders

Some human genetic disorders are also X-linked or Y-linked, which means the faulty gene is carried on these sex chromosomes. Other genetic disorders are carried on one of the other 22 pairs of chromosomes; these chromosomes are known as **autosomes** or autosomal (non-sex) chromosomes.

Autosomal Recessive Disorders

Some genetic disorders are caused by recessive alleles of a single gene on an autosome. An example of an **autosomal recessive genetic disorder** is cystic fibrosis. Children with **cystic fibrosis** have excessively thick mucus in their lungs, which makes it difficult for them to breathe. The inheritance of this recessive allele is the same as any other recessive allele, so a Punnett square can be used to predict the probability that two **carriers** of the disease will have a child with cystic fibrosis. Recall that carriers have the recessive allele for a trait but do not express the trait. What are the possible genotypes of the offspring in the following table (**Table** 12.1)? What are the possible phenotypes?

TABLE 12.1: Cystic Fibrosis

	F	**f**
F	**FF** (normal)	**Ff** (carrier)
f	**Ff** (carrier)	**ff** (affected)

According to this Punnett square, two parents that are carriers (Ff) of cystic fibrosis gene have a 25% chance of having a child with cystic fibrosis (ff).

Automsomal Dominant Disorders

Huntington's disease is an example of an **autosomal dominant disorder**. This means that if the dominant allele is present, then the person will express the disease.

The disease causes the brain's cells to break down, leading to muscle spasms and personality changes. Unlike most other genetic disorders, the symptoms usually do not become apparent until middle age. You can use a simple Punnett square to predict the inheritance of a dominant autosomal disorder, like Huntington's disease. If one parent has Huntington's disease, what is the chance of passing it on to the children? If you draw the Punnett square, you will find that there is a 50 percent chance of the disorder being passed on to the children.

Vocabulary

- **autosomal dominant genetic disorder**: Caused by dominant alleles of a single gene on an autosome.
- **autosomal recessive genetic disorder**: Caused by recessive alleles of a single gene on an autosome.
- **autosome**: Any chromosome that is not a sex chromosome.
- **carrier**: Person that carries the recessive allele for a trait but does not express the trait.
- **cystic fibrosis**: Autosomal recessive genetic disorder characterized by excessively thick mucus in the lungs.
- **Huntington's disease**: Autosomal dominant genetic disorder characterized by muscle spasms and personality changes.

Summary

- Autosomal recessive genetic disorders, such as cystic fibrosis, are caused by recessive alleles of a single gene on an autosome.
- Autosomal dominant genetic disorders, such as Huntington's disease, are caused by dominant alleles of a single gene on an autosome.

Practice

Use the resource below to answer the questions that follow.

- **What are Genetic Disorders?** at http://learn.genetics.utah.edu/content/disorders/whataregd/

1. What are multifactorial disorders? What is an example of a multifactorial disorder?
2. What are single-gene disorders? What is an example of a single-gene disorder?
3. What causes galactosemia? How is it diagnosed? How is it treated?
4. What causes Colon Cancer? How is it diagnosed? How is it treated?
5. What is newborn genetic screening? How is it carried out?

Review

1. Can you be a carrier of an autosomal dominant recessive disorder?
2. One parent is a carrier of the cystic fibrosis gene, while the other parent does not carry the allele. Can their child have cystic fibrosis?

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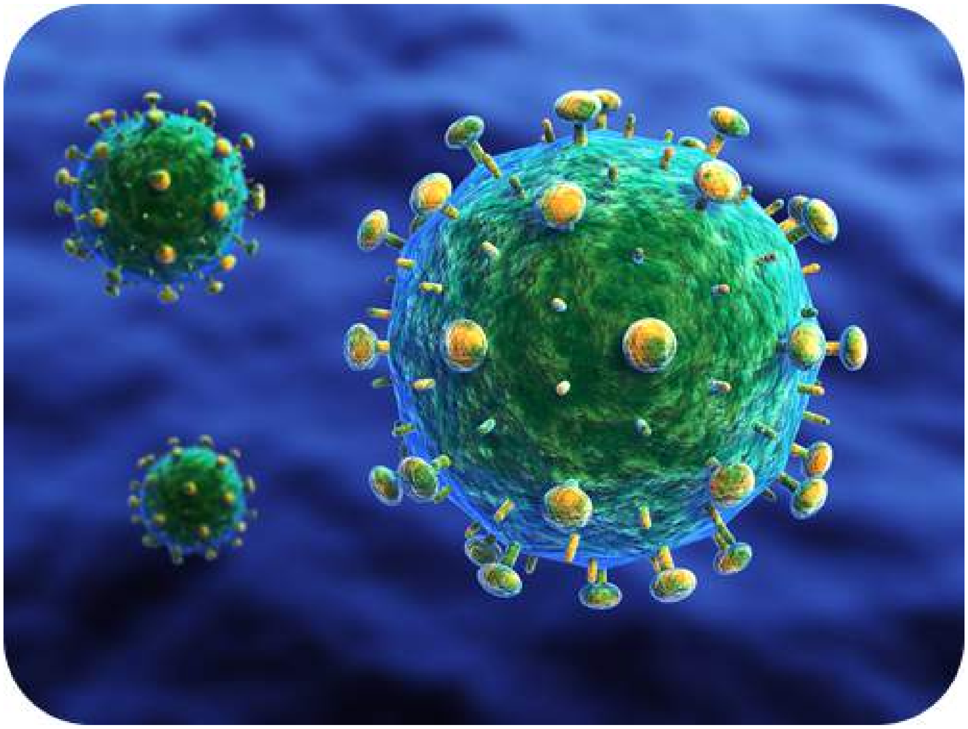
Contents

CONCEPT 1 Virus Structures

- Describe the structure of viruses.



Is this a cell or a virus?

It is actually a representation of the HIV virus, the virus that causes AIDS. All the little "knobs" on the outside of the virus help to give the virus structure. And it is this structure that must be identified by a vaccine.

Structure of Viruses

Viruses vary in their structure. A virus particle consists of DNA or RNA within a protective protein coat called a **capsid.** The shape of the capsid may vary from one type of virus to another. The capsid is made from the proteins that are encoded by viral genes within their genome.

The shape of the capsid serves as one basis for classification of viruses. The capsid of the mimivirus shown below is icosahedral. Virally coded proteins will self-assemble to form a capsid. Some viruses have an envelope of phospholipids and proteins. The envelope is made from portions of the host's cell membrane. It surrounds the capsid and helps protect the virus from the host's immune system. The envelope may also have receptor molecules that can bind with host cells. They make it easier for the virus to infect the cells.

Helical Viruses

Helical capsids are made up of a single type of protein subunit stacked around a central axis to form a helical structure. The helix may have a hollow center, which makes it look like a hollow tube. This arrangement results in rod-shaped or filamentous virions. These virions can be anything from short and very rigid, to long and very flexible. The well-studied tobacco mosaic virus (TMV) is an example of a helical virus.

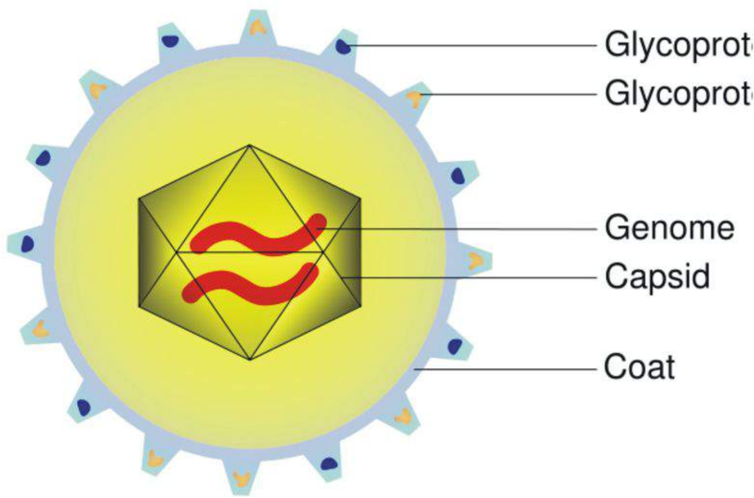


FIGURE 1.1
Diagram of a Cytomegalovirus. The capsid encloses the genetic material of the virus. The envelope which surrounds the capsid is typically made from portions of the host cell membranes (phospholipids and proteins). Not all viruses have a viral envelope. In this figure, glycoproteins are identified on the coat of the virus as "Glycoprot."

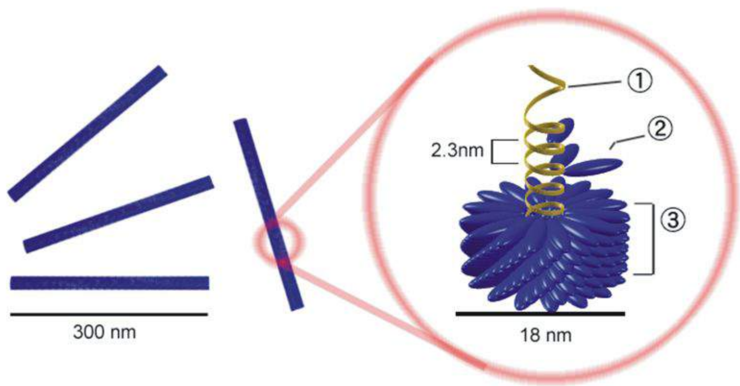


FIGURE 1.2
A helical virus, tobacco mosaic virus. Although their diameter may be very small, some helical viruses can be quite long, as shown here. 1. Nucleic acid; 2. Viral protein units, 3. Capsid. TMV causes tobacco mosaic disease in tobacco, cucumber, pepper, and tomato plants.

Icosahedral Viruses

Icosahedral capsid symmetry gives viruses a spherical appearance at low magnification, but the protein subunits are actually arranged in a regular geometrical pattern, similar to a soccer ball; they are not truly spherical. An icosahedral shape is the most efficient way of creating a hardy structure from multiple copies of a single protein. This shape is used because it can be built from a single basic unit protein which is used over and over again. This saves space in the viral genome.

Complex Viruses

Complex viruses possess a capsid which is neither purely helical, nor purely icosahedral, and which may have extra structures such as protein tails or a complex outer wall. Viral protein subunits will self-assemble into a capsid, but the complex viruses DNA also codes for proteins which help in building the viral capsid. Many phage viruses are complex-shaped; they have an icosahedral head bound to a helical tail. The tail may have a base plate with protein tail fibers. Some complex viruses do not have tail fibers.

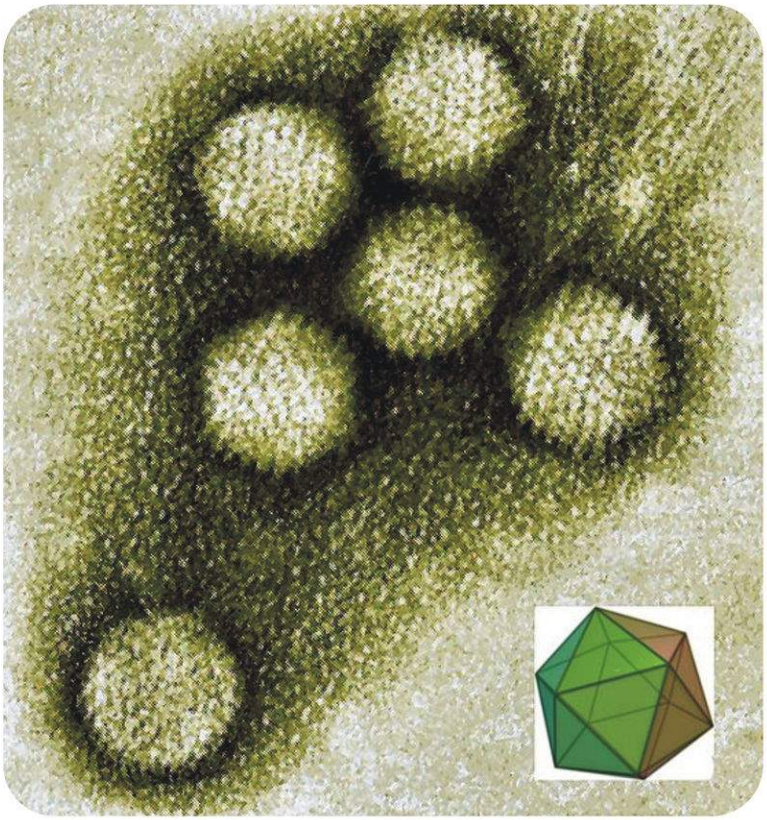


FIGURE 1.3
Adenovirus, an icosahedral virus. An icosahedron is a three-dimensional shape made up of 20 equilateral triangles. Viral structures are built of repeated identical protein subunits, making the icosahedron the easiest shape to assemble using these subunits.

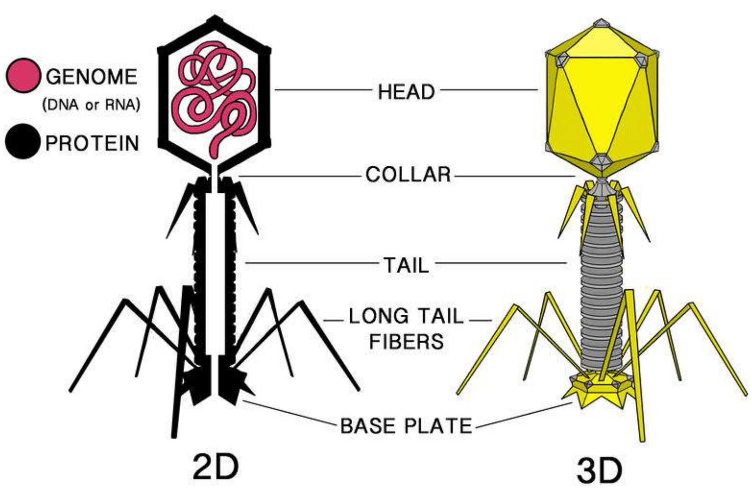


FIGURE 1.4
This "moon lander"-shaped complex virus infects *Escherichia coli* bacteria.

Enveloped Viruses

Some viruses are able to surround (envelop) themselves in a portion of the cell membrane of their host. The virus can use either the outer membrane of the host cell, or an internal membrane such as the nuclear membrane or endoplasmic reticulum. In this way the virus gains an outer lipid bilayer known as a **viral envelope** . This membrane is studded with proteins coded for by both the viral genome and the host genome. However, the lipid membrane itself and any carbohydrates present come entirely from the host cell. The influenza virus, HIV, and the varicella zoster virus are enveloped viruses.

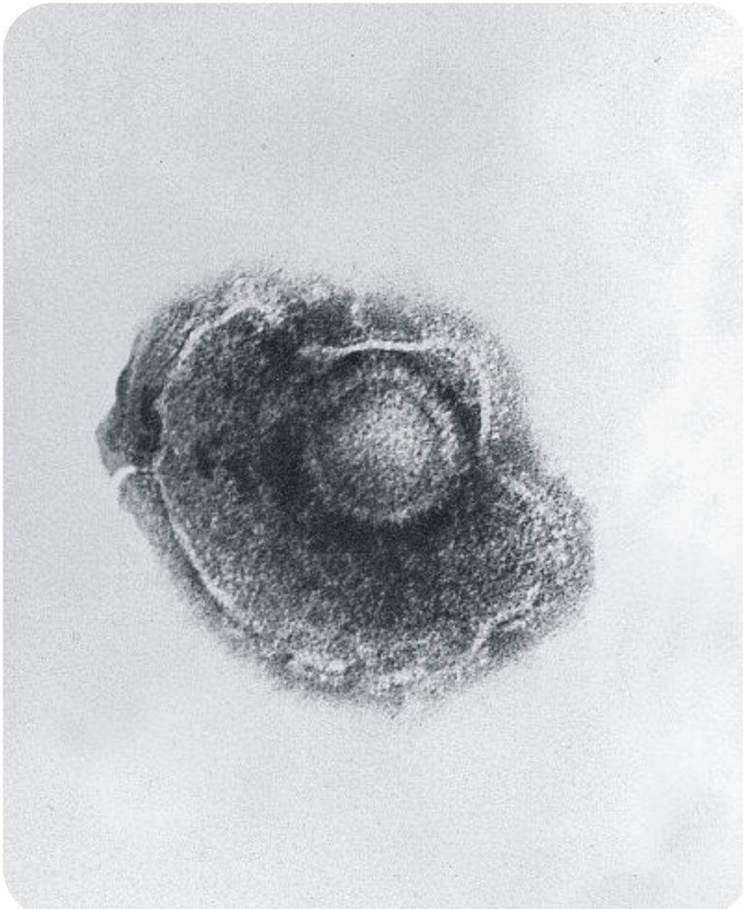


FIGURE 1.5
An enveloped virus. Varicella zoster virus causes chicken pox and shingles.

The viral envelope can give a virus some advantages over other capsid-only viruses. For example, they have better protection from the host's immune system, enzymes and certain chemicals. The proteins in the envelope can include glycoproteins, which act as receptor molecules. These receptor molecules allow host cells to recognize and bind the virions, which may result in easier uptake of the virion into the cell. Most enveloped viruses depend on their envelopes to infect cells. However, because the envelope contains lipids, it makes the virus more susceptible to inactivation by environmental agents, such as detergents that disrupt lipids.

Summary

- Viruses have different shapes. They can be cylindrical, icosahedral, complex, or enveloped.

Practice I

Use these resources to answer the questions that follow.

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

1. Describe viral structure.
2. Describe the capsid and viral envelope.

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

1. Illustrate examples of viral structure.

Practice II

- **Virus Particles Structure and Function** at http://www.wisc-online.com/Objects/ViewObject.aspx?ID=MBY101 .

Review

1. Describe variation in capsid shape in viruses.

2. Compare the structures of a prokaryote and a virus. If you prefer, you may draw a diagram of each and label the different parts of each structure.

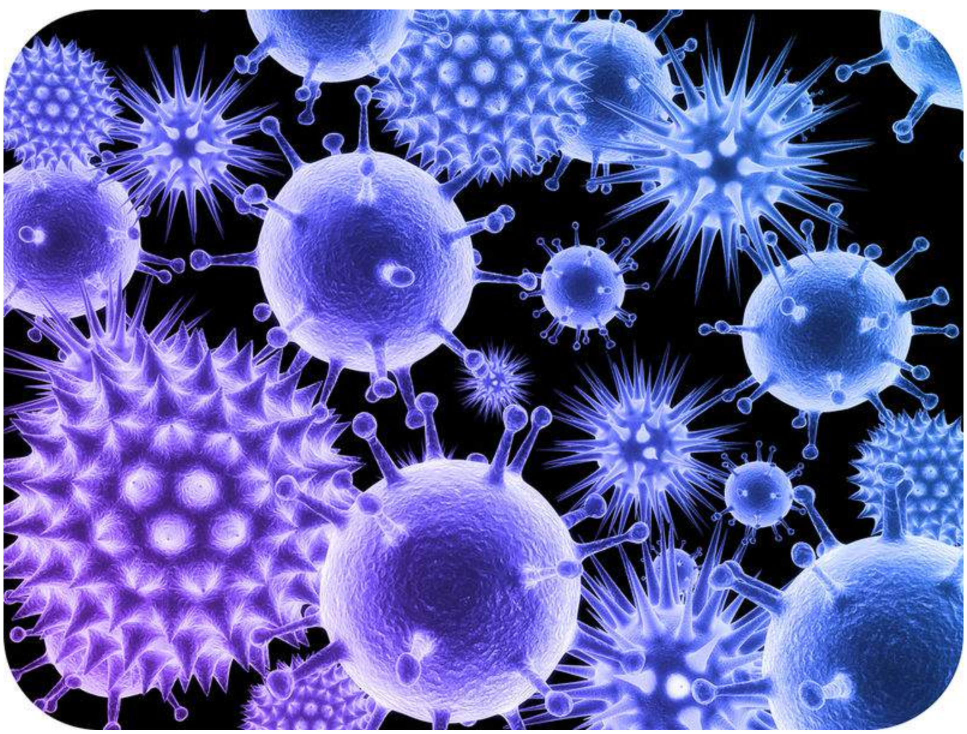
References

1. Emmanuel Boutet. . CC-BY-SA 2.5
2. Y. Tambe. . GNU-FDL 1.2
3. User:GrahamColm/Wikipedia. . Public Domain
4. Laura Guerin. . CC BY-NC 3.0
5. Courtesy of Centers for Disease Control and Prevention/Dr. Erskine Palmer/B.G. Partin. . Public Domain

CONCEPT 2 Viruses

- Describe the features and list examples of viruses.

- **AIDS**
- **ATP**
- **cell**
- **enzyme**
- **evolution**
- **genetic material**
- **homeostasis**
- **host cell**
- **replicate**
- **ribosome**
- **virus**



What causes the common cold?

That miserable cough and runny nose is caused by one villain: a virus. Viruses come in many different shapes, including the prickly balls you see here. They are so tiny that they can only be seen with a very powerful microscope.

What is a Virus?

We have all heard of viruses. The flu, the common cold, and many other diseases are caused by viruses. But what is a virus? Do you think viruses are living? Which domain do they belong to? Bacteria? Archaea? Eukarya?

Are Viruses Alive?

The answer is actually "no." A **virus** is essentially DNA or RNA surrounded by a coat of protein (**Figure** 2.1). It is not made of a **cell** , and cannot maintain a stable internal environment (**homeostasis**). Recall that a cell is the basic unit of living organisms. So if a virus is not made of at least one cell, can it be living? Viruses also cannot reproduce on their own—they need to infect a **host cell** to reproduce. So a virus is very different from any of the organisms that fall into the three domains of life.

Though viruses are not considered living, they share two important traits with living organisms. They have **genetic material** like all cells do, and they can evolve. As the process of **evolution** has resulted in all life on the planet today, the classification of viruses has been controversial. It calls into question the very definition of life.

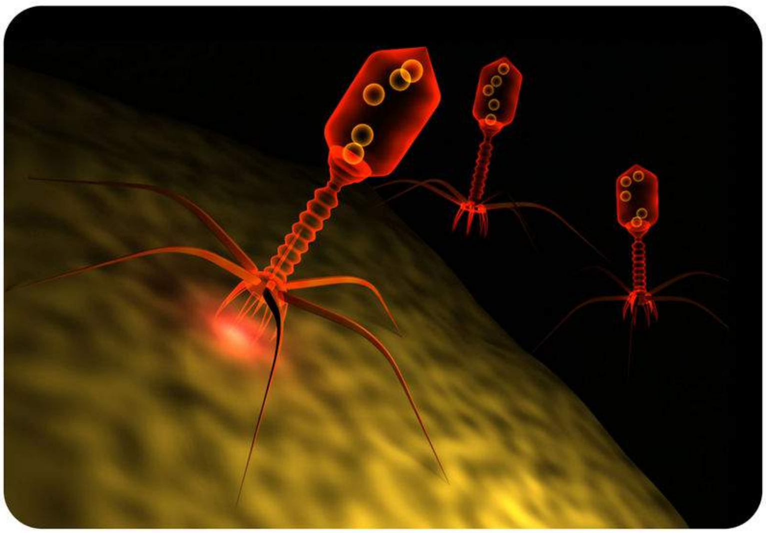


FIGURE 2.1
These little "alien" looking creatures are viruses, and these specific viruses infect *Escherichia coli* bacteria. Shown is a representation of viruses infecting a cell. The virus lands on the outside of the cell and injects its genetic material into the cell.

Replication

Viruses infect a variety of organisms, including plants, animals, and bacteria. Once inside the host cell, they use the cell's own **ATP** (energy), **ribosomes** , **enzymes** , and other cellular parts to make copies of themselves. The host cell makes a copy of the viral DNA and produces viral proteins. These are then packaged into new viruses. So viruses cannot **replicate** or reproduce on their own; they rely on a host cell to make additional viruses.

Viruses and Human Disease

Viruses cause many human diseases. In addition to the flu and the common cold, viruses cause rabies, diarrheal diseases, **AIDS** , cold sores, and many other diseases (**Figure** 4.1). Viral diseases range from mild to fatal.

Vocabulary

- **AIDS** : Acquired immune deficiency syndrome, which is a fatal condition, unless treated with proper medications, caused by the human immunodeficiency virus (HIV).
- **ATP** : Adenosine triphosphate; a usable form of energy inside the cell.
- **cell** : Basic unit of structure and function of a living organism; the basic unit of life.
- **enzyme** : Protein that speeds up chemical reactions.

FIGURE 2.2
Cold sores are caused by a herpes virus.

- **evolution** : Process in which something passes to a different stage, such as a living organism turning into a more advanced or mature organism; the change of the inherited traits of a group of organisms over many generations.
- **genetic material** : DNA and RNA
- **homeostasis** : Maintaining a stable internal environment.
- **host cell** : Cell infected by a virus.
- **replicate** : To make a copy of, as in viral replication or DNA replication.
- **ribosome** : Cell structure on which proteins are made; not surrounded by a membrane; found in both prokaryotic and eukaryotic cells.
- **virus** : Non-living particle consisting of RNA or DNA surrounded by a protein coat.

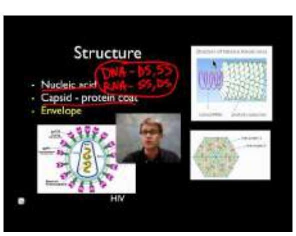
Summary

- A virus is composed of DNA or RNA surrounded by a coat of protein.
- Viruses are not considered living things because they cannot reproduce on their own, and they are not comprised of cells.

Practice

Use the resources below to answer the questions that follow.

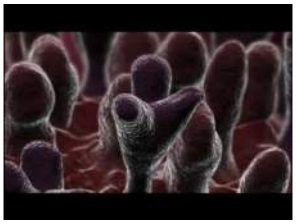
- **Viruses** at http://www.youtube.com/watch?v=L8oHs7G_syI (8:06)



MEDIA
Click image to the left for more content.

1. How do viruses reproduce? How does this differ from other organisms?
2. What kinds of nucleic acids can viruses have?
3. Explain one of the theories as to how viruses came to be.
4. What is the importance of the "envelope" to a virus? What is the envelope made of?
5. What is a difference between the lytic cycle of a virus and the lysogenic cycle?

- **How Flu Viruses Attack** at http://www.youtube.com/watch?v=TVLo2CtB3GA (3:48)



MEDIA

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1. What is one way a flu virus can kill a human?
2. Do mutations make viruses more deadly? Why or why not?

Review

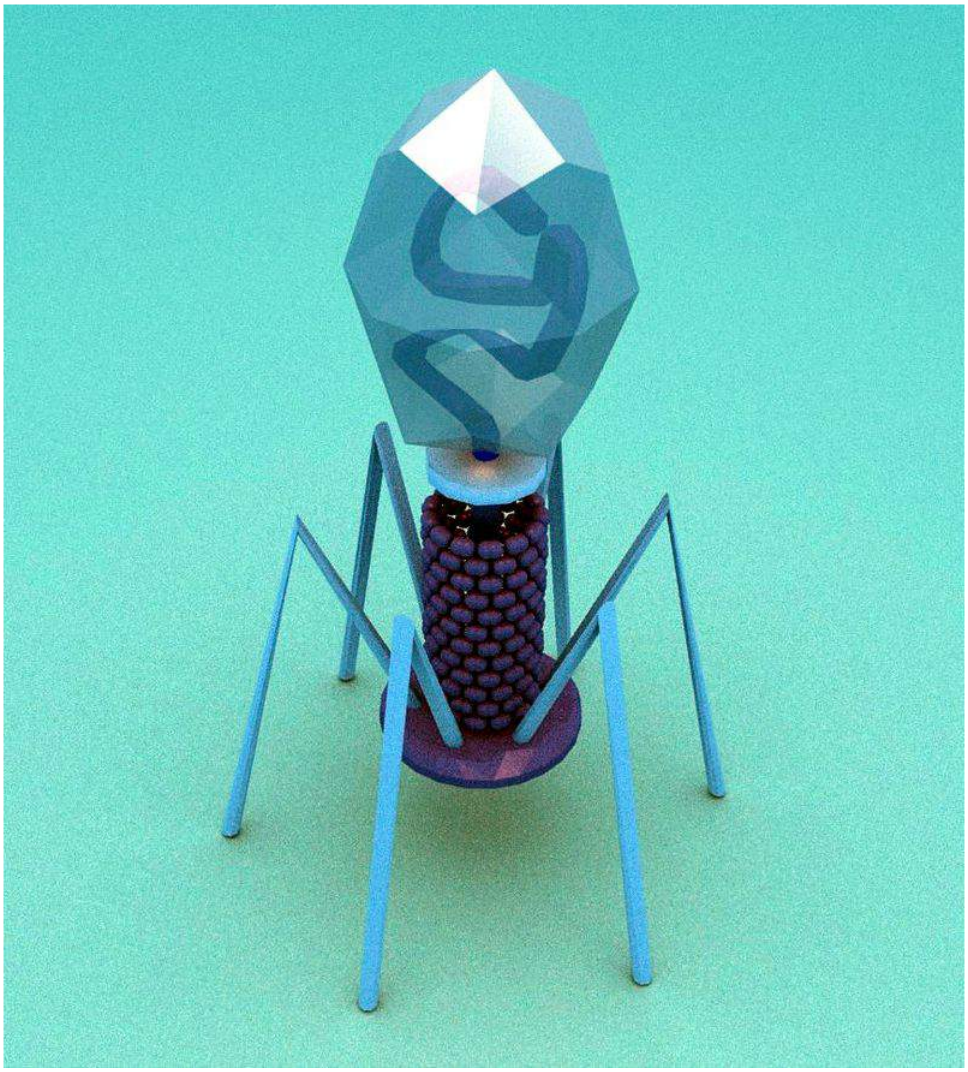
1. Is a virus a living thing? Why or why not?
2. Name some examples of human diseases caused by a virus.

References

1. Image copyright Monika Wisniewska, 2010. . Used under license from Shutterstock.com
2. Metju12. . Public Domain

CONCEPT 3 Viruses

- Describe a virus.



What is a virus? Is it even a living organism?

This alien-looking thing is a virus. But is it prokaryotic or eukaryotic? Or neither? Or both? A virus is essentially genetic material surrounded by protein. That's it. So, is a virus prokaryotic or eukaryotic? Or neither? Or both?

Viruses: Prokaryotes or Eukaryotes?

Viruses , like the one depicted in **Figure** 3.1 , are tiny particles that may cause disease. Human diseases caused by viruses include the common cold and flu. Do you think viruses are prokaryotes or eukaryotes? The answer may surprise you. Viruses are not cells at all, so they are neither prokaryotes nor eukaryotes.

Viruses contain DNA but not much else. They lack the other parts shared by all cells, including a plasma membrane, cytoplasm, and ribosomes. Therefore, viruses are not cells, but are they alive? All living things not only have cells; they are also capable of reproduction. Viruses cannot reproduce by themselves. Instead, they infect living hosts, and

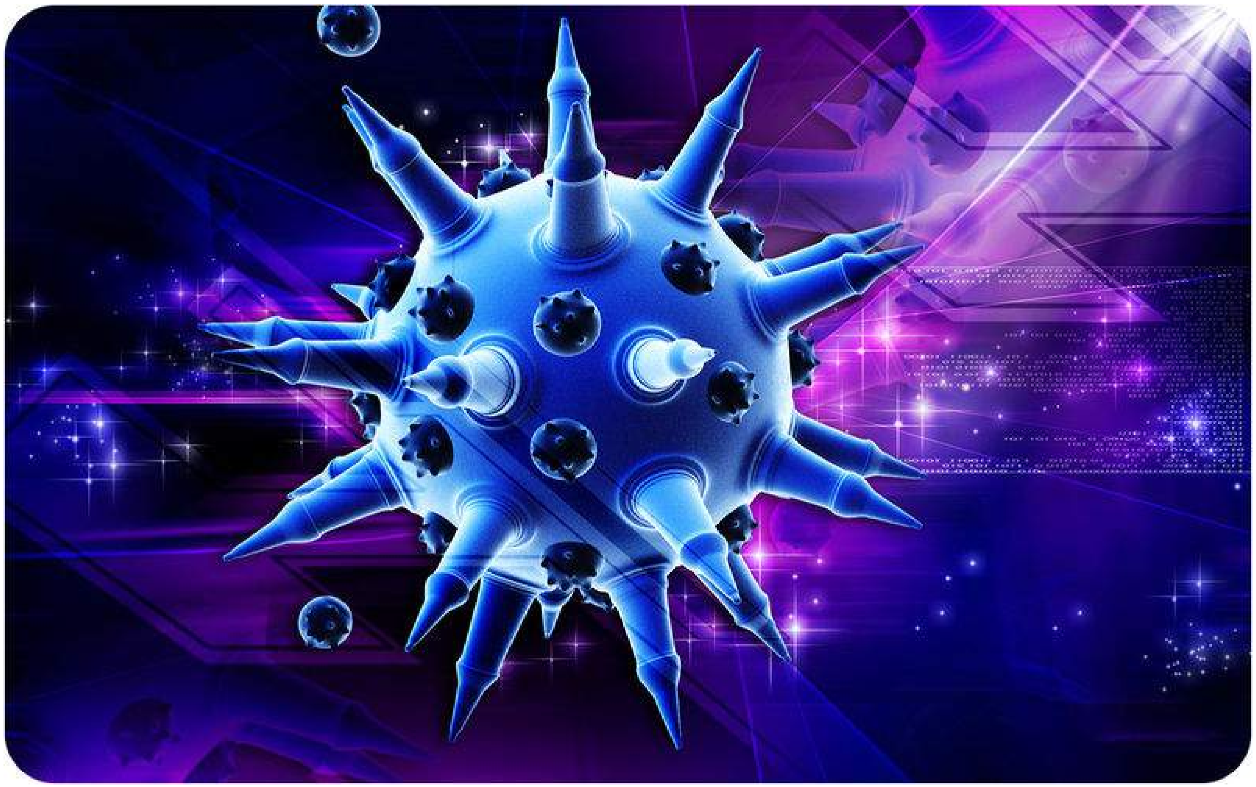
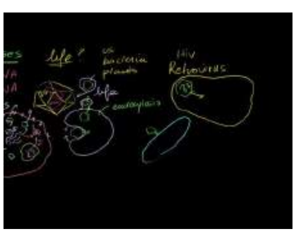


FIGURE 3.1
Cartoon of a flu virus. The flu virus is a tiny particle that may cause illness in humans. What is a virus? Is it a cell? Is it even alive?

use the hosts' cells to make copies of their own DNA. For these reasons, most scientists do not consider viruses to be living things.

An overview of viruses can be seen at http://www.youtube.com/watch?v=0h5Jd7sgQWY (23:17).



MEDIA
Click image to the left for more content.

Summary

- Viruses are neither prokaryotic or eukaryotic.
- Viruses are not made of cells. Viruses cannot replicate on their own.
- Most scientists do not consider viruses to be living.

Practice

Use this resource to answer the questions that follow.

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

1. Describe a virus.
2. Why are viruses considered parasites?
3. Describe the outside covering of a virus.
4. What do the lytic and lysogenic cycles describe?

Review

1. What is a virus?

2. Explain why viruses are not considered to be living.

References

1. Image copyright KannonImages, 2010. . Used under license from Shutterstock.com

CONCEPT 4 Viruses and Human Disease

- Explain how viruses cause human disease.

Viral or bacterial?

Doesn't look like fun. The flu is caused by an influenza virus. And usually a slightly different virus every season.

Viruses and Human Disease

Viruses cause many human diseases. In addition to the flu and HIV, viruses cause rabies, measles, diarrheal diseases, hepatitis, polio, cold sores and other diseases (see **Figure** 4.1). Viral diseases range from mild to fatal. One way viruses cause disease is by causing host cells to burst open and die. Viruses may also cause disease without killing host cells. They may cause illness by disrupting homeostasis in host cells.

Some viruses live in a dormant state inside the body. This is called **latency** . For example, the virus that causes chicken pox may infect a young child and cause the short-term disease chicken pox. Then the virus may remain

FIGURE 4.1
Cold Sore. Cold sores are caused by a herpes virus.

FIGURE 4.2
Shingles. Shingles is a disease caused by the same virus that causes chicken pox.

latent in nerve cells within the body for decades. The virus may re-emerge later in life as the disease called shingles. In shingles, the virus causes painful skin rashes with blisters (see **Figure** 4.2).

Some viruses can cause cancer. For example, human papillomavirus (HPV) causes cancer of the cervix in females. Hepatitis B virus causes cancer of the liver. A viral cancer is likely to develop only after a person has been infected with a virus for many years.

The Flu

Influenza, or flu, is a contagious respiratory illness caused by influenza viruses. Influenza spreads around the world in seasonal epidemics. An **epidemic** is an outbreak of a disease within a population of people during a specific time. Every year in the United States, about 200,000 people are hospitalized and 36,000 people die from the flu. Flu pandemics can kill millions of people. A **pandemic** is an epidemic that spreads through human populations across a large region (for example a continent), or even worldwide. Three influenza pandemics occurred in the 20th century and killed tens of millions of people, with each of these pandemics being caused by the appearance of a new strain of the virus. Most influenza strains can be inactivated easily by disinfectants and detergents.

Emerging Viral Diseases

Modern modes of transportation allow more people and products to travel around the world at a faster pace. They also open the airways to the transcontinental movement of infectious disease vectors. One example of this occurring is **West Nile Virus** , which scientists believe was introduced to the United States by an infected air traveler. With the use of air travel, people are able to go to foreign lands, contract a disease and not have any symptoms of illness until they get home, possibly exposing others to the disease along the way. See *Virus Crisis* at http://www.neok12.com/php/watch.php?v=zX0b0954067a71795a6c647b&t=Microorganisms for additional information.

Often, new diseases result from the spread of an existing disease from animals to humans. A disease that can be spread from animals to humans is called a **zoonosis** . When a disease breaks out, scientists called **epidemiologists** investigate the outbreak, looking for its cause. Epidemiologists are like detectives trying to solve a crime. The information epidemiologists learn is important to understand the pathogen, and help prevent future outbreaks of disease.

A deadly strain of avian flu virus named H5N1 has posed the greatest risk for a new influenza pandemic since it first killed humans in Asia in the 1990s. The virus is passed from infected birds to humans. Fortunately, the virus has not mutated to a form that spreads easily between people.

Several lethal viruses that cause viral hemorrhagic fever have been discovered, two of which are shown below. Ebola outbreaks have been limited mainly to remote areas of the world. However, they have gained extensive media attention because of the high mortality rate—23 percent to 90 percent—depending on the strain. The primary hosts of the viruses are thought to be apes in west central Africa, but the virus has also been isolated from bats in the same region.

FIGURE 4.3

The Ebola virus (left), and Marburg virus (right), are viruses that cause hemorrhagic fevers that can cause multiple organ failure and death.

People get exposed to new and rare zoonoses when they move into new areas and encounter wild animals. For example, severe acute respiratory syndrome (**SARS**) is a respiratory disease which is caused by the SARS coronavirus. An outbreak in China in 2003 was linked to the handling and consumption of wild civet cats sold as food in a market. In 2005, two studies identified a number of SARS-like coronaviruses in Chinese bats. It is likely that the virus spread from bats to civets, and then to humans.

Summary

- Viruses cause many human diseases by killing host cells or disturbing their homeostasis.
- Viruses are not affected by antibiotics. Several viral diseases can be treated with antiviral drugs or prevented with vaccines.

Practice I

Use these resources to answer the questions that follow.

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

1. Describe the influenza virus.
2. Describe HIV.

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

1. How does a virus infect a host cell?
2. List 3 human illnesses caused by viruses.
3. Why are epidemics and pandemics of concern?

Practice II

- **Virus Matching Exercises** at http://www.wisc-online.com/Objects/ViewObject.aspx?ID=MBY2804 .

Review

1. How do viruses cause human disease?

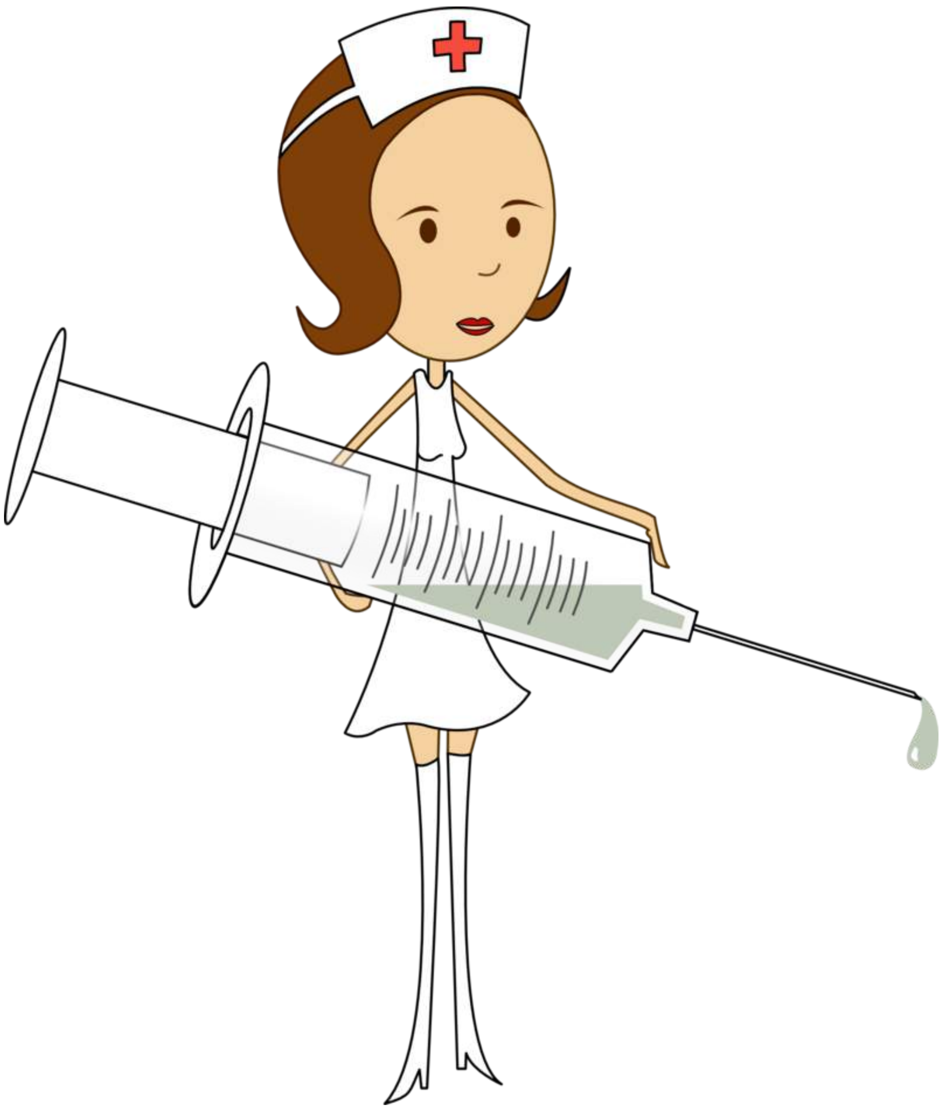
2. What is an epidemic? Why can the flu be considered an epidemic?

References

1. User:Metju12/Wikimedia Commons. . Public Domain
2. Preston Hunt. . CC BY 3.0
3. Ebola virus: Courtesy of CDC/Cynthia Goldsmith; Marburg virus: Courtesy of CDC/Dr. Erskine Palmer, Russell Regnery, Ph.D.. . Public Domain

CONCEPT 5 Control of Viruses

- Describe how viruses can be controlled.



What's the best part of going to the doctor?

Most people don't like having a shot at the doctor's office. But these are necessary. They protect you from some very dangerous viruses.

Control of Viruses

People have been able to control the spread of viruses even before they knew they existed. In 1717, Mary Montagu, the wife of an English ambassador to the Ottoman Empire, observed local women inoculating their children against smallpox, a contagious viral disease that was often deadly. **Inoculation** involves introducing a small amount of virus into a person's body to allow their body to build up immunity to the virus. This early smallpox inoculation involved putting smallpox crusts into the nostril of a healthy person.

Vaccines

Because viruses use the machinery of a host cell to reproduce and stay within them, they are difficult to get rid of without killing the host cell. Vaccines were used to prevent viral infections long before the discovery of viruses. A **vaccine** is a mixture of antigenic material and other immune stimulants that will produce immunity to a certain pathogen or disease. The term "vaccine" comes from Edward Jenner's use of cowpox (*vacca* means cow in Latin), to immunize people against smallpox.

The material in the vaccine can either be weakened forms of a living pathogen or virus, dead pathogens (or inactivated viruses), purified material such as viral proteins, or genetically engineered pieces of a pathogen. The material in the vaccine will cause the body to mount an immune response, so the person will develop **immunity** to the disease. Smallpox was the first disease people tried to prevent by purposely inoculating themselves with other types of infections such as cowpox. **Vaccination** is an effective way of preventing viral infections. Vaccinations can be given in schools, shown below, health clinics, and even at home. Their use has resulted in a dramatic decline in morbidity (illness) and mortality (death) associated with viral infections such as polio, measles, mumps, and rubella. Genetically engineered vaccines are produced through recombinant DNA technology. Most new vaccines are produced with this technology.

FIGURE 5.1

A young student receives a vaccine.

A worldwide vaccination campaign by the World Health Organization led to the eradication of smallpox in 1979. Smallpox is a contagious disease unique to humans and is caused by two *Variola* viruses. The eradication of smallpox was possible because humans are the only carriers of the virus. To this day, smallpox is the only human infectious disease to have been completely eradicated from nature. Scientists are hoping to eradicate polio next.

Antiviral Drugs

While people have been able to prevent certain viral diseases by vaccinations for many hundreds of years, the development of antiviral drugs to treat viral diseases is a relatively recent development. **Antiviral drugs** are medications used specifically for treating the symptoms of viral infections. The first antiviral drug was **interferon** , a substance that is naturally produced by certain immune cells when an infection is detected. Over the past twenty years the development of antiretroviral drugs (also known as antiretroviral therapy, or ART) has increased rapidly. This has been driven by the AIDS epidemic.

Like antibiotics, specific antivirals are used for specific viruses. They are relatively harmless to the host, and therefore can be used to treat infections. Most of the antiviral drugs now available are designed to help deal with

HIV and herpes viruses. Antivirals are also available for the influenza viruses and the Hepatitis B and C viruses, which can cause liver cancer.

Antiviral drugs are often imitation DNA building blocks which viruses incorporate into their genomes during replication. The life cycle of the virus is then halted because the newly synthesized DNA is inactive. Similar to antibiotics, antivirals are subject to drug resistance as the pathogens evolve to survive exposure to the treatment. HIV evades the immune system by constantly changing the amino acid sequence of the proteins on the surface of the virion. Researchers are now working to extend the range of antivirals to other families of **pathogens** .

Summary

- Several viral diseases can be treated with antiviral drugs or prevented with vaccines.

Practice

Use this resource to answer the questions that follow.

- **Questions and Answers on the Use of HIV Medications to Help Prevent the Transmission of HIV** at http://www.cdc.gov/hiv/topics/treatment/resources/qa/art.htm .

1. Can HIV medications help prevent the transmission of HIV?
2. What does ART do? How do we know when it is working?

Review

1. What is a vaccine?

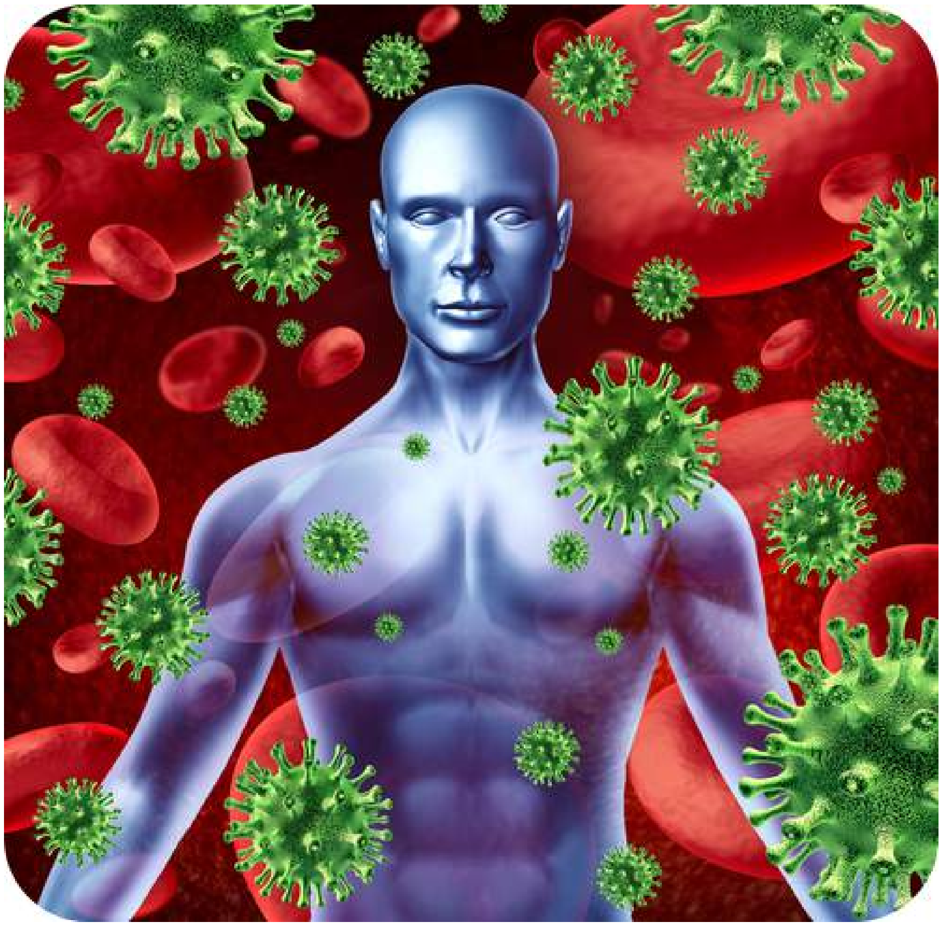
2. Apply lesson concepts to decide how strep throat and flu can be treated or prevented. Create a chart to summarize your ideas.

References

1. PV2 Andrew W. McGalliard. . Public Domain

Concept 6 Viruses in Research and Medicine

- Identify how viruses are used in research and medicine.



Can viruses be helpful, or just harmful?

Viruses are extensively used in research and medicine to both understand basic biology and to improve human health. Imagine having a tool that is able to inject its DNA into a host cell. The possibilities of using such a tool are endless. That tool would be a virus.

Viruses in Research

Viruses are an extremely important tool in the study of molecular and cellular biology. Since viruses infect cells by moving their genetic material into the host cell's nucleus, they are helpful in the investigation of the functions of cells. For example, the use of viruses in research has helped our understanding of the basics of molecular genetics, such as DNA replication, transcription, RNA processing, translation, protein transport, and immunology.

Viruses and Medicine

Geneticists often use viruses as vectors to introduce genes into cells that they are studying. A **viral vector** is a tool commonly used by molecular biologists to place genetic material into cells. To be a useful viral vector, the virus is modified so that it will not cause disease, and it will infect only certain types of cells. **Phages** are often used as vectors to genetically modify bacteria.

In a similar fashion, **viral therapy** uses viruses to genetically modify diseased cells and tissues. Viral therapy shows promise as a method of **gene therapy** and in the treatment of cancer. Gene therapy is the insertion of genes into a person's cells and tissues to treat a disease. In the case of a genetic disease, the defective gene is replaced with a working gene. Although the technology is still new, it has been used with some success.

Scientists have focused on gene therapy for diseases caused by single-gene defects, such as cystic fibrosis, hemophilia, muscular dystrophy and sickle cell anemia. In gene therapy, the correct version of the gene is introduced to human cells by using a viral vector such as the adenovirus shown below.

Phages have been used for over 60 years as an alternative to antibiotics in the former Soviet Union and Eastern Europe. They are seen as a hope against multi-drug-resistant strains of many bacteria because they can infect and kill these "superbugs". However, in the case of MRSA (Methicillin-resistant *Staphylococcus aureus*), a phage infecting the bacterium produces a toxin that makes the bacterium more virulent and difficult to contain.

Viruses that infect cancer cells are being studied for their use in cancer treatments. **Oncolytic viruses** are viruses that lyse and kill cancer cells. Some researchers are hoping to treat some cancers with these viruses.

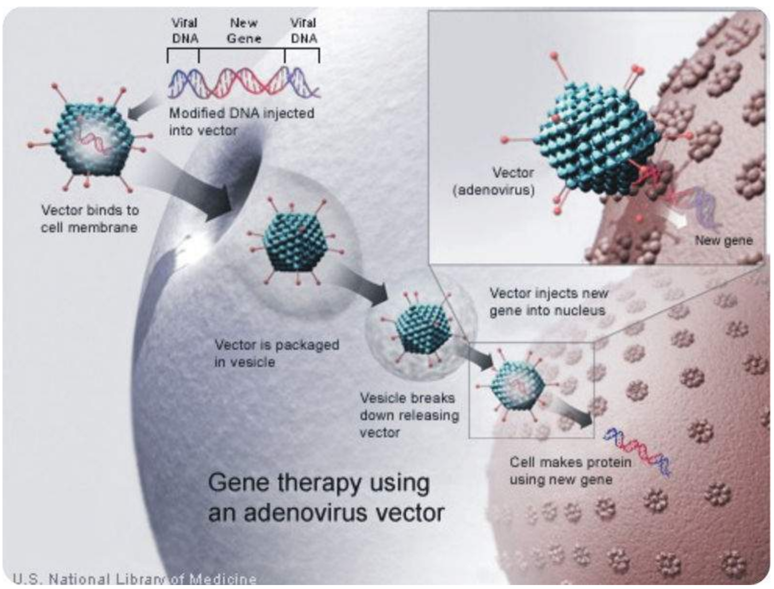


FIGURE 6.1

Gene therapy using an Adenovirus vector. A new gene is inserted into an adenovirus vector, which is used to introduce the modified DNA into a human cell. If the treatment is successful, the new gene will get into the nucleus and into the target cell DNA to make a functional protein.

Summary

- Viruses are useful tools in scientific research and medicine.
- Viruses help us understand molecular biology. They are also used in gene therapy.

Practice

Use this resource to answer the questions that follow.

- **Results of world-first viral therapy trial in cancer patients published in Nature** at http://www.biologynews.net/archives/2011/08/31/results_of_worldfirst_viral_therapy_trial_in_cancer_patients_published_in_nature.html .

1. What is viral therapy?
2. How were these viruses used in this study?
3. What did the study demonstrate?

Review

1. Why are viruses especially useful tools for understanding molecular biology?
2. What might scientists learn by studying how viruses invade and use host cells?

References

1. Courtesy of National Institutes of Health. . Public Domain